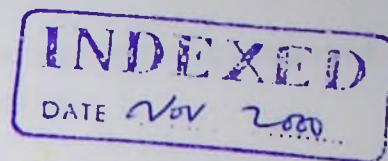


EFFICIENCY OF A SYSTEMIC INSECTICIDE (*DIMETHOATE*) TO PREVENT
APHID INFESTATION AND INFECTION OF APHID-BORNE VIRUSES IN
POTATO (*SOLANUM TUBEROSUM* LIN.).



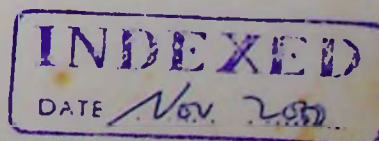
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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
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IN AGRICULTURE OF MAKERERE UNIVERSITY

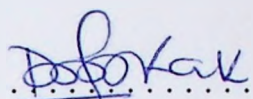
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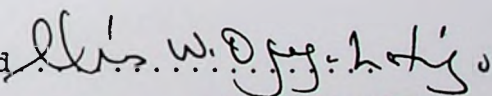
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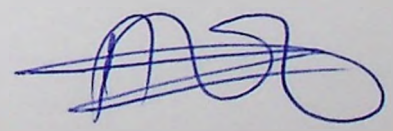
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DEDICATION

To my parents whose love and respect for
education was my inspiration.

And my brothers and sisters, I owe so much.

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ABSTRACT

Field experiments were conducted at Namulonge Agricultural and Animal Production Research Institute (NAARI) during the 1994 short rains (SR) and the 1995 long rains (LR), and at Kalengyere Research Station (KRS) during the 1995LR. The studies evaluated the efficiency of a systemic insecticide (dimethoate) in preventing aphid infestation and infection of aphid-borne viruses in potato (*Solanum tuberosum* L.). A screen house experiment was also conducted at NAARI in the 1995LR to establish the onset of mature plant resistance to virus infection in potato in order to limit insecticide spray application to critical growth periods of potato plants.

The response of aphids to dimethoate spray treatment on seven *Solanum* potato varieties varied significantly between Kalengyere and Namulonge and, between aphid species infesting potato, particularly at Namulonge. This affected the ability of dimethoate to prevent aphid infestation and, consequently, the spread of aphid-borne viruses in potato.

At Namulonge, dimethoate suppressed all potato infesting aphids except *Myzus persicae* (Sulz.). This led to heavy *M. persicae* infestation on sprayed than unsprayed potatoes. In contrast weekly dimethoate sprays effectively controlled aphid colonisation at Kalengyere, and population development in sprayed potatoes. Unsprayed potatoes at Kalengyere were heavily infested by aphids, with rapid aphid population growth occurring between the fifth and the sixth weeks after plant emergence. A comparison between Namulonge and Kalengyere showed that there was higher aphid pressure at Kalengyere than

at Namulonge and, a higher aphid pressure at Namulonge during the long rains than the short rains.

The commonest potato aphid species caught in aphid traps were not the most abundant aphid species from potato plants. In addition, correlations between total trap catches and aphid infestation indices from plants did not reveal significant and consistent correlations within seasons, locations and insecticide treatments. However, pooled data revealed that percentage of potato plants infested by aphid was significantly correlated with the total number of alate aphids trapped. Aphid collections from plants at Namulonge and Kalengyere showed that aptarae aphids adequately determined the proportion of potato plants infested by aphids. At Kalengyere however, potato infestation by aphids was basically a function of alate aphids on both sprayed and unsprayed potatoes.

Seed potato tuber indexing for latent infection with three aphid-borne potato viruses and one mechanically transmitted virus before planting indicated that Kalengyere Research Station has potential of providing seed potato free from aphid-borne viruses. However, seed from three of the seven varieties were infected with a mechanically transmitted virus.

Attempt to prevent the spread of aphid-borne viruses in field grown potato using weekly spray of dimethoate spray at both NAARI and Kalengyere gave contrasting results. At NAARI, all the potato varieties used in the study were infected with potato leaf roll virus (PLRV) in the first season of their introduction from Kalengyere to Namulonge, irrespective of the

insecticide treatment. All the varieties were, however, free from potato virus Y (PVY) and potato virus S (PVS) infection.

At Kalengyere, the total effectiveness of dimethoate against all potato infesting aphid species and, the absence of aphid-borne viruses in field grown potatoes, probably indicate the ability of dimethoate to control aphids and aphid-borne viruses in *Solanum* potato at this site. It was also observed that whereas there was higher aphid pressure at Kalengyere than at Namulonge there was a greater virus pressure at Namulonge than at Kalengyere.

Virus inoculation of screen house grown potato plants at ten-day intervals after plant emergence using potato leaf roll virus infected aphids showed that potato plants inoculated after flowering may produce seed tubers which are free from aphid-borne viruses.

It was concluded from these studies that use aphicides in field grown potato, differences of various potato cultivars in susceptibility to both aphid and virus attack, and the on-set of mature plant resistance can reasonably reduce infection and spread of aphid-borne viruses in *Solanum* potato.

CHAPTER 1

I N T R O D U C T I O N

1.1 Origin, World Distribution and Importance of *Solanum* Potato

The present day cultivated potato (*Solanum tuberosum* Lin.) originated in the Andes highlands of South America in parts of the present day Peru and Bolivia (Burton, 1966; Horton, 1987; Anon., 1988; Hawkes, 1992). This is also the centre of genetic diversity of the *Solanum* potato, its pests and diseases (Anon., 1988). The domestication of the modern potato as a crop probably took place between 7000 and 8000 years ago (Dodds, 1965; Hawkes, 1992).

The potato was introduced to Europe through Spain in 1573 (Horton, 1987), and was brought to Africa by European colonialists and missionaries about the 18th Century (Burton, 1966; Horton, 1987; Anon., 1990). In Uganda, the crop was introduced around the 1890's by christian missionaries as a back yard garden crop especially in the highland areas in the former districts of Kigezi (Kabale, Rukungiri and Kisoro) and Bugisu (Mbale) (Anon., 1994b).

Before the Second World War, two thirds of the world potatoes were grown in continental Europe. After 1945, production declined in Europe but increased in developing countries, especially in Africa where growth in potato production has been up to 47% of the 1945 level (Horton, 1987; Horton and Anderson, 1992). Potato is presently

grown in 140 countries; the majority of which are in tropical and sub-tropical zones, a third of them being developing countries (Beukema and van der Zaag, 1990; Midmore, 1992).

The potato is the fourth most important food crop in the world after wheat, maize and rice (Anderson, 1981; Horton and Anderson, 1992). It ranks first among root and stem tuber crops and plantains (Burton, 1966) and it accounts for 52.9% of world production of all root and tuber crops (Simmonds, 1971; Anon., 1990).

