MANAGEMENT OF POTATO APHID TRANSMITTED VIRAL DISEASES BY INTEGRATING BORDER CROPS, INSECTICIDES AND MINERAL OIL

BY

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DECLARATION

I declare that this is my original work and has not been presented for an award of a degree in any other university.

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To

my Maker

who must get the entire honour

for giving me the ability and strength to complete this work

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ABSTRACT

Potato (*Solanum tuberosum* L.) is one of the most important root crops grown in Kenya. However, its productivity is greatly affected by aphid transmitted viral diseases. Lack of enough certified seeds for farmers and knowledge on field diagnosis of viral diseases has led to accumulation of viral diseases in farmers' fields. Two field experiments were carried out in Kabete and Tigoni during the 2006/2007 short rains and 2007 short and long rains. The objectives of the study were to determine the effect of border crops on potato crop growth and management of potato aphids and viruses and to evaluate the effectiveness of combining border crops, mineral oil and insecticides in managing potato aphids and viruses.

In one experiment, maize, wheat and sorghum were used as border while Tigoni and Asante potato varieties were the test crops. The experiment was laid down in radomized complete block design with split plot arrangement. Potato crop growth was established by measuring potato and border crops height, photosynthetically active radiation interception and Potato leaf area index. Aphid population was monitored weekly using leaf samples and yellow sticky traps placed inside the potato and the edge of border crops. In the other experiment, maize border together with either mineral oil or bifenthrin or both were tested. The treatments consisted of spraying mineral oil on border crops alone, spraying mineral oil on potato alone, spraying bifenthrin on border crops alone, spraying bifenthrin on potato crop alone, spraying bifenthrin followed by mineral oil on potatoes crop alone, spraying bifenthrin followed by mineral oil on border crops alone, spraying bifenthrin on both border crops and potatoes, spraying mineral oil on both border crops and potato and a control which did not have any spray. The experiment was laid down in randomized complete block design. Aphid population was monitored weekly using leaf samples,

yellow water pan traps and yellow sticky traps placed inside the potato and the edge of border crops. Tuber yield was determined at harvest and Double-Antibody Sandwich Enzyme- Linked Immunosorbent Serological assay (DAS-ELISA) was used to determined virus titre on potato tubers. Data was subjected to analysis of variance (ANOVA) using the PROC ANOVA procedure of Genstat software and means were separated by the Least Significant difference test at 5%probability level.

Border crops had significant effect on the potato height and light interception but did not affect potato leaf area index. Aphid species identified were *Aphis gossypii, Macrosiphum euphorbiae, Myzus persicae* and *Rophalosiphum maidis.* More aphids were recorded on traps placed in potatoes than at the edges of border crops. All the border crops significantly ($p<0.05$) reduced potato aphids and PVY infection. The lowest aphid population was recorded in wheat-bordered plots while lowest PVY titre was recorded in wheat and maize bordered plots. However, there was reduction in potato tuber yield on sorghum-bordered plots compared to the plots without border crops. Although spray treatments did not reduce aphid population and viruses during the long rains, Mineral oil and bifenthrin treated plots significantly reduced aphid population and virus titre on potato tubers during the short rains. Lowest aphid population was recorded in plots where mineral oil was applied on potatoes while control plots had the highest aphid population. Yields were not significantly ($p<0.05$) different among treatments.

The results obtained in this study show that integrating border crops, insecticides and mineral oil is beneficial in the management of potato aphids and associated viruses in seed potato production. The effective distance between border crops and potatoes and the maximum potato plot size need to be determined.

CHAPTER 1: INTRODUCTION

1.1 Background information

Potato (*Solanum tuberosum* L.) is an annual plant of the solanaceae, or nightshade family, commonly grown for its starchy tuber. It is the world's most grown tuber crop and the fourth most cultivated food crop after wheat (*Triticum aestivum*), rice (*Oryza sativa*) and maize (*Zea mays*) (KARI, 2006; Anon, 2007). It is also known to be the world's most important tuber crop with annual production of approximately 300 million tonnes with an estimated production area of 18.9 million hectares (FAOSTAT, 2004; Hansen *et al.*, 2004). Increased popularity of the potato in developing countries is attributed to its high nutritional value, palatability, simplicity of propagative amplification, ease of cooking and convenience (Were, 1996; Alisdair *et al.*, 2001).

The potato is an important food and cash crop in east and central Africa. It is socio-economically important in the growing areas for both commercial and resource poor farmers because of its short maturity period and the ability to be grown throughout the year (Kabira, 2002). It also plays an important role in national food security, poverty alleviation and income generation (Kabira *et al.*, 2006). It is rated as the second most important food crop after maize in Kenya with 500,000 farmers being directly engaged in potato farming and the highest consumption rate mainly found in urban areas (MOA, 2005; KARI, 2006). The average potato consumption in Kenya is recorded to be 0.55 kilogram's per capita (Theisen, 2007).

1.2 Constraints in potato production in Kenya

Potato production in Kenya is becoming an important area of investment due to economic decline of competing crops such as maize, pyrethrum and barley and increasing demand from consumers, processors and exporters (Nyoro, 2002). Recently, there has been a decline in the area-under potato cultivation countrywide from 94,153 ha in 1997 to 93,000 ha in 2001. The average plot size of farms planted with potatoes is less than 0.5 ha (FAOSTAT, 2001). Although it is an important crop, an average yield of 12-15 t / ha for high yielding varieties and 4-6 t / ha for low yielding varieties has been maintained with most farmers harvesting less than 10 t / ha which is low compared to the world average of 17 t / ha (Kabira *et al.*, 2006). The national average potato yield figures for Kenya have also fluctuated considerably over the recent years, from over 11.1 t/ha in 2004 to around 7.3 t/ ha in 2006 (MOA, 2007). The low yields are attributed to low use of inputs, intensive and continuous cultivation, declining soil fertility, poor crop husbandry especially disease and pest management, and lack of adequate certified seeds within economic reach of small-scale poor farmers (MOA, 2005; Kabira *et al.*, 2006). Research carried out by Tegemeo Institute of Agriculture and Development indicated that farmers planting certified seeds harvested 40-60 bags/acre while those using local seeds harvested 20-40 kg/acre. However, certified seeds were expensive at Ksh.38/kg compared to the locally sold seeds at Ksh.13/kg (Ayieko and Tschirley, 2006).

After the collapse of the ADC (Agricultural Development Corporation) potato seed programme in Kenya because of subdivision of potato multiplication farms by wealthy individuals in early 1990s, the National Potato Research Center (NPRC) became the only provider of certified seeds, which are relatively expensive and unavailable to farmers

(Kabira, 2002; Ngige, 2006). This has forced farmers to plant seeds from their own fields or buy small tubers from neighbors or local market which allows disease build up resulting in low yields even when recommended fertilizer and fungicide rates are used (Tambang, 2007). The use of high quality seed potatoes has been known since before the turn of the century as the only method of choice for preventing decline in vigour that occurs due to the accumulation of pathogens when tubers are repeatedly recycled for "seed". Traditional potato production involves use of seed tubers that need to be continually monitored and evaluated for the presence of pathogens (FAO, 2007).

Diseases rank high among the factors limiting potato production in Kenya. The most important disease worldwide is late blight caused by *Phytopthora infestans* while bacteria wilt caused by *Ralstonia solanacearum* is the second in importance (Hijmans *et al.*, 2000). Critical studies conducted show that viral diseases are least understood and field diagnostics difficult but can cause yield losses in potato fields free of fungal and bacterial diseases (Roberts *et al.*, 2007). Potato viruses are known to reduce yields unnoticed, for example, Khurana and Garg (2003) reported that potato virus X reduced tuber yield of variety Kenya Baraka and Roslin Eburu by 12 % and 10 % respectively, while potato leave roll virus reduced tuber yield of the two varieties by 68% and 37%, respectively. The most important viral diseases in Kenya are: potato leave roll virus (PLRV), potato virus Y (PVY), potato virus S (PVS), potato virus X (PVX) and potato virus M (PVM) (Khurana, 2000; Kabira *et al.*, 2006).

Several species of insects attack seed potatoes in the field and in storage either as pests or predators. Aphids which are virus vectors are the key pests of great concern in seed potato production while potato tuber moth (*Phthorimaea operculella* (Zeller) is of major importance in ware production internationally (Hanafi, 2004). Other insect pests include cutworms, wireworms, leaf eating caterpillars, beetles and spider mites (Stefan Keller, 2003; Kabira *et al.*, 2006; Anon, 2007). Apart from virus transmission, high population of aphids leads to yield losses of approximately 44% (Kibaru, 2003). Weeds along roads and other non-cultivated areas contribute to aphid problem in neighboring fields; *Brassica* spp. and black nightshades serve as early season host plants where aphids increase before spreading to host plants (Godfrey *et al.*, 2006). Potato cyst nematode *Globodera rotochiensis* is also known to cause serious crop losses of up to 80% in seed potato production (Nugaliyadde *et al.*, 2000).

1.3 Justification

The formal seed sector in Kenya accounts for less than 1% of total the seed potato requirements. This leads to high cost and acute scarcity of seed potato tubers causing farmers to obtain seeds by selection from one season to another and periodically going outside their farms to bring seeds from the market. The locally obtained seeds may be of low quality or infected with diseases, which results in the recycling of diseases from season to season. Viral diseases are difficult to diagonise and their symptoms are always confused with low soil nutrition. The diseases are also not easy to manage because they are transmitted either by potato colonizing aphids or aphid species not associated with the potato crop. Management of potato viruses has also received little attention. This has resulted in the build up of aphid-borne viruses in seed crops, which amplifies in later plantings of seed, spreading viruses to other potato growing areas. Viral infection in potato is known to reduce yield through seed degeneration. The most important viral diseases in Kenya are PLRV, PVY, PVS and PVX. Crops planted with virus-infected tubers can be severely stunted, resulting in huge yield losses and poor tuber quality. However, farmers' knowledge on virus infection and control strategies is scanty. Use of border crops is a simple cultural technique that requires no specialized equipment and is compatible with all current production practices. It can effectively reduce potato virus Y (PVY) infection in field by mechanically blocking viruliferous alate aphids from landing on potatoes or causing them to lose stylet-borne viruses hence infection is lost. Systemic and contact insecticides play an important role in control of aphid population in stores and in the field. Mineral oil is known to inhibit acquisition and inoculation of aphids. Integration of border crops, mineral oil and insecticides can be more effective in reduction of aphid population than any single method. Therefore, studies on the use of border crops, insecticides and mineral oil can make great contribution in control of potato aphids and associated viruses in seed potato production.

1.4 Objectives

The overall objective of this study was to establish an effective strategy of managing potato aphids and aphid-transmitted viruses, for improved seed potato quality and quantity.

The specific objectives were:

1. To evaluate the effect of border crops on potato crop growth and management of potato aphids and aphid transmitted viruses in seed potato production.

2. To evaluate the effectiveness of integrating border crops, insecticides and mineral oil in the management of potato aphids and associated viruses.

CHAPTER 2: LITERATURE REVIEW

2.1 Potato crop

Potato (*Solanum tuberosum L.*) originated in Andes in southern Peru (Hawkes, 1994). British farmers and colonial officials introduced it to Kenya during the 1888s and since then it has expanded in its primary cultivated area (from 120,000 to 126,000 hectares), total production and usage (FAO, 2007). Currently it is utilized for human consumption, stock feed, starch, spirits and industrial alcohol, although no much effort has been made to develop potato varieties with appropriate qualities to meet the increased demand of rapidly growing industries in the country (Kabira, 2000).

Potato contributes a great deal to human diet for a large cross-section of Kenyan population in crop growing areas and in large towns (Guyton *et al.*, 1994). It is mainly consumed at the commercial level as French fries (chips), crisps in restaurants and take away facilities in major towns in Kenya (Walingo, 2000). In homes especially within producing areas, they are consumed daily for mid-day and evening meals as stews or mashes.

Potato production is concentrated in humid tropical highlands mainly in the cool high altitude areas with well-distributed rainfall and an elevation of between 1,500 and 3,000 meters above sea level (MOA /JICA, 2002; KARI, 2007). The main potato growing areas are found in Central, Eastern and Rift valley provinces. Other areas include Coast, Western, Nairobi and Nyanza provinces. Central province produces more than 53 percent with nearly all the districts producing some potatoes and Nyandarua district being the largest and most diversified potato producing area, while Eastern and Rift valley provinces produce a combined total of 44 percent. The main growing regions in the Rift Valley province are; - Mau escarpment region, Dundori, Mau Narok, Molo, western highlands of Kericho, Bomet and Uasin Gishu districts. The main growing region in Eastern province is Meru district (MOA / GTZ, 1998; MOA, 2005).

Potato requires deep, well-drained fertile soils with a pH of 5.5-6.0 and cool growing season with an average daily temperature of 15-18 ^{0}C. Temperatures above 21 ^{0}C have adverse effects on the growth of potatoes. It requires appropriate agronomic practices, disease and pest control and storage management practices for production of healthy seeds.

Common potato varieties in Kenya are: Dutch Robyjn, Kenya Karibu (kp90172.3), Kenya Sifa (720097), Kenya Faulu (KP90142.7), Kenya Mavuno (KP90131.10) Asante (381381.20), Tigoni (381381.13), Kerr's Pink, Anett, Desiree, Kenya Baraka, Roslin Eburu (B 53), Roslin Tana, Roslin Bvumbwe, Kenya Dhamana and Kenya Chaguo (Khurana and Garg, 2003; ECAPAPA, 2006). The varieties Nyayo, Roslin Tana, Asante and Furaha are used for making French fries while Kerr's pink, Dutch Robyjin and medium tubers of Tigoni are used for crisps. Asante variety is grown mostly for distant markets because of its good storability (Walingo *et al.*, 1996; Kabira, 2000; Kabira *et al.*, 2006).

2.2 Potato aphids

Aphids are small, soft bodied insects that suck nutrients from plant tissues and form colonies on the underside of leaves and around flowers and are of greater economic importance as potato pests world wide because of their ability to acquire and transmit plant viruses (Robert *et al.,* 2000; Robert and Bourdin, 2001; Cornel *et al.*, 2004). The most destructive aphid pest of potato worldwide is green peach aphid, *Myzus persicae* (Sulzer) (Blackman and Eastop, 2000; Kabira *et al.*, 2006). Other potato infesting aphid species of worldwide importance include: *Macrosiphum euphorbiae* (Thomas), *Aulacorthum solani, Aphis gossypii, Aphis fabae and Rhopalosiphum maidis* (Raman and Radcliffe, 1992; Robert and Bourdin, 2001; Halbert *et al.*, 2003; Cameron and Fletcher, 2005). They are known to infest the crop with viruses such as potato leaf roll virus and mosaic viruses such as potato viruses Y, A, S and M while feeding on plant sap (Kabira *et al.*, 2006).

There are two types of aphids: Apteral and winged. Apteral (wingless) type of aphids is known to cause within- field spread of potato leaf roll virus while walking from plant to plant (Anon, 2007; Hodgson, 1991). *Myzus persicae* is the most efficient, cosmopolitan and commonly abundant vector of potato leaf roll virus (Robert and Bourdin, 2000; Jones *et al.*, 2003). It acquires more potato leaf roll virus and it is able to transmit the virus as soon as it feeds at high temperatures (Syller, 1994). Winged aphids (alates) are known to transmit viral diseases from one field to another. They can travel hundreds of miles with assistance from winds. Trivial flight occurs at canopy levels as aphids move a few feet at a time to search for a suitable host. Aphids use vision to locate fields and chemical and gustatory clues to find a suitable host. It is during this host finding period when some viruses like PVY are spread or lost. For example, winged aphids are especially attracted to the green-dark interfaces of field edges and tend to land in greatest numbers at the field margins. This is why a crop border other than potato will protect a seed lot from PVY spread by winged aphids (Suranyi *et al.*, 1998).

Aphid reproduction includes the alternation of sexual and asexual phases. Asexual reproduction, known as parthenogenesis involves only females that give birth to live young (rather than laying eggs) and it is the process that enables aphids to reproduce rapidly and efficiently in favorable nutritional conditions. Some aphids have a single sexual generation (cyclical parthenogenesis) while others are totally asexual (obligate parthenogenesis). Parthenogenic reproduction allows aphids to rapidly exploit a suitable environment since they do not have to spend energy on finding a mate. However, asexually reproducing populations have a low genetic variability hence few genotypes are spread over large geographic areas (Koyama *et al.*, 2004; Zamoum *et al.*, 2005). All potato-colonizing aphids undergo four nymph instars and a newly born aphid becomes a reproducing adult within 7 days. Under favorable environmental conditions, aphid populations double after every two days and a single female can give birth to 100 or many progenies (Suranyi *et al.*, 1998; Hanafi, 2004).

2.3 Potato viruses

Potato crop is subject to more than 30 viral diseases whose field diagnosis is difficult because symptoms are similar for different viruses (Salazar, 1996; Miha and Atirib, 2000; Roberts *et al.*, 2007). All potato viruses are obligate, contain a single stranded DNA and infection of new hosts depends upon assisted transmission, which can either be mechanical, through wounds or biological through vectors (Radcliffe *et al.*, 2002). Aphids are the most important potato virus vectors (Ragsdale *et al.*, 2001). Among the

600 known viruses transmitted by invertebrates, aphid transmitted viruses account for about 50% (Cerruti and Fereres, 2006). There are 13 potato viruses that are transmitted by aphids (Brunt, 2001). The most important viral diseases are Potato leaf roll virus (PLRV), Potato virus Y (PVY), Potato virus S (PVS), Potato virus X (PVX), Potato virus A (PVA) and Potato virus M (PVM) (Kabira *et al.*, 2006). Potato leaf roll virus (PLRV) and Potato virus Y (PVY) are of major concern to seed potato producers because they decrease yields by 50-80% in crops grown from infected seeds and seed certification programs have low tolerance for virus infection (Robert *et al.*, 2000; Gutbrod and Mosley, 2001).

Aphid-transmitted viruses differ in how they are acquired, how they circulate within the body of the vector, how they are transmitted to healthy plants, and how long a vector remains infective after acquisition. Once acquired, the aphid may be capable of transmission immediately, or a latent period may be required where the vector remains capable of transmission for minutes to hours (Berger *et al.*, 1987; Proeseler and Weding, 1975; Phone and Harris, 1977). With other viruses the vector remains capable of transmission for days or even its lifetime (Sylvester, 1980). Virus transmission patterns have been classified based on where virus is located in the vector, its association with various internal organ systems, and how long the vector retains ability to transmit (Radcliffe *et al.*, 2002). We have four categories of virus transmission: non - persistently transmitted, semi persistently transmitted, persistently transmitted (circulative) and persistently transmitted (propagative). For non- persistent transmission, virus particles are carried on stylets of the vector and acquisition and transmission of the virus do not require contact of aphid- stylets with the phloem; the capacity of the vector to transmit and also time required for virus acquisition and transmission is very short (few seconds). The virus particles (charge) are found on the mouthparts and the foregut of aphid and it is lost immediately the aphid feeds on a health plant. Ability of the aphid to transmit PVY after this is only determined by presence of infected plant where the aphid can get innoculum (Martin *et al.*, 1997; Suranyi, 1999; Doring *et al.*, 2006). All aphid transmitted potato viruses are non - persistent except Potato leaf roll virus (Mathews, 1992; Khurana, 2000; Radcliffe *et al.*, 2002). In contrast, persistently transmitted viruses are taken up from the phloem, so a latent period exists between acquisition and onset of ability to transmit. This occurs to enable the virus to pass through the gut into the hemocoel and enter accessory salivary glands before transmission can take place. Transmission doesnot take place until 24 hours or more after virus particle acquisition (Suranyi, 1999; Doring *et al.*, 2006). The virus is acquired during feeding which can start in less than 15 minutes but can last for hours. A vector that acquires a persistently transmitted virus usually remains infective for life and it is capable of transmission even following a molt (Khurana, 2000; Radcliffe *et al.*, 2002).

Potato leaf roll virus (PLRV) is a phloem- limited luteovirus which is the most economically important viral disease affecting potato production worldwide causing yield quantity and quality loses of up to 80% (Machangi, 2003; Alvarez and Srinivasan, 2005; KARI, 2006). It is more troublesome in tropics and subtropics where temperatures are generally high leading to high aphid populations. The virus belongs to genus polerovirus and family luteoviridae. Its particle is difficult to study because it is small and isometric measuring 24 to 25nm in diameter and occurs in low concentrations in infected plants so it largely depends on vector transmission (Kibaru, 2003; Burrows and Zitter, 2005). It is mostly transmitted by potato colonizing aphids. Green peach aphid, *Myzus persicae*(Sulzer) is considered to be by far the most efficient transmitter of PLRV and in secondarily infected plants; it is found in phloem tissues and companion cells (Vanden Heavel *et al.,* 1995; Suranyi, 1999; Alvarez and Srinivasan, 2005; Anon, 2007). Bacteria endosymbionts also plays a role in PLRV transmission (Vanden Heuwel *et al.,* 1994). Other potential PLRV vectors include *Aullacorthum solani* and *Aphis gossypii* (Foster and Woodford 1997). Foliar symptoms don't occur if inoculation occurs after flowering although tubers develop net necrosis (Were, 1996). If inoculation occurs before flowering, infected leaves have a characteristic upright character, roll inwards; have a pale appearance, become stiff, yellow, leathery and brittle in texture. Young leaves remain smaller than healthy ones, plants may have stunted growth, phloem necrosis and net tubers necrosis (Burrows and Zitter, 2005; Kabira *et al.,* 2006; Anon, 2007). Severity of tuber net necrosis varies depending on time of infection and mostly increases during storage resulting in a product that is unsuitable for processing (Anon, 2007). Once a mature plant is inoculated, virus can be detected in the tubers in seven days and within two weeks, nearly all tubers can be infected (Suranyi *et al.,* 1998). Secondary infection is more damaging in plants than primary infected plants. The severity depends on the virus isolate, potato cultivar and prevailing environmental conditions (Khurana, 2000). Potatoes are more susceptible to virus infection during vegetative growth before flowering and least susceptible when the plants are senescing (Difonzo *et al.,* 1994; Whitworth *et al.,* 2000)

Potato virus Y (PVY) belongs to the family potyviridae; genus potyvirus and is currently regarded as one of the major problems in seed potato production worldwide (Stevenson, 2001; Halbert *et al.*, 2003; Burrows and Zitter, 2005; ; Doring *et al.*, 2006; Grzela, *et al.*, 2007). It has characteristic flexuous, filamentous particles ca 750 x 11nm and it is transmitted non–persistently by more than 50 aphid species including species that cannot colonize but can probe on potatoes (Salazar, 1996; Heimbach *et al.*, 1998). *Myzus persicae* is the most effective vector of PVY. Other aphid species include *Aphis fabae*, *Macrosiphum euphorbiae*, *Myzus certus*, *Rophalosiphum maidis* and *Rophalosiphum padi* (Brunt *et al.*, 1996; Radcliffe *et al.*, 2002; Halbert *et a*l., 2003; Doring *et al.*, 2006). Machinery and grafting tools can also transmit PVY mechanically. Weeds such as *solanum* species act as important virus sources (Brunt *et al.*, 1996; Burrows and Zitter, 2005). Several cereal aphids have been found to cause transmission of PVY causing epidemics (Difonzo *et al.*, 1997). PVY acquisition is associated with intracellular ingestion and inoculation with salivation (Martin *et al.*, 1997). Several strains of PVY have been identified and described and differ in symptomatology in potatoes (Blanko-Urgoiti *et al.*, 1998; Carnegie and Van de Haar, 1999; Ohshima *et al.*, 2000; Nie and Singh, 2002). They include PVY^o, which causes mosaic symptoms, PVY^c which causes stipple streak and the necrotic strain - PVY^N. Mixed infections are caused by mixed genomes commonly produced by a hybrid strain called $PVY^{N:O}$ and PVY^{NTN}. PVY^{NTN} commonly causes tuber necrosis (Walkey, 1991; Salazar, 1996; Burrows and Zittter, 2005). Symptoms manifested by PVY infected plants differ among varieties, virus strain present and environmental conditions during growth and storage. They range from severe to symptom less. Infected plants may have leaf mottling, rugore wrinkling, leaf deformation, necrotic spots and veinal necrosis which starts as patches or rings and grows to affect entire leaflet resulting to leaf drop and premature death of stems. Other infected plants may have bushy growth at the top of the plant with few leaves at the bottom of the stem. Infected tubers may show tuber necrosis depending on the environmental conditions. However, plants infected with mild strains and tolerant cultivars may develop milder foliage symptoms without necrosis, leaf drop or premature death of shoots (Kus, 1990; Jones *et al.*, 2003). PVY strains can interact with other potato viruses such as Potato virus X (PVX) and Potato virus A (PVA) resulting in heavy yield losses (Burrows and Zitter, 2005).

Potato virus X is a wide spread virus infecting many commercial stocks worldwide. It causes yield losses up to 15% in some varieties (Anon, 2007). The virus is mechanically transmitted by plant-to-plant contact, machinery contact in the field or seed graders and cutters. Some chewing insects can also transmit it. However, it is not aphid transmitted. PVX is a latent virus it usually causes mosaic but the symptoms are not visible to the naked eye (Kabira *et al.,* 2006; Anon, 2007).

Potato virus S (PVS) is the most common virus in potato, virtually symptom less and has little effect in most widely grown potato varieties (Anon, 2007). It is transmitted by infected sap, by plant-to-plant contact, machinery contact in the field, seed graders and cutters. It can also be transmitted by infected tubers and rarely by aphids (Kabira *et al.*, 2006; Anon, 2007).

2.4 Management of potato aphids and viruses

Although several strategies of potato virus control and management have been repeatedly published and reviewed, control of potato aphid populations remains the most effective method of managing viruses in seed production (Radclliffe and Ragsdale, 2002; Doring *et al.*, 2006). Several methods of controlling potato viruses have been recommended which include: chemical control, cultural control, biological control, and site-specific management methods.

Border or barrier crops are crops, which interfere with the phototactic responses of vector aphids by disrupting host plant selection and restricting virus spread (Antignus, 2000). They are secondary plants used within or bordering a primary crop that manipulates aphid flight behavior and virus transmission. Border crops use is a simple cultural technique applied to reduce virus incidence in seed potato. It is easy to plant, requires no specialized equipment, it is compatible with current production practices and can be applied in any cultivar and around a field of any size and shape (Difonzo, 1996; Suranyi, 1999). They are plant species that are appealing to aphid landing, attractive to natural enemies and may significantly impact on the pressure from viruliferous vectors (Jones, 1993; Hooks and Fereres, 2006). Border crops are known to significantly reduce non-persistently transmitted aphid-borne viruses by intercepting viruliferous alate pest migration regardless of direction of attack (Difonzo, 1996; Fereres, 2000). They can also act as natural sinks for non-persistent viruses hence don not reduce aphid numbers landing in the protected crop.

Choice of barrier crop is important because it should not be a host of any potential insect pest or pathogen able to damage the protected crop and it can be of market value in terms of yield to the farmer (Kibaru, 2003). Trap crops can also act as border crops but success depends on inherent characteristics of the trap crop, economic value of the crop, spatial and temporal characteristics of the crop, agronomic and economic requirements of the production system and behavior and movement patterns of insect pest (Shelton and Badenes-perez, 2006). Efficacy of border crops on the other hand depends on kind of virus pattern (monocyclic or polycyclic), height of barrier crop at time of maximum risk of infection and extent of competition between barrier crop and the protected crop (Fereres, 2000). Moreover, barrier crop should not host any pest, which can damage the protected crop but should be appealing to aphid landing and attractive to their natural enemies. They should also be able to allow sufficient residence time to allow aphid probing before taking-off occurs (Cerruti and Fereres, 2006). Barrier crops are more widely adaptable than mulches or floating row covers, since they are easier to install and keep in place, and don't lose effectiveness due to weathering or as canopy closes (Radcliffe *et al.*, 2002). Studies done by Jones (1993) reported that for border crops to be effective they should be taller than the protected crop which is contrary to other studies which state that they need not be taller than the protected crop or be more than a few meters wide (Difonzo *et al.*, 1996; Thieme *et al.*, 1998). A fallow border left to the outside with no gap between the barrier crop and the protected crop takes advantage of the tendency of winged aphids to alight at the interface of fallow ground and green crop and enables immigrating alates carrying PVY to feed first or stylet probe on the border crop hence lose their virus inoculum before moving into the potatoes (Difonzo *et al.*, 1996; Kibaru, *et al.*, 2003). Although some authors have argued that border crops may lter environmental conditions surrounding protected crops leading to reduced yields, esearch has shown that crop borders does not adversely affect yields (Fereres, 2000; ?rasad and Kudada, 2005).

Treatment of barrier crops with insecticides to control potato viruses has produced mixed effects. Difonzo *et al.* (1997) found that spraying barrier crops with insecticides at the appropriate time increased their effectiveness in control of aphids and viruses while Radcliffe *et al.*, (2002) recorded that routinely treating borders of spring planted wheat and forage sorghum with insecticides to control cereal aphids did not increase their efficiency in control of PVY compared to untreated border crops.

Insecticide (aphicides) use is a direct method of controlling vectors, which is regularly used in convectional seed potato growing despite many criticisms since 1950s (Radcliffe and Ragsdale, 2002; Doring *et al.*, 2006). Insecticides applied at planting or plant emergences are known to significantly reduce within field spread of potato leaf roll virus (PLRV) (Hanafi, 1998; 2000; Boiteau and Singh, 1999). A preventive program of insecticide applications at 2 to 3 week intervals is considered necessary in seed potato production (Godfrey *et al.*, 2006). This spray regime does not act fast enough to kill aphids but it prevents virus spread by effectively reducing resident aphid populations particularly *Myzus persicae* which colonizes lower canopy (Radcliffe *et al.*, 2002; Jones *et al.*, 2003). Research shows that the control of *M. persicae* worldwide remains almost exclusively based on insecticides (Margaritopoulos *et al.*, 2007). It has been argued that insecticides are generally not effective in the control of Potato virus Y (PVY) and majority of PVY vectors. This is because time of virus acquisition and transmission is too short for aphicides to kill the vector and also majority of PVY vectors belong to species which do not colonize potatoes but briefly probe potato as a non host plant (Suranyi, 1999; Kibaru, 2003; Halbert *et al.*, 2003). Heimbach *et al.*, (1998) and Perring *et al.*, (1999) carried out field studies to evaluate efficiency of systemic insecticides in control of PVY and found successful control in six studies and failure in nine studies. Moreover, studies to investigate the impact of reduced imidacloprid rates on aphid abundance and PVY transmission within potato fields revealed a 2.3 to 2.7 fold increase of virus infection in foliar- treated plots at the end of the growing season (Andrei *et al.*, 2002). Synthetic pyrethroids have been found to be more effective in control of PVY (Perring *et al.*, 1999). However, the main problem of insecticide use is development of vector resistance to the active ingredient, which severely limits a grower's choice of aphicides (Robert *et al.*, 2000). Although non-potato colonizing vectors are less prone to resistance build-up, resistance can build-up due to increased probing activity or mobility after insecticide application (Boiteau *et al.*, 1997; Collar *et al.*, 1997). Over- use of insecticides also promotes insecticide-resistance in aphids. Over the years there has been lack of understanding of aphid population dynamics and economic pressures in potato production. This has resulted to over use of insecticides. This imbalance between aphid populations and management strategies can be corrected through detailed studies of the tri- tropic interactions of aphids, natural enemies and potato crop (Andrews *et al.*, 2004). Neglecting differences among different groups of pesticides, their mode of action and efficiency in control of aphids, we have a lot of associated environmental and health costs (Fenton *et al.*, 2005). Some farmers have used fungicides to control aphids with little success. Fungicides interfere with entomophthorales that infect *Myzus persicae* and ıterfere with on set of mycoses but do not cause *Myzus persicae* out break (Lagnaoui nd Radcliffe, 1998; Rossils *et al.*, 2001).

Mineral oils are consistently more effective in controlling the spread of potato virus Y (PVY) than are insecticides (Brachet *et al.*, 2001; Radcliffe *et al.*, 2002). Application of chemicals is always ineffective because aphids can transit such viruses within seconds before they are disabled. Mineral oil has been successful in controlling persistently transmitted viruses because it doesnot spread to a film immediately after spraying, but covers the leaf surface with small droplets, which stretch to join together after 24-36 hours after application (Walkey, 1991; Asjes, 2000; Hanafi, 2000). It also persists in the field on the plants for 10-14 days although it may be washed off by rain or irrigation water and must be re-applied frequently to cover new foliage (Hanafi, 2000). The mechanism involved in potato virus control by mineral oil is not fully understood although it appears to be a complex contact- based action. It is conceivable that inhibitory amounts of oil particles are carried on aphid mouthparts during subsequent feeding times, which kills virus particles (Powell, 1992). Since aphids use tiny hollow hairs to detect special chemicals which identify the plant as a host or a non- host, mineral oil is perceived to interfere with critical aphid behavior making it un able to communicate with its environment. Mineral oil is also known to interfere with the specific binding sites of the virions on the aphid stylets and hence reduce transmission efficiency (Wang and Pirone, 1996). Although both acquisition and inoculation by aphids are inhibited by mineral oil, this inhibition is not related to differences in feeding behavior that can be detected by monitoring stylet penetration electronically (Powell, 1992). However, mineral oils appear to interfere with normal leaf exploratory processes of aphids and ncrease their pre- probing time on oil coated leaves (Powel, 1992). Stylet oils (JMS stylet oil) have been developed that control virus transmission without phytotoxicity on sensitive plants such as potato (Hanafi, 1998 and 2000). Plant derived antifeedants and a white wash improves PVY control over mineral oil alone (Marco, 1986; Powell *et al.*, 1998). White wash sprays have also been found to be effective in reduction of PVY in peppers (Marco, 1993). Conventional insecticides when mixed with mineral oils can also reduce aphid-borne virus spread.

Cultural control methods such as encouraging beneficial insect, use of virus resistant cultivars and control of over wintering weeds are effective in control of aphids and associated viruses (Cornell *et al.*, 2004). Most strict aphid control strategy have not been successful in preventing the spread of some viral diseases like PLRV unless measures are taken to keep virus source plants within and outside the crop at a minimum. Hairy nightshade, *Solanum sarrachoides* (Sendtner) is one of the preferred hosts of green peach aphid. *Myzus persicae* was reported to transmit PLRV from potato to nightshades and also become viruliferious after feeding on infected nightshade plants. Virus transmission from night shade plants to potato was also found to be four times that of potato to potato or potato to night shade (Alvarez and Srinivasan, 2005). This is important because weeds along ditch banks, roads, in farmyards, and other non-cultivated areas contribute directly to the aphid problem. Mustards serve as early season host plants where aphid populations increase before spreading to other host plants like commercial potatoes. Black nightshades, other solanaceous plants and volunteer potatoes act as reservoirs for potato leaf roll virus. Rouging infected potato plants to reduce the incidence of infection and spread of the disease within a field is important. Removal of the diseased plant, the three lants on each side of the diseased plant in the same row, and the three closest plants in adjacent rows is recommended in seed fields for effective control. Growing potato plants where vector populations are few or absent also plays role in reduction of potato aphids (Suranyi *et al.*, 1998; Jones *et al.*, 2003). The management of temporal plant susceptibility with vector occurrence by presprouting of tubers, early haulm destruction or early harvest, management of plant nutrition and the reproduction of vectors serve as a partial control method (Doring *et al.*, 2006). Knowledge of aphid host finding behavior, isolation of sources of innoculum, using crop borders and early harvest is important in control of spread of viruses by winged aphids (Godfrey *et al.*, 2006).

Many parasites and predators like lady beetles, their larvae, lacewing larvae, and syrphid fly larvae attack aphids on potatoes and reduce their population (Stoltz *et al.*, 1997; Tae and Long, 1998). Parasitic fungus, *Entomophthora aphids*, also plays a role in reduction of green peach aphid populations. The only problem with biological control is that most materials available for aphid control are highly disruptive of natural enemy populations.

Site specific pest management or precision pest management by use of geographic information systems (GIS) technology can be used to determine within field, spatio-temporal distribution of insects to help in formulation of the appropriate control measure. This method has been applied in the management of *Myzus persicae* by use of Methamidophos spray application (Weisz *et al.*, 1995; Macrae, 1998; Suranyi *et al.*, 2002). Application of spray only on targeted areas effectively controlled *Myzus persicae* and reduced treatment costs by 70% compared to application in the entire field. The main problem with this technique is that it is not yet established in small-scale farming systems because it requires a high input (Radcllife *et al.*, 2002).

CHAPTER 3: EVALUATION OF BORDER CROPS IN THE MANAGEMENT OF POTATO APHIDS AND APHID TRANSMITTED VIRUSES IN SEED POTATO PRODUCTION

3.1 Abstract

Potato is an important food crop worldwide but its productivity is greatly reduced by potato viruses and aphid vectors. Field experiments were carried out during the 2006/2007 short rains and 2007 long rains in Kabete and Tigoni. The objective was to evaluate the effect of various border crops on potato growth and management of potato aphids and aphid transmitted viruses in seed potato production. Potato varieties used were Tigoni and Asante and the border crops were maize, wheat and sorghum. Potato growth was established by measuring potato and border crops height, photosynthetically active radiation and potato leaf area index. Aphid population was monitored weekly using leaf samples and yellow sticky traps placed inside the potato and the edge of border crops.

Border crops significantly affected potato height and light interception but did not affect leaf area index. Aphid species identified were *Aphis gossypii, Macrosiphum euphorbiae, Myzus persicae* and *Rophalosiphum maidis.* More aphids were recorded on traps placed in potatoes than at the edges of border crops. All the border crops significantly ($p \leq 0.05$) reduced potato aphids and PVY infection. The lowest aphid population was recorded in the wheat-bordered plots while the lowest PVY titre was recorded in both wheat and maize bordered plots. However, there was reduction in potato tuber yield on the sorghum-bordered plots compared to the plots without border crops.

The results obtained in this study show that border crops use is a beneficial strategy in the management of potato aphids and associated viruses in seed potato production.

Determination of the effective distance between border crops and potatoes and the maximum potato plot size need to be determined.

3.2 Introduction

Aphid transmitted viruses are known to pose a serious threat to potato production worldwide (Cerruti and Fereres, 2006; Toor *et al.*, 2003). They are least understood by farmers and field diagnosis is rather difficult. Un availability of adequate certified seeds in the country also forces farmers to plant own saved seeds or buy seeds from the market which are infected with viruses (Tambang, 2007). The most important potato viral diseases are Potato leaf roll virus (PLRV), Potato virus Y (PVY), Potato virus S (PVS), Potato virus X (PVX), Potato virus A (PVA) and Potato virus M (PVM) (Kabira *et al.*, 2006). Potato leaf roll virus (PLRV) and Potato virus Y (PVY) are of major concern to seed potato producers world wide because they are known to cause serous yield loses (Mitsuru *et al.*, 2006; Alvarez and Srinivasan, 2005). The PLRV is transmitted by colonizing aphids in a persistent manner while PVY is transmitted non-persistently. Non-persistently transmitted aphid-borne viruses are the most abundant, widespread and difficult to control among all plant viruses (Fereres, 2000; Suranyi, 1999).

Over the years, insecticides have been ineffective in the control of PVY. This has been attributed to the complex biological process of acquisition and transmission of PVY, which occurs within seconds before aphicides can kill the vectors (Kibaru, 2003; Fereres, 2000). By virtue of the non-persistent transmission mode, PVY is spread by aphids, which don not colonize but briefly probe on potato plants. This has enabled border/ barrier crops to be the most effective method in the control of PVY. Since aphids must sample epidermal tissue of plants to determine their suitability as a host, they lose or spread PVY to barrier crops before feeding on potato plants. This makes barrier crops to act as real natural sinks for non-persistently transmitted viruses (Cerruti and Fereres, 2006; Halbert *et al.*, 2003). This experiment tested the effect of crop borders on potato growth and reduction of non- persistently transmitted viruses and associated vectors.

3.3 Experimental layout, design and crop husbandry

The experiment was carried out at the National Potato Research Center (NPRC), KARI Tigoni and the Faculty of Agriculture, University of Nairobi, Field Station. Treatments were laid out in a randomized complete block design with a split plot arrangement and replicated three times. The main plots consisted of potato varieties while subplots had border crop treatments. Border crops evaluated were: maize (*Zea mays*), wheat (*Triticum aestivum*) and sorghum (*Sorghum bicolor L*). Controls consisted of plots without border crops. Plots of 4.7 m x 4.7 m were planted with certified seed potato varieties Tigoni and Asante from the National potato research centre, Tigoni. The distance between blocks was 2 m while a gap of 1 m separated the subplots. Each sub plot consisted of 5 rows of potato plants with nine hills in every row. Two outer rows acted as guard rows while sampling was done in the three inner rows. A border of one-meter width surrounded each potato plot. Maize was planted in three rows at spacing of 75 cm between rows and 30 cm within rows while wheat and sorghum were drilled into three rows each 30 cm apart. Maize, sorghum and wheat were tested because they are known to be hosts of aphid species, which are vectors of PVY. Potatoes were planted two weeks after border crops emergence at a spacing of 75cm by 30cm. Diammonium phosphate (DAP) amounting to 222.2 Kg/ ha (i.e 40 kg N / ha and 102 kg P_2O_5 /ha) was applied and thoroughly mixed with soil before planting seed tubers. Weeding and irrigation in plots was done as weeds arose while ridging was done on 5th week after emergence of potatoes. Late blight and other fungal diseases were controlled by three spray applications of Metalaxyl (Ridomyl) at a rate of 2.4 kg a.i / ha.

3.3.1. Determination of the effect of border crops on potato height, photosynthetically active radiation interception and leaf area index.

Plant height was determined by measuring heights of five potato plants and five border crops per plot. Measurements were done during the 2nd, 4th, 8th, 12th and 14th week after potato emergence in Tigoni site. In Kabete site, measurements were started before potato emergence and continued in the 4th, 8th, 11th, 14th and 17th week after potato emergence. Photosynthetically active radiation (PAR) was determined using a sun fleck ceptometer at the ground level of both potatoes and border crops.

Leaf area measurement was done on 4th, 7th and 14th week after potato crop emergence using the leaf disc method. One plant was selected at random and carefully uprooted from each treatment plot. Soil was washed off the roots in running water and partitioned from the shoots. A cork- borer was then used to extract nine discs of known diameter from the plant leaves, then all leaves were removed and weighed together with the discs. Fresh weights of leaves and discs were determined. The relationship between weight and area of the discs was used to determine total leaf area per plant, which was then divided by area occupied by a single plant in the field to determine the leaf area index. Shoots and roots were put in paper bags every time samples were taken from the field. They were ven- dried at a temperature of 60°C for three days after which the dry weights were measured.

3.3.2 Monitoring of aphid population

Aphid population was monitored on leaves and by use of yellow sticky traps. Sampling of aphids on leaves was done weekly from second week after emergence to maturity. Ten potato plants were randomly selected from each plot then three leaves were picked from top, middle and bottom of each plant. The leaves from each plant were put in separate labeled paper bags and stored at 4^0C until aphids were counted and identified at the Entomology Laboratory of the Department of Plant Science and Crop Protection. Alate aphids were monitored using yellow sticky traps. The traps consisted of 30 cm x 30 cm cardboard discs wrapped with yellow polythene and adhesive insect glue was applied on the surface. The discs were mounted 0.5 m above the ground level. Two traps were mounted on each plot; one inside the plot and another at the edge of every border crop. The traps were replaced weekly and taken to the laboratory where aphids were then counted and identified. The aphid features were determined through insitu observation under dissecting microscope (Table 3.1).

Table 3.1: Features used to identify different aphid species as described by Martin (1983)

Aphid species	Body colour	Lateral abdomial spiracles	Antennal tubercles	Shape of siphunculi	Dorsal abdominal pigmentation
Macrosiphum euphorbiae	Green	Absent from first to seventh segment	Well developed with inner margin diverging distally	Cylindrical or tapering	Absent or completely green
Myzus persicae	Green or olive green	Absent from first to seventh segment	Well developed with inner sides parallel	Clavate	Dorsal black patch
Aphis gossypii	Green, olive yellow, orange or black	Well developed on first to seventh segment	Little developed or absent		Less developed black transverse bars

3.3.3 Assessment of virus disease incidence and virus titre in potato tubers

Viral incidence was estimated by identifying plants within a plot that showed leaf roll and mosaic symptoms expressed as a proportion of the total number of plants in the plot. This was done for all the 24 plots at each site. Virus incidence was determined on the 2nd, 3rd, 5th, 7th and 9th weeks after potato emergence. At physiological maturity, eight potato tubers were picked randomly from the center three rows of each plot and sprouted. The tubers were then processed and serologically assayed for the presence of potato virus Y, potato virus X, potato leaf roll virus, potato virus M, potato virus A and potato virus S. Double Antibody Sandwich – Enzyme Linked Immunosorbent Assay (DAS ELISA) method as described by Clark and Adams (1977) was used. Virus titre was not done in Kabete season one.

DAS ELISA was conducted as follows: Each well of microtitre plates were coated with y-globulin and incubated at room temperature for 5 hours. Potato sprouts were then removed from tubers by use of surgical blades, mixed with extraction buffer in extraction bags and grinded. The plates were then sequentially washed in Phosphate buffered saline-in tween (PBST) and dried. 100µl of grinded samples were added to each plate well and incubated at 4^0c overnight. The plates were sequentially washed again and conjugate antiserum (IAG-AP) added to each well and incubated for 5 hours. The plates were washed again after 5 hours and substrate buffer was added to each well and left for 30-60 minutes at room temperature. After this step, visual assessment of infected samples was done by observation of yellow colour development. Finally, photometric measurements of absorbance at 405nm wavelength to determine positive samples using ELISA reader was done.

3.3.4 Determination of the effects of border crops on tuber yield.

Tuber yield and yield components were determined at physiological maturity. Dehaulming was done two weeks before harvesting .The tubers were carefully dug out separately for each plot and graded according to Kabira *et al.* (2006) into ware (>55 mm), seeds (35-55 mm) and chatts (<25 mm). Tuber of different grades were weighed separately for each plot and total weight determined.

3.3.5 Data analysis

Data was subjected to analysis of variance (ANOVA) using the PROC ANOVA procedure of Genstat (Lawes Agricultural Trust Rothamsted Experimental station 2006, version 9) and differences among the treatment means were compared using the Fisher's protected LSD test at 5% probability level. Correlation analyses were done using the same program.

3.4 Results

3.4.1 Effects of border crop on potato height, photosynthetically active radiation interception and leaf area index.

Potato height varied significantly ($p \leq 0.05$) between varieties in both Kabete and Tigoni sites (Table 3.2). Tigoni variety was taller than Asante variety over the two sites. Although border crops did not affect potato height in Tigoni site, maize and sorghum borders increased potato height in Kabete but wheat had no effect on potato height. Kabete site had taller plants than Tigoni. There were no significant interactions between border crops and potato varieties. Potato heights in plots bordered by different border crops were not significantly different in all sampling periods in Tigoni site (Figure 3.1). However, border crop heights differed significantly. Potato height in Kabete site was not different from crop emergence up to the 8^{th} week, thereafter, wheat and non-bordered plots maintained the lowest potato heights (Figure 3.2). Border crops heights were significantly different during the growth period with maize being the tallest and wheat the shortest.

Photosynthetically active radiation intercepted by non-bordered potato plots was significantly ($p \leq 0.05$) higher than that of crop bordered potato plots. There were no significant differences among border crop types (Table 3.3). Potato varieties intercepted similar levels of PAR. Border crops did not affect potato leaf area development (Table 3.4).

Table 3.2: Potato and crop border height (Averaged over 4 sampling periods) during May-October 2007 long rains at NPRC, Tigoni and April-September 2007short rains at Kabete.

	Tigoni site					
	Potato height (cm)			Border crop height (cm)		
Border crop type (B)	Tigoni	Asante	B-mean	Tigoni	Asante	B-mean
No- border	51.7	33.3	42.5a	0.0	0.0	0.0
Maize	49.4	34.6	42.0a	104.0	101.6	102.8a
Sorghum	56.6	34.7	45.6a	57.5	53.1	55.3c
Wheat	55.3	41.3	48.3a	71.0	67.6	69.3b
Variety mean	**53.3a**	**36.0b**		**58.1a**	**55.6a**	
LSD (P≤0.05) Variety		4.5			ns	
LSD (P≤0.05) Border type		ns			9.9	
CV%		3.4			3.9	

	Kabete site					
	Potato height (cm)			Border crop height (cm)		
Border crop type (B)	Tigoni	Asante	B- mean	Tigoni	Asante	B- mean
No- border	54.9	35.9	45.4b	0.0	0.0	0.0
Maize	61.9	42.1	52.0a	159.3	144.2	151.8a
Sorghum	60.9	46.8	53.9a	93.8	94.6	94.2b
Wheat	52.0	43.2	47.6b	59.8	67.3	63.5c
Variety mean	**57.4a**	**42.0b**		**78.2a**	**76.5a**	
LSD (P≤0.05) Variety		13.5			ns	
LSD (P≤0.05) Border type		5.0			13.2	
CV%		4.6			1.4	

Table 3.3: Percentage of photosynthetically active radiation interception in potato varieties and border crops during April 2007- September 2007 long rains at Kabete

	% Potato PAR			% Border crop PAR		
Border crop type (B)	Tigoni	Asante	B- mean	Tigoni	Asante	B- mean
No- border	81.5	83.4	82.5 a	100.0	100.0	100.0 a
Maize	66.4	70.6	68.5 b	71.4	71.5	71.5 b
Sorghum	74.9	77.4	76.1 b	76.5	72.4	74.4 b
Wheat	68.5	69.0	68.8 b	74.5	72.8	73.6 b
Variety mean	**72.8**	**75.1**		**80.6**	**79.2**	
LSD ($P \leq 0.05$) variety		ns			ns	
LSD ($P \leq 0.05$) Border type		7.8			4.1	
CV%		2.0			1.9	

Table 3.4: Leaf area index of potato varieties subjected to different border crops during April 2007- September 2007 long rains at Kabete

	Tigoni site			Kabete site		
	Potato Leaf area index			Border crop Leaf area index		
Border crop type (B)	Tigoni	Asante	B-mean	Tigoni	Asante	B-mean
No- border	1.0	0.9	0.9a	0.9	0.8	0.9a
Maize	0.8	1.0	0.9a	0.8	1.0	0.9a
Sorghum	1.1	1.3	1.2a	1.1	1.2	1.1a
Wheat	1.1	0.8	0.9a	1.1	0.8	0.9a
Variety mean	**1.0a**	**1.0a**		**1.0**	**1.0**	
LSD ($P \leq 0.05$) variety		ns			ns	
LSD ($P \leq 0.05$) Border type		ns			ns	
CV%		12.2			10.7	

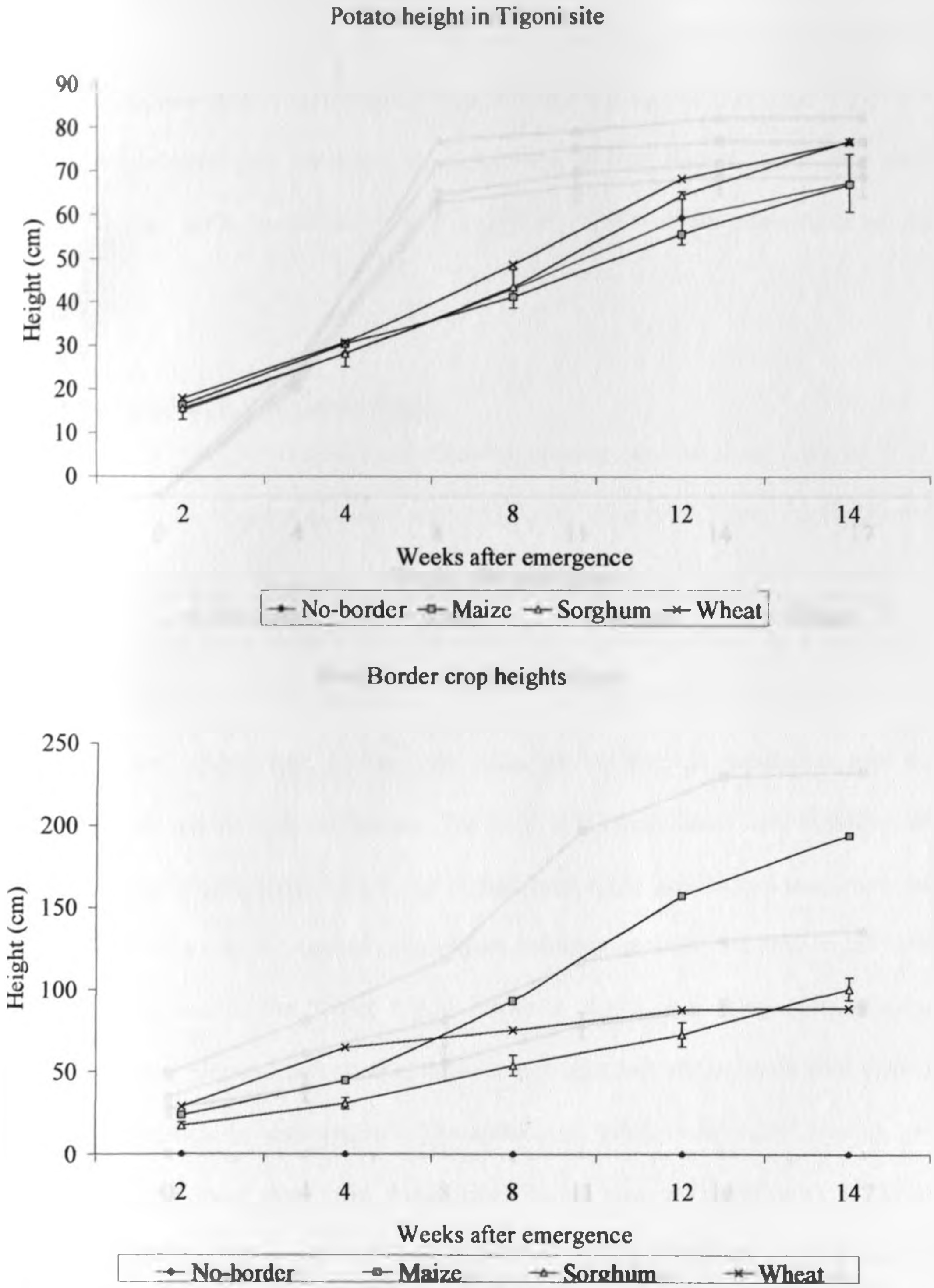


Figure 3.1. Height of potato plants and different border crops during the 2007 long rains at NPRC, Tigoni site (LSD bars inserted). (Data is averaged across two varieties)

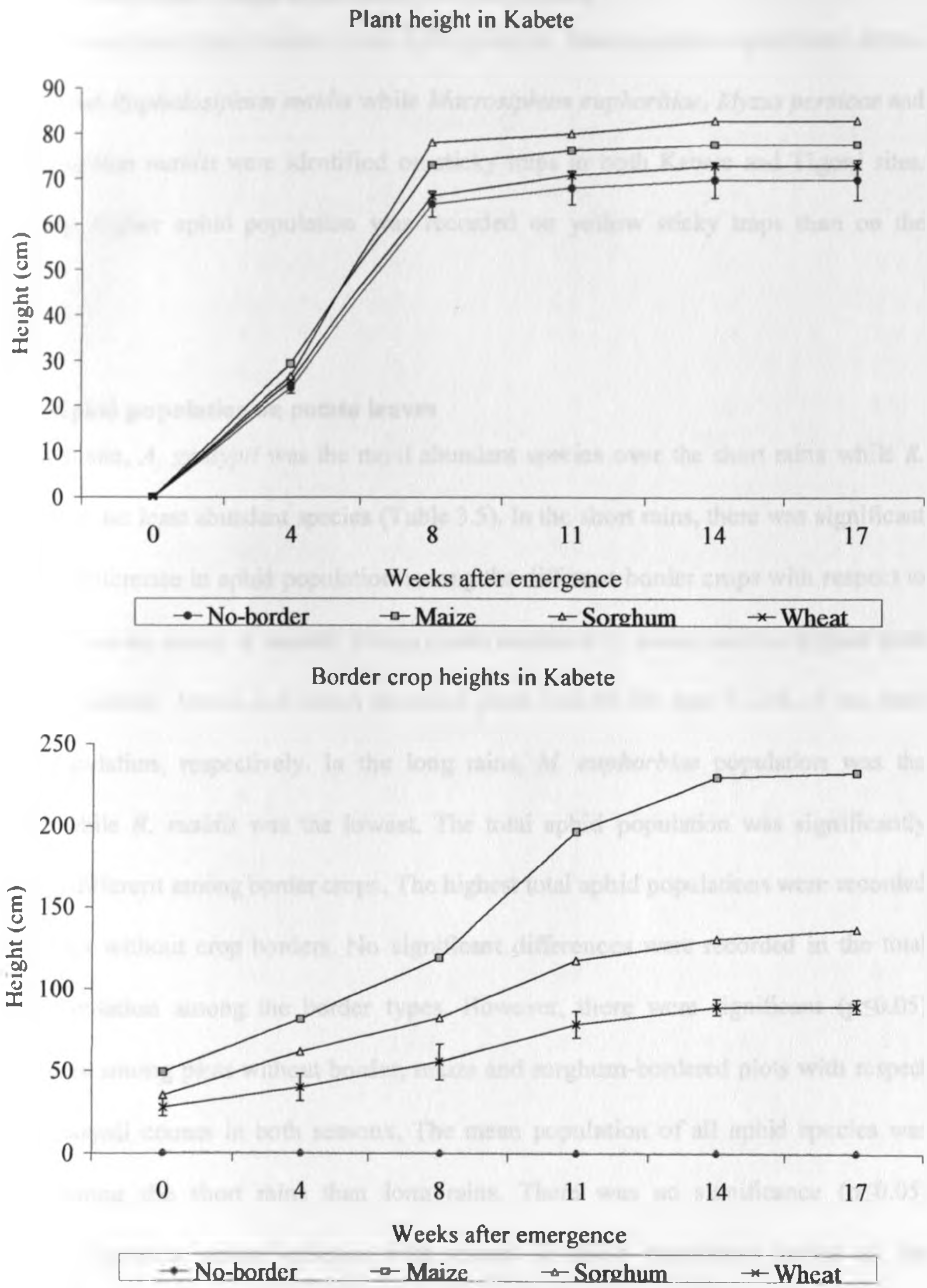


Figure 3.2. Height of potato plants and different border crops during the 2007 long rains at Kabete site (LSD bars inserted). (Data is averaged across two varieties)

3.4.4 Effect of border crops on potato aphid population

Aphid species identified on leaves were *Aphis gossypii, Macrosiphum euphorbiae, Myzus persicae* and *Rophalosiphum maidis* while *Macrosiphum euphorbiae, Myzus persicae* and *Rophalosiphum maidis* were identified on sticky traps in both Kabete and Tigoni sites. Generally, higher aphid population was recorded on yellow sticky traps than on the leaves.