Nutritively, potato has more edible protein than other roots and tubers. In terms of protein productivity per unit edible portion per hectare per day, potato produces $1.5 \text{ kg ha}^{-1} \text{ day}^{-1}$ of edible protein. This compares well with those of wheat (1.6), lentils (1.6) and groundnuts (1.6). It is superior in protein productivity to other starchy foods, for example, sweet potatoes (1.0), rice (1.0) and cassava (0.1). It can thus be used to supplement cassava, banana and sweet potato based diets (Anon., 1990; Beukema and van der Zaag, 1990; Ewell, 1991). Eaten alone potato has the necessary energy, protein and essential vitamin supply that can support the human body with minimal supplementation (Horton, 1987; Anon., 1990).

Potato is historically well known for supporting high population densities because of its high dry matter productivity and its short growth period (Rhoades, 1982; Horton, 1987). This is true in the case of Uganda. It is not by accident that potato production is becoming

increasingly important in Ugandan highlands which happen to be highly populated and most families in these areas depend on it for food and sometimes cash income.

1.2 Potato Production and Utilisation

Published world data on potato production and utilization is not quite reliable because of the low volume of international trade in the crop compared to crops such as tea or coffee (Horton, 1987; Horton and Anderson, 1992). By the nature of potato production on many small holdings, its local domestic consumption and sale in local markets, and sometimes secondary use at farm level, makes data collection on potato production and utilisation difficult (Ewell, 1991). In the case of Uganda, information on production and utilisation is scanty and sometimes misleading mainly because of lack of attention the crop has received until recently.

In the last five decades, potato production has decreased in developed countries due to commodity substitution, especially in the chemical and livestock industry. However, productivity has remained outstandingly high mainly due to heavy capital input (Beukema and van der Zaag, 1990; Midmore, 1992). In Asia, potato production has remained stable in countries with centrally planned economies but increased grossly in terms of both yields per unit area and total hectareage under the crop in countries with free market economy (Midmore, 1992). In Africa,

potato production has increased but only due to the increase in area under potato, with little increase in productivity. In East Africa, potato production has increased at a rate of 7.1% per annum during the last 15 years (Ewell, 1991; Sikka et al., 1992) also with no significant increase in productivity. Generally, the balance of world potato production is gradually shifting from developed to developing countries, and from temperate to tropical and sub-tropical zones (Midmore, 1992).

In Uganda, before 1968, promotion of potato production was not part of government agricultural policy although policy makers were aware of the potential of the crop as a food and possibly a cash crop. In 1968, a National Potato Research and Development Programme (NPRDP) was initiated in the former Kigezi district. By then, the national average yield was about 5 MT ha⁻¹ (Anon., 1994b). In 1974, eleven varieties were developed by the NPRDP in collaboration with Makerere University, United States Agency for International Development (USAID) and International Potato Centre (CIP). The yields of these varieties ranged from 20 to 60 MT ha⁻¹ (Anon., 1994b). By 1993, the Food and Agricultural Organisation estimated 39000 hectares to be under potato cultivation in Uganda with an average yield of 7 MT ha⁻¹ (Anon., 1993b) although the NPRDP estimates the total area under potato crop to be 45000 hectares (Anon., 1994b).

From 1981 to 1993 the total land area under potato cultivation in Uganda increased by 69.6% being 23000 hectares in 1981 and 39000 hectares in 1993 (Anon., 1993b).

Productivity over the same period increased by 7.54%, from 6.7 MT ha⁻¹ in 1981 to 7.2 MT ha⁻¹ in 1992 but it decreased to 6.9 MT ha⁻¹ in 1993. However, there has been a general increase of 74.6% in tonnage of potato production from 170,000 in 1981 to 270,000 metric tonnes in 1993 (Anon., 1993b). The increase in potato production therefore, has been due to more land being brought under *Solanum* potato cultivation than increase in yield per unit area.

In most cultures where *Solanum* potato was introduced, the crop was initially considered unfit as human food. It was always associated with taboos and possible cause of ill-health (Hawkes, 1992). In Western Europe, potato began to be recognised as human food in the 18th Century, after learning that it was good at ensuring food security and its ability to support rapidly growing populations (Burton, 1966; Horton and Anderson, 1992). Initially, the crop was used to feed animals and later used in industry to make starch and alcohol. In the Netherlands and Japan, potato is still an important source of industrial starch while in Eastern Europe potato is still important as fodder and a source of industrial starch and alcohol (Beukema and van der Zaag, 1990).

In Asia the potato is an important human food especially in countries with high population densities, such as China, India and Bangladesh. It is still an important source of industrial alcohol and starch in China (Horton, 1987), and is also reported to be used to make expensive cosmetics (Katafire M., personal communication).

Human consumption, however, takes precedence over any other use, potato being eaten both as fresh dishes and industrial preserved packs (Beukema and van der Zaag, 1990; Horton and Anderson, 1992).

Taking Africa and other developing regions in general (Majisu, 1982; Nganga, 1982; Midmore, 1992) and Uganda in particular, much of the potato is freshly consumed, some is used as seed while a small fraction is wasted potatoes. Presently, there is no potato processing industry in Uganda, either to manufacture industrial chemicals or to preserve it as human food for future consumption. The Ministry of Agriculture, Animal Industry and Fisheries reports of 43 recipes of potato preparation and preservation. None of which however, is yet exploited to process potato on a commercial scale (Anon., 1994a).

In farming systems of Western Europe and America, potato production is highly mechanised and production costs have consequently declined. In these regions, potato cultivation is a specialised agricultural business enterprise especially in seed potato production. In developing countries, monocrop potato are not rare but intercropping with beans, sorghum, maize or sugar cane is a common practice (Beukema and van der Zaag, 1990; Sikka L.C., 1991 personal communication). However, Sikka *et al.* (1992) noted that commercial and profitable potato production should be based on cultivation in pure stands without disturbing the present land under traditional food crops.

1.3 Potato Production Constraints in Uganda

Production of potato in Uganda, like in many other tropical and sub-tropical countries, is hampered by high disease and pest pressure. These make the generation of disease-free seed potato difficult and expensive (Burton, 1966; Sikka *et al.*, 1992). In addition to this, most farmers are not aware of some of the potato pests and diseases other than those that directly destroy either leaves, tubers or both.

In Uganda, bacterial wilt caused by *Pseudomonas solanacearum* (E. Smith), *Verticilium* and *Fusarium* fungal wilts, and several virus infections have hampered increased potato productivity in most areas of Uganda (Kanzikwera, 1994).

Potato insect pests in Uganda have not received the due attention they deserve even in areas where potato is the main food and cash income crop. The most important insect pests of potato in the tropics, Uganda inclusive, are aphids (Raman and Radcliffe, 1992) which are mainly sap sucking bugs. They also transmit major potato viruses that contribute a lot to seed potato degeneration, leading to reduced productivity of the seed progeny.

Among the potato infesting aphids, *Myzus persicae* (Sulz.) is of paramount importance (Raman 1984; 1985) as it persistently transmits potato leaf roll virus (PLRV). This is the most important virus infection that greatly reduces potato tuber size and yield per unit area (Beemster and

Rozendaal, 1972; Morales-Bermudez, 1982; DiFonzo et al., 1994). Other important potato infesting aphids include *Macrosiphum euphorbiae* (Kalt.), *Aulacorthum solani* (Kalt.), *Aphis nasturtii* (Kalt.), *Aphis gossypii* (Glov.) and the root and sprout aphid *Rhopalosiphoninus latysiphon* (Davidson). These aphid species together with *M. persicae* transmit potato virus Y (PVY) potato virus A (PVA), potato virus M (PVM) and potato virus S (PVS) to mention a few (Smith, 1977; Hooker, 1981) although the later can also be transmitted by contact (Wardrop et al., 1989).

The control of virus infection in the potato industry in Uganda has not received the attention it deserves. It has been restricted to Kalengyere Research Station which is the main seed source for the country. In the same station, more focus has been put on the viruses than their vectors. In view of this, a study was conducted at Namulonge Research Station representing low elevations and Kalengyere Research Station representing high elevations of Uganda. The purpose of the study was to document the incidence of the main potato viruses, their common aphid vectors and evaluate how the two can be jointly managed. This was done in an effort to improve on the health status of potato especially seed potato whose poor quality could be one of the main factors contributing to the cause of low potato yields in Uganda.

CHAPTER 2

L I T E R A T U R E R E V I E W

2.1 Introduction

The potato (*Solanum tuberosum* Lin.) is a host of many arthropod species. At least 300 arthropod taxa are known to have either part or all their life time on potato. The greatest arthropod pest diversity associated with potato production occurs in the South and Central America where the crop and its related species originate (Anon.,1988). However, each region or *Solanum* potato production system has its own pest complex (Raman and Radcliffe, 1992).

Globally, there are insect pests that are common to all potato growing regions. These include the potato tuber moth (*Phthorimae operculella*, Zeller), cut worms (*Agrotis* spp.), coccinellids for instance (*Epilachna* spp.), thrips (*Frankliniella* spp.), leaf hoppers (*Empoasca* spp.) mites (*Tetranychus* spp.), Colorado potato beetle (*Leptinotarsa decemlineata*) and several aphid species (Raman and Radcliffe, 1992). In East Africa, Kibata (1982) reported key pests of the potato as including the potato tuber moth, the brown and black cut worms (*Agrotis* spp.), wire worms (*Agroetes* spp.), pentatomid bugs for instance *Nezara* spp., shield bugs and several aphid species. Among these potato arthropod pests, aphids take a key position in determining the health status of a potato crop in all seed and ware

potato production programmes, but most especially in the cultivation of seed potato.

2.2 Important Potato-Colonizing Aphids

At least 15 aphid species are able to colonize potato (Auclair, 1989). Those that find potato a preferred host include *Myzus persicae* Sulz., *Macrosiphum euphorbiae* Kalt., *Aphis nasturtii* Kalt., *Aphis gossypii* Glover, *Aularcorthum solani* Kalt. and the subterranean aphid *Rhopalosiphoninus latysiphon* (Dav.).

In Kenya, four aphid species namely *M. persicae*, *A. solani*, *M. euphorbiae* and *A. gossypii* were found commonly associated with *Solanum* potato in different potato growing areas (Nderitu and Mueke, 1986). In the case of Uganda little is known about insect pests of potato in both general and specific aspects.

2.3 Aphids as *Solanum* Potato Pests

Aphids are polyphagous plant sap sucking bugs of great economic importance (Richards and Davies, 1977). When abundant, aphids have a potential of causing direct plant injury (Kolbe, 1970). The effect of aphid infestation on *Solanum* potato can be broadly categorised as being direct or indirect effects (Harrewijn, 1989). In *Solanum* potato, aphids are primarily important as vectors of potato viruses (Nderitu and Mueke, 1986; Harrewijn, 1989).

2.3.1 Direct effects

The direct effects of aphid activity on the hosts include sucking of plant sap, injection of toxic saliva, interference with the physiological systems and removal of amino-nitrogen (Wellings *et al.*, 1989). Aphids cause physical injury to plant hosts by disrupting the plant tissues leading to reduced water flow. They also deplete the plants' carbohydrate reserves and growth hormones, leading to stunting and sometimes plant death (Schepers, 1989; Wellings *et al.*, 1989).

In a main season potato crop, direct feeding damage caused by aphids is insignificant and difficult to separate from effects of virus infection resulting from feeding by those aphids (Harrewijn, 1989; Beukema and van der Zaag, 1990). Schepers (1989), nevertheless reported a yield loss of about 10% when a population of about 500 aphids per 100 compound leaves was found in the potato crop. Reports by Kolbe (1970) indicate that yield losses in potato due to aphid feeding is experienced after a very heavy aphid attack, and such attack may not occur in a main season potato crop.

2.3.2 Indirect effects

Aphids cause indirect damage to their hosts through honey dew excretion and deposition and virus transmission. The honey dew deposits encourage growth of opportunistic

microflora, mainly saprophytic sooty mould fungi, on hosts which interfere with the photosynthetic activity of the host. This phenomenon is often observed in off-season potato crops and it may not be a problem if a potato crop receives adequate rain.

Virus transmission by aphids to host plants is of greater importance than any damage done to it (Wellings *et al.*, 1989). The effects of the aphids as vectors of viruses depend much more on how active the aphids involved are than on their numbers (Jayasinghe, 1988; Harrewijn, 1989). In this regard, it is not easy to set action thresholds against aphids as virus vectors since, a small but very active aphid population is able to do more harm than many sedentary and virus-free individuals.

2.4 Aphids and Virus Transmission in *Solanum* Potato

There are more than 20 viruses and one viroid known to infect potato under natural conditions (Smith, 1977; Hooker, 1981; Raman, 1985). Beemster and Rozendaal (1972) described 20 potato-infecting viruses in terms of their physical properties, strain symptomology, and mode of transmission. They stated that most of the potato viruses are cosmopolitan and in this context, they may probably occur in Uganda.

The main source of virus infection in potato is primarily from arthropod vectors which transmit the viruses from alternative hosts or potato volunteer plants to a main

potato crop (Raman, 1985). Another source of infection is the secondarily infected previous season's seed. Whatever source of infection, aphids play a leading role in the spread of insect-borne viruses in potato (Hooker, 1982; Raman, 1984; 1985; Sylvester, 1989) although leaf hoppers, white flies, nematodes and fungi may also play a part in the transmission of some potato viruses (Beemster and Rozendaal, 1972; Hooker, 1982).