3.4.4.1 Aphid population on potato leaves

At Tigoni site, *A. gossypii* was the most abundant species over the short rains while *R. maidis* was the least abundant species (Table 3.5). In the short rains, there was significant ($p \leq 0.05$) difference in aphid population among the different border crops with respect to all aphid species except *R. maidis*. Potato plants bordered by maize had the highest total aphid population. Maize and wheat bordered plots had 40.5% and 17.2% of the total aphid population, respectively. In the long rains, *M. euphorbiae* population was the highest while *R. maidis* was the lowest. The total aphid population was significantly ($p \leq 0.05$) different among border crops. The highest total aphid populations were recorded in potatoes without crop borders. No significant differences were recorded in the total aphid population among the border types. However, there were significant ($p \leq 0.05$) differences among plots without border, maize and sorghum-bordered plots with respect to A. gossypii counts in both seasons. The mean population of all aphid species was higher during the short rains than long rains. There was no significance ($p \leq 0.05$) difference between potato varieties with respect to aphid population during all the sampling periods.

Table 3.5: Mean number of aphids per 30 leaves of potato plants during the January-June 2007 short rains and May-October 2007 long rains at NPRC, Tigoni.

	Short rains				
	Aphid species				
Treatments	A. g	M. e	M. p	R. m	Total
No border	5.8	1.8	3.5	0.9	12.0
Maize	10.3	3.5	6.3	1.3	21.4
Sorghum	4.3	1.3	3.4	1.4	10.4
Wheat	3.4	2.2	3.3	0.2	9.1
LSD (P≤0.05)	4.6	1.5	2.0	ns	8.1
CV%	65.7	54.8	64.7	87.7	64.5
Variety*					
Tigoni	6.3	2.7	5.3	1.1	15.3
Asante	5.6	1.6	3.0	0.9	11.1
LSD (P≤0.05)	ns	ns	ns	ns	ns
CV%	33.4	40.1	33.4	77	19.7

	Long rains				
	Aphid species				
Treatments	A. g	M. e	M. p	R. m	Total
No border	0.8	0.6	0.3	0.1	1.8
Maize	0.1	0.3	0.1	0.1	0.6
Sorghum	0.2	0.4	0.1	0.1	0.8
Wheat	0.2	0.3	0.0	0.1	0.6
LSD (P≤0.05)	0.2	ns	0.1	ns	0.2
CV%	12.2	16.1	18.3	45.8	14.9
Variety*					
Tigoni	0.3	0.3	0.2	0.0	0.8
Asante	0.3	0.4	0.1	0.1	0.9
LSD (P≤0.05)	ns	ns	ns	ns	ns
CV%	29.8	25.1	42.7	0.0	8.1

M. e=*Macrosiphum euphorbiae;* M. p=*Myzus persicae;* A. g = *Aphis gossypii;*

R. m=*Rophalosiphum maidis* and ns- Denotes not significant at (P≤0.05).

(* denotes that data is averaged across two varieties)

At Kabete site, *R. maidis* was the most abundant while *M. persicae* was the least abundant species in the short rains (Table 3.6). Border crops significantly reduced aphid population over the short rains except *Rophalosiphum maidis*. *Macrosiphum euphorbiae* was the most abundant while *M. persicae* was the least abundant species in the long rains. *Macrosiphum euphorbiae* and *R. maidis* populations were significantly ($p \leq 0.05$) different among border crops during the long rains season with non- bordered plots supporting the highest aphid populations. The total population of all aphid species was higher during the short rains than during the long rains. The total aphid population differed among border crops during both the short and long rains with non- bordered plots generally supporting the highest total aphid population. Plots without border crops had (48.6%) of the total aphid population in the two seasons. There was no significant ($p \leq 0.05$) difference between the potato varieties with respect to aphid population during all the sampling periods.

Table 3.6: Mean number of aphids per 30 leaves of potato plants during the October 2006- February 2007 short rains and April-September 2007 long rains at Kabete.

Short rains					
	Aphid species				
Treatments	A.g	M.e	M.p	R.m	Total
No border	1.2	3.0	1.0	8.3	13.5
Maize	0.2	1.6	0.1	0.4	2.3
Sorghum	0.8	1.8	0.2	5.1	7.9
Wheat	0.6	1.8	0.2	1.2	3.8
LSD ($P \leq 0.05$)	0.7	1.2	0.5	ns	7.8
CV%	33.4	13	56.8	125.3	47.5
Variety*					
Tigoni	0.7	2.7	0.5	5.1	5.3
Asante	0.7	1.4	0.3	2.4	8.3
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns
CV%	33.7	38.6	48.7	147.4	86.6

Long rains					
	Aphid species				
Treatments	A.g	M.e	M.p	R.m	Total
No border	0.2	0.7	0.0	0.6	1.5
Maize	0.1	0.4	0.1	0.1	0.7
Sorghum	0.2	0.2	0.1	0.1	0.6
Wheat	0.1	0.1	0.2	0.1	0.5
LSD ($P \leq 0.05$)	ns	0.2	ns	0.1	0.2
CV%	29.9	42.1	104.7	27.7	29.9
Variety*					
Tigoni	0.1	0.2	0.1	0.3	0.7
Asante	0.2	0.5	0.1	0.1	0.9
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns
CV%	76.0	35.8	129.5	59.9	45.3

M.e=Macrosiphum euphorbiae; M.p=Myzus persicae; A.g = Aphis gossypii;

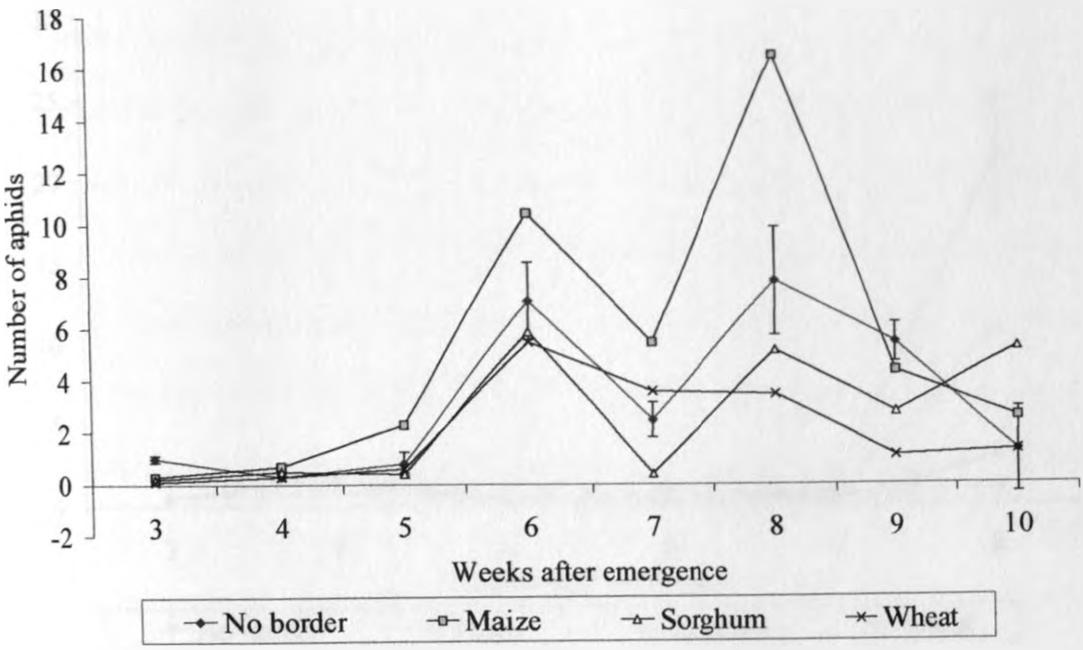
R.m=Rophalosiphum maidis and ns- Denotes Not significant at ($p \leq 0.05$).

(* denotes that data is averaged across two varieties)

t Tigoni site, aphid population gradually increased during the short rains in all the eatments and declined on the 6^{th} week after emergence (Figure 3.3). There was a opulation build up in the 7^{th} week, which attained peak for the maize border at 8^{th} week nd made it significantly different from all other weeks of growth. There was significant $p \leq 0.05$) difference in border crops with respect to the total aphid counts over the potato growth period. Non- bordered plots supported the highest total aphid populations recorded on the third week after emergence but from the 4^{th} week to the 9th week, maize bordered plots had the highest population. Total aphid population counts in non- bordered plots remained high from the 4^{th} to 8^{th} week after emergence during the long rains. Aphid population differed significantly ($p \leq 0.05$) between border crops over the two seasons.

At Kabete site, Aphid population remained generally low during the short rains from emergence up to the 7^{th} week after crop emergence (Figure 3.4). Aphid population increased drastically after the 7^{th} week in all the treatments attaining a peak at 8^{th} week after emergence. Aphid population recorded on the 7^{th} week differed from those of other weeks of growth. Maize bordered plots maintained the lowest aphid population over the short rains. Differences of aphid population numbers between non - bordered plots and other crop bordered plots were significantly ($p \leq 0.05$) high during the 5^{th}, 6^{th}, 7^{th} and 8^{th} weeks after emergence. During the long rains, aphid population increased in all the treatments for the first two weeks attaining a peak between the 4^{th} and 5^{th} week after emergence then declined in all treatments. Aphid population was significantly ($p \leq 0.05$) different among border crops over all the sampling periods except the 7^{th} week after emergence during the long rains.

Mean number of aphids during short rains



Mean number of aphids during long rains

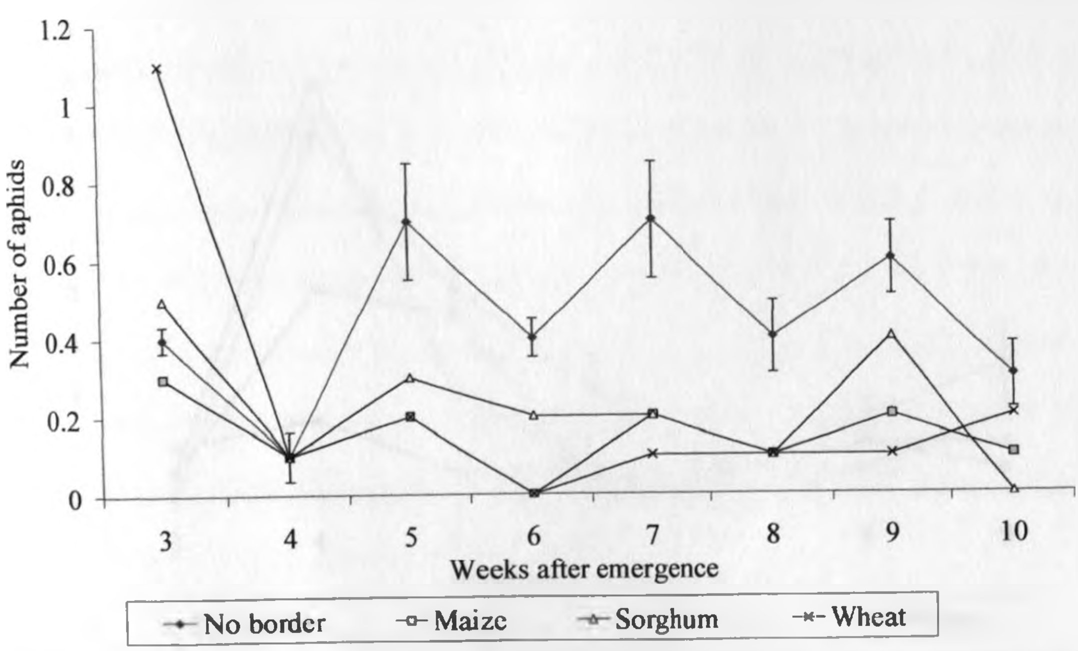


Figure 3.3. Aphid population collected in leaf samples in different border crop treatments during the 2007 short rains and long rains at NPRC, Tigoni (LSD bars inserted). (Data is averaged across two varieties)

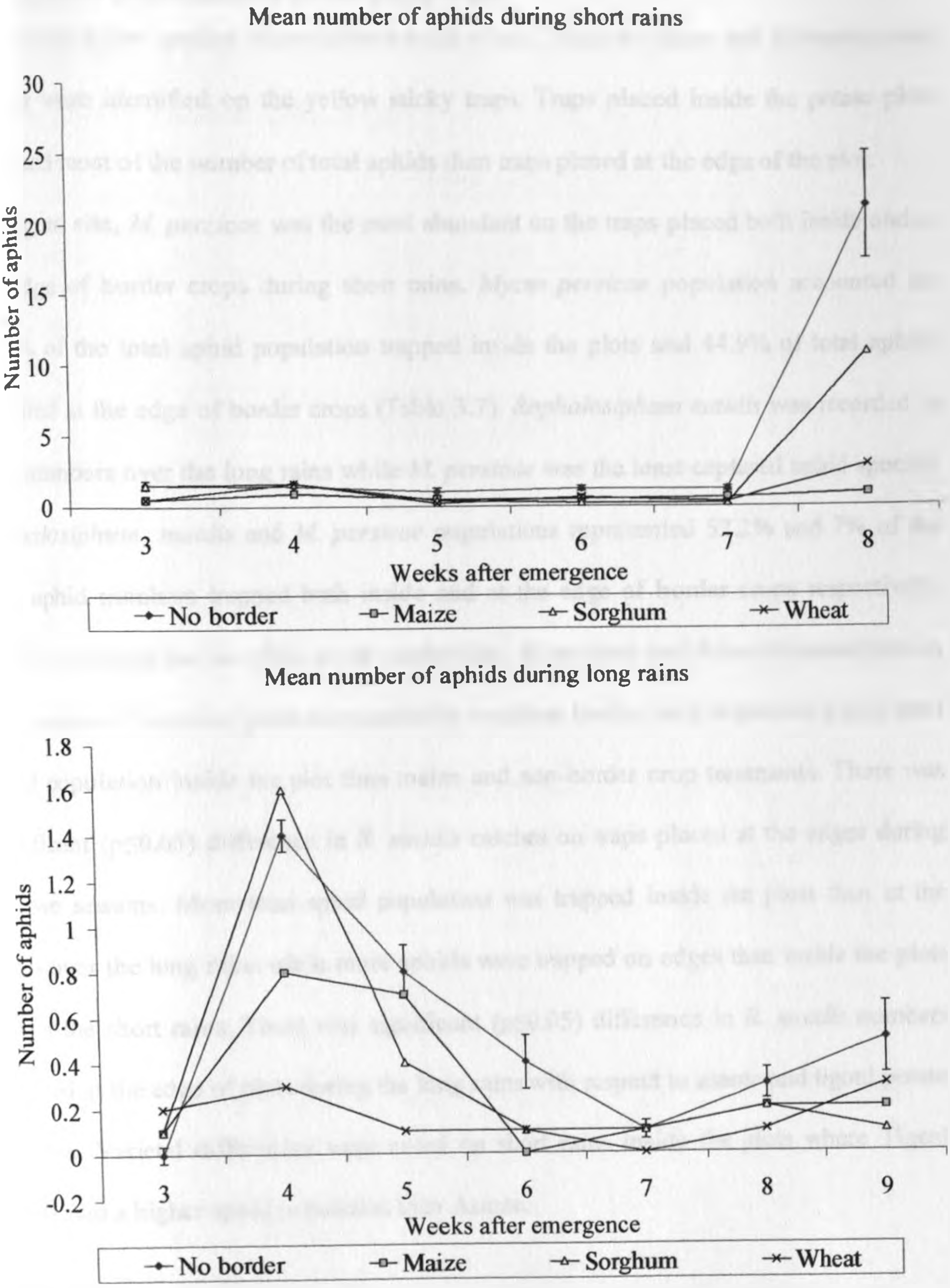


Figure 3. 4. Aphid population trends in leaf samples collected from plots subjected to different border crops during the 2007 short and long rains at Kabete (LSD bars inserted). (Data is averaged across two varieties)

3.4.2 Aphid population on yellow sticky traps

Three alate aphid species *Macrosiphum euphorbiae*, *Myzus persicae* and *Rophalosiphum maidis* were identified on the yellow sticky traps. Traps placed inside the potato plots captured most of the number of total aphids than traps placed at the edge of the plot.

At Tigoni site, *M. persicae* was the most abundant on the traps placed both inside and at the edge of border crops during short rains. *Myzus persicae* population accounted for 43.8% of the total aphid population trapped inside the plots and 44.9% of total aphids captured at the edge of border crops (Table 3.7). *Rophalosiphum maidis* was recorded in high numbers over the long rains while *M. persicae* was the least captured aphid species. *Rophalosiphum maidis* and *M. persicae* populations represented 52.2% and 7% of the total aphid numbers trapped both inside and at the edge of border crops respectively. Border crop type had no effect on *M. euphorbiae*, *M.persicae* and *R.maidis* inside plots in both seasons. However, plots surrounded by sorghum border crop registered a high total aphid population inside the plot than maize and non-border crop treatments. There was significant ($p \leq 0.05$) difference in *R. maidis* catches on traps placed at the edges during the two seasons. More total aphid population was trapped inside the plots than at the edges over the long rains while more aphids were trapped on edges than inside the plots during the short rains. There was significant ($p \leq 0.05$) difference in *R. maidis* numbers captured at the edge of plots during the long rains with respect to asante and tigoni potato varieties. Varietal differences were noted on short rains inside the plots where Tigoni variety had a higher aphid population than Asante.

Table 3.7: Mean number of alate aphid catches per one sticky trap placed inside the plot and at the edge of border crops during the January-June 2007 short rains and May-October 2007 long rains at NPRC, Tigoni.

	Short rains							
	Inside plot				Outside plot			
Treatments	M. e	M. p	R. m	Total	M. e	M. p	R. m	Total
Border type								
No-border	3.5	5.1	3.9	12.5	4.7	8.7	5.6	19.0
Maize	5.8	7.1	3.0	15.9	4.1	5.7	4.4	14.2
Sorghum	4.2	6.6	3.3	14.1	2.6	4.4	2.5	9.5
Wheat	3.3	5.6	4.1	13.0	2.6	7.1	5.3	15.0
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns	4.0	2.5	ns
CV%	43.8	24.4	14.5	19.5	37.3	20.3	29.8	29.9
Variety*								
Tigoni	5.0	6.6	3.8	15.4	4.3	6.9	4.3	15.5
Asante	3.4	5.6	3.4	12.4	2.8	6.1	4.7	13.6
LSD ($P \leq 0.05$)	ns	ns	ns	2.6	ns	ns	ns	ns
CV%	54.6	17.7	30.1	3.6	53.8	14.0	23.7	13.9

	Long rains							
	Inside plot				Outside plot			
Treatments	M. e	M. p	R. m	Total	M. e	M. p	R. m	Total
Border type								
No-border	2.5	1.2	4.6	8.3	2.6	0.9	4.2	7.7
Maize	3.2	0.2	4.3	7.7	4.1	0.6	2.0	6.7
Sorghum	4.7	0.6	6.2	11.5	2.3	0.2	3.3	5.8
Wheat	3.3	0.5	4.8	8.6	3.1	0.3	3.7	7.1
LSD ($P \leq 0.05$)	ns	ns	ns	3.0	ns	ns	1.6	ns
CV%	11.9	64.2	14.4	13.1	23	63.2	13.4	11.4
Variety*								
Tigoni	3.7	0.3	4.6	8.6	3.6	0.3	1.4	5.3
Asante	3.1	0.9	5.3	9.3	2.5	0.7	5.1	8.3
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns	ns	1.0	ns
CV%	21.4	47.7	18.9	20.3	43.1	68.9	9	13.5

M. e=Macrosiphum euphorbiae; M. p=Myzus persicae ;R. m=Rophalosiphum maidis and ns- Denotes not significant at ($p<0.05$). (* denotes that data is averaged across two varieties)

At Kabete, *M. persicae* was the most abundant and *R. maidis* the least abundant aphid species on sticky traps placed inside the plot while *M. euphorbiae* was the most abundant and *R. maidis* the least abundant on traps placed at the edge of border crops during the short rains (Table 3.8). Generally, border crop types did not affect the total aphid populations of *M. euphorbiae* and *R. maidis* inside the plots in both seasons. *Rophalosiphum maidis* population was 66.6% and 70% of the total aphid population trapped inside and at the plot edges respectively, while *M. persicae* population was 10.6% and 10% of the total aphids trapped inside and at the plot edges respectively. Where else aphids trapped at the edges of different crop borders over the short rains were not significantly ($p \leq 0.05$) different; traps at edges of plots without crop borders captured the highest aphid population during long rains. High population of aphids was recorded over the long rains than the short rains. There was no significant ($p \leq 0.05$) difference on total aphid population in all the treatments on traps placed inside the plots during the two seasons and aphid population did not differ between potato varieties over both seasons.

Table 3.8: Mean number of alate aphid catches per one sticky trap placed inside potato plots and at the edge of border crops during the October 2006- February 2007 short rains and April-September 2007 long rains at Kabete.

Short rains								
	Inside plot				Outside plot			
Treatments	M. e	M. p	R. m	Total	M. e	M. p	R. m	Total
Border type								
No-border	2.5	7.0	0.0	9.5	4.8	3.7	0.2	8.7
Maize	2.7	5.7	0.2	8.6	1.7	3.7	0.0	5.4
Sorghum	3.0	4.2	0.5	7.7	5.5	3.2	0.5	9.2
Wheat	1.8	2.5	1.2	5.5	2.5	2.8	1.3	6.6
LSD (P≤0.05)	ns	3.8	ns	ns	ns	ns	ns	ns
CV%	20.0	41.2	126.0	21.9	48.9	32.3	129.9	24.5
Variety*								
Tigoni	2.8	5.5	0.8	9.1	1.9	0.7	0.5	3.1
Asante	2.2	4.2	0.1	6.5	5.3	6.0	0.5	11.8
LSD (P≤0.05)	ns	ns	ns	ns	ns	2.4	ns	ns
CV%	43.2	14.8	204.1	10.4	61.4	20.1	61.2	51.5

Long rains								
	Inside plot				Outside plot			
Treatments	M. e	M. p	R. m	Total	M. e	M. p	R. m	Total
Border type								
No-border	9.8	5.5	26.1	41.4	11.4	7.9	42.7	62.0
Maize	8.6	3.4	25.3	37.3	6.3	2.0	21.9	30.2
Sorghum	9.2	2.8	27.6	39.6	3.2	3.1	21.1	27.4
Wheat	8.3	5.1	26.3	39.7	5.7	3.7	21.9	31.3
LSD (P≤0.05)	ns	ns	ns	ns	6.7	4.9	20.8	30.5
CV%	5.6	31.2	8	10.4	20.8	17.5	19.5	13.2
Variety*								
Tigoni	11.3	6.8	31.3	49.4	6.9	4.1	28.0	39.0
Asante	6.7	1.6	21.4	29.7	6.3	4.3	25.4	36.0
LSD (P≤0.05)	ns	2.6	ns	ns	ns	ns	ns	ns
CV%	36.9	17.5	12.4	16.2	28	54.1	19.4	17.1

M. e=Macrosiphum euphorbiae; M. p=Myzus persicae and R.m=Rophalosiphum maidis

ns- Denotes not significant at (p<0.05). (* denotes that data is averaged across two varieties)

At Tigoni site, total aphid population trend on traps placed inside plot during the short rains showed slight decline from the 3rd to the 4th week after emergence which was followed by a build up in all the treatments (Figure 3.5). Alate aphid landing rates reached the peak in Maize, Sorghum and plots without border crops on the 9th week and Wheat-bordered plots on the 10th week after emergence of potato crop. Total aphid population was significantly ($p \leq 0.05$) different on the 3rd, 4th and 8th weeks after emergence. Over the long rains season, highest alate aphid population peaks in all the treatments except wheat- bordered plots were reached on the 7th week after emergence. Although aphid population trapped inside the plots over the short rains was not significantly different in all sampling periods, there was significant ($p \leq 0.05$) difference on aphid trapped during the long rains with respect to border crop types.

The highest total aphid population peak on traps placed at the edge of border crops during the short rains in all the treatments except maize was reached on the 9th week after emergence (Figure 3.6). Aphid population was significantly ($p \leq 0.05$) different among border crops in all-sampling periods except on the 3rd and 7th weeks after emergence. During the long rains, aphid population in maize, wheat and non-bordered plots attained a peak between 6th and 7th week after emergence. Total aphid counts in reference to all treatments were significantly ($p \leq 0.05$) different in the traps placed at the edges of border crops in all the sampling periods except on 5th and 10th week after emergence. Traps placed at the edges trapped the lowest and the highest total aphid population on sorghum and non bordered plots respectively during the short and long rains. The lowest aphid population was recorded on traps placed at the edges of sorghum- bordered plots.