2.5 Mechanisms of Virus Transmission in *Solanum* Potato

Viruses can be grouped according to their mode of transmission (Beemster and Rozendaal, 1972; Sylvester, 1989). A few potato viruses, for instance, potato virus X (PVX) and potato virus S (PVS), are transmitted by contact (Hooker, 1981; 1982; Khalil and Shalla, 1982; Wardrop *et al.*, 1989). The rest of the potato-infecting viruses are transmitted by aphids, either persistently or non-persistently (Beemster and Rozendaal, 1972; Smith, 1977; Hooker, 1981; 1982).

In non-persistent virus transmission, the virus particles adhere onto the stylets of the aphid during the feeding process. The aphid can thus acquire or transmit such a virus in a brief period of probing of the epidermal cells of the host plant. Potato viruses transmitted this way are sometimes referred to as being stylet-borne (Beemster and Rozendaal, 1972; Hooker, 1981; Sylvester, 1989). The aphid loses infectivity after a short time

mainly after another feeding process or molting stage (Hooker, 1981, 1982; Sylvester, 1989).

In persistently transmitted viruses, the virus has to be ingested by the aphid in which it undergoes cyclic changes before it can be transmitted to another host. In the aphid, the virus undergoes modification, circulates through the aphid's body and eventually enters the aphid's salivary glands (Raman, 1985; Sylvester, 1989). An aphid will transmit or acquire this type of virus if it probes and feeds on the phloem contents of the host plant (Hooker, 1981; Jayasinghe, 1988; Sylvester, 1989). These viruses are sometimes referred to as circulative viruses. Once the aphid is infected with such a virus, it remains infective for life (Hooker, 1982; Raman, 1985). Among the potato infecting viruses, it is only the potato leaf roll virus (PLRV) that is transmitted in this way (Hooker, 1981, 1982; Raman, 1985; Jayasinghe, 1988; Sylvester, 1989).

It is known that all aphid-borne potato infecting viruses are transmitted non-persistently except PLRV and sometimes potato virus Y (PVY), although transmission experiments of the later virus have always given conflicting results (Hille Ris Lambers, 1972; Raman, 1985; Singh and Boiteau, 1986). Some common potato viruses in this group include potato virus A (PVA), potato virus S (PVS) and potato virus Y (PVY) (Beemster and Rozendaal, 1972; Hille Ris Lambers, 1972; Hooker, 1981, 1982). Potato virus S is transmitted by both contact and aphids (Hooker, 1981; Khalil and Shalla, 1982; Wardrop *et al.*, 1989).

All aphid-transmitted viruses infecting potato are stylet-borne except potato leaf roll virus (PLRV). The PLRV is persistently transmitted and, specifically by *M. persicae* (Hooker, 1991; 1992; Raman, 1985; Jayasinghe, 1988). Transmission studies using other aphid species have not produced conclusive results (Sylvester, 1989).

Style-borne viruses are transmitted by any aphid species as long as the aphid is infected and it probes the epidermal cells of the host plant. However, different aphid species transmit different viruses with differing efficiencies. This is because of anatomical, physiological and behavioural differences among aphid species (Hille Ris Lambers, 1972; Wellings *et al.*, 1989), and morphological differences among potato cultivars (Nderitu and Mueke, 1986; Gibson and Rice, 1989). Because of this, few aphid species find *Solanum* potato a suitable host to effectively colonise and very few therefore are able to efficiently transmit potato viruses. Boiteau *et al.* (1988) collected 62 aphid genera or species and found that only seven of them were able to colonise the potato, and *M. persicae* was the only efficient vector of PVY.

Among the potato colonising aphids only *M. persicae* is capable of transmitting PLRV. It also transmits other potato viruses more efficiently than most other aphid species that infest potato (Schepers, 1972; Raman, 1985). The inherent differences in potato cultivars, aphid species and potato viruses call for an integrated approach when planning an aphid and virus control strategy.

2.6 Effects of Virus Infection on Performance of *Solanum* Potato

Some potato virus infections cause visible and defined symptoms on potato foliage. The symptoms of some viruses on potato may overlap while other viral infections may show no symptoms on the host plant (Hooker, 1981; Glinka and Gordeichuk, 1982; Khalil and Shalla, 1982; Mih *et al.*, 1993; Omer and El-Hassan, 1992). However, many viral infections in potato cause distinct vegetative and poor yield effects which may include leaf rolling and curling, leaf mosaic and chlorosis, inter-veinal banding, leaf drop, plant stunting, production of few and small sized tubers and consequently low yields (Beemster and Rozendaal, 1972; Reestman, 1972; Schepers, 1972; Smith, 1977; Hooker, 1981; 1982; Jayasinghe *et al.*, 1989; Beukema and van der Zaag, 1990). Potato leaf roll virus in particular causes tuber net necrosis (de Bokx, 1972; DiFonzo *et al.*, 1994) while PVS causes no visible symptoms on the foliage (Beemster and Rozendaal, 1972; Hooker, 1981; Khalil and Shalla, 1982).

The effects of virus infection on potato yields depend on type of virus, potato variety and conditions of crop growth (Reestman, 1972; Jayasinghe *et al.*, 1989; Beukema and van der Zaag, 1990). Yield decline also depends on the number of generations of using the same seed stocks after the initial virus infection (Omer and El-Hassan, 1992). Reduction in yield through primary infected potato crop is usually much lower than that from seed-borne or secondary

infected crop (Reestman, 1972; Beukema and van der Zaag, 1990). Thus for the production of seed potatoes, tubers for planting should be free of any virus infection (Burton, 1966; Reestman, 1972). If planting material is infected, the yield decline will be great in the subsequent seed progeny (Glinka and Gordeichuk, 1982). Progressive yield decline is observed if seed potato is saved from successive crops (Omer and El-Hassan, 1992) hence the need to renew seed regularly to reduce the build-up of virus infection.

Yield reduction effects in potato due to virus infection may also depend on the potato cultivar and conditions during growth (Beemster and Rozendaal, 1972; Wiersma, 1972; 1989). In *Solanum* potato, some cultivars with resistance against PVY, PVS and PVX have been identified. Not much is known about resistance to PLRV (Wiersma, 1972; Beukema and van der Zaag, 1990; DiFonzo *et al.*, 1994). In terms of plant growth conditions, a potato crop grown on poor soil may be more affected by virus infection than that grown on fertile soil, even if the two have the same levels of virus infection (Beemster and Rozendaal, 1972; Hille Ris Lambers, 1972; Wiersema, 1989). Split application of nitrogen also tends to encourage virus infection in *Solanum* potato than a single dose at planting (Reestman, 1972; Harrewijn, 1989).

Potato yield depression also depends on the nature of virus or virus strain infecting potato (Hooker, 1982). The potato leaf roll virus depresses potato yields more than any potato virus in one season after infection (Hille Ris Lambers, 1972; Hooker, 1982; Jayasinghe, 1988). Other

potato viruses, for instance, PVY, PVX and PVS although mild, have profound effects on yield if infected potatoes are continuously used as seed for many generations (Reestman, 1972; Hooker, 1982). Mixed virus infections in potato have greater yield reducing effects than single viral infections (Jayasinghe *et al.*, 1989).