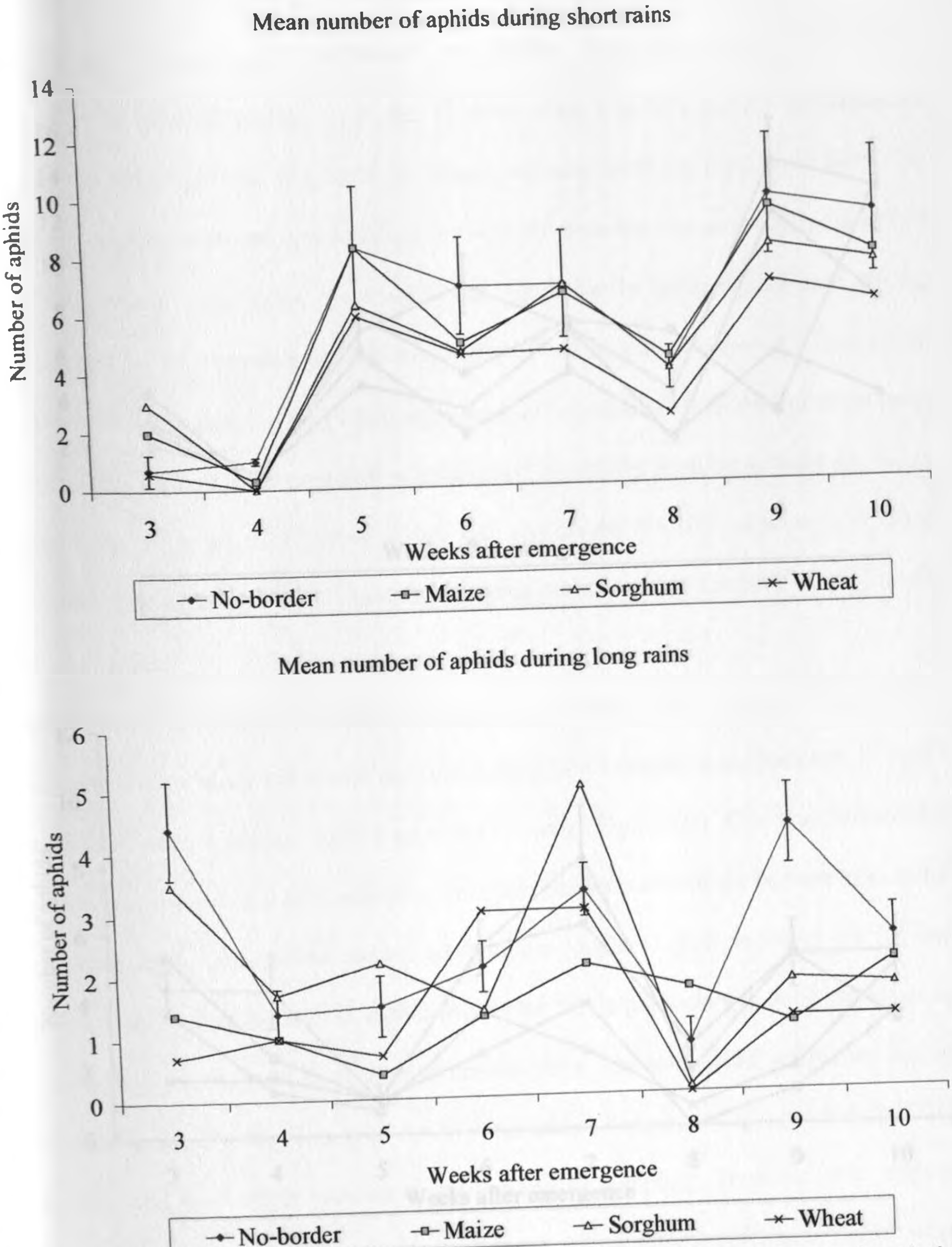


Figure3. 5. Alate aphid population trends on sticky traps placed inside potato plots during the 2007 short and long rains at NPRC, Tigoni (LSD bars inserted). (Data is averaged across two varieties)

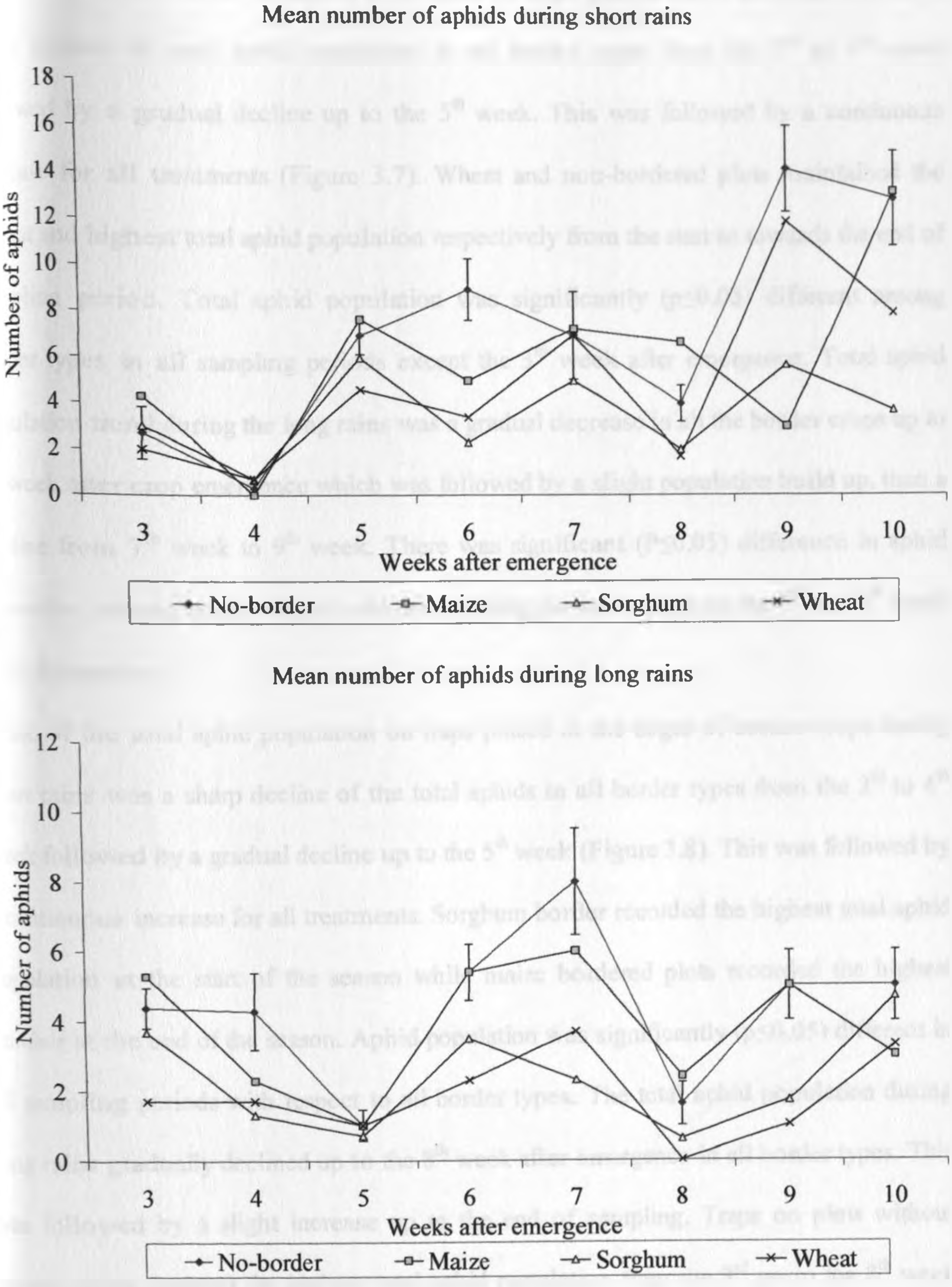


Figure 3.6. Trends of alate aphid population on sticky traps placed at the edge of border crops during the 2006/2007 short and long rains at NPRC, Tigoni (LSD bars inserted). (Data is averaged across two varieties)

In Kabete site, the trend during the short rains on traps placed inside the plots showed a sharp decline of total aphid population in all border types from the 3rd to 4th week followed by a gradual decline up to the 5th week. This was followed by a continuous increase for all treatments (Figure 3.7). Wheat and non-bordered plots maintained the lowest and highest total aphid population respectively from the start to towards the end of sampling period. Total aphid population was significantly ($p \leq 0.05$) different among border types in all sampling periods except the 3rd week after emergence. Total aphid population trend during the long rains was a gradual decrease in all the border crops up to 6th week after crop emergence which was followed by a slight population build up, then a decline from 7th week to 9th week. There was significant ($P \leq 0.05$) difference in aphid population among border crops in all-the sampling periods except on the 4th and 6th week after emergence.

Trend of the total aphid population on traps placed at the edges of border crops during short rains was a sharp decline of the total aphids in all border types from the 3rd to 4th week followed by a gradual decline up to the 5th week (Figure 3.8). This was followed by a continuous increase for all treatments. Sorghum border recorded the highest total aphid population at the start of the season while maize bordered plots recorded the highest number at the end of the season. Aphid population was significantly ($p \leq 0.05$) different in all sampling periods with respect to all border types. The total aphid population during long rains gradually declined up to the 8th week after emergence in all border types. This was followed by a slight increase up to the end of sampling. Traps on plots without border crops captured the highest total aphid population from the 3rd up to the 8th week after emergence. Alate aphid landing rates were lowest on the 5th and 8th weeks after emergence during the short and long rains, respectively.

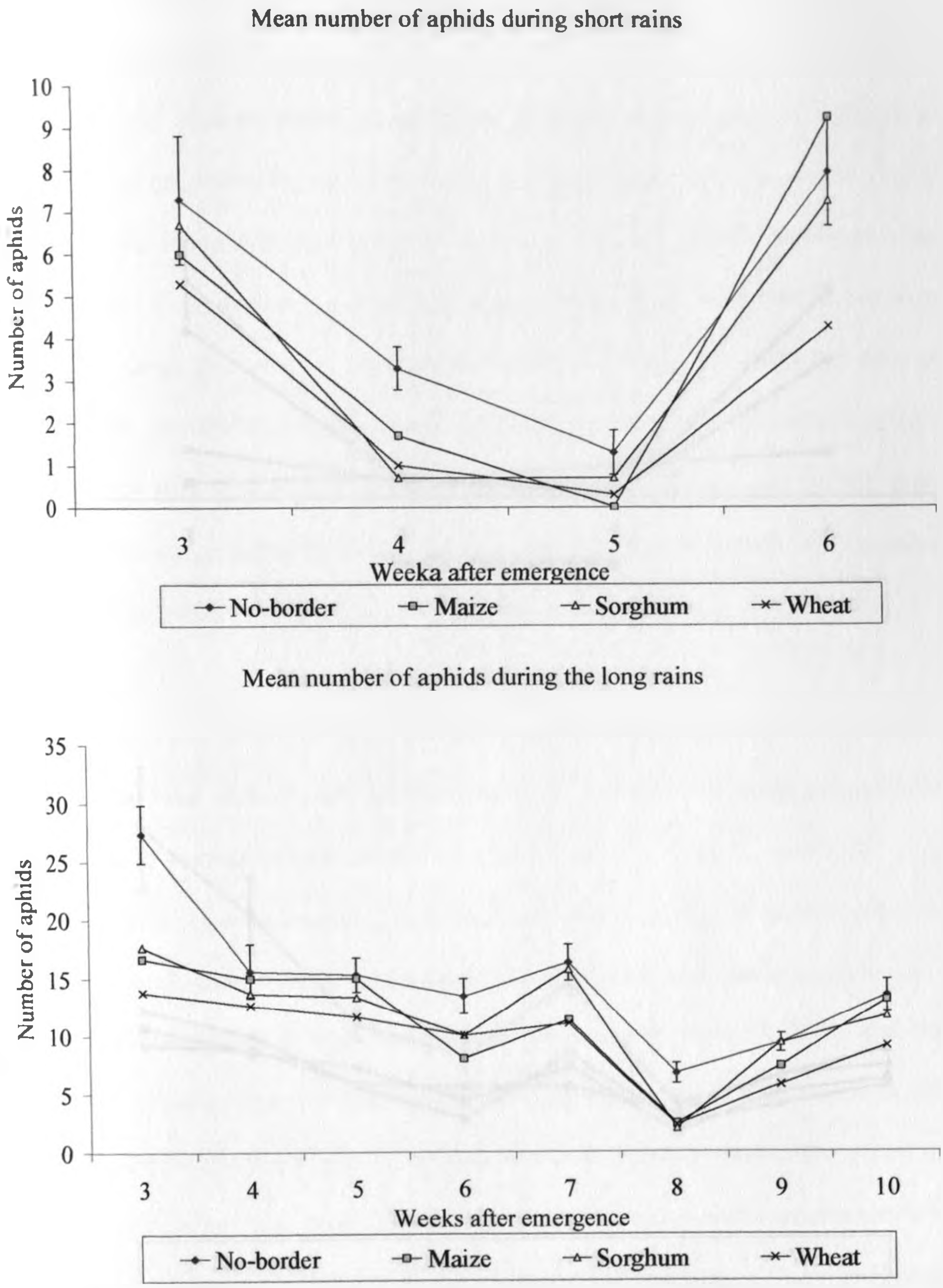


Figure 3.7. Trends of the mean alate aphid population on sticky traps placed inside potato plots during the 2006/ 2007 short and long rains at Kabete (LSD bars inserted). (Data is averaged across two varieties)

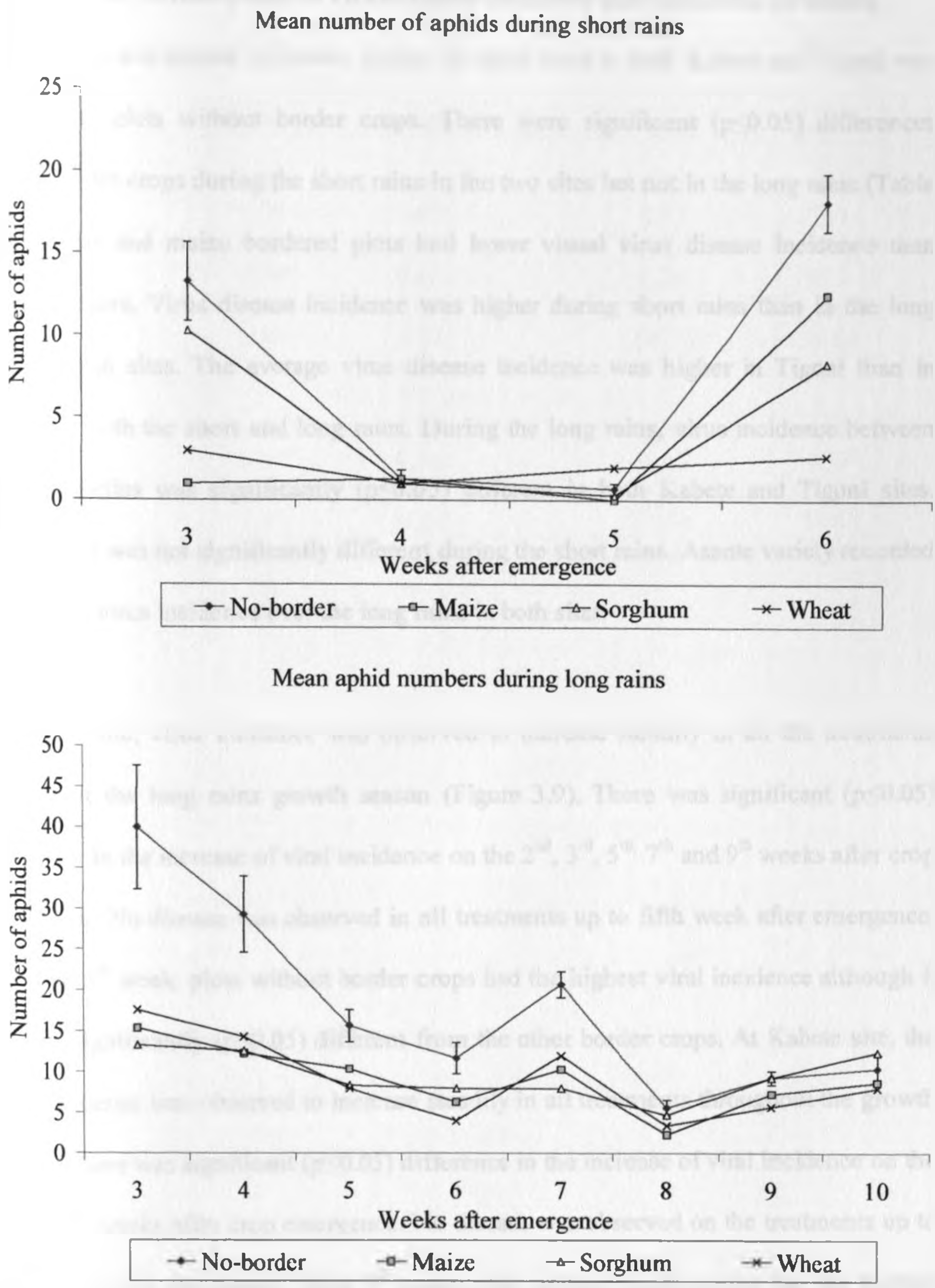


Figure 3.8.Alate aphid population dynamics on sticky traps placed at the edge of border crops during the 2006/2007 short and long rains at Kabete (LSD bars inserted). (Data is averaged across two varieties)

3.4.5 Effect of border crops on virus disease incidence and virus titre on tubers

The highest viral disease incidence during the short rains in both Kabete and Tigoni was recorded in plots without border crops. There were significant ($p \leq 0.05$) differences among border crops during the short rains in the two sites but not in the long rains (Table 3.9). Wheat and maize bordered plots had lower visual virus disease incidence than fallow borders. Virus disease incidence was higher during short rains than in the long rains in both sites. The average virus disease incidence was higher in Tigoni than in Kabete in both the short and long rains. During the long rains, virus incidence between potato varieties was significantly ($p \leq 0.05$) different in both Kabete and Tigoni sites. However, it was not significantly different during the short rains. Asante variety recorded the highest virus incidence over the long rains in both sites.

At Tigoni site, virus incidence was observed to increase steadily in all the treatments throughout the long rains growth season (Figure 3.9). There was significant ($p \leq 0.05$) difference in the increase of viral incidence on the 2^{nd}, 3^{rd}, 5^{th}, 7^{th} and 9^{th} weeks after crop emergence. No disease was observed in all treatments up to fifth week after emergence. After the 5^{th} week, plots without border crops had the highest viral incidence although it was not significantly ($p \leq 0.05$) different from the other border crops. At Kabete site, the virus incidence was observed to increase steadily in all treatments throughout the growth season. There was significant ($p \leq 0.05$) difference in the increase of viral incidence on the 5^{th} and 7^{th} weeks after crop emergence. No disease was observed on the treatments up to third week after emergence. After 5^{th} week, plots without border crops had the highest viral incidence.

Table 3.9: Percentage visual virus disease incidence in potato plots surrounded by different border crops during the short and long rains at NPRC, Tigoni and Kabete.

	Short rains		Long rains	
Treatment	Tigoni	Kabete	Tigoni	Kabete
Border type				
Fallow-border	0.92	0.81	0.23	0.14
Maize	0.80	0.67	0.15	0.11
Sorghum	0.80	0.73	0.21	0.10
Wheat	0.79	0.46	0.21	0.12
LSD (P≤0.05)	0.04	0.09	ns	ns
CV%	2.50	5.50	18.70	34.80
Variety*				
Tigoni	0.83	0.59	0.03	0.00
Asante	0.83	0.74	0.37	0.23
LSD (P≤0.05)	ns	ns	0.15	0.22
CV%	1.20	11.60	21.30	54.00

ns- Denotes not significant at ($p<0.05$). (* denotes that data is averaged across two varieties)

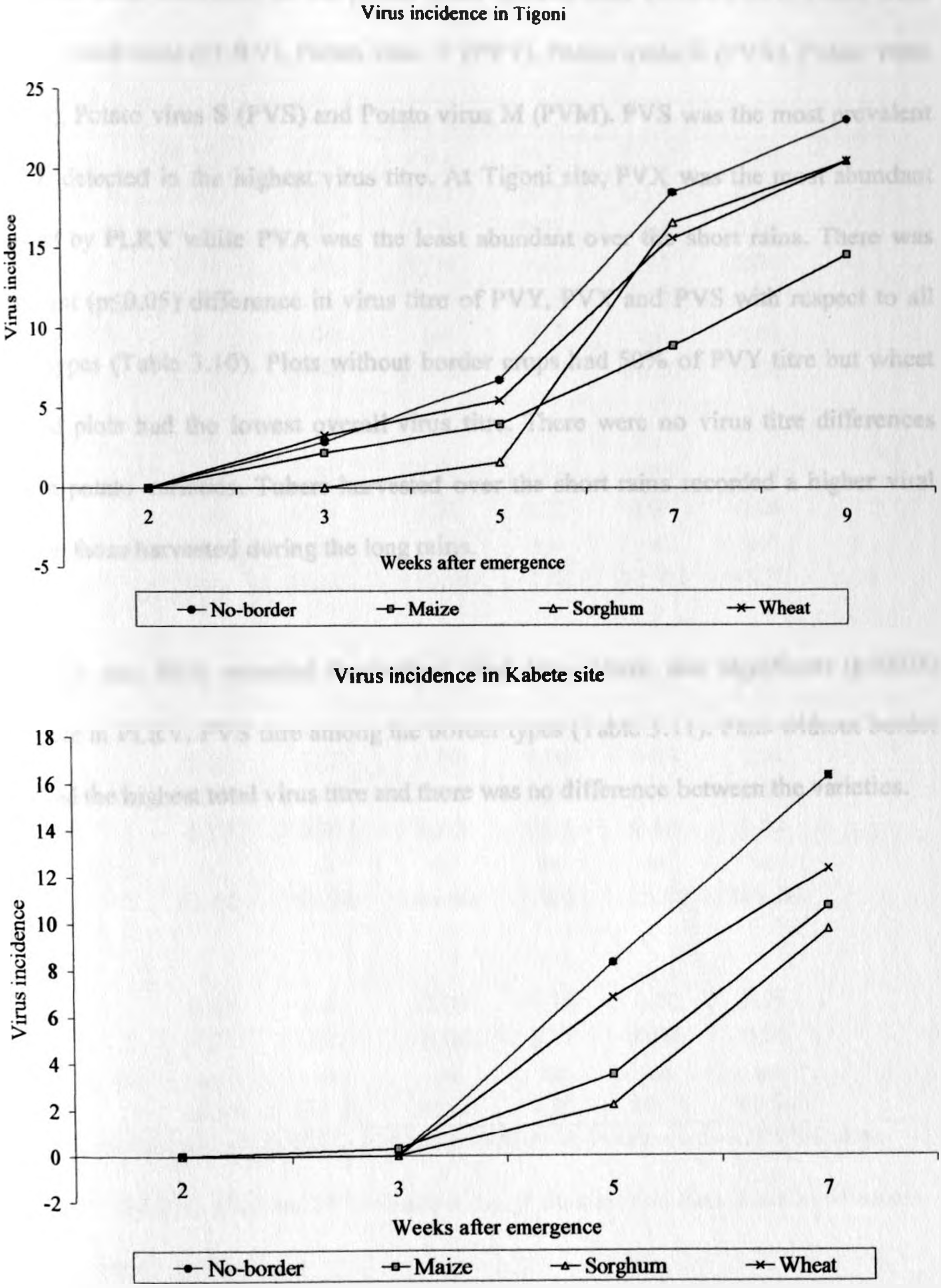


Figure 3.9 Potato virus incidence progress curves, in potato plots surrounded by different border crops during the 2007 long rains at NPRC, Tigoni and Kabete (LSD bars inserted).

Six viruses were identified in the potato tuber sprouts after DAS-ELISA. These were Potato leaf roll virus (PLRV), Potato virus Y (PVY), Potato virus X (PVX), Potato virus A (PVA), Potato virus S (PVS) and Potato virus M (PVM). PVS was the most prevalent and was detected in the highest virus titre. At Tigoni site, PVX was the most abundant followed by PLRV while PVA was the least abundant over the short rains. There was significant ($p \leq 0.05$) difference in virus titre of PVY, PVX and PVS with respect to all border types (Table 3.10). Plots without border crops had 50% of PVY titre but wheat bordered plots had the lowest overall virus titre. There were no virus titre differences between potato varieties. Tubers harvested over the short rains recorded a higher viral titre than those harvested during the long rains.

At Kabete site, PVS recorded the highest viral titre. There was significant ($p \leq 0.05$) difference in PLRV, PVS titre among the border types (Table 3.11). Plots without border crops had the highest total virus titre and there was no difference between the varieties.

Table 3.10: Potato virus titre on tubers harvested over the 2007 short rains and long rains at NPRC, Tigoni.

	Short rains					
Treatments	PLRV	PVX	PVA	PVS	PVM	PVY
No- border	0.31	0.03	0.01	0.67	0.13	0.09
Maize	0.32	0.06	0.01	0.73	0.08	0.04
Sorghum	0.34	0.05	0.04	0.63	0.11	0.06
Wheat	0.31	0.01	0.01	0.57	0.10	0.04
LSD (P≤0.05)	ns	0.04	ns	0.13	ns	0.01
CV%	15.40	50.30	109.80	19.30	62.30	8.90
Variety*						
Tigoni	0.16	0.01	0.01	0.33	0.05	0.04
Asante	0.16	0.03	0.01	0.32	0.05	0.06
LSD (P≤0.05)	ns	ns	ns	ns	ns	ns
CV%	5.80	66.60	109.80	17.00	11.70	48.10

	Long rains					
Treatments	PLRV	PVX	PVA	PVS	PVM	PVY
No- border	0.17	0.03	0.04	0.89	0.09	0.01
Maize	0.15	0.08	0.02	0.96	0.07	0.01
Sorghum	0.11	0.01	0.06	0.75	0.06	0.01
Wheat	0.12	0.01	0.02	0.66	0.03	0.00
LSD (P≤0.05)	ns	ns	ns	ns	ns	ns
CV%	34.10	55.90	46.40	7.00	45.10	109.20
Variety*						
Tigoni	0.12	0.04	0.03	0.75	0.07	0.01
Asante	0.15	0.02	0.04	0.88	0.06	0.01
LSD (P≤0.05)	ns	ns	ns	ns	ns	ns
CV%	26.90	121.80	86.40	7.80	89.20	49.30

PLRV-Potato leaf roll virus, PVX- Potato virus X, PVA-Potato virus A, PVS-Potato virus S, PVM-Potato virus M, PVY-Potato virus. (* denotes that data is averaged across two varieties)

Table 3.11: Potato virus titre on tubers planted during April 2007 – September 2007 long rains in plots surrounded by border crops at Kabete

Treatments	PLRV	PVX	PVA	PVS	PVM	PVY
No-border	0.18	0.02	0.05	1.11	0.45	0.01
Maize	0.14	0.01	0.04	1.10	0.15	0.00
Sorghum	0.14	0.02	0.02	1.16	0.33	0.00
Wheat	0.11	0.03	0.03	1.06	0.24	0.00
LSD (P≤0.05)	0.06	ns	ns	0.08	ns	ns
CV%	9.00	72.40	37.70	7.20	55.50	122.90
Variety*						
Tigoni	0.13	0.01	0.03	1.10	0.29	0.01
Asante	0.15	0.03	0.04	1.12	0.29	0.00
LSD (P≤0.05)	ns	ns	ns	ns	ns	ns
CV%	22.00	75.40	40.30	4.30	77.50	223.70

PLRV-Potato leaf roll virus, PVX- Potato virus X, PVA-Potato virus A, PVS-Potato virus S, PVM-Potato virus M, PVY-Potato virus.

(* denotes that data is averaged across two varieties)

3.4.6 Effect of border crops on potato tuber yield

At Tigoni site, plots without border crop had the highest total tuber yield during the short rains season (Table 3.12). On the other hand, wheat and sorghum significantly reduced total tuber weights. Sorghum bordered plots had the lowest total tuber yield during the long rains season. More seeds than ware potato grades were produced over both the short and long rains. Total yield weights and ware weights were significantly ($p \leq 0.05$) different among border crop types during the two seasons. There was significant ($p \leq 0.05$) difference in chatts weights among treatments during the short rains and seed weights during the long rains. Plots without border crops had 17.5% more total yield during the short rains than in long rains season. Wheat bordered plots recorded 18% less total yield during short rains than long rains. Plots without border crops produced 38% and 19% more unmarketable tubers weights than sorghum bordered plots during the short and long rains respectively. Higher tuber yield was recorded during the long rains than short rain season in Tigoni site in terms of the total weight and ware. Differences in ware weight between varieties were significantly ($p \leq 0.05$) different during the two seasons at Tigoni. Tigoni variety had higher yield than Asante in the short rains while Asante had higher yields in the long rains.

At Kabete site, total yield weights were significantly ($p \leq 0.05$) different among border crop treatments in both seasons (Table 3.13). Plots without border crops produced higher total tuber weight compared to the other border types during the two seasons. The plots without border crops had 18.4% and 36.6% more total tuber weights during short and long rain seasons respectively. Long rain season was recorded to have higher total tuber yield than short rains. There was no significant (p≤0.05) difference between varieties for total tuber yield.

Table 3.12: Potato tubers mean grade weight during the short and long rains season at NPRC, Tigoni.

Short rains				
	Tuber weight (kg)			
Treatments	Ware(>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total weight
No-border	15.4	16.6	1.4	33.4
Maize	8.2	18.5	1.8	28.5
Sorghum	8.3	16.2	0.9	25.4
Wheat	7.5	17.0	1.2	25.7
LSD (P≤0.05)	5.8	ns	0.5	5.7
CV%	40.7	11.3	18.9	14.0
Variety*				
Tigoni	6.2	18.0	1.4	25.6
Asante	13.5	16.1	1.3	30.9
LSD (P≤0.05)	2.9	ns	ns	ns
CV%	8.5	11.0	31.5	5.6

Long rains				
	Tuber weight (kg)			
Treatments	Ware (>55mm)	Seed (25-55mm)	Chatts (<25mm)	Total weight
No-border	11.9	14.6	1.1	27.6
Maize	10.2	17.4	0.9	28.5
Sorghum	7.5	13.6	0.9	22.0
Wheat	13.1	17.3	1.1	31.5
LSD (P≤0.05)	3.5	3.8	ns	6.2
CV%	22.5	20.3	5.1	18.3
Variety*				
Tigoni	12.1	17.8	1.1	31.0
Asante	9.2	13.6	0.9	23.7
LSD (P≤0.05)	1	ns	ns	ns
CV%	2.7	11.8	23.8	7.9

ns denotes Not significant at p≤0.05. (* denotes that data is averaged across two varieties)

Table 3.13: Potato tubers mean grade weight during October- February 2006 short rains and April-September 2007 long rains at Kabete.