2.7 Control of Aphids in *Solanum* Potato

The aphid control measures that can be adopted in *Solanum* potato depend on whether the product of the crop is to be used either for consumption (ware) or as seed. Some control measures, however, overlap the two potato utilities (Harrewijn, 1989). More attention is required for aphid control in seed than ware potato crop as the *Solanum* potato industry is based on availability of high quality disease-free seed (Oie-Dharma, 1969; Sikka *et al.*, 1992). The control of potato-infesting aphids like that of other crop pests can be based on natural, cultural and chemical measures (Rose, 1963; Smith and van den Bosch, 1967; Mathews, 1984; Oonyu, 1992).

2.7.1 Natural control

There are key factors in nature that limit the build-up of high aphid populations on their hosts. These factors include adverse weather conditions and natural enemies (Doutt, 1967; Shands *et al.*, 1972; Oonyu, 1992). Heavy

rainfall, strong winds, high or very low temperature and humidity may drastically reduce aphid numbers (Shands et al., 1972). Biological control agents also affect infestation of a crop by aphids. A combination of abiotic and biotic factors would have a capacity of checking aphid infestation in a crop if properly exploited (Doutt, 1967; Tanada, 1967).

Natural enemies of aphids include predators, parasitoids and pathogens. Van Emden et al. (1969) presents a comprehensive list of aphid natural enemies in various orders and families of arthropods and several species of fungi. Among aphid predators are 48 species in the family Coccinellidae, 50 species in the family Syrphidae, eight species in the family Anthocoridae, four species in the families Chamaemyiidae and Nabidae, two species in each of the families Cantharidae, Cecidomyiidae and Miridae and one species in the family Pentatomidae. In the order Neuroptera, 26 species are known to prey on aphids and in the order Acarina, two species, namely, *Bochartia kuyperi* (Oud.) and *Thisumena lepida* (Thorek) also prey on aphids, *M. persicae* in particular.

Aphid parasitoids include 40 species in the family Aphidiidae and six species in the family Aphelinidae.

Ten species of entomogenous fungi are known to infect aphids (van Emden et al., 1969). Aphids are also attacked by viral diseases (Doutt, 1967). All these natural enemies together with the influence of climate appreciably reduce the population density of aphids in potato crop.

Not all the aphid natural enemies may occur in a given geographical area. In East Africa, the natural enemies of aphids that have been recorded include fungi in the genus *Entomophthora*, coccinellid predators such as *Cheilomenes lunata* (Fab.), *C. sulphurea* (Oliv.), *C. aurora* (Gerst.), *C. vicina* (Mul.), *Hippodamia variagata* (Goez.), *Platynaspis capicola* (Crot.) *Scymnus trepidulus* (Weise), *Adelia sexareata* (Weise), *A. bipunctata* (Lin.), *Xanthogramma calopus* (Loew), *Oris* spp. *Melonostoma bituberculatum* (Beck.) and *M. infuscatum* (Beck.) (Oonyu, 1992; Ogenga-Latigo et al., 1993).

The use of natural control measures to prevent aphid infestation has got several shortcomings. The abiotic factors can not be precisely predicted and they are, therefore unreliable. Biological agents are influenced by complex interactions between themselves and abiotic factors (Tanada, 1967). Hence, natural control may not meet the economic pest threshold set for the crop (van Emden et al., 1969; Shands et al., 1972) and, natural enemies therefore seem to be of little importance (Ogenga-Latigo et al., 1993). For instance, predators and parasitoids are attacked by parasites and hyperparasites while insect epizootics are greatly influenced by temperature and humidity. Natural enemies also have a tendency of competing for the same host (Tanada, 1967). Sometimes, the host insects may develop resistance to the pathogen (Doutt, 1967) or avoid predators by release of warning pheromones when attacked and thus increasing the dispersal of aphids

on the host plants (Carver, 1989). Biological control agents are often density dependent and start to operate when the crop has already been colonised (Hodek *et al.*, 1972). Consequently, they are not able to deter virus spread even if they were able to keep aphid density in a crop low enough not to cause physical plant damage (Carver, 1989; Gibson and Rice, 1989).

2.7.2 Cultural control

Cultural control is the modification of a cropping system such that crop plants can either withstand, resist, or escape pest attack (Rose, 1963). Practices that may be adopted to control aphids include early planting, intercropping, strip cropping, fertilization, crop rotation, irrigation, pre- and post-season sanitation, weed control and host resistance. Cultural control strategies may not be entirely dependable so they have to be supplemented by natural or sometimes chemical control (Shands *et al.*, 1972).

The control of aphids using host resistance may be due to temporal, physiological reasons and variation in growth habit in different crop cultivars (Smith and van den Bosch, 1967; Martin, 1973). Some plants are known to produce antifeedants, repellents or chemicals that are similar to aphid alarm pheromones. Any of these protective mechanisms are likely to reduce aphid infestation. Other plants have pubescent leaves which deter aphid feeding. These features

can help plants to retard aphid attack (Auclair, 1989). However, they may not significantly reduce aphid infestation.

In *Solanum* potato production, cultural control measures against aphids may be useful in ware potato crop where yield reduction due to aphid feeding is often insignificant and current season virus infection may not adversely affect yield. In seed potato cultivation, aphids must be prevented from colonising the seed crop however low the aphid population density in a crop may be. In this context, control measures such as host plant resistance may encourage aphid restlessness as they look for a suitable host. This will enhance the spread of potato aphid-borne viruses particularly non-persistent ones (Auclair, 1989; Carver, 1989; Harrewijn and Minks, 1989). Thus, breeding for host resistance in potato should aim more at virus resistance than aphid resistance (Harrewijn, 1989; Raman and Radcliffe, 1992).

2.7.3 Chemical control

Agricultural pesticides are often the only means of reducing pest population significantly and rapidly although pressure against their use is constantly mounted by environmentalists (Mathews, 1984). A number of granular and liquid insecticide formulations are reported to keep aphid infestation under check in many broad leaved annual crops. Granular systemic insecticides which are in use include Phorate (Thimet), Disulfoton (Disyston) and

Carbofuran (Furadan). However, much of the aphid control in many crops is by use of liquid insecticide formulations. The commonly available insecticides include Dimethoate (Rogor), Malathion-E (Malathion), Aldicarb (Temik), Demiphion (Cymetox), Demeton-S-methyly (Metasystox), Phosphamidon (Dimecron), Diazinon (Neocide), Metamidophos (Tamaron), Formothion (Alfix), Endosulfan (Thiodan), Primicarb (Aphox), and Parathion-E (Parathion) (Kibata, 1982; Mathews, 1984; Hill and Waller, 1988; Oonyu, 1992).

In a number of crops, aphids are controlled to prevent direct feeding damage on the current crop in order to enhance yields (Oonyu, 1992). Yield gains in potato as a result of using insecticides to reduce direct feeding damage of aphids are marginally useful and gains only occur at very high aphid populations (Kolbe, 1970; Schepers, 1972; Harrewijn, 1989). Such aphid populations may not occur in a commercial, main season *Solanum* potato crop. Insecticides have always been used in potato cultivation to prevent the spread of aphid-borne viruses, however, reports of successful use of insecticide in controlling potato aphid-borne viruses have sometimes been conflicting (Schepers, 1972; 1989). Quick-acting pyrethroids have been found effective at controlling the spread of non-persistent viruses within the field but not infections from outside it (Hooker, 1982; Atiri and Jimoh, 1990). On the other hand, the spread of persistently transmitted viruses is reported to be significantly reduced by systemic insecticide sprays. However, this control measure can prevent virus spread

within the crop but not from outside it (Raman, 1985; Harrewijn, 1989). On the whole, insecticides, especially systemic ones, are more effective at preventing the spread of persistent viruses than non-persistent ones (Broadbent, 1957; Schepers, 1972; 1989; Harrewijn, 1989).

The effectiveness of a systemic insecticide in reducing virus spread can be enhanced by applying the insecticide granules at planting or spraying a liquid formulation immediately after plant emergence (Beemster and Rozendaal, 1972; Beukema and van der Zaag, 1990). If this is combined with use of virus-free seed stocks in an area with low vector pressure, virus infection in *Solanum* potato can be greatly reduced (Hooker, 1982; Jayasinghe, 1988).

In Kenya the commonest insecticides that have been used in potato for controlling aphid infestation with the aim of reducing the spread of aphid-borne viruses infecting potato are mainly Dimethoate (Rogor), Demeton-S-methyl (Metasystox) and Diazinon (Neocide) (Kibata, 1982). In Uganda, scanty work has been done to document either the aphid species commonly infesting *Solanum* potato or the occurrence of four main potato infecting virus that are thought to occur universally in the tropics. Little efforts have also been made to evaluate some control measures that can be employed to prevent aphid infestation in potato and prevent or reduce the spread of aphid-borne potato viruses. This study was initiated in response to the issues raised above.

2.8 Objectives of the study

In any potato production system, acceptable control of key potato pests is by use of insecticides (Kibata, 1982; Raman and Radcliffe, 1992). The use of insecticides to control *Solanum* potato pests in Uganda is minimally known and scantily documented. Farmers are also not aware of the possible dangers of insect pests such as aphids to a potato crop as long as they do not damage the foliage or tubers. A study was therefore initiated to determine the aphid species infesting potato and the detrimental effects they pose to the potato industry in high and low elevations of Uganda. The specific objectives of the study were to:

- i) Determine the aphid species commonly infesting *Solanum* potato in low and high elevations of Uganda.
- ii) Assess the occurrence of four potato infecting viruses in low and highland Uganda.
- iii) Evaluate the relative resistance of seven potato cultivars to aphid infestation and infection with four potato viruses and how host resistance can be enhanced with regular systemic insecticide applications.

CHAPTER 3

EFFECT OF WEEKLY DIMETHOATE SPRAY ON APHID COLONIZATION AND POPULATION DEVELOPMENT ON *SOLANUM* POTATO

3.1 INTRODUCTION

Alate aphids arrive in an area of vegetation in random and undirected flight (Broadbent, 1957; Harrewijn, 1989; van Harten, 1989). Evidence suggests that alate potato aphids, especially *Myzus persicae* (Sulz.), alight on both host and non-host plants with equal chances (van Emden *et al.*, 1969; Heathcote, 1972). Air-borne aphids (alates) are particularly attracted to green and yellow colours and this enables potato aphids to locate their hosts (van Emden *et al.*, 1969; Gibson and Rice, 1989). Because of this visual attraction, the aphids will inevitably land on a newly emerged potato crop, and settle and colonise it if they find the plants suitable as hosts.

The first colonizers of a potato crop are winged aphids. The total number of winged aphids that alight on the crop are less important than the period of flight at a given time of plant growth (Broadbent, 1957; Hille Ris Lambers, 1972; Harrewijn, 1989). This is because crop infection with aphid-borne viruses, which is more important than the usual aphid colonisation and feeding, is most likely to occur early in the season when the young potato plants are more susceptible to virus infection before

acquiring mature plant resistance. If some of the initial potato crop colonizing aphids are viruliferous, they are likely to introduce potato viruses in the crop at an early plant age (Schepers, 1972; Raman and Radcliffe, 1992; DiFonzo *et al.*, 1994).

It is not easy to stop aphids alighting on the crops. However, attempts should be made to stop them from feeding on or colonizing it. Once the viral infections have been introduced into the crop, the offsprings of the first immigrants will also enhance virus spread in the crop (Hodek *et al.*, 1972). Hence the need to prevent aphid population establishment in a young potato crop. In this study, an attempt was made to establish the role of a systemic insecticide, dimethoate (0,0-dimethyl-S-(N-methyl carbamoyl)-methyl), in preventing the colonisation of *Solanum* potato by aphids.

3.2 MATERIALS AND METHOD

3.2.1 Site Selection and Study Area

The study was conducted at Namulonge Agricultural and Animal Production Research Institute (NAARI) during the short rains (SR) (September - December) of 1994 and at NAARI and Kalengyere Research Station (KRS) during the long rains (LR) (February - May) of 1995.

Namulonge (NAARI) is located 27 km North-east of Kampala at longitude 32° 27' E, latitude 0° 32' N and a mean

elevation of 1150 m above sea level (a.s.l.). The area is warm and humid and receives an average of 1270 mm of rain annually. Its mean monthly maximum temperature is 29°C while the mean minimum is 16°C. The soils are fertile and well drained.

Kalengyere is located in South-western Uganda, 29° 48' E and 1° 13' S, about 480 km from Kampala. It is 2400 m a.s.l., its annual rainfall averages 1600 mm and its mean monthly maximum and minimum temperatures are 21.5°C and 11°C, respectively. The area is cool and windy, and night temperatures can sometimes drop below 10°C in July and August. The soils at Kalengyere are young, light and of volcanic origin, with high organic matter content (Sendiwanyo, 1992).

3.2.2 Establishment of field experiment

Seven *Solanum* potato varieties namely; Rutuku, 382171.4, Kisoro, Kabale, Victoria, 381403.1 and Sangema were used. Three replicates, each consisting of two main plots were set up in a split-plot arrangement of a randomised complete block design. At Namulonge, each main plot measured 30.0 m long and 4.8 m wide and the main plots in a replicate were separated by a 2 m wide alley. In each main plot, seven sub-plots each measuring 4.8 m by 3.0 m (14.4 m²) and separated from each other by a 1.5 m wide alleys were set.