	Tuber weight (kg)	
	Short rains 2006	Long rains 2007
Treatments	Total weight	Total weight
Border type		
No -border	35.3	36.7
Maize	28.8	36.6
Sorghum	28.8	23.3
Wheat	29.0	35.7
Mean	**30.5**	**33.0**
LSD (P≤0.05)	5.1	6.1
CV%	15.0	1.6
Variety*		
Tigoni	29.0	38.0
Asante	32.0	28.0
Mean	**30.5**	**33.0**
LSD (P≤0.05)	ns	ns
CV%	15.0	10.5

Ns= not significant at p≤0.05 and Total weights = Seed + Ware + Chatts. (Data is averaged across two varieties)

3.4.7 Relationship between growth parameters, aphid population, virus incidence and yield.

There was a significant positive correlation between aphid population and virus disease incidence at Tigoni and Kabete sites during the short rains (Table 3.14). Aphid population and tuber yield were not significantly correlated in Kabete site, but were significantly negative correlated in Tigoni site.

There was significant negative correlation between border PAR, potato PAR and potato tuber yield in Kabete during the long rains (Table 3.15). Border and potato heights were significantly negatively correlated with aphid population, virus incidence and virus titre.

However, Aphid population significantly positively correlated with virus disease accumulation and affected tuber yield negatively.

Border and potato height were not significantly correlated with aphid population, virus incidence and potato tuber yield at Tigoni site during the long rains. However, virus titre negatively correlated with border height (Table 3.16). There was a significant positive correlation between aphid population, virus incidence and virus titre and a negative correlation between aphid population, virus disease and yield.

Table 3.14: Relationship between aphids, viral incidence and potato tuber yield at Kabete and Tigoni during the 2006 short rains.

	Kabete site		
	Aphid population	Virus incidence	
Virus incidence	0.85*		
Yield	-0.23	-0.69**	
	Tigoni site		
	Aphid population	Virus incidence	Virus titre
Virus incidence	0.99*		
Virus titre	0.83**	0.78*	
Yield	-0.99*	-0.97**	-0.90*

Correlation is significant at the 0.05 level (two tailed)

(Virus titre was not determined in Kabete site)

Table 3.15: The relationships between border crops height, border crops Photosynthetically active radiation (PAR) interception, potato crop height, potato PAR, aphid populations, virus incidence and potato tuber yield at Kabete during the long rains 2007.

	Border PAR	Potato PAR	Border height	Potato height	Aphid population	Virus incidence	Virus titre
Potato PAR	0.88*						
Border height	-0.86*	-0.76*					
Potato PAR	-0.73*	-0.37	0.81**				
Aphids	-0.84*	0.85*	-0.97*	-0.66			
Virus incidence	0.86*	0.53	-0.81*	-0.96*	0.68		
Virus titre	0.87*	0.99*	-0.76*	-0.35	0.86**	0.51	
Yield	-0.98*	-0.96*	0.45	0.60	-0.88*	-0.75*	-0.95*

Correlation is significant at the 0.05 level (two tailed)

Table 3.16: The relationships between border crops height, potato crop height, aphid populations, virus incidence and potato tuber yield at Tigoni during the long rains 2007.

	Border height	Potato height	Aphid population	Virus incidence	Virus titre
Potato height	0.28				
Aphids	-0.27	0.26			
Virus incidence	-0.40	0.27	0.99**		
Virus titre	-0.70**	-0.13	0.85*	0.90**	
Yield	0.43	0.37	-0.80*	-0.78*	-0.90**

PAR interception was not determined in this site.

3.5 Discussion

3.5.1 Effect of border crops on potato growth, photosynthetically active radiation and potato leaf area index

Maize and sorghum bordered plots had taller potato plants than other plots on only one experimental site. This can be attributed to the shading effect of the tall border crops, which encourages competition for light, hence initiate increase in the protected plants height. However, it contrasts report by Srinivas and Elawande (2006) who reported that maize border does not cause shading effect on the protected plants. The results showed that border crops significantly affected potato PAR. Spatial arrangement of border crops can modify the environmental conditions that may influence the protected crops growth and yield either negatively or positively (Fereres, 2000). It is evident that border crops do not affect potato leaf area development.

3.5.2 Effect of border crops on potato aphid population

Four aphid species were found infesting potatoes. These were *Aphis gossypii, Macrosiphum euphorbiae*, *Myzus persicae* and *Rophalosiphum maidis* as reported by Luiza (2006), Halbert *et al.* (2003) and Salazar (1996) who found the aphid species to be the most important colonizers of potato plants.The high predominance of *Aphis gossypii* on leave samples reported in this study is in agreement with work done by Perez *et al.* (2004) and Rongai *et al.* (1998). The study revealed that Macrosiphum euphorbiae was the most abudant on leaves during the long rains. As reported by Machangi (2003). Higher total aphid population was found in the potato plots without border crops than on the crop-bordered plots in Kabete site. This can be attributed to the ability of border crops to block migrating insect pests from reaching the host plant by acting as natural barriers (Srinivas and Elawande (2006). This contradicts Fereres (2000) findings that barrier crops acted as natural sinks and did not reduce the number of aphids landing on protected crop.

Maize bordered plots recorded a higher total aphid population than wheat and sorghum bordered plots in Tigoni site during the short rains. This can be attributed to the wide spatial arrangement of maize compared to wheat and sorghum. Aphid populations are known to differ in different spatial arrangements of border crops depending on the developmental stage of the border crop, which negatively affects pest establishment (Ebwongu *et al.*, 2001). Total alate aphid population during the long rains did not differ among border types. This is supported by work done by Damicone and Edelson, (2007) who reported that alate landing rates did not differ among treatments after using sorghum border crops and intercrops to control cucurbit virus disease. The low levels of aphid population during the long rains compared to the short rains can be explained by the prevailing climatic conditions. Mean maximum temperatures of 27.4^{0}C were experienced during the short rains and 18.7^{0}C during the long rains in both Kabete and Tigoni site. The high temperatures during the short rains might have increased the reproduction rate and migration of aphids leading to increased population build up (Guillemaud *et al.*, 2003).

Peak periods of aphid infestation during the short rains were at the 8th week after crop emergence, while over the long rains, it was between the 3rd and 5th week after emergence. The difference in peak periods over the two seasons might have been caused by wet conditions in the month of November, March and April which are known to promote growth of weeds and other plants where aphids build up before migrating to target crops (Thackray *et al.,* 2002). The early peak period during the long rains is of great importance in this study and can be used to determine the critical time of maximum virus transmission by aphid vectors. This is because Handiziz and Legorburu (2002) found the first third of vegetative period (four weeks after crop emergence) as the most important period of virus infection.

More alate aphids were trapped by yellow sticky traps placed at the edges of non bordered plots than on crop bordered plots. This is in agreement with Kibaru, (2003) report, who found more aphids of all species in traps placed in fallow borders than in traps placed in crop bordered plots. The higher population of total aphids trapped inside the plots than at the edges of border crops might be attributed to the fact that more aphids are normally available near the host plant. The aphids caught at the edge of border crops are the ones migrating from non-host plants or nearby volunteer plants and in most cases are few. Individual migrants are known to be few in number because migration costs have to be offset by secondary hosts through effective reproduction success, which requires several generations of reproduction and in many cases not achieved (Radcliffe *et al.,* 2002; Ward *et al.,* 1998).

3.5.3 Effect of border crops on potato virus incidence and virus titre on tubers

Higher virus incidence was recorded on plots without border crops than the crop bordered plots during the short rains. This can be attributed to the ability of barrier crops to either hold the population of aphids or reduce the virus content in the viruliferous vectors through stylet probing on the border crops (Cerruti and Fereres, 2006, Hanafi, 2000). Since low PVY titre was recorded in maize and the wheat bordered plots in Tigoni site during the short rains, it can be hypothesized that infective aphids lost their virus charge while probing on the border crops hence they cleansed their mouthparts and reduced their potential to transmit and spread viruses to the protected crop (Damicone and Edelson, 2007 and Prasad and Kudada, 2005). It can also be proposed that the border crops acted as sinks for the virus rather than acting as a physical barrier (Difonzo *et al.*, 1996).

Border crops reduced PVY titre only during the short rains. This study agrees to a great extent with Fereres, (2000) findings that barrier crops were effective in the reduction of PVY and CMV virus transmission in pepper for some seasons or years but not all. The ability of border crops to reduce the spread of virus was attributed to reduction of the number of viruliferous aphids landing on the protected crop through intercepting viruliferous alate pest migration regardless of the direction of attack (Difonzo, 1996; Fereres, 2000). The low levels of PVY can be associated with the low level of virus titre on the planted potato seeds and the low total population of wingless *M. persicae* recorded on leaf samples in the two seasons and sites. The correlation results showed that aphid population highly correlated with virus infection on plants. This is supported by Kanavaki and Margaritopoulos (2006) and Sertkaya and Sertkaya (2005) who reported that *M. persicae* had the highest propensity in PVY transmission compared to all the other potato aphids. The lower levels of PLRV on the crop bordered plots than in plots without border crops can be attributed to the ability of border crops to hold or block aphids from reaching the target plants (Osakabe and Kenichiro, 2002). PVS was the most abundant virus in the potato tubers. This is in agreement with report by Machangi *et al.* (2004). Asante variety recorded a numerically higher viral load than Tigoni variety. These results are in agreement with Luiza, (2006).

3.5.4 Effect of border crops on potato yield

Sorghum borders reduced yields more than all the other treatments. Yield is a complex attribute to measure and losses in yield cannot be entirely attributed to either aphids or virus infection because it is affected by different parameters. It has been argued that border crops may modify the environmental conditions influencing the protected crop by providing different microclimatic conditions within plots hence increasing competition for light, moisture and nutrients between the protected crops and border crops resulting to reduced yield (Fereres, 2000). Damicone and Edelson, (2007) reported a 50% reduction in pawpaw total yield after using grain sorghum border crops. Maize and wheat border crops were effective in potato seed production and did not significantly reduce seed yield. These results are consistent with the findings of Fereres (2002) that on using maize border crops in potato crops; the border crops did not result in reduction in yield. Since Prasad and Kudada, (2005) and Muniyappa *et al.*, (2002) reported yield increase after protecting plants using physical barriers, the results of this study show that there was significant difference in the total yield among different border crop treatments during the long rains. Therefore, careful selection of border crop should be based on its market value and the targeted potato tuber grade to enable farmers to obtain maximum benefit.

Border crops use is an effective strategy in aphid and virus management. Validation of safe planting distances and deployment of non-host barrier crops as observed by Coutts *et al.* (2004) can increase the efficiency of border crops. The study revealed that certain border crops which helps, in the reduction of potato aphids and viruses do not affect potato yield. With this knowledge, wheat border crops can be effectively used in controlling aphids and associated viruses without negatively affecting farmers' yield.

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CHAPTER 4: INTEGRATION OF BORDER CROPS, INSECTICIDES AND MINERAL OIL IN THE MANAGEMENT OF POTATO APHIDS AND APHID TRANSMITTED VIRUSES

4.1 Abstract

Potato aphids and aphid transmitted viruses are major constraints to potato production in Kenya. Studies were carried out in both Kabete and Tigoni to evaluate the effectiveness of combining border crops, mineral oil and bifenthrin (Brigade®) in management of potato aphids and associated viruses. Tigoni potato variety and maize border crop were used. Aphid population was monitored weekly using leave samples, water pan traps and yellow sticky traps placed inside the potato and at the edge of border crops.

Aphid species identified were *Aphis gossypii, Macrosiphum euphorbiae, Myzus persicae* and *Rophalosiphum maidis.* The results revealed that *Aphis gossypii* was the abundant aphid species while *M. persicae* was the least abundant. Although spray treatments did not reduce aphid population and viruses during the long rains, mineral oil and bifenthrin treated plots significantly reduced aphid population and virus titre on potato tubers during the short rains. Lowest aphid population was recorded in plots where mineral oil was applied on potatoes while control plots had the highest aphid population. Yields were not significantly ($p<0.05$) different among treatments. This study demonstrates that integrating border crops, insecticides and mineral oil is beneficial in the management of potato aphids and associated viruses in seed potato production. Further trials should be carried out to determine the application rate and frequency of mineral oil and bifenthrin, which can control viruses at minimum cost with maximum returns to farmers.

4.2 Introduction

Approaches to the management of potato aphids and associated viruses are categorized as either preventive or therapeutic (Ragsdale *et al.*, 2001). Prevention measures focuses on the reduction of innoculum to manageable levels while therapeutic action focuses on total clearance of vectors (Franc, 2001). Over the years insecticides and mineral oil have been used in the control of potato aphids and associated viruses. Although research shows that the suppression of virus vectors worldwide remains almost exclusively based on insecticides, insecticides are only effective in the management of persistently transmitted viruses (Radcliffe *and* Ragsdale, 2002; Margaritopoulos *et al.*, 2007). This is because for an aphid to transit virus persistently, a feeding period of more than 20 minutes is required, followed by a period of 24 hours or more that must occur between virus acquisition and transmission. This long period between virus acquisition and transmission provides enough time for insecticides to kill aphids before virus transmission (Suranyi, 1999; Hanafi, 2000; Kibaru, 2003).

Non-persistently transmitted viruses are transmitted within a very short time after acquisition (Suranyi, 1999; Lovieno *et al.*, 2005) and this enables aphids to transmit viruses before they are killed by insecticides (Fereres, 2000; Radcliffe *et al.*, 2002). Viruses are also transmitted by aphid species that do not colonize potatoes and this makes it difficult to be targeted by insecticides (Halbert *et al.*, 2003). It has been argued for a long time that mineral oil is more effective in the control of aphids and reduction of non-persistently transmitted viruses than insecticides (Brachet *et al.*, 2001). Although the mechanism applied in the reduction of virus innoculum by oils is not fully understood, efficiency of mineral oils is attributed to the ability to persist on the plants surface for 10-

14 days (Hanafi, 2000; Radcliffe *et al.*, 2002). Mineral oil is also reported to affect insect feeding behavior and cause suffocation to insects. Since aphids that transmit all viruses occur in the same complex in the field, integration of insecticide and mineral oil can be an effective control method of all viruses. Hence a study was conducted to evaluate the efficacy of integrating insecticides, mineral oil and border crops in the management of potato aphids and associated viruses.

4.3 Materials and methods

4.3.1 Experimental layout and design

The study was carried out at the National Potato Research Centre (NPRC) Tigoni and the University of Nairobi Field Station, Kabete. The treatments consisted of spraying mineral oil on border crops, spraying mineral oil on potato alone, spraying bifenthrin on border crops alone, spraying bifenthrin on potato alone, spraying bifenthrin followed by mineral oil on potatoes alone, spraying bifenthrin followed by mineral oil on border crops alone, spraying bifenthrin on both border crops and potatoes, spraying mineral oil on both border crops and potato and a control which did not have any spray. Treatments were arranged in a randomized complete block design (RCBD) and replicated three times. Bifenthrin was tested because it was the most popular insecticide used by farmers while Mineral oil has shown to be very effective in control of non-persistent viruses (Kibaru, 2003).

Plots of 4.7 m x 4.7 m were planted with certified seed potato variety Tigoni. The distance between blocks was 2 m while a gap of 1 m separated the experimental plots. Each experimental plot consisted of 5 rows of potato plants with nine hills in every row.

Two outer rows acted as guard rows while sampling was done in the three inner rows. A maize border of one-meter width surrounded each potato plot and was planted in three rows at a spacing of 75 cm between rows and 30 cm within rows. Maize was evaluated because most farmers in Kenya rotate or intercrop maize with potatoes. Potatoes were planted two weeks after border crop emergence at a spacing of 75cm by 30cm. Diammonium phosphate (DAP) amounting to 222.2 kg (i.e 40 kgN /ha and 102 kgP_2O_5 / ha) was applied and thoroughly mixed with soil before planting seed tubers. Weeding was done as weeds arose while ridging was done on 5th week after emergence of potatoes. Late blight and other fungal diseases were controlled by three spray applications of Metalaxyl (Ridomyl) at a rate of 2.4 kg a.i / ha.

4.3.2 Insecticide and mineral oil application

Applications of the spray treatment of Brigade® (bifenthrin 2.4l a.i / ha), and mineral oil (DC Tron) were done on weekly basis. In bifenthrin followed by mineral oil application, each chemical was repeated after a fortnight. First application was done 2 weeks after potato crop emergence using a knapsack sprayer calibrated at 4 psi and repeated once every week.

4.3.3 Monitoring of aphid population

Aphid population was monitored on leaves, by use of yellow sticky traps and water pan traps. Leaves were used to monitor wingless (apteral) form of aphids while yellow sticky and water traps monitored winged (alate) form. Sampling of aphids on leaves was done weekly from second week after emergence to maturity. Ten potato plants were randomly selected from each plot and three leaves were picked from top, middle and bottom of each plant. The leaves from each plant were put in separate labeled paper bags and stored at 4^0C until aphids were counted and identified at the Entomology Laboratory of the department of Plant Science and Crop Protection of The University of Nairobi. Yellow sticky traps consisted of 30 x 30 cm cardboard discs wrapped with yellow polythene and adhesive insect glue was applied on the surface. The discs were mounted 0.5 m above the ground level. Two traps were mounted on each plot; one inside the plot and another at the edge of every border crop. In each plot a yellow water pan trap was placed within the potato crops at the center of the plots. Water was filled to ¾ full in each pan and a liquid detergent (GEAPOL – Heavy duty surface and dish washing detergent) added to break surface tension so as to have trapped insects sinking to the bottom. Aphids were collected after seven days and the traps replaced weekly. The aphids were then preserved in 60% alcohol and taken to the lab for counting and identification.

Features used to identify different aphid species as described by Martin (1983).

Aphid species	Body colour	Lateral abdominal spiracles	Antennal tubercles	Shape of siphunculi	Dorsal abdominal pigmentation
Macrosiphum euphorbiae	Green	Absent from first to seventh segment	Well developed with inner margin diverging distally	Cylindrical or tapering	Absent or completely green
Myzus persicae	Green or olive green	Absent from first to seventh segment	Well developed with inner sides parallel	Clavate	Dorsal black patch
Aphis gossypii	Green, olive yellow, orange or black	Well developed on first to seventh segment	Little developed or absent		Less developed black transverse bars

4.3.4 Assessment of virus disease incidence and virus titre in potato tubers

Viral incidence was estimated by identifying plants within a plot that showed leaf roll and mosaic symptoms expressed as a proportion of the total number of plants in the plot. This was done for all the 24 plots at each site. Virus incidence was determined on the 2nd, 3rd, 5th, 7th and 9th weeks after potato emergence. At physiological maturity, eight potato tubers were picked randomly from the center three rows of each plot and sprouted for DAS-ELISA analysis. They were then processed and serologically assayed for the presence of potato virus Y, potato virus X, potato leaf roll virus, potato virus M, potato virus A and potato virus S. Double antibody sandwich – enzyme linked Immunosorbent assay (DAS ELISA) method as described by Clark and Adams (1977) was used.

DAS ELISA was conducted as follows: Each well of plates were coated with y-globulin and incubated at room temperature for 5 hours. Potato sprouts were then removed from tubers by use of surgical blades, mixed with extraction buffer in extraction bags and grinded. The plates were then sequentially washed in Phosphate buffered saline- in tween (PBST) and dried. 100µl of grinded samples were added to each plate well and incubated at 4^0c overnight. The plates were sequentially washed again and conjugate antiserum (IAG-AP) added to each well and incubated for 5 hours. The plates were washed again after 5 hours and substrate buffer was added to each well and left for 30-60 minutes at room temperature. After this step, visual assessment of infected samples was done by observation of yellow colour development. Finally, photometric measurements of absorbance at 405nm wavelength to determine positive samples using ELISA reader.

4.3.5 Potato tuber yield assessment

Dehaulming was done at physiological maturity. Fourteen days after dehaulming, the tubers were carefully dung out separately for each plot. They were then graded according to Kabira *et al.* (2006) into ware (>55mm), seeds (35-55mm) and chatts (<25mm). Different grades of tubers were weighed separately for each plot and total tuber weight was determined.

4.3.6 Data analysis

Data was subjected to analysis of variance (ANOVA) using the PROC ANOVA procedure of Genstat (Lawes Agricultural Trust Rothamsted Experimental station 2006,version 9) and differences among the treatment means were compared using the Fisher's protected LSD test at 5% probability level.

4.4 Results

4.4.1 Effect of border crops, insecticides and mineral oil on aphid populations

4.4.1.1 Aphid population on potato leaves

Four aphid species were identified during the sampling period at Kabete and Tigoni. These were *Aphis gossypii*, *Macrosiphum euphorbiae*, *Myzus persicae* and *Rophalosiphum maidis*. At Tigoni site, *A. gossypii* was the highest in number while M. *euphorbiae* was the lowest (Table 4.1). *Aphis gossypii* and *M. euphorbiae* population was 50.1% and 4% of the total aphid numbers, respectively. There were significant ($p \leq 0.05$) differences among treatments in all the aphid species. Wheat bordered plots had the highest total aphid population compared to maize and sorghum bordered plots. There was no significant ($p \leq 0.05$) difference between the sprayed and the non-sprayed plots in the total aphid population.

At Kabete site, *Rophalosiphum maidis* was the most abundant, while *M. persicae* was the least abundant. *Rophalosiphum maidis* and *M. persicae* population was 44.2% and 5.9% of the total aphid population respectively. There was significant ($p \leq 0.05$) difference among treatments in *Aphis gossypii* and *Macrosiphum euphorbiae* population, but not in *M. persicae* and *R. maidis* population. Maize and non-bordered plots treated with chemical spray were not significantly different with respect to all aphid species numbers in both Tigoni and Kabete sites. Spray treatment did not significantly reduce aphid populations in both Tigoni and Kabete.

Table 4.1: Mean number of different aphid species per 30 leaves collected on potatoes surrounded by different border crops with or without chemical spray treatment during January to June 2007 short rains inTigoni and Kabete.

Tigoni site

Treatments	Aphid species A. g	M. e	M. p	R. m	Total
No-border	8.7	0.5	3.8	5.1	18.1
Maize	1.5	0.4	1.5	0.6	4.0
Sorghum	0.7	0.2	0.7	0.4	2.0
Wheat	10.6	0.3	6.0	3.9	20.8
No-border and spray	5.3	0.6	1.9	3.8	11.6
Maize and spray	5.9	0.9	2.2	1.2	10.2
Sorghum and spray	2.9	0.3	2.5	0.4	6.1
Wheat and spray	12.7	0.8	4.2	6.2	23.9
LSD (P≤0.05)	4.2	0.6	2.5	4.0	8.86
CV%	17.4	8.9	19.9	35.2	21.5

Kabete site

Treatments	Aphid species A. g	M. e	M. p	R. m	Total
No-border	0.1	0.2	0.0	0.4	0.7
Maize	0.1	0.4	0.1	0.8	1.4
Sorghum	0.3	0.5	0.1	0.9	1.8
Wheat	0.1	0.2	0.0	0.4	0.7
No-border and spray	0.0	0.3	0.0	0.1	0.4
Maize and spray	0.1	0.3	0.0	0.0	0.4
Sorghum and spray	0.0	0.4	0.1	0.0	0.5
Wheat and spray	0.0	0.1	0.0	0.0	0.1
LSD (P≤0.05)	0.2	0.3	ns	ns	ns
CV%	35.6	14.7	39.8	76.1	30.8

A. g = *Aphis gossypii*, M. e = *Macrosiphum euphorbiae*, M. p = *Myzus persicae*,

R. m = *Rophalosiphum maidis* and ns= not significant

The aphid population at Tigoni site remained low between 3rd and 6th weeks for all treatments except in maize bordered plots treated with chemical spray (Table 4.2). Aphid population in all treatments then increased after the 7th week attaining the highest population at 8th week after emergence. There were significant differences among treatments in total aphid population in all the sampling periods except the 5th and 7th week after potato crop emergence. Total aphid population at Kabete site increased in all plots without chemical application attaining a peak at the 6th week after emergence. Aphid population in the sprayed and non sprayed plots did not differ significantly over the sampling period.

At Tigoni site, Aphid population was low throughout the season and there were no significant differences among spray treatments (Table 4.3). *Aphis gossypii* had the highest population and *M. euphorbiae* the lowest during the short rains. *Aphis gossypii* and *Macrosiphum euphorbiae* constituted 49.6% and 2.1% of the total aphid population respectively. There were significant ($p \leq 0.05$) differences among spray treatments in all aphid species except *M. euphorbiae*. Control (non- sprayed plots) had the highest total aphid population. Mineral oil application on either potato or border crops did not have significant effect on the total aphid populations. Application of a combination of bifenthrin and mineral oil on potato crop alone was not significantly ($p \leq 0.05$) different from application of mineral oil in potato crop alone in reducing aphid populations.

Table 4.2: Total aphid population trends on leaves over several monitoring times in response to spray treatments using different border crops during January-June 2007 long rains in NPRC, Tigoni and the October 2007- February 2008 short rains, in Kabete.

Tigoni site

	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
No-border	0.2	0.5	1.6	2.5	1.9	58.2	17.4	62.2	18.1
Maize	1.5	0.8	3.8	2.1	1.6	11.2	1.0	9.1	3.9
Sorghum	0.1	0.4	0.8	1.0	1.2	9.5	0.5	2.7	2.0
Wheat	0.2	8.1	0.9	1.6	0.6	80.3	51.6	23.0	20.8
No-border and spray	0.5	1.5	1.2	1.8	5.5	43.5	5.9	32.4	11.5
Maize and spray	1.2	0.3	7.8	25.8	13.4	24.3	2.0	7.1	10.2
Sorghum and spray	0.2	0.3	2.7	7.6	6.1	13.9	11.2	5.5	5.9
Wheat and spray	0.0	2.9	1.3	1.8	18.5	86.4	26.9	54.0	24.0
LSD ($P \leq 0.05$)	1.0	4.8	ns	16.4	ns	52.6	26.4	43.1	12.7
CV%	47.7	60.6	59.6	47.6	76.7	17.2	37	44.6	21.5

Kabete site

	Weeks after potato emergence				
Treatments	3	4	5	6	Mean
No-border	0.0	0.0	0.6	2.3	0.7
Maize	0.3	0.7	1.0	3.5	1.4
Sorghum	0.7	1.9	0.3	4.3	1.8
Wheat	0.0	0.2	0.5	2.0	0.7
Control and spray	0.0	0.2	0.3	1.3	0.4
Maize and spray	0.8	0.5	0.0	0.2	0.4
Sorghum and spray	0.7	1.1	0.0	0.2	0.5
Wheat and spray	0.0	0.0	0.1	0.1	0.1
LSD ($P \leq 0.05$)	0.7	1.5	ns	ns	0.4
CV%	55.0	57.6	48.7	64.7	30.8

ns= not significant

Table 4.3: Mean number of different aphid species per 30 leaves collected from maize bordered plots subjected to varying spray treatments during the May-October 2007, long rains and November 2007-March 2008 short rains season in NPRC, Tigoni

Long rains

	Aphid species				
Treatments	A. g	M. e	M. p	R. m	Total
Control	0.0	0.0	0.0	0.0	0.0
Bifenthrin +Mineral oil on Border	0.0	0.1	0.1	0.0	0.2
Bifenthrin +Mineral oil on Potato	0.0	0.1	0.0	0.0	0.1
Bifenthrin on Border	0.0	0.1	0.0	0.0	0.1
Bifenthrin on Potato	0.1	0.1	0.0	0.0	0.2
Bifenthrin on Potato +Border	0.0	0.0	0.0	0.0	0.0
Mineral oil on Border	0.1	0.0	0.0	0.0	0.1
Mineral oil on Potato	0.0	0.0	0.0	0.0	0.0
Mineral oil on potato +Border	0.0	0.0	0.0	0.0	0.0
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns
CV%	41.5	12.8	74.6	45.8	17.4

Short rains

	Aphid species				
Treatments	A. g	M. e	M. p	R. m	Total
Control	6.4	0.1	0.1	5.0	11.6
Bifenthrin +Mineral oil on Border	2.3	0.1	0.3	2.8	5.5
Bifenthrin +Mineral oil on Potato	0.6	0.0	0.0	0.8	1.4
Bifenthrin on Border	3.2	0.2	0.4	3.5	7.3
Bifenthrin on Potato	2.8	0.2	0.1	2.4	5.5
Bifenthrin on Potato +Border	2.8	0.1	0.2	1.9	5.0
Mineral oil on Border	2.0	0.1	0.4	1.6	4.1
Mineral oil on Potato	0.2	0.0	0.0	0.2	0.4
Mineral oil on potato +Border	1.1	0.1	0.1	1.0	2.3
LSD ($P \leq 0.05$)	2.7	ns	0.2	2.1	4.7
CV%	28.4	47.1	14.1	9.8	17.2

A. g = *Aphis gossypii*, M. e = *Macrosiphum euphorbiae*, M. p = *Myzus persicae*, R. m = *Rophalosiphum maidis* and ns= not significant

Aphid population remained very low in Kabete site during the long rains. There were no significant ($p \leq 0.05$) differences among treatments in all aphid species (Table 4.4). *Aphis gossypii* was the most abundant, while *M. euphorbiae* was the least abundant during the short rains. There were significant ($p \leq 0.05$) differences among treatments in all aphid species. Control (non- sprayed plots) plots recorded the highest total aphid population. Potato plots treated with bifenthrin followed by mineral oil had 7.5% more aphid population compared to plots treated with bifenthrin alone. Application of bifenthrin or mineral oil on potato crop was not significantly ($p \leq 0.05$) different from application of bifenthrin or mineral oil on border crops in reducing aphid populations.

Aphid population peak in Tigoni site during the long rains was attained on the 8th week after emergence (Table 4.5). Trace levels of aphid numbers were experienced through out the sampling period. Total aphid population during the short rains remained low from the start of sampling up to the 7th week after emergence in all the treatments except control plots. The aphid population increased thereafter attaining a peak between 9th and 10th week after emergence. There were significant ($p \leq 0.05$) differences among treatments in total aphid population in all sampling periods except in the 3rd and 4th week after potato crop emergence.

Aphid population was very low in Kabete site during the long rains. There were no significant ($p \leq 0.05$) differences among treatments over all the sampling periods (Table 4. 6). Major aphid population peak during the short rains was attained between 8th and 9th week after potato crop emergence. Aphid population was not significantly ($p \leq 0.05$) different among treatments during the 3rd and 4th week after emergence. However, it was significantly different in all the other sampling periods. Aphid population remained high in the control plots from the 5th week up to the end of sampling.

Table 4.4: Mean number of different aphid species per 30 leaves collected from maize bordered plots subjected to varying spray treatments during the April-September 2007, long and November 2007-March 2008 short rains in Kabete

Long rains					
	Aphid species				
Treatments	A. g	M. e	M. p	R. m	Total
Control	0.1	0.1	0.0	0.0	0.2
Bifenthrin +Mineral oil on Border	0.1	0.0	0.0	0.0	0.1
Bifenthrin +Mineral oil on Potato	0.0	0.0	0.0	0.0	0.0
Bifenthrin on Border	0.0	0.0	0.0	0.0	0.0
Bifenthrin on Potato	0.0	0.1	0.0	0.0	0.1
Bifenthrin on Potato +Border	0.0	0.1	0.0	0.0	0.1
Mineral oil on Border	0.0	0.0	0.0	0.0	0.0
Mineral oil on Potato	0.1	0.1	0.0	0.0	0.2
Mineral oil on potato +Border	0.0	0.0	0.0	0.0	0.0
LSD (P≤0.05)	ns	ns	ns	ns	ns
CV%	30.1	68.8	72.2	58.1	22.5

Short rains					
	Aphid species				
Treatments	A. g	M. e	M. p	R. m	Total
Control	2.2	0.6	0.5	2.1	5.4
Bifenthrin +Mineral oil on Border	0.9	0.1	0.2	0.7	1.9
Bifenthrin +Mineral oil on Potato	0.1	0.0	0.0	0.1	0.2
Bifenthrin on Border	0.2	0.2	0.4	0.6	1.4
Bifenthrin on Potato	0.6	0.1	0.3	0.5	1.5
Bifenthrin on Potato +Border	0.7	0.0	0.1	0.5	1.3
Mineral oil on Border	0.6	0.2	0.1	0.6	1.5
Mineral oil on Potato	0.0	0.0	0.1	0.1	0.2
Mineral oil on potato +Border	0.5	0.6	0.7	0.4	2.2
LSD (P≤0.05)	0.6	0.3	0.5	0.6	1.3
CV%	48.8	39.1	55.3	30.8	29.1

A. g = *Aphis gossypii*, M. e = *Macrosiphum euphorbiae*, M. p = *Myzus persicae*,

R. m = *Rophalosiphum maidis* and ns= not significant

Table 4.5: Aphid population trends in response to different spray treatments using different border crops during the 2007 long and short rains in Tigoni

	Long rains								
	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Bifenthrin +Mineral oil on Border	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
Bifenthrin +Mineral oil on Potato	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bifenthrin on Border	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Bifenthrin on Potato	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.4	0.1
Bifenthrin on Potato +Border	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mineral oil on Border	0.0	0.0	0.0	0.1	0.0	0.3	0.0	0.1	0.1
Mineral oil on Potato	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Mineral oil on potato +Border	0.0	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV%	0	116.2	31.9	24.7	86.6	40.7	31.9	57.5	17.4

	Short rains								
	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	0.2	0.1	1.6	2.0	3.4	12.4	28.9	44.8	11.7
Bifenthrin +Mineral oil on Border	0.2	0.1	0.1	0.7	1.9	8.0	20.0	13.6	5.6
Bifenthrin +Mineral oil on Potato	0.0	0.1	0.1	0.0	0.7	0.6	8.5	2.2	1.5
Bifenthrin on Border	0.3	0.2	0.2	0.3	1.1	8.9	33.3	13.5	7.2
Bifenthrin on Potato	0.0	0.0	0.0	0.0	3.4	1.8	5.1	33.2	5.4
Bifenthrin on Potato +Border	0.2	0.3	0.4	0.6	0.9	13.7	6.4	17.5	5.0
Mineral oil on Border	0.2	0.3	0.9	0.2	0.9	6.0	12.3	11.1	4.0
Mineral oil on Potato	0.0	0.1	0.0	0.0	0.1	0.2	1.8	1.7	0.5
Mineral oil on potato +Border	0.0	0.0	0.1	0.6	0.2	1.7	8.9	6.6	2.3
LSD ($P \leq 0.05$)	ns	ns	0.7	1.0	3.1	9.9	23.8	30.3	4.7
CV%	50.6	41.7	5.9	63.0	62.8	35.1	18.8	47.9	17.2

ns= not significant

Table 4.6: Aphid population trends over several sampling periods in response to spray treatments using different border crops during the 2007 long and short rains in Kabete

Long rains

Treatments	Weeks after potato emergence							
	3	4	5	6	7	8	9	Mean
Control	0.3	0.3	0.4	0.1	0.1	0.2	0.2	0.2
Bifenthrin +Mineral oil on Border	0.3	0.3	0.0	0.1	0.1	0.1	0.0	0.1
Bifenthrin +Mineral oil on Potato	0.0	0.0	0.0	0.3	0.1	0.0	0.1	0.1
Bifenthrin on Border	0.0	0.0	0.1	0.0	0.0	0.2	0.1	0.1
Bifenthrin on Potato	0.3	0.3	0.0	0.0	0.1	0.0	0.3	0.1
Bifenthrin on Potato +Border	0.0	0.0	0.1	0.0	0.2	0.2	0.2	0.1
Mineral oil on Border	0.1	0.1	0.1	0.1	0.3	0.0	0.0	0.1
Mineral oil on Potato	0.2	0.2	0.2	0.0	0.1	0.2	0.3	0.2
Mineral oil on potato +Border	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0
LSD ($P \leq 0.05$)	ns	ns	0.2	ns	ns	ns	ns	0.1
CV%	106.4	106.4	41.8	37.7	72.7	26.5	4.6	22.5

Short rains

Treatments	Weeks after potato emergence							
	3	4	5	6	7	8	9	Mean
Control	0.3	0.3	0.1	1.3	5.4	14.0	16.0	5.4
Bifenthrin +Mineral oil on Border	0.2	0.3	0.1	0.3	0.2	7.3	4.9	1.9
Bifenthrin +Mineral oil on Potato	0.0	0.0	0.1	0.0	0.0	0.6	1.0	0.2
Bifenthrin on Border	0.2	0.3	0.2	0.4	2.1	2.5	4.3	1.4
Bifenthrin on Potato	0.3	0.8	0.0	0.3	0.2	1.7	6.8	1.4
Bifenthrin on Potato +Border	0.2	0.5	0.1	0.0	0.8	3.5	4.4	1.4
Mineral oil on Border	0.1	0.1	0.1	0.3	0.2	2.4	6.9	1.4
Mineral oil on Potato	0.2	0.2	0.0	0.1	0.1	0.8	0.3	0.2
Mineral oil on potato +Border	0.1	0.1	0.3	0.1	1.8	3.9	9.5	2.3
LSD ($P \leq 0.05$)	ns	ns	ns	0.5	2.7	5.2	8.2	1.3
CV%	52.9	57.5	73.3	34.0	45.8	22.1	30.6	29.1

ns= not significant

4.4.1.2 Aphid population on yellow sticky traps

Three aphid species were identified in yellow sticky traps placed both inside the plots and at the edges of crop borders. These were *Macrosiphum euphorbiae, Myzus persicae* and *Rophalosiphum maidis. Myzus persicae* was the most abundant and *Macrosiphum euphorbiae* the least on traps placed both inside and at the edge of plots in Tigoni site (Table 4.7). *Myzus persicae* consisted of 42.8% and 50% of total aphid population on traps placed inside and at the edge, respectively. *Macrosiphum euphorbiae* comprised 18% and 20% of total aphid population trapped inside and at the edge of plots respectively. Spray treated plots were not significantly ($p \leq 0.05$) different from non-sprayed plots in aphid population. There were no significant differences among treatments in aphid species trapped inside and at the edge of potato plots except for *M. euphorbiae* on traps placed at the edge of border crops. Traps placed inside the plots recorded a lower total aphid population than traps at the edges. At Kabete, Spray treated plots were not significantly ($p \leq 0.05$) different from non-sprayed plots in reducing aphid population. Traps placed inside the plots recorded a higher total aphid population than the traps at the edges.

Table 4.7 Mean number of alate aphid catches on sticky traps placed inside the plot and at the edge of border crops during the 2006 short rains at NPRC, Tigoni and Kabete

Tigoni site

	Inside the plot				Outside the plot			
	Aphid species				Aphid species			
Treatment	M. e	M. p	R. m	Total	M. e	M. p	R. m	Total
Control	0.4	0.5	0.8	1.7	1.3	2.5	0.9	4.7
Maize	0.3	1.1	1.1	2.5	1.1	2.3	1.4	4.8
Sorghum	0.6	1.2	1.0	2.8	0.8	1.7	1.5	4.0
Wheat	0.4	1.5	0.9	2.8	0.6	1.7	1.0	3.3
Control and spray	0.5	0.8	1.3	2.6	1.4	2.4	1.3	5.1
Maize and spray	0.3	1.2	0.8	2.3	0.6	2.0	0.7	3.3
Sorghum and spray	0.5	1.3	0.5	2.3	1.0	1.8	0.6	3.4
Wheat and spray	0.7	1.1	1.4	3.2	0.5	1.6	0.7	2.8
LSD ($P \leq 0.05$)	ns	ns	ns	ns	0.8	ns	ns	ns
CV%	35.5	10.4	10.5	14.2	35.6	13.7	25.7	18.5

Kabete site

	Inside the plot				Outside the plot			
	Aphid species				Aphid species			
Treatment	M. e	M. p	R. m	Total	M. e	M. p	R. m	Total
Control	0.6	1.8	0.3	2.7	0.8	1.7	0.3	2.8
Maize	1.1	1.9	0.3	3.3	0.7	0.8	0.3	1.8
Sorghum	1.2	1.6	0.3	3.1	0.7	1.3	0.8	2.8
Wheat	0.3	1.2	1.0	2.5	0.3	0.6	0.4	1.3
Control and spray	0.3	1.1	0.9	2.3	0.7	1.5	0.9	3.1
Maize and spray	0.4	1.5	0.3	2.2	0.8	1.6	0.2	2.6
Sorghum and spray	0.6	0.8	0.6	2.0	0.3	1.0	0.5	1.8
Wheat and spray	0.6	1.2	0.4	2.2	0.8	1.2	0.2	2.2
LSD ($P \leq 0.05$)	0.8	ns	ns	ns	ns	ns	ns	ns
CV%	44.4	36.4	87.5	37.4	37.4	30.6	68.6	2.1

M. e = Macrosiphum euphorbiae, M. p = Myzus persicae, R. m = Rophalosiphum maidis

and ns= not significant

Rophalosiphum maidis had the highest population while *M. persicae* had the least during the long rains in Tigoni site. The population of *R. maidis* and *M. persicae* on traps placed both inside and at the edge of plots was 53.9% and 12.9% of the total aphids, respectively (Table 4.8). More total alate aphids were trapped inside the plot than at the edges. There were significant ($p \leq 0.05$) differences among treatments in *R. maidis* population both inside and outside potato plots. *Rophalosiphum maidis* was the most abundant (44%), while *M. persicae* was the least abundant (16%) during the short rains on traps placed both inside and at the edge of plots. There were significant ($p \leq 0.05$) differences among treatments in all aphid species in most cases. Traps placed at the edge of plots on which bifenthrin followed by mineral oil or mineral oil alone was applied on crop borders recorded the lowest total alate aphid population.

Rophalosiphum maidis had the highest aphid population and *M. persicae* the least in traps placed inside and at the edge of crop borders during both the long and short rains in Kabete site. The population of *R. maidis* and *M. persicae* was 61.9% and 14.3% of the total aphid population respectively (Table 4.9). During the long rains, treatments were only significantly ($p \leq 0.05$) different with respect to *R. maidis* and total aphid population. Traps placed at the edge of crop borders captured fewer aphid numbers than traps inside the plot. There were significant ($p \leq 0.05$) differences among treatments in all aphid species during the short rains. Mineral oil application on potatoes was the most effective method in reducing total aphid population. The highest aphid population was trapped inside untreated plots (control plots). Generally, traps placed at the edge of plots where chemical spray was applied in border crops had lower aphid population than traps placed on the potato treated plots.

Table 4.8 Mean number of alate aphid catches on sticky traps placed inside the plot and at the edge of border crops during the 2007 long and short rains at NPRC, Tigoni

	Long rains							
	Inside the plot				Outside the plot			
	Aphid species				Aphid species			
Treatment	M. e	M.p	R.m	Total	M.e	M.p	R.m	Total
Control	0.6	0.3	0.8	1.7	0.4	0.2	0.7	1.3
Bifenthrin +Mineral oil on Border	0.4	0.3	0.5	1.2	0.1	0.1	0.3	0.5
Bifenthrin +Mineral oil on Potato	0.4	0.3	0.8	1.5	0.3	0.2	0.5	1.0
Bifenthrin on Border	0.3	0.0	1.0	1.3	0.3	0.2	0.4	0.9
Bifenthrin on Potato	0.6	0.0	0.5	1.1	0.2	0.1	1.0	1.3
Bifenthrin on Potato +Border	0.5	0.2	0.6	1.3	0.3	0.0	0.5	0.8
Mineral oil on Border	0.5	0.2	0.3	1.0	0.4	0.1	0.5	1.0
Mineral oil on Potato	0.5	0.1	0.5	1.1	0.2	0.3	0.8	1.3
Mineral oil on potato +Border	0.6	0.1	0.6	1.3	0.3	0.0	0.6	0.9
LSD (P≤0.05)	ns	ns	0.5	ns	ns	ns	0.4	0.7
CV%	22.2	58.3	8.1	13.4	21.5	40.5	22.4	22.4

	Short rains							
	Inside the plot				Outside the plot			
	Aphid species				Aphid species			
Treatment	M.e	M.p	R.m	Total	M.e	M.p	R.m	Total
Control	4.4	2.2	6.9	13.5	2.9	1.8	5.4	10.1
Bifenthrin +Mineral oil on Border	2.2	0.8	1.6	4.6	1.3	0.6	1.4	3.3
Bifenthrin +Mineral oil on Potato	0.6	0.3	1.3	2.2	2.5	0.7	2.8	6.0
Bifenthrin on Border	2.4	1.2	3.1	6.7	1.7	1.3	2.4	5.4
Bifenthrin on Potato	3.0	0.9	2.4	6.3	2.2	0.4	2.1	4.7
Bifenthrin on Potato +Border	2.8	1.0	2.1	5.9	2.4	1.0	1.8	5.2
Mineral oil on Border	2.9	1.0	2.9	6.8	1.6	0.4	2.0	4.0
Mineral oil on Potato	0.6	0.4	0.7	1.7	1.9	0.7	2.5	5.1
Mineral oil on potato +Border	2.7	1.1	2.0	5.8	2.4	0.8	1.7	4.9
LSD (P≤0.05)	1.0	0.7	1.2	2.0	0.9	0.7	1.0	1.5
CV%	10.2	7.6	7.8	8.1	12.6	29.1	13.1	11.1

M. e = *Macrosiphum euphorbiae*, M. p = *Myzus persicae*, R. m = *Rophalosiphum maidis* and ns= not significant

Table 4.9 Mean number of different alate aphid species caught on sticky traps placed inside the plot and at the edge of maize borders during the 2007 long and short rains at Kabete

Long rains

	Inside the plot				Outside the plot			
	Aphid species				Aphid species			
Treatment	M.e	M.p	R.m	Total	M.e	M.p	R.m	Total
Control	0.7	0.4	2.0	3.1	0.5	0.3	2.2	3.0
Bifenthrin +Mineral oil on Border	0.8	0.3	2.2	3.3	0.3	0.3	1.7	2.3
Bifenthrin +Mineral oil on Potato	0.9	0.2	2.0	3.1	0.5	0.2	2.0	2.7
Bifenthrin on Border	0.7	0.1	1.4	2.2	0.3	0.1	1.1	1.5
Bifenthrin on Potato	0.8	0.3	1.8	2.9	0.5	0.1	0.9	1.5
Bifenthrin on Potato +Border	0.6	0.4	1.7	2.7	0.5	0.3	1.5	2.3
Mineral oil on Border	0.7	0.1	1.6	2.4	0.4	0.0	1.2	1.6
Mineral oil on Potato	0.9	0.3	2.5	3.7	0.3	0.0	1.2	1.5
Mineral oil on potato +Border	0.7	0.0	1.7	2.4	0.7	0.1	1.8	2.6
LSD ($P \leq 0.05$)	ns	ns	0.8	1.3	ns	ns	1.1	1.5
CV%	7.7	47.2	11	12.6	11.2	15.7	19.4	16.5

Short rains

	Inside the plot				Outside the plot			
	Aphid species				Aphid species			
Treatment	M.e	M.p	R.m	Total	M.e	M.p	R.m	Total
Control	8.1	5.5	14.8	28.4	5.6	2.2	11.1	18.9
Bifenthrin +Mineral oil on Border	2.7	2.3	7.1	12.1	1.2	2.3	4.3	7.8
Bifenthrin +Mineral oil on Potato	2.1	2.2	4.1	8.4	2.3	2.0	6.5	10.8
Bifenthrin on Border	3.8	3.7	7.9	15.4	1.4	1.4	3.0	5.8
Bifenthrin on Potato	3.1	3.1	6.0	12.2	1.5	1.3	4.6	7.4
Bifenthrin on Potato +Border	2.5	2.8	6.5	11.8	1.2	1.5	4.8	7.5
Mineral oil on Border	3.0	3.1	6.2	12.3	1.1	1.3	4.0	6.4
Mineral oil on Potato	1.1	1.0	3.6	5.7	2.0	1.4	4.2	7.6
Mineral oil on potato +Border	2.6	3.0	5.7	11.3	1.1	0.4	3.5	5.0
LSD ($P \leq 0.05$)	1.7	1.4	2.2	3.7	1.4	1.0	1.7	2.8
CV%	12	8.1	5.1	5.9	40.5	22.4	27.6	28.1

M. e = *Macrosiphum euphorbiae*, M. p = *Myzus persicae*, R. m = *Rophalosiphum maidis* and ns= not significant

The trend of alate aphid population trapped inside the plots in Tigoni site during the long rains showed a slight decline of aphid population from the 3rd to 4th week after emergence in all the treatments. This was followed by an increase in all treatments attaining a minor peak between the 5th and 6th week (Table 4.10). Major peak for all treatments was attained on the 9th week after emergence. The major aphid population peak in traps placed at the edge of crop borders was observed in the 5th and 6th in all treatments except maize bordered plots, control and sorghum spray bordered spray treated plots which was attained on the 9th week after emergence. Spray treatment did not significantly ($p \leq 0.05$) reduce aphid population trapped inside and at the edge of border crops over the sampling period.

Aphid population trapped inside potato plots during the long rains in Tigoni site remained low over all the sampling period. The aphid population peaks were attained between the 9th and 10th week after plant emergence (Table 4.11). Aphid population was not significantly ($p \leq 0.05$) different in the treatments over the sampling times except on the 9th week after potato emergence. Aphid population declined in all treatments except in non- sprayed and mineral oil sprayed plots between the 3rd and 4th week. Alate aphids trapped at the edge of border crops attained a major peak between 5th and 7th weeks for all treatments except in plots were mineral oil and bifenthrin followed by mineral oil was applied in potatoes. Aphid population increased after the 9th week except in control plots and plots treated with bifenthrin in both potatoes and crop borders. There were significant ($p \leq 0.05$) differences among treatments in the total aphid population on the 7th, 8th and 9th weeks after potato crop emergence.

Table 4.10: Mean number of alate aphid catches on sticky traps placed inside and at the edge of maize border surrounding potato plots subjected to different bifenthrin and mineral oil spray treatments during the 2006 short rains at NPRC, Tigoni

Inside potato crop

	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	2.3	2.3	3.3	4.3	4.7	4.3	5.0	3.3	3.7
Maize	3.0	3.0	4.7	3.7	6.3	3.3	8.7	4.0	4.6
Sorghum	2.7	2.3	4.7	6.3	3.7	3.0	12.0	3.7	4.8
Wheat	3.7	2.7	6.0	5.7	3.0	3.7	9.3	4.3	4.8
Control and spray	3.0	2.0	3.3	5.0	2.7	5.7	11.3	3.0	4.5
Maize and spray	2.7	2.3	6.7	4.7	3.7	4.0	7.0	3.7	4.3
Sorghum and spray	3.7	2.3	5.7	6.0	4.0	3.0	6.7	3.7	4.4
Wheat and spray	4.0	3.0	5.7	4.7	5.7	5.3	8.7	4.3	5.2
LSD ($P \leq 0.05$)	ns	ns	ns	ns	3.2	ns	5.8	ns	ns
CV%	24.3	40.9	15.0	42.2	48.0	14.6	29.9	55.1	14.2

At the edge of border crops

	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	3.0	2.0	12.3	11.3	4.7	7.0	10.3	3.3	6.7
Maize	4.3	2.3	8.3	8.0	6.7	4.7	16.0	4.0	6.8
Sorghum	3.7	4.0	10.0	7.0	3.7	3.7	10.0	6.3	6.0
Wheat	3.7	3.3	7.0	9.7	5.0	3.7	6.3	3.3	5.3
Control and spray	4.7	2.0	10.0	10.7	5.7	4.7	14.3	5.0	7.1
Maize and spray	3.0	2.7	8.7	7.3	5.7	3.0	8.7	3.3	5.3
Sorghum and spray	4.7	2.0	8.0	6.0	4.7	3.7	8.3	5.7	5.4
Wheat and spray	3.7	2.3	8.7	5.3	3.7	6.0	5.7	3.0	4.8
LSD ($P \leq 0.05$)	ns	1.5	ns	ns	ns	2.9	ns	ns	ns
CV%	26.6	34.3	32.0	33.9	54.0	23.1	26.3	44.4	18.5

ns= not significant

Table 4.11: Mean number of alate aphid catches on sticky traps placed inside and at the edge of maize border surrounding potato plots subjected to different bifenthrin and mineral oil spray treatments during the 2007 long rains at NPRC, Tigoni

Inside the potato plots

	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	2.7	2.7	4.3	4.3	3.3	3.0	2.7	6.3	3.7
Bifenthrin +Mineral oil on Border	2.0	2.0	2.7	3.7	3.3	3.3	4.7	4.3	3.3
Bifenthrin +Mineral oil on Potato	3.3	2.0	2.3	3.7	2.3	3.0	2.0	8.7	3.4
Bifenthrin on Border	3.7	2.3	3.0	4.0	3.0	2.7	3.0	4.3	3.3
Bifenthrin on Potato	2.7	2.0	3.0	2.3	3.7	3.7	2.0	5.3	3.1
Bifenthrin on Potato +Border	3.3	2.3	3.0	3.3	2.7	3.7	2.7	4.7	3.2
Mineral oil on Border	3.3	2.3	2.7	3.3	2.0	3.0	2.7	4.3	3.0
Mineral oil on Potato	2.0	3.7	3.0	2.3	3.3	3.3	2.0	4.7	3.0
Mineral oil on potato +Border	4.0	2.0	3.3	3.0	4.0	2.3	2.0	5.7	3.3
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns	ns	1.9	ns	ns
CV%	14.8	32.9	24.4	33.8	38.6	59.0	45.2	39.8	13.4

At the edge of border crops

	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	2.0	2.0	2.3	3.7	4.7	3.7	3.7	3.7	3.2
Bifenthrin +Mineral oil on Border	2.7	2.3	3.0	3.0	2.0	2.7	2.0	2.7	2.5
Bifenthrin +Mineral oil on Potato	2.7	2.7	2.3	2.7	2.3	2.7	3.0	5.0	2.9
Bifenthrin on Border	3.3	2.3	3.0	2.0	2.3	3.0	3.7	3.3	2.9
Bifenthrin on Potato	3.0	2.3	4.3	3.7	3.7	3.7	3.3	2.7	3.3
Bifenthrin on Potato +Border	3.0	2.7	2.3	3.7	2.3	2.3	2.3	3.3	2.7
Mineral oil on Border	3.7	2.7	2.0	4.7	3.0	2.0	2.0	4.0	3.0
Mineral oil on Potato	3.3	2.0	3.0	4.0	3.7	3.3	2.0	5.3	3.3
Mineral oil on potato +Border	3.7	2.7	3.3	3.7	2.7	3.0	2.0	2.3	2.9
LSD ($P \leq 0.05$)	ns	ns	ns	ns	2.0	1.5	1.4	ns	ns
CV%	30.7	28.7	49.3	42.7	43.8	45.6	42.3	41.1	22.4

ns= not significant

The trend of alates population trapped inside the plots in Tigoni site during the short rains showed a slight decline of aphid population from the 3rd to 4th week after emergence in all treatments except plots treated with bifenthrin in both potato and border (Table 4.12). Aphid population numbers were observed to be low on the 6th week of crop growth. It then increased continuously thereafter in all the treatments attaining second peak between the 7th and 8th week after crop emergence. Plots treated with mineral oil or bifenthrin followed by mineral oil application on potato significantly reduced aphid population and resulted in the lowest population over all the sampling period. Alate aphid population trapped at the edge of crop borders were observed to have the same trend with the population trapped inside the plots. Aphid population peaks were attained at the 5th week and between the 7th and 8th week after crop emergence. Spray treatment significantly ($p \leq 0.05$) reduced aphid population over the sampling period with mineral oil being the most effective.

The trend of alates population trapped inside and at the edge of plots at Kabete site during the short rains was a sharp decline of aphid population from the 3rd to 4th week after emergence in all treatments. This was followed by a slight decline in all treatments attaining the lowest numbers on the 5th week (Table 4.13). Aphid population after the 5th week increased sharply up to the 6th week of sampling. Spray treatment did not reduce aphid population in crop-bordered plots during the sampling period.