At Kalengyere, because of nature of the terrain, each main plot consisted of 8 sub-plots the same size (14.4 m^2) as those at Namulonge. However, one sub-plot in each main plot was used as a dummy plot in order to make the set-up symmetrical since an odd number (7) of varieties was used. The main plots and sub-plots were separated from each other as at Namulonge.

At both Namulonge and Kalengyere, the main plots in each replicate comprised of a systemic insecticide treatment while the sub-plot was the potato varieties. Between the main plots in each replicate and within the alleys and along the borders, maize (var. Longe 1) was grown at Namulonge and wheat (var. UW0036) at Kalengyere to serve as barriers against insecticide drift during spraying. For each potato variety (sub-plot), four row-plots each with 12 tubers were planted. The seed tubers within each row were planted at a spacing of 40 cm from each other, while the rows within a sub-plot were 75 cm apart giving a seed rate of 33,333 tubers per hectare. A wider spacing than the recommended one (70 cm by 30 cm) was used in order to avoid early plant contact and prevent aphids moving from one plant to another early in the season. The crop was kept weed free and given regular fungicide sprays to prevent fungal attack.

The two insecticide spray treatments studied were:

T_1 = No insecticide spray, and

T_2 = Weekly spray of dimethoate 40 EC at a rate of 2 ml per litre of water equivalent to $1190 \text{ g a.i. ha}^{-1}$.

The systemic insecticide was used in order to determine the extent to which it can prevent aphid colonisation, population build-up, viral infection and spread in *Solanum* potato. This was done on three assumptions;

- (a) that aphids that would alight on the plants would be prevented from feeding on several of them, or if they feed on the crop after spray application, they would die before colonising the crop.
- (b) that winged and non-winged aphids found in the potato crop at the time of spray application would be killed.
- (c) the young aphids deposited on the crop by adult alates in the course of colonisation would be killed if they feed on the insecticide treated plants.

3.2.3 Aphid flight activity above the potato crop

The flight activity of alate aphids above the potato crop was monitored using four yellow water traps (Raman, 1984; van Harten, 1989) per replicate placed 1.5 m above the ground on metallic stands. The traps were made of yellow circular 30 cm top diameter plastic basins. The yellow colour is known to attract potato aphids, and most especially *M. persicae*, which is the most important *Solanum* potato virus vector (van Emden *et al.*, 1969; Hille Ris Lambers, 1972; Raman, 1984, 1985). The traps were painted dark grey outside to improve on their attractiveness

(Taylor and Palmer, 1972; Raman, 1984). A circular shape was preferred because it presents the same shape and size from all directions (Taylor and Palmer, 1972). Each trap contained water up to 2 cm below the top of the basin. Three drops of a liquid detergent (*Tide*) was added to each trap to break surface tension and prevent the aphids from flying off once trapped (Taylor and Palmer, 1972; Raman, 1984, 1985). The traps were set 7.5 m by 12.0 m apart at Namulonge while those at Kalengyere were placed 13.5 m apart along the contour because of the nature of the terrain.

Aphid trapping began when 75% of the potato plants had emerged (3-4 weeks after planting). The captured aphids were removed from traps twice every week on Tuesdays and Fridays. The aphids were collected in plastic pollen-collecting vials (one vial per replicate) containing 95% ethanol, and taken to the laboratory for identification. The traps were then cleaned, refilled with fresh water and detergent and reset.

In the laboratory, potato infesting aphids were separated from other aphid species using identification keys (Anon., 1979a, 1979b; Blackman and Eastop, 1984; van Harten, 1989) and each species preserved in fresh 95% ethanol. At Namulonge, trapping was done for nine weeks in the 1994 short rains (SR) and for six weeks during the 1995 long rains (LR) season, while at Kalengyere it was carried out over a period of nine weeks during the 1995LR. The average prevalence of each aphid species for each week were plotted against time of sampling.

3.2.4 Aphid colonisation, incidence and infestation on *Solanum* potato

To assess aphid colonisation and population levels on potato plants, the plants in a row were sampled alternately leaving out those at the end of the rows. A total of 20 plants were sampled from each sub-plot, five from each row, and the proportion of plants infested by aphids recorded. Before the plants reached flower-bud stage, aphid counts were made from whole plants. Thereafter, a maximum of three main stems per plant were sampled and all the leaves on it examined. Sampling covered the period of trapping described in Section 3.2.3. The aphids were counted as alates and aptarae and the totals for each category per plot worked out. Samples of the aphids were also collected from each sub-plot, preserved in 95% ethanol and taken to the laboratory for identification as described in Section 3.2.3.

Data collected on aphid species abundance in sprayed and unsprayed plots were analysed using MSTAT-C statistical package and mean relative species occurrence over the sampling period tabulated. The mean abundance per week for each potato infesting aphid species from experimental plots subjected to the insecticide treatments above were plotted against time of sampling in weeks. Data on aphid counts and percentage aphid infested plants were subjected to analysis of variance (ANOVA) to test the significance of the treatments. Means for total number of aphids per

plant and percentage aphid infested plants per week, for each variety were plotted against sampling time. Correlation analysis was performed to assess the relationship between total number of alate aphids trapped in yellow water traps, alate and aptarae aphids collected from potato plants, number of aphids per plant and percentage aphid infested plants. Correlation and regression relationships between percentage aphid infested potato plants and number of alates and aptarae counted in sprayed and unsprayed potato plots were also analysed.

3.3 RESULTS

3.3.1 Aphid flight activity and potato crop colonization

Relative occurrence of the aphid species caught in yellow water traps, representing aphid flight activity over the potato crop, is presented in Figure 1 and Table 1. The relative incidence of aphid species colonizing *Solanum* potato are presented in Table 2 and Figure 2.

At Namulonge, during the 1994 short rains (SR), there was a higher trap catch of *Aphis gossypii* (Glover) than any other aphid species. The proportion of this aphid species increased gradually from the first to the ninth week after plant emergence (Figure 1). For the other species, there was a gradual decline in the population of *Myzus persicae* (Sulz.), *Macrosiphum euphorbiae* (Kalt.), *Aphis nusturtii* (Kalt.) and *Aulacorthum solani* (Kalt.) from the first to

the fifth weeks after crop emergence. Thereafter, their population stabilised (Figure 1). A similar population increase of *A. gossypii* from traps over other aphid species was obtained at Namulonge during the 1995 long rains (LR), although *A. solani* was not caught in traps during this season (Figure 1).

At Kalengyere, during the 1995LR, trap catches indicated a high proportion of *M. euphorbiae* (Figure 1). Its population decreased from the first to the fourth week and then steadily increased till the ninth week after plant emergence (Figure 1). Other species occurred erratically, their proportions being less than 20% in all weeks. *A. solani* was rare and was caught in traps only in the seventh week of sampling (Figure 1).