Table 4.12: Mean number of alate aphid catches on sticky traps placed inside and at the edge of maize border surrounding potato plots subjected to different bifenthrin and mineral oil spray treatments during the 2007 short rains at NPRC, Tigoni

Inside the potato plots

	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	0.7	5.0	23.3	3.3	21.7	24.3	12.0	17.0	13.4
Bifenthrin +Mineral oil on Border	1.7	1.0	6.7	1.3	3.0	9.7	6.0	7.0	4.5
Bifenthrin +Mineral oil on Potato	0.0	0.0	3.0	0.7	2.7	5.7	3.0	2.0	2.1
Bifenthrin on Border	1.7	1.3	17.3	2.3	7.7	11.0	4.0	8.0	6.7
Bifenthrin on Potato	0.3	0.3	10.0	2.7	9.7	11.7	7.3	8.7	6.3
Bifenthrin on Potato +Border	0.0	1.3	10.3	0.3	9.7	13.7	4.0	8.0	5.9
Mineral oil on Border	0.7	0.7	8.0	2.0	13.0	16.7	4.3	9.0	6.8
Mineral oil on Potato	0.7	0.0	2.7	1.3	2.7	2.7	0.7	2.7	1.7
Mineral oil on potato +Border	2.0	1.7	7.0	0.3	11.3	14.3	3.7	5.7	5.8
LSD ($P \leq 0.05$)	1.6	1.8	10.8	2.8	7.3	7.3	3.2	5.0	2.0
CV%	52.7	13.5	22.5	56.4	10.3	14.7	33.6	32.3	8.1

At the edge of border crops

	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	1.7	2.3	20.3	0.7	17.7	17.3	9.3	11.7	10.1
Bifenthrin +Mineral oil on Border	0.0	0.7	9.0	0.7	2.0	3.0	5.3	6.0	3.3
Bifenthrin +Mineral oil on Potato	1.0	0.3	10.7	0.0	8.3	11.0	8.0	9.3	6.1
Bifenthrin on Border	0.7	0.3	8.3	4.7	7.7	10.3	3.7	6.7	5.3
Bifenthrin on Potato	0.3	0.0	6.0	1.7	7.3	9.7	7.7	5.0	4.7
Bifenthrin on Potato +Border	0.7	0.3	5.7	0.3	10.3	13.3	5.0	5.7	5.2
Mineral oil on Border	1.0	0.0	7.7	0.7	6.7	9.7	4.3	2.3	4.0
Mineral oil on Potato	1.0	1.0	9.7	0.3	8.3	9.7	5.0	5.3	5.0
Mineral oil on potato +Border	0.7	0.3	6.0	0.0	10.0	10.0	6.7	5.3	4.9
LSD ($P \leq 0.05$)	1.7	0.8	5.8	2.2	5.2	6.0	4.5	3.4	1.5
CV%	37.8	15.7	18.1	55.6	30.7	21.1	19.0	26.2	11.1

ns= not significant

Table 4.13: Trends of the mean alate aphid catches on sticky traps placed at inside plots during the short rains 2007 at Kabete

Inside potato crop					
	Weeks after potato emergence				
Treatments	3	4	5	6	Mean
Control	5.7	0.0	0.3	4.3	2.6
Maize	5.3	1.7	0.0	6.0	3.3
Sorghum	7.0	1.3	0.3	3.7	3.1
Wheat	5.0	0.7	0.0	4.0	2.4
Control and spray	4.7	0.3	0.0	4.0	2.3
Maize and spray	2.0	0.3	0.0	6.3	2.2
Sorghum and spray	3.7	1.3	0.0	3.0	2.0
Wheat and spray	1.7	1.3	0.0	5.7	2.2
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns
CV%	56.3	25	173	32	37.4

At the edge of border crops					
	Weeks after potato emergence				
Treatments	3	4	5	6	Mean
Control	7.0	1.0	0.0	3.0	2.8
Maize	3.7	0.7	0.7	2.3	1.8
Sorghum	6.0	1.7	0.0	3.3	2.8
Wheat	2.7	0.0	0.0	2.3	1.3
Control and spray	5.3	0.0	1.3	5.7	3.1
Maize and spray	5.0	1.3	0.3	3.3	2.5
Sorghum and spray	2.3	1.7	0.0	3.3	1.8
Wheat and spray	4.7	0.3	1.0	2.3	2.1
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns
CV%	6.3	46	125	18	2.1

ns= not significant

aphid population trapped inside potato plots during the long rains in Kabete site attained peak between the 3rd and 4th week after plant emergence (Table 4.14). There were no significant ($p \leq 0.05$) differences among treatments in total aphid population in all sampling periods except on the 4^{th} and 5^{th} week after potato emergence. Treatments were not significantly different in alate aphid population trapped at the edge of crop borders over all the sampling times except at the 9^{th} and 10^{th} week after emergence.

The trend of alates population trapped inside the plots at Kabete site during the short rains was a slight decline of aphid population from the 3^{rd} to 4^{th} week after emergence in all treatments (Table 4.15). Aphid population numbers were observed to be the lowest in number in the 4^{th} week of crop growth. It then increased in all treatments attaining a peak at the 8^{th} week. Plots treated with mineral oil or bifenthrin followed by mineral oil application on potato significantly reduced the total aphid population and supported the lowest population. Alate aphid population trapped at the edge of border crops were observed to have the same trend with the population trapped inside the plots. Aphid population peak was attained at the 8^{th} week after crop emergence in all the treatments except control plots. Spray treatment significantly ($p \leq 0.05$) reduced aphid population over the sampling period.

Table 4.14: Trends of the mean number of alate aphid catches on sticky traps placed inside and at the edge of border crops during the 2007 long rains at Kabete

	Inside the potato plots								
	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	4.7	6.3	1.0	3.3	1.7	0.3	3.7	3.0	3.0
Bifenthrin +Mineral oil on Border	4.3	6.7	3.7	3.3	2.0	2.0	2.7	1.7	3.3
Bifenthrin +Mineral oil on Potato	3.3	1.7	4.7	4.0	4.0	0.0	3.7	3.3	3.1
Bifenthrin on Border	3.0	1.7	2.7	0.7	2.3	1.0	3.0	3.0	2.2
Bifenthrin on Potato	4.7	3.7	2.0	2.0	3.3	0.0	4.7	2.7	2.9
Bifenthrin on Potato +Border	2.0	3.0	1.7	2.7	5.3	0.3	4.0	2.3	2.7
Mineral oil on Border	2.7	2.0	2.7	4.3	2.7	0.0	2.7	2.0	2.4
Mineral oil on Potato	4.3	1.7	6.7	4.7	5.0	1.0	3.0	2.7	3.6
Mineral oil on potato +Border	4.3	1.7	2.0	4.7	2.3	1.0	2.3	1.0	2.4
LSD ($P \leq 0.05$)	ns	ns	3.6	ns	ns	ns	ns	ns	ns
CV%	21.1	32.0	29.6	27.2	16.5	27.0	49.7	55.4	12.6

	At the edge of border crops								
	Weeks after potato emergence								
Treatments	3	4	5	6	7	8	9	10	Mean
Control	6.3	2.0	3.0	2.3	4.3	0.7	3.3	2.0	3.0
Bifenthrin +Mineral oil on Border	4.3	2.3	0.3	0.7	1.0	1.7	0.3	7.3	2.2
Bifenthrin +Mineral oil on Potato	6.3	4.3	1.7	3.0	3.7	0.0	1.0	1.7	2.7
Bifenthrin on Border	1.7	2.7	0.7	0.7	2.0	0.3	1.3	2.0	1.4
Bifenthrin on Potato	1.0	1.0	2.0	2.0	2.3	1.0	1.7	1.3	1.5
Bifenthrin on Potato +Border	3.7	1.0	1.7	2.7	4.0	2.3	0.0	3.0	2.3
Mineral oil on Border	2.0	0.0	2.7	2.3	2.0	1.0	0.3	2.3	1.6
Mineral oil on Potato	1.3	1.3	1.3	2.3	2.7	0.3	1.0	1.0	1.4
Mineral oil on potato +Border	3.3	4.0	1.0	3.0	2.7	2.0	3.7	1.7	2.7
LSD ($P \leq 0.05$)	ns	ns	ns	ns	ns	ns	3.1	2.5	ns
CV%	44.8	49.8	38.4	50.8	11.7	6.2	52.7	56.9	16.5

ns= not significant

Table 4.15: Trends of the mean number of alate aphid catches on sticky traps placed inside and outside potato plots during the 2007 short rains at Kabete

Inside the potato plots

Treatments	Weeks after potato emergence							
	3	4	5	6	7	8	9	Mean
Control	26.0	13.3	19.0	28.0	32.3	48.3	32.0	28.4
Bifenthrin +Mineral oil on Border	8.0	4.0	6.0	11.7	17.0	26.3	12.0	12.1
Bifenthrin +Mineral oil on Potato	2.3	0.7	2.3	4.3	9.3	28.3	11.3	8.4
Bifenthrin on Border	13.0	6.0	10.7	21.7	9.0	22.3	25.0	15.4
Bifenthrin on Potato	10.0	3.3	6.7	10.7	15.7	21.3	17.7	12.2
Bifenthrin on Potato +Border	6.7	2.7	6.3	11.7	16.7	22.0	17.0	11.9
Mineral oil on Border	6.7	5.7	5.7	10.0	16.7	24.3	16.7	12.2
Mineral oil on Potato	0.7	0.7	2.0	3.7	8.7	15.3	8.7	5.7
Mineral oil on potato +Border	6.3	2.0	4.7	10.0	12.7	26.0	17.0	11.2
LSD ($P \leq 0.05$)	6.7	3.8	5.8	12.9	10.7	16.3	8.3	3.7
CV%	15.3	23.4	18.4	36.4	5.8	14.3	10.9	5.9

At the edge of border crops

Treatments	Weeks after potato emergence							
	3	4	5	6	7	8	9	Mean
Control	19.7	12.0	11.0	24.0	18.7	23.3	23.7	18.9
Bifenthrin +Mineral oil on Border	3.3	4.7	4.0	8.7	12.0	15.0	7.0	7.8
Bifenthrin +Mineral oil on Potato	5.3	5.3	5.3	7.3	8.7	15.0	5.0	7.4
Bifenthrin on Border	2.0	2.0	4.0	2.3	5.3	14.0	11.0	5.8
Bifenthrin on Potato	7.0	4.0	7.0	7.0	16.3	18.0	16.3	10.8
Bifenthrin on Potato +Border	5.0	2.3	4.7	7.0	13.3	14.3	5.3	7.4
Mineral oil on Border	3.3	2.3	5.0	8.0	7.3	12.3	6.3	6.4
Mineral oil on Potato	3.7	2.7	4.0	10.0	5.3	12.7	15.3	7.7
Mineral oil on potato +Border	3.3	2.0	3.0	4.7	5.3	10.3	6.0	5.0
LSD ($P \leq 0.05$)	5.6	5.0	4.9	7.6	12.1	9.6	7.8	2.8
CV%	29.1	24.3	30.0	31.1	45.5	31.0	12.6	28.1

ns= not significant

4.4.1.3 Aphid population on water pan traps

Three alate aphid species were identified in water traps in both Kabete and Tigoni sites. These were *Macrosiphum euphorbiae*, *Myzus persicae* and *Rophalosiphum maidis*. *Macrosiphum euphorbiae* was the most abundant during the long rains while *M. persicae* was the least abundant (Table 4.16). *Macrosiphum euphorbiae* and *M. persicae* constituted 50% and 10% of the total aphid population respectively. There were significant ($p \leq 0.05$) differences among treatments in all aphid population except *M. persicae*. *Rophalosiphum maidis* recorded the highest aphid population while *M. euphorbiae* population was the lowest during the short rains. *Rophalosiphum maidis* and *M. euphorbiae* was 52% and 22% of the total aphid population. There were significant ($p \leq 0.05$) differences among treatments in all aphid species. Mineral oil application on potato was 97.4% effective in reduction of potato aphids. Application of chemical spray on potatoes was not different in reduction of aphids from application on border crops.

Rophalosiphum maidis had the highest total aphid population during the long rains while *M. persicae* had the lowest population (Table 4.17). *Rophalosiphum maidis* and *M. persicae* comprised 70% and 10% of the total aphid population respectively. Total aphid population was significantly ($p \leq 0.05$) different among treatments. *Macrosiphum euphorbiae* was the most abundant, while *M. persicae* was the least abundantaphid species during the short rains. There were significant ($p \leq 0.05$) differences among treatments. Application of chemical spray in potatoes was more effective in the reduction of aphids than application on crop borders. Plots treated with mineral oil on potatoes were not significantly ($p \leq 0.05$) different from plots treated with bifenthrin followed by mineral oil on potato.

Table 4.16: Mean number of aphids in water traps from plots treated with different spray applications during the 2007 long and short rains in NPRC, Tigoni

Long rains

Treatment	Aphid species			
	M. e	M. p	R. m	Total
Control	1.3	0.1	0.7	2.1
Bifenthrin +Mineral oil on Border	0.2	0.4	0.4	1.0
Bifenthrin +Mineral oil on Potato	0.6	0.3	0.8	1.7
Bifenthrin on Border	0.6	0.1	0.3	1.0
Bifenthrin on Potato	0.7	0.0	0.5	1.2
Bifenthrin on Potato +Border	0.9	0.2	0.4	1.5
Mineral oil on Border	0.9	0.1	0.3	1.3
Mineral oil on Potato	0.5	0.3	0.9	1.7
Mineral oil on potato +Border	0.2	0.1	0.3	0.6
LSD ($P \leq 0.05$)	0.8	ns	0.5	1.0
CV%	39	65.7	52.2	43.9

Short rains

Treatment	Aphid species			
	M. e	M. p	R. m	Total
Control	27.3	24.3	43.7	95.3
Bifenthrin +Mineral oil on Border	12.3	9.7	12.7	34.7
Bifenthrin +Mineral oil on Potato	0.7	3.3	8.0	12.0
Bifenthrin on Border	8.0	9.7	21.3	39.0
Bifenthrin on Potato	4.7	7.7	18.0	30.4
Bifenthrin on Potato +Border	3.7	12.0	27.0	42.7
Mineral oil on Border	6.3	7.0	14.0	27.3
Mineral oil on Potato	2.0	2.0	3.7	7.7
Mineral oil on potato +Border	2.0	2.3	7.0	11.3
LSD ($P \leq 0.05$)	9.7	8.9	18.0	20.7
CV%	41.2	9.2	25.8	24.8

M. e = *Macrosiphum euphorbiae*, M. p = *Myzus persicae*, R. m = *Rophalosiphum maidis* and ns= not significant

Table 4.17: Mean number of aphids in water traps placed in plots treated with different spray applications during the 2007 long and short rains in Kabete

Long rains

	Aphid species			
Treatment	M. e	M. p	R. m	Total
Control	0.9	0.6	2.5	4.0
Bifenthrin +Mineral oil on Border	0.7	0.6	2.3	3.6
Bifenthrin +Mineral oil on Potato	0.5	0.4	1.9	2.8
Bifenthrin on Border	0.6	0.3	1.6	2.5
Bifenthrin on Potato	0.3	0.3	2.1	2.7
Bifenthrin on Potato +Border	0.6	0.2	1.6	2.4
Mineral oil on Border	0.5	0.3	1.4	2.2
Mineral oil on Potato	0.5	0.2	1.9	2.6
Mineral oil on potato +Border	0.3	0.2	2.2	2.7
LSD ($P \leq 0.05$)	ns	ns	ns	1.3
CV%	17.9	68.0	13.7	12.6

Short rains

	Aphid species			
Treatment	M. e	M. p	R. m	Total
Control	41.7	9.3	25.0	76.0
Bifenthrin +Mineral oil on Border	10.3	8.3	9.3	27.9
Bifenthrin +Mineral oil on Potato	3.3	2.3	5.3	10.9
Bifenthrin on Border	27.3	4.7	6.7	38.7
Bifenthrin on Potato	2.7	4.3	13.0	20.0
Bifenthrin on Potato +Border	2.0	3.0	5.0	10.0
Mineral oil on Border	21.0	5.0	12.0	38.0
Mineral oil on Potato	3.3	0.7	6.3	10.3
Mineral oil on potato +Border	11.3	5.3	10.7	27.3
LSD ($P \leq 0.05$)	8.9	3.7	6.8	12.6
CV%	27.0	12.3	19.1	20.1

M. e = *Macrosiphum euphorbiae*, M. p = *Myzus persicae*, R. m = *Rophalosiphum maidis* and ns= not significant

aphid population trapped during the long rains in Tigoni site did not differ among treatments in all sampling periods (Table 4.18). However, there were significant ($p \leq 0.05$) differences among treatments in total aphid population in all sampling periods except on the 3rd week after potato emergence during the short rains. Aphid population peaks were attained between the 4th and 6th and 9th and 10th weeks after potato emergence. Minor peak of aphid population was attained between the 4th and 5th weeks of plant growth during the long rains There were significant ($p \leq 0.05$) differences among treatments in total aphid population in all sampling periods except in the 3rd week after potato crop emergence. Mineral oil recorded the lowest total aphid population through out the sampling period except on the 3rd, 4th and 6th weeks after crop emergence while control plots had the highest aphid population.

Aphid population in Kabete site during the long rains was low. There was no significant ($p \leq 0.05$) difference among treatments over all the sampling periods (Table 4. 19). The general trend was a slight increase of aphid population in all treatments except on plots treated with bifenthrin and mineral oil on border, mineral oil on border, mineral on both potato and border and bifenthrin on potato between 4th and 5th week after crop emergence. This was followed by a gradual decline in aphid population in all the treatments. There were significant ($p \leq 0.05$) differences among treatments in total aphid population during the long rains. Potato plots treated with bifenthrin on border and potatoes had the lowest total aphid population

Table 4.18: Trends of the mean number of alate aphid catches in water traps placed inside potato plots during the 2007 long and short rains at NPRC, Tigoni

	Long rains								
	Weeks after potato emergence								
Treatment	3	4	5	6	7	8	9	10	Mean
Control	4.7	6.3	1.0	3.3	1.7	0.3	3.7	3.0	3.0
Bifenthrin +Mineral oil on Border	4.3	6.7	3.7	3.3	2.0	2.0	2.7	1.7	3.3
Bifenthrin +Mineral oil on Potato	3.3	1.7	4.7	4.0	4.0	0.0	3.7	3.3	3.1
Bifenthrin on Border	3.0	1.7	2.7	0.7	2.3	1.0	3.0	3.0	2.2
Bifenthrin on Potato	4.7	3.7	2.0	2.0	3.3	0.0	4.7	2.7	2.9
Bifenthrin on Potato +Border	2.0	3.0	1.7	2.7	5.3	0.3	4.0	2.3	2.7
Mineral oil on Border	2.7	2.0	2.7	4.3	2.7	0.0	2.7	2.0	2.4
Mineral oil on Potato	4.3	1.7	6.7	4.7	5.0	1.0	3.0	2.7	3.6
Mineral oil on potato +Border	4.3	1.7	2.0	4.7	2.3	1.0	2.3	1.0	2.4
LSD ($P \leq 0.05$)	ns	ns	3.6	ns	ns	ns	ns	ns	ns
CV%	21.1	32.0	29.6	27.2	16.5	27.0	49.7	55.4	43.9

	Short rains								
	Weeks after potato emergence								
Treatment	3	4	5	6	7	8	9	10	Mean
Control	3.3	4.7	19.7	2.0	6.0	15.3	19.3	25.0	11.9
Bifenthrin +Mineral oil on Border	1.7	1.0	2.0	1.0	5.3	9.3	10.7	3.7	4.3
Bifenthrin +Mineral oil on Potato	1.3	3.0	0.3	4.0	0.0	1.0	1.7	0.7	1.5
Bifenthrin on Border	1.0	2.3	11.7	2.3	2.0	5.0	6.3	8.3	4.9
Bifenthrin on Potato	1.0	1.7	6.0	1.7	2.3	1.7	8.7	7.3	3.8
Bifenthrin on Potato +Border	0.7	0.7	6.3	0.7	6.0	15.3	19.3	25.0	9.3
Mineral oil on Border	1.0	0.3	4.3	0.3	2.7	1.7	9.7	7.3	3.4
Mineral oil on Potato	1.7	1.0	0.3	1.0	0.7	1.7	0.7	0.7	1.0
Mineral oil on potato +Border	2.3	1.0	0.0	1.0	0.7	3.0	1.3	2.0	1.4
LSD ($P \leq 0.05$)	ns	2.4	9.9	2.1	4.6	5.5	9.2	20.6	3.1
CV%	18.9	9.8	18.7	31.1	35.7	33.1	30.7	64.7	24.8

ns= not significant

Table 4.19: Trends of the mean number of alate aphid catches on water traps placed inside potato plots during the 2007 long and short rains at Kabete

Long rains

	Weeks after potato emergence						
Treatment	3	4	5	6	7	8	Mean
Control	3.3	4.7	2.7	1.7	1.7	0.3	2.4
Bifenthrin +Mineral oil on Border	2.0	0.3	1.0	0.3	0.3	1.7	0.9
Bifenthrin +Mineral oil on Potato	0.7	1.0	3.7	1.0	1.0	1.3	1.4
Bifenthrin on Border	0.7	2.3	2.0	0.3	0.3	0.0	0.9
Bifenthrin on Potato	2.3	2.3	1.3	0.7	0.7	0.0	1.2
Bifenthrin on Potato +Border	0.7	2.3	1.7	0.7	0.7	0.0	1.0
Mineral oil on Border	1.7	1.7	2.3	0.7	0.7	0.7	1.3
Mineral oil on Potato	1.0	2.3	2.7	1.0	1.0	0.3	1.4
Mineral oil on potato +Border	0.7	0.7	0.7	0.7	0.7	0.7	0.7
LSD ($P \leq 0.05$)	ns	2.9	ns	ns	ns	ns	ns
CV%	70.5	23.6	19.2	49.5	49.5	72.1	10.4

Short rains

	Weeks after potato emergence							
Treatment	3	4	5	6	7	8	9	Mean
Control	4.3	4.3	1.7	7.3	10.0	15.7	32.7	10.9
Bifenthrin +Mineral oil on Border	1.7	3.0	2.0	2.3	2.0	6.0	11.0	4.0
Bifenthrin +Mineral oil on Potato	0.0	1.3	1.0	0.0	0.7	1.3	6.7	1.6
Bifenthrin on Border	1.7	1.3	0.7	1.7	3.3	4.7	25.3	5.5
Bifenthrin on Potato	0.3	0.7	5.7	0.7	2.7	3.3	6.7	2.9
Bifenthrin on Potato +Border	1.3	0.3	1.3	1.3	0.7	0.3	4.7	1.4
Mineral oil on Border	1.0	3.0	1.3	1.7	1.7	10.7	18.7	5.4
Mineral oil on Potato	0.0	0.3	1.3	0.0	0.7	0.7	7.3	1.5
Mineral oil on potato +Border	1.3	0.7	3.7	3.0	4.0	2.3	12.3	3.9
LSD ($P \leq 0.05$)	0.3	0.7	0.4	0.5	2.7	5.2	8.2	2.0
CV%	52.9	57.5	73.3	34.0	45.8	22.1	30.6	20.1

ns= not significant

4.4.2 Effect of border crops, insecticides and mineral oil on virus disease incidence and virus titre

Virus incidence increased steadily in all treatments through out the potato growth period in both Tigoni and Kabete sites (Table 4.20). No disease was observed on all treatments up to the 5th week after potato emergence. After the 5th week, control plots had the highest virus incidence in the two sites. There were significant ($p \leq 0.05$) differences among treatments in the virus disease incidence over the sampling period after the 5th week of crop growth.

Six viruses were identified in the potato tuber sprouts after DAS- ELISA. These were: Potato leaf roll virus (PLRV), Potato virus Y (PVY), Potato virus X (PVX), Potato virus A (PVA), Potato virus S (PVS) and Potato virus M (PVM). PVS was the most prevalent and was detected in the highest virus titre (Table 4.21). At Tigoni site, PVS was the most abundant followed by PLRV and PVM was the least abundant during the short rains. There was significant ($p \leq 0.05$) difference among treatments in virus titre of PLRV, PVA and PVS. Spray treatment did not significantly reduce virus titre.

PVS was also the most prevalent virus during the long rains in Tigoni site. It comprised of 80% of the total virus titre detected in tubers (Table 4.22). Although there were no significant ($p \leq 0.05$) differences among treatments in all viruses disease titre over the long rains, treatments differed significantly during the short rains. All treatments were effective in management of PLRV and PVY except control plots. Virus titre was not significantly different in all spray treated plots except control plots. Total virus titre was not different for all treatments except in control plots.

ble 4.20: Virus incidence on potato plants on maize bordered plots treated with eral oil and bifenthrin during the 2007 short rains, in NPRC, Tigoni and Kabete

	Tigoni site					
	Weeks after emergence					
eatment	2	3	5	7	9	Total
ontrol	0.0	0.0	5.9	20.7	22.9	49.5
fenthrin +Mineral oil on Border	0.0	0.0	3.7	7.4	7.4	18.4
fenthrin +Mineral oil on Potato	0.0	0.0	0.0	5.2	5.9	11.1
ifenthrin on Border	0.0	0.0	1.5	3.7	5.9	11.1
ifenthrin on Potato	0.0	0.0	1.5	11.8	11.8	25.1
ifenthrin on Potato +Border	0.0	0.0	0.7	9.6	11.8	22.1
ineral oil on Border	0.0	0.0	1.8	5.2	5.2	12.2
ineral oil on Potato	0.0	0.0	0.0	2.9	2.9	5.9
ineral oil on potato +Border	0.0	0.0	2.2	7.4	6.7	16.2
SD ($P \leq 0.05$)	ns	ns	3.4	8.3	9.6	20.0
V%	0.0	0.0	25.8	14.7	21.3	17.8

	Kabete site					
	Weeks after emergence					
reatment	2	3	5	7	9	Total
ontrol	0.0	0.0	3.7	10.4	14.0	28.1
Bifenthrin +Mineral oil on Border	0.0	0.0	2.6	6.7	8.1	17.4
Bifenthrin +Mineral oil on Potato	0.0	0.0	0.0	4.1	5.2	9.2
Bifenthrin on Border	0.0	0.0	0.7	8.1	4.8	13.7
Bifenthrin on Potato	0.0	0.0	0.7	2.6	5.2	8.5
Bifenthrin on Potato +Border	0.0	0.0	0.0	0.7	1.1	1.8
Mineral oil on Border	0.0	0.0	0.4	2.9	2.9	6.2
Mineral oil on Potato	0.0	0.0	0.0	0.4	1.1	1.5
Mineral oil on potato +Border	0.0	0.0	0.7	5.6	7.4	13.7
LSD ($P \leq 0.05$)	ns	ns	1.3	4.5	4.5	8.6
CV%	0.0	0.0	21.7	26.2	9.8	10.5

s denotes- Not significant

PVS was the most abundant virus in Kabete site during both the long and short rains (Table 4.23). There were no significant (p≤0.05) differences among treatments in all virus titres during the long rains. However, virus titre differed significantly among treatments during the short rains season except in PVM and PVX. All treatments significantly reduced PLRV and PVY titre except bifenthrin application on border crops, potatoes and control. PVS infection was the highest while PVY was the least in both Tigoni and Kabete sites in the two seasons.

Table 4.21: Virus titre on potato tubers subjected to different treatments and harvested during the 2006/2007 short rains, in NPRC, Tigoni

	Potato viruses						
Treatment	PLRV	PVX	PVA	PVS	PVM	PVY	Mean
No border	0.09	0.01	0.00	0.29	0.02	0.00	0.07
Maize	0.17	0.03	0.00	0.49	0.04	0.05	0.13
Sorghum	0.10	0.02	0.00	0.38	0.05	0.04	0.10
Wheat	0.17	0.02	0.00	0.35	0.05	0.06	0.11
No border and spray	0.19	0.03	0.00	0.48	0.08	0.03	0.14
Maize and spray	0.16	0.05	0.01	0.37	0.11	0.04	0.12
Sorghum and spray	0.15	0.04	0.00	0.36	0.04	0.02	0.10
Wheat and spray	0.22	0.04	0.01	0.42	0.09	0.05	0.14
LSD (P≤ 0.05)	0.08	ns	ns	0.13	ns	ns	ns
CV%	10.50	40.80	86.90	19.00	23.50	33.90	30.40

PLRV-Potato leaf roll virus, PVX- Potato virus X, PVA-Potato virus A, PVS-Potato virus S, PVM-Potato virus M, PVY-Potato virus and ns= not significant

Table 4.22: Virus titre in potato tubers harvested during the 2007 long and short rains in NPRC, Tigoni

Treatment	Long rains						
	PLRV	PVA	PVM	PVS	PVX	PVY	Mean
Control	0.14	0.05	0.05	0.69	0.02	0.01	0.16
Bifenthrin +Mineral oil on Border	0.18	0.03	0.00	0.75	0.01	0.04	0.17
Bifenthrin +Mineral oil on Potato	0.17	0.03	0.05	0.77	0.04	0.01	0.18
Bifenthrin on Border	0.14	0.03	0.16	0.99	0.01	0.02	0.23
Bifenthrin on Potato	0.16	0.03	0.00	0.80	0.01	0.01	0.17
Bifenthrin on Potato +Border	0.10	0.05	0.10	0.74	0.02	0.06	0.18
Mineral oil on Border	0.20	0.02	0.00	0.78	0.01	0.00	0.17
Mineral oil on Potato	0.06	0.01	0.00	0.42	0.00	0.00	0.08
Mineral oil on potato +Border	0.13	0.02	0.01	0.77	0.01	0.02	0.16
LSD ($P \leq 0.05$)	ns	0.03	ns	ns	ns	ns	ns
CV%	22.60	69.10	127.90	6.70	52.90	26.30	13.2

Treatment	Short rains						
	PLRV	PVA	PVM	PVS	PVX	PVY	Mean
Control	0.20	0.07	0.12	1.26	0.04	0.14	1.69
Bifenthrin +Mineral oil on Border	0.13	0.02	0.09	0.90	0.02	0.00	1.16
Bifenthrin +Mineral oil on Potato	0.01	0.01	0.05	0.78	0.03	0.00	0.88
Bifenthrin on Border	0.13	0.02	0.06	0.92	0.01	0.00	1.15
Bifenthrin on Potato	0.02	0.07	0.08	0.88	0.06	0.00	1.11
Bifenthrin on Potato +Border	0.04	0.02	0.06	0.80	0.01	0.00	1.08
Mineral oil on Border	0.05	0.02	0.05	0.76	0.01	0.01	0.90
Mineral oil on Potato	0.00	0.02	0.05	0.77	0.03	0.00	0.88
Mineral oil on potato +Border	0.09	0.03	0.09	0.72	0.04	0.00	0.96
LSD ($P \leq 0.05$)	0.14	0.05	0.05	ns	0.04	0.14	0.49
CV%	96.60	34.00	16.70	20.90	32.60	173.20	23.10

PLRV-Potato leaf roll virus, PVX- Potato virus X, PVA-Potato virus A, PVS-Potato virus S, PVM-Potato virus M, PVY-Potato virus and ns= not significant

Table 4.23: Virus titre in potato tubers harvested during the 2007 long and short rains, in Kabete

Treatment	Long- rains						
	PLRV	PVA	PVM	PVS	PVX	PVY	Mean
Control	0.13	0.09	0.00	0.79	0.01	0.01	0.17
Bifenthrin +Mineral oil on Border	0.12	0.03	0.32	0.92	0.03	0.00	0.24
Bifenthrin +Mineral oil on Potato	0.11	0.05	0.06	0.77	0.00	0.00	0.17
Bifenthrin on Border	0.10	0.01	0.13	0.77	0.01	0.00	0.17
Bifenthrin on Potato	0.12	0.02	0.17	0.93	0.05	0.00	0.21
Bifenthrin on Potato +Border	0.13	0.08	0.67	0.86	0.05	0.01	0.30
Mineral oil on Border	0.14	0.06	0.04	0.88	0.01	0.00	0.19
Mineral oil on Potato	0.09	0.02	0.01	0.73	0.00	0.00	0.14
Mineral oil on potato +Border	0.14	0.12	0.10	0.85	0.04	0.00	0.21
LSD (P≤0.05)	ns	ns	0.56	0.14	ns	ns	0.11
CV%	10.20	52.50	49.60	7.00	17.10	110.80	3.7

Treatment	Short rains						
	PLRV	PVA	PVM	PVS	PVX	PVY	Mean
Control	1.31	0.20	0.09	1.02	0.04	0.04	2.70
Bifenthrin +Mineral oil on Border	0.37	0.07	0.10	0.96	0.02	0.00	1.50
Bifenthrin +Mineral oil on Potato	0.15	0.13	0.07	0.86	0.01	0.00	1.21
Bifenthrin on Border	1.12	0.03	0.06	0.64	0.01	0.01	1.86
Bifenthrin on Potato	0.75	0.02	0.07	0.15	0.03	0.00	1.01
Bifenthrin on Potato +Border	0.06	0.20	0.07	0.59	0.00	0.00	0.91
Mineral oil on Border	0.05	0.06	0.05	0.87	0.02	0.00	1.05
Mineral oil on Potato	0.01	0.08	0.05	0.43	0.01	0.00	0.58
Mineral oil on potato +Border	0.16	0.14	0.04	0.93	0.01	0.00	1.29
LSD (P≤0.05)	0.61	0.14	ns	0.52	ns	0.02	0.97
CV%	44.10	94.70	10.20	14.40	34.00	173.20	7.00

PLRV-Potato leaf roll virus, PVX- Potato virus X, PVA-Potato virus A, PVS-Potato virus S, PVM-Potato virus M, PVY-Potato virus and ns= not significant

4.4.3 Effect of border crops, insecticides and mineral oil on potato tuber yield

More seed than either ware or chatts were produced in both Tigoni and Kabete sites. Total weight was significantly ($p \leq 0.05$) different among all treatments in both Tigoni and Kabete sites (Table 4.24). However, yield from sprayed and non- sprayed plots was not significantly ($p \leq 0.05$) different. However, Tigoni recorded higher yield than Kabete site. And the sites produced 55.6% and 44.4% of the total tuber yield respectivelly. Yield was not significant ($p \leq 0.05$) different in all treatments during both the long and short rains in Tigoni site (Table 4.25). More seeds than ware and chatts were produced in all treatments. Mineral oil application yielded the highest ware yield during the long rains. There were no significant ($p \leq 0.05$) differences among treatments on tuber yield produced over both long and short rains in Kabete site (Table 4.26). Although all treatments produced more seed than ware or chatts, they were not significantly different among treatments and Tigoni site yielded more than Kabete site. More (10%) seed was produced in bifenthrin application on the treated plots than the control.

Table 4.24: Weight in (kg) of potato tubers harvested from plots surrounded by different border crops and treated with insecticides during October 2006- February 2007 at Kabete and January – June 2007 at NPRC, Tigoni

Treatment	Kabete site	Tigoni site
No-border	26.8	43.5
Maize	28.3	34.7
Sorghum	27.7	40.3
Wheat	27.5	42.7
No-border and spray	22.2	43.3
Maize and spray	27.8	27.4
Sorghum and spray	27.0	34.5
Wheat and spray	25.7	33.7
LSD ($P \leq 0.05$)	ns	9.4
CV%	7.6	3.3

Table 4.25: Weight (kg) of different grades of potato tubers harvested from plots surrounded by maize borders and treated with insecticides and mineral oil during the May to October 2007 long rains and October to March 2008 short rains, at NPRC, Tigoni

	Long rains			
Treatment	Ware >55 mm	Seed 25-55 mm	Chatts <25 mm	Total weight
Control	15.3	24.7	1.2	41.2
Bifenthrin +Mineral oil on Border	17.2	18.1	0.7	36.0
Bifenthrin +Mineral oil on Potato	18.5	27.7	1.6	47.8
Bifenthrin on Border	18.5	26.0	1.6	46.1
Bifenthrin on Potato	17.9	31.0	1.4	50.3
Bifenthrin on Potato +Border	14.9	31.2	1.2	47.3
Mineral oil on Border	19.1	25.2	1.4	45.7
Mineral oil on Potato	14.9	31.2	1.2	47.3
Mineral oil on potato +Border	11.7	27.1	1.0	39.8
LSD ($P \leq 0.05$)	ns	ns	ns	ns
CV%	31.5	6.5	12.6	8.9

	Short rains			
Treatment	Ware > 55 mm	Seed 25-55 mm	Chatts < 25 mm	Total weight
Control	11.3	19.8	2.5	33.6
Bifenthrin +Mineral oil on Border	12.6	21.8	1.8	36.3
Bifenthrin +Mineral oil on Potato	9.2	16.5	2.3	28.0
Bifenthrin on Border	10.8	19.2	1.8	31.7
Bifenthrin on Potato	11.7	22.4	2.2	36.2
Bifenthrin on Potato +Border	7.0	16.1	2.3	25.4
Mineral oil on Border	9.3	17.3	1.7	28.3
Mineral oil on Potato	9.6	18.3	2.4	30.3
Mineral oil on potato +Border	8.5	14.8	2.2	25.5
LSD ($P \leq 0.05$)	ns	ns	ns	ns
CV%	0.6	9.7	15.4	6.0

ns= not significant

Table 4.26: Weight (kg) of different grades of potato tubers harvested from plots surrounded by maize borders and treated with insecticides and mineral oil during the April to September 2007 long rains and October to March 2008 short rains, at Kabete

	Long rains			
Treatment	Ware > 55 mm	Seed 25-55 mm	Chatts < 25 mm	Total weight
Control	8.5	17.2	1.0	26.7
Bifenthrin +Mineral oil on Border	8.9	21.4	1.1	31.4
Bifenthrin +Mineral oil on Potato	8.8	18.5	1.1	28.4
Bifenthrin on Border	6.8	17.1	1.1	25.0
Bifenthrin on Potato	9.0	19.0	1.3	29.3
Bifenthrin on Potato +Border	9.8	16.9	1.3	28.0
Mineral oil on Border	7.8	21.5	1.3	30.6
Mineral oil on Potato	7.7	17.5	1.3	26.5
Mineral oil on potato +Border	11.3	19.8	1.0	32.1
LSD (P≤0.05)	ns	ns	ns	ns
CV%	8.1	4.2	6.3	4.7

	Short rains			
Treatment	Ware >55 mm	Seed 25-55 mm	Chatts <25 mm	Total weight
Control	0.7	7.8	0.8	9.3
Bifenthrin +Mineral oil on Border	0.0	8.5	0.8	9.3
Bifenthrin +Mineral oil on Potato	0.8	11.0	1.0	12.8
Bifenthrin on Border	0.7	8.7	1.3	10.7
Bifenthrin on Potato	0.8	11.7	0.8	13.3
Bifenthrin on Potato +Border	1.7	11.5	0.7	13.8
Mineral oil on Border	0.3	9.7	1.0	11.0
Mineral oil on Potato	1.3	11.3	0.8	13.5
Mineral oil on potato +Border	0.8	7.8	0.8	9.5
LSD (P≤0.05)	1.1	3.0	ns	ns
CV%	70.6	19.3	17.7	19.9

ns= not significant

4.5 Discussion

4.5.1 Effect of integrating different border crops with bifenthrin spray on aphid population.

From this study, spraying did not reduce aphid population infesting potato plants. The failure of spray treatment could be attributed to the effectiveness of the chemical applied and mode of spraying. Spray treatment can be less effective especially when it does not cover the lower canopy where aphids like *M. persicae* colonize (Radcllife *et al.*, 2002). Movement during spraying can also impact on the population of colonizing aphids because Klostermeyer, (1959) found it to be able to promote interplant movement activity of aphids. Reports by Kerns and Stewart (2000) suggested that sublethal dosages of bifenthrin have a negative effect on aphid population growth as dosage increases. The high aphid populations and aphid peaks on the 6th week at Kabete and 8th week in Tigoni could be explained by the prevailing weather conditions which determine the kind of aphid species, abundance and nature of infestation. Cocu *et al.*, (2005) observed that rainfall was negatively correlated with aphid numbers while temperature was positively correlated to aphid population increase.. Increase in aphid numbers was observed when temperatures were relatively high (16.9^{0}C to 18^{0}C) in this experiment.

4.5.2 Effect of integrating maize borders with bifenthrin and mineral oil on aphid population

The occurrence of aphid peaks between the 8th and 10th week after potato crop emergence during the long and short rains can be attributed to the prevailing hot weather (high mean temperatures) in the months of April and December on the two sites. The aphids peaks obtained in sticky traps between 3rd and 4th weeks of plant growth is of importance in potato crop production. Handizi and Legorburu (2002) found the first third of the vegetative period (4 weeks after potato crop emergence) to be the most important time for virus infection. These peak periods can be used to determine the critical period of maximum virus transmission and management. The low levels of aphid populations during the long rains can be explained by the prevailing climatic conditions. Mean temperatures (13^0C minimum and maximum 18^0C) and rainfall (116mm) experienced over the growth period in both Kabete and Tigoni sites may have affected the rates of reproduction and flight of aphids. It has been observed that precipitation and low temperatures have a negative impact on aphid population build up (Cocu *et al.*, 2005). Precipitation reduces aphid flight by limiting take- off, preventing essential movement of wingless aphids and drowning aphids. Guillemaud *et al.*, (2003) reported that temperatures also played a great role in the reproduction and migration of Green peach aphids.

Although spray treatment was ineffective in reduction of aphids over the long rains, it was significantly effective during the short rains. It is evident that application of mineral oil on potato plots was effective in suppressing aphid population in the potato crop. This is in agreement with findings of Karagounis *et al.*, (2006) and Martin Lopez *et al.*, (2005) that application of mineral oil to control aphids caused 80%-88% aphids mortality. Kibaru, (2003) attributed the occurrence of low aphid population on mineral oil treated plots than control plots to the reduction of settling behavior and larvioposition of *M. persicae* within 24 hours after application of the treatment. Mineral oil persists in the field on potato plants for 10-14 days (Hanafi, 2000). This can be hypothesized to be one of the major factors, which contributed to low aphid population because spray treatment was done on weekly basis before the other chemical was exhausted in the plant tissues.

Bifenthrin was also effective in the reduction of potato aphid population. Bifenthrin is a systemic insecticide with a rapid breakdown effect. This enables it to kill aphids feeding under the leaves when applied to the upper surface.

Plots treated with bifenthrin followed by mineral oil were found to be an effective method in reducing potato aphid population. This is in accordance with earlier findings by Martin Lopez *et al.* (2005) that aphid mortality rates achieved by spraying either a mixture of imidacloprid with mineral oil or imidacloprid with rapeseed oil were significantly higher than those achieved by imidacloprid alone within 24 hours. Mineral oil delays stylet penetration of aphids on plants while insecticides kill the aphids immediately (Powell *et al.* 1998 and Suranyi, 1999). The effectiveness of integrating mineral oil and insecticides might have been increased by presence of maize border crops which blocks pests migrating from neighboring fields from attacking the protected crop (Srinivas and Elawande, 2006). Results of this study are in agreement with a report by Boucher and Durgy (2004) that integrating border crops with sprays are much more effective in the control of insect pests on crops than a single method.

4.5.3 Effect of integrating border crops and insecticides on virus disease incidence and virus titre

High viral incidence was recorded on control plots than mineral oil or bifenthrin treated plots during the short rains in both Kabete and Tigoni sites. This is inconsistent with Lovieno *et al.*(2005) and Perring *et al,* (1999) findings. Insecticides are known to be of inconsistent benefit in controlling virus spread. However, the success of insecticides in control of viruses is determined by whether the virus is persistently or non- persistently transmitted. Bifenthrin spray treatment did not reduce the viral titre during the short rains.

This might be attributed to the failure of the chemical to reduce aphid population since aphid population is positively correlated with virus titre.

It is evident that PVS was the most abundant virus in the experiment. This result is inconsistent with reports by Anon, (2007), Kabira *et al.* (2006) and Machangi *et al.* (2004) that PVS is the most common virus in potatoes and is rarely transmitted by aphids. The low levels of Potato virus titre obtained in all treatments can be attributed to the low virus titre on seeds. Planting disease free certified seeds are known to produce tubers with a low viral titre compared to planting uncertified seed when other management practices are kept constant (Machangi, 2003). Although bifenthrin and mineral oil were not effective in control of PLRV during the long rains, they were effective over the short rains. The latent period required between PLRV acquisition and transmission gives insecticides sufficient time to effectively kill aphids and control PLRV (Suranyi, 1999; Hanafi, 2000). It was evident from the experiment that mineral oil had lower virus titre compared to other treatments. This is in agreement with Lovieno *et al.*, (2005) findings that mineral oil treated plots had lower virus infection compared to other plots. Presence of mineral oil on plant surface reduces virus acquisition and inoculation hence reducing infection on plants (Powell, 1992).

Virus titre between plots treated with chemical spray either on crop borders or in potatoes was not significantly different. This is in agreement with findings of Difonzo *et al.* (1996) that routinely treating borders of spring planted winter wheat and forage sorghum with insecticides to control cereal aphids did not increase their efficiency in reducing PVY compared to un-treated border crops. This study did not show the difference between insecticides and mineral oil in management of persistent and non- persistent potato viruses since the viral load was very low. However, integration of border crops with mineral oil and insecticides was very effective in the reduction of virus titre in all plots compared to control plots.

4.5.4 Effect of integrating border crops and insecticides on tuber yield

Potato tuber yield was not different in all treatments in the experiment. This is in agreement with findings of Thackray *et al.* (2002). The indication that more seeds were produced compared to ware and chatt grades in the experiment shows that these methods of controlling aphids and associated viruses are effective in promotion of seed production. Total tuber yield during the long rains was observed to be higher than during the short rains. This might be attributed to the wet weather during the long rains (Luiza, 2006).

Integration of border crops with mineral oil and insecticides has been found to be effective in the management of potato aphids and aphid transmitted viruses. Mineral oil treated plots had no significant difference with bifenthrin treated plots in reduction of aphid population and virus titre. Therefore, careful selection of the management strategy to be applied should be based on farmers choice.

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CHAPTER 5: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

This study revealed that certain border crops are effective in the management of potato aphids and aphid transmitted viruses. It was evident from the results of this study that border had little or no effect on the growth and yield of the protected crop. Height of border crop was also found to be of little effect on the protected crops growth and development. Although maize and wheat significantly affected potato light interception, this had little effect on the yield. The spacing used from border crop to the protected potato crop was found to be effective because it did not affect potato yield.

The main aphids identified infesting potatoes were *Aphis gossypii*, *Macrosiphum euphorbiae*, *Myzus persicae* and *Rophalosiphum maidis*. These are major potato aphid species, which transmit viruses in potatoes. *Aphis gossypii* was abundant on leaves duringthe short rains while *M.euphorbiae* was abundant during the long rains. The high abundance of *M. euphorbiae* on leaves during the long rains in both Kabete and Tigoni sites is in agreement with work reported by Machangi, (2003). The prevalence of *M. euphorbiae* during cold weather suggests that low temperatures favor its population increase. Crop bordered plots had less total aphid population compared to non-bordered plots. The study revealed that wheat and sorghum borders are more effective in the reduction of aphid population than maize borders. The high aphid population in maize bordered plots can be attributed to its wide spatial arrangement compared to sorghum and wheat. This shows that if the spacing of maize can be altered it can be effective in the reduction of aphid population.

The study showed that plots without border crops had higher level of virus incidence than crop bordered plots and it can therefore be deduced that the border crops played a role in reduction of viral load on potatoes. Six viruses were found infesting potato tubers. These were Potato leave roll virus (PLRV), Potato virus Y (PVY), Potato virus S (PVS), Potato virus M (PVM), Potato virus A (PVA) and Potato virus X (PVX). Potato virus S was the most abundant followed by PLRV, PVM, PVA, PVX and lastly PVY. Since PVY virus titre was much lower on maize and wheat bordered plots than non-bordered plots, there is a clear indication that the two border crops can be used by farmers to control viral diseases in their farms. There was more tuber yield in plots without border crops than in crop bordered plots. However, sorghum bordered plots produced lower seed tuber yield than maize and wheat bordered plots. This implies that choice of type of border crop should be based on the targeted tuber grade.

Integration of maize border crop with mineral oil and bifenthrin was found to be an effective strategy in management of potato aphids. Application of either mineral oil or bifenthrin on maize bordered plots was found to be very effective in reduction of total potato aphid population. Although the treatments were not able to significantly reduce aphid populations over the long rains, it was evident during the short rains that there was no clear-cut difference on their efficiency. Application of chemicals on either border or on potatoes was not different in reduction of total aphid population although low total aphid numbers were found on plots where spray was applied on potatoes. This is an indication that farmers can use any method with maximum reduction of aphid infestation. Since the highest total viral titre was recorded on control plots, it can therefore be deduced that the other treatments controlled viral load to some extent. The low levels of

PVY in the experiment is a clear indication of the effectiveness of this methods in management of potato viruses since the potatoes planted did not have any viral load.

Potato tuber yield was not different in all the treatments. This shows that all the treatments had equal effects on yield and farmers choice should be based on the efficiency to control aphids and associated viruses.

5.2 Conclusions and Recommendations

This study revealed that border crops were effective and practical method of reducing aphids and PVY incidence. Wheat and sorghum border crops were the most efficient border crops in reduction of aphid numbers while wheat and maize borders were efficient in virus control. Although high total tuber yield was obtained on plots without border crops, the study showed that maize and wheat borders did not affect seed production negatively. It was evident from the results that efficiency of border crops could be improved by using non-host plants that will be able to block aphids or encourage increase in natural enemies. Border crop use is an affordable virus management strategy to farmers since it is compatible with current production practices and requires no specialized technology investment.

Application of either mineral oil or bifenthrin proved to be effective in the management of potato aphids and associated viruses. Integration of maize border with either of the chemical sprays played a great role on aphid reduction. The studies also revealed that all the spray applications had equal effect on yield of potato tubers. Although spraying bifenthrin or mineral oil alone seemed to have similar effect on aphid population with spraying mineral oil followed by bifenthrin in the short term, single solutions are ineffective in the long term. This is because of development of resistance by pests and diseases. Therefore, farmers selection of the management method to employ should be based on the long term effects.

Based on the above conclusions, the following recommendations can be made:

Wheat, sorghum and maize borders can be recommended as efficient methods of aphid and aphid transmitted viruses management in seed potato production. Reduction of spacing distances of maize borders can improve its ability to reduce aphid populations.

Screening of border crops which are suited to different agro-ecological zones and socio-economic uses should be done.

Integrating border crops with mineral oil and bifenthrin should be recommended as a long term efficient method of control of aphids and associated viruses in seed potato production. However, optimal spacing between potato plot and border crops should be established. Maximum potato plot size which will enable large scale producers to achieve maximum benefits with minimum risks should also be established.

Further trials should be carried out to evaluate the optimal mineral oil application rates and frequency useful for controlling viruses with minimal management cost.

More attention should be given to breeding virus-resistant cultivars that would lead to decreased pesticide use and thus promote more integrated environment-friendly strategies for the control of viral disease vectors.

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CHAPTER 7: APPENDICES

ppendix 1. Standard procedure for carrying out Double antibody sandwich – enzyme ked Immunosorbent assay (DAS ELISA) serological technique for potato virus ection.

Coat each well of the plates with y- globulin
and incubate at room temperature for 5 hours.

↓

Sample preparation.

Washing ↓ NB: The plates are sequentially washed
in Phosphate buffered saline- in tween (PBST)
and carefully dried before next step.

Add 100ul of grinded samples into each plate well and incubate at 4^0C over night.

Washing ↓ NB: The plates are sequentially washed
in Phosphate buffered saline- in tween (PBST)
and carefully dried before next step.

Add conjugate antiserum (IgG-AP) to each plate well and incubate for 5 hours at room temperature.

Washing ↓ NB: The plates are sequentially washed
in Phosphate buffered saline- in tween (PBST)
and carefully dried before next step.

Add substrate (p- nitro phenyl phosphate) solution to each plate well and leave for 30- 60 minutes at room temperature, for reaction to occur.

↓

Visual assessment of infected samples (yellow color in wells of ELISA plates)

↓

Photometric measurement of absorbance at 405nm wavelength to determine positive samples using ELISA reader

Appendix 2. Average monthly rainfall (mm) and ambient temperatures (^0C) in Kabete.

Year	Month	Rainfall (mm)	No. of rain days	Maximum temperature	Minimum temperature
2006	September	25.9	6	22.7	12.4
2006	October	87.4	8	24.8	14.0
2006	November	348.1	18	22.0	14.7
2006	December	246.0	12	22.9	14.6
2007	January	30.2	6	23.6	14.3
2007	February	90.0	9	25.4	13.9
2007	March	52.6	8	25.0	14.4
2007	April	348.4	17	24.2	14.9
2007	May	184.2	7	22.6	14.5
2007	June	83.1	5	22.2	12.7
2007	July	25.2	5	20.5	12.1
2007	August	52.6	8	20.7	12.5
2007	September	89.1	10	22.6	12.4
2007	October	25.0	7	23.6	14.0
2007	November	66.6	13	22.8	14.5
2007	December	42.4	9	23.1	13.6
2008	January	51.4	4	24.5	13.3
2008	February	31.6	4	25.1	13.3
2008	March	178.1	10	25.5	14.5

Source: Kenya Agromaterological Department, Kabete

Appendix 3. Average monthly rainfall (mm) and ambient temperatures (^0C) in Tigoni.

Year	Month	Rainfall (mm)	No. of rain days	Maximum temperature	Minimum temperature
2007	January	263.0	4	18.5	15.3
2007	February	333.0	4	18.8	14.9
2007	March	824.0	6	18.0	13.7
2007	April	492.1	16	16.9	14.4
2007	May	276.4	13	16.9	14.3
2007	June	132.1	8	14.7	13.6
2007	July	27.2	3	13.6	12.6
2007	August	18.1	13	13.1	14.3
2007	September	96.8	11	15.7	13.5
2007	October	56.8	8	17.2	14.3
2007	November	89.6	11	16.7	13.3
2007	December	67.1	7	17.4	13.9
2008	January	62.1	11	17.8	14.4
2008	February	85.5	7	17.9	14.6
2008	March	304.1	15	19.2	14.4

Source: Kenya Agromaterological Department, NPRC, Tigoni

Appendix 4. Analysis of variance of total height of border crops during the 2007 long rains in Kabete

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
Block stratum	2	19	9.5	0.07	
Block. Variety stratum					
Variety	1	17.4	17.4	0.13	0.749
Residual	2	258.7	129.4	1.17	
Block.Variety.Crop stratum					
Crop	3	71979.3	23993.1	217.24	<.001
Variety. Crop	3	412.4	137.5	1.24	0.337
Residual	12	1325.3	110.4		
Total	23	74012.1			

Appendix 5. Analysis of variance of total height of border crops during the 2007 long rains in NPRC, Tigoni

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
Block stratum	2	78.79	39.39	1.01	
Block. Variety stratum					
Variety	1	38.81	38.81	1	0.423
Residual	2	77.63	38.81	0.63	
Block.Variety.Crop stratum					
Crop	3	33011.24	11003.75	179.22	<.001
Variety. Crop	3	15.9	5.3	0.09	0.966
Residual	12	736.78	61.4		
Total	23	33959.14			

Appendix 6. Analysis of variance of total aphid population on potato leave samples during the short rains, 2006 in Kabete

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
Block stratum	2	166.2	83.1	0.6	
Block. Variety stratum					
Variety	1	53.1	53.1	0.38	0.599
Residual	2	276.9	138	3.58	
Block.Variety.Crop stratum					
Crop	3	463.7	155	4	0.035
Variety. Crop	3	102.5	34.2	0.88	0.477
Residual	12	464	38.7		
Total	23	1526			

Appendix 7. Analysis of variance of total aphid population on potato leave samples during the 2007 short rains in Tigoni

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
Block stratum	2	1157	579	21.4	
Block. Variety stratum					
Variety	1	181	181	6.7	0.122
Residual	2	54.02	27	0.64	
Block.Variety.Crop stratum					
Crop	3	557.2	186	4.38	0.027
Variety. Crop	3	91.31	30.4	0.72	0.56
Residual	12	508.8	42.4		
Total	23	2550			

Appendix 8. Analysis of variance of total viral incidence during the 2007 short rains, in Kabete

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
BLOCK stratum	2	24.79	12.39	0.5	
BLOCK. *Units* stratum					
TREATMENT	8	1659.25	207.41	8.36	<.001
Residual	16	396.83	24.8		
Total	26	2080.87			

Appendix 9. Analysis of variance of total viral incidence during the 2007 short rains, in NPRC, Tigoni

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
BLOCK stratum	2	206.6	103.3	0.77	
BLOCK. *Units* stratum					
TREATMENT	8	3995.8	499.5	3.73	0.012
Residual	16	2139.8	133.7		
Total	26	6342.2			

Appendix 10. Analysis of variance of total aphid population on potato leave samples during the 2007 short rains, in Kabete

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
Block stratum	2	61.71	30.85	1.38	
Block. *Units* stratum					
Treatment	8	551.67	68.96	3.09	0.026
Residual	16	356.91	22.31		
Total	26	970.29			

Appendix 11. Analysis of variance of total aphid population water traps during the 2007 short rains, in Kabete

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
Block stratum	2	163.19	81.59	2.4	
Block. *Units* stratum					
Treatment	8	2248.52	281.06	8.26	<.001
Residual	16	544.15	34.01		
Total	26	2955.85			

Appendix 12. Analysis of variance of total aphid population sticky traps during the 2007 short rains, in Kabete

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
Block stratum	2	32.67	16.33	0.81	
Block. *Units* stratum					
Treatment	8	1012.67	126.58	6.28	<.001
Residual	16	322.67	20.17		
Total	26	1368			

Appendix 13. Analysis of variance of total aphid population sticky traps during the 2007 short rains, in NPRC, Tigoni

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Variance ratio	Pr.>F
Block stratum	2	50.074	25.037	6.4	
Block.*Units* stratum					
Treatment	8	173.63	21.704	5.55	0.002
Residual	16	62.593	3.912		
Total	26	286.296			