A comparison of aphid trap catches and aphid collections from potato plants revealed that the most abundant aphid species on potato at Namulonge during the 1994SR was *M. persicae* while trap catches showed a high proportion of *A. gossypii* and a low proportion of *A. solani* (Table 1). In the 1995LR, more *M. persicae* was collected from potato, while traps again caught more *A. gossypii* than any other aphid species (Table 1). At Kalengyere during the 1995LR, there was a high proportion of *M. persicae* in the crop while the most abundant potato aphid from traps was *M. euphorbiae* (Table 1). Neither *A. nusturtii* nor *A. gossypii* were collected from plants at this location, although they were evident in the traps. At both NAARI and KRS, the proportion of *A. solani* in traps and plants was low.

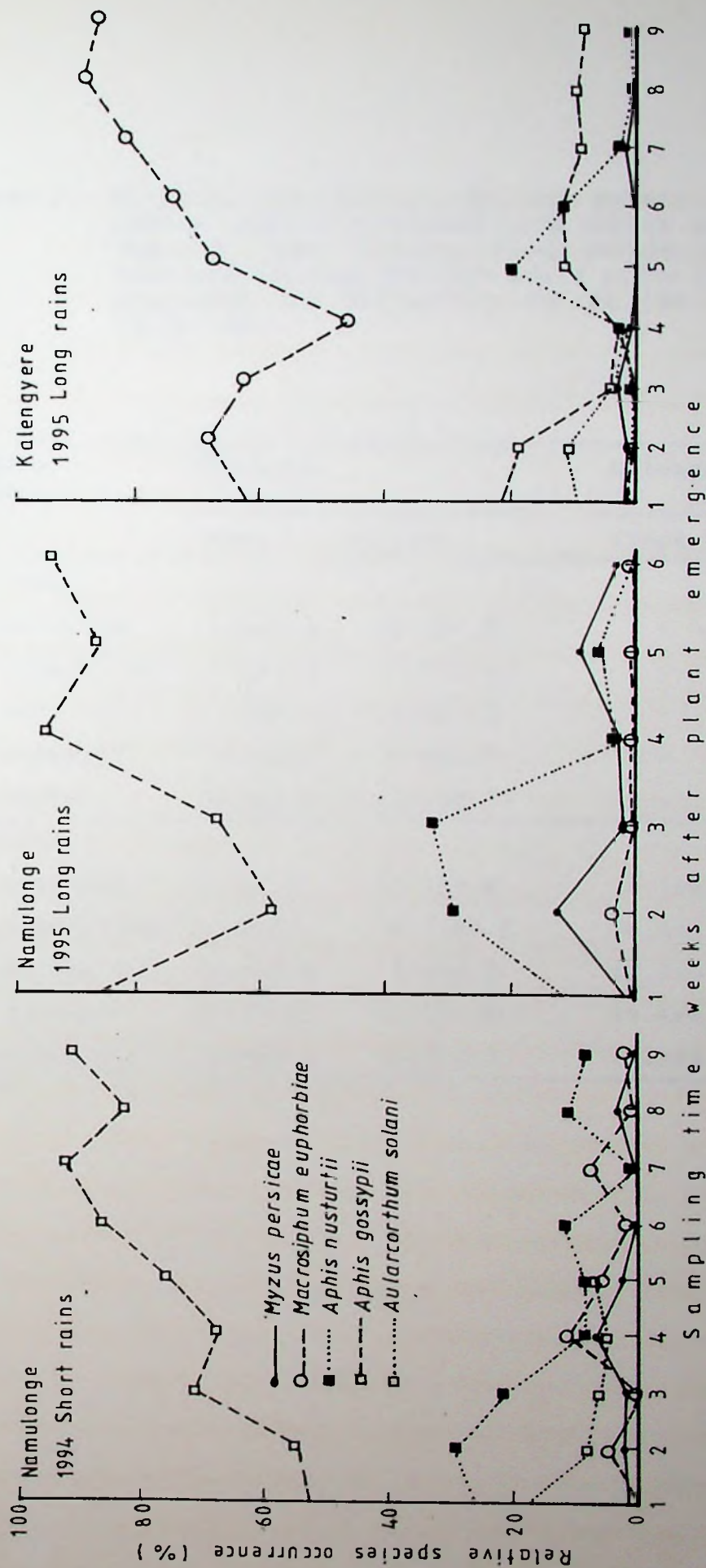


Fig.1: Relative species occurrence (%) of *Solanum* potato infesting aphids caught in yellow water (*Moericke*) traps at Namulonge during the 1994 short rains and at Kalengyere in the 1995 long rains.

Table 1: Relative occurrence (%) of potato infesting aphids species collected from yellow water traps and the same species from potato plants at Namulonge during the 1994 short rains (SR) and at Namulonge and Kalengyere during the 1995 long rains (LR).

Aphid species	Namulonge		Kalengyere	
	Traps	Potato	Traps	Potato
1994SR				
<i>M. persicae</i>	2.6±0.6	18.1±1.5	-	-
<i>M. euphorbiae</i>	3.4±0.8	0.7±0.2	-	-
<i>A. nusturtii</i>	13.0±1.8	13.5±1.2	-	-
<i>A. gossypii</i>	74.3±3.2	8.8±1.0	-	-
<i>A. solani</i>	6.6±1.8	5.6±0.7	-	-
1995LR				
<i>M. persicae</i>	5.7±1.8	55.2±2.0	6.5±3.0	22.0±1.6
<i>M. euphorbiae</i>	0.19±0.1	0.7±0.2	44.6±6.0	16.9±1.4
<i>A. nusturtii</i>	13.4±3.0	5.6±0.8	12.5±3.8	0.0±0.0
<i>A. gossypii</i>	80.7±3.8	10.1±1.0	19.6±4.0	0.0±0.0
<i>A. solani</i>	0.04±0.0	0.5±0.2	4.3±2.3	4.5±0.7

3.3.2 Effect of dimethoate on potato-infesting aphid species and their population build-up on *Solanum* potato

The aphid species composition and population trend of each species on potato plants sprayed or not treated with dimethoate are presented in Table 2 and Figure 2, respectively. The number and species composition on sprayed and unsprayed potatoes differed greatly at both Namulonge (NAARI) and Kalengyere.

At Namulonge, during the 1994SR, ^{more} *A. nusturtii* were collected on unsprayed potatoes than any other aphid species while during the 1995LR, more *M. persicae* were collected from plots receiving the same treatment (Table 2). The populations of other aphid species in unsprayed potato were low and varied considerably, only stabilising after the fifth week of sampling (Figure 2A and B). All the potato infesting aphids were collected from unsprayed potato at least in all sampling times.

At Kalengyere, aphid collections in unsprayed potatoes showed that the most abundant aphid species on potato was *M. persicae* (Table 2 and Figure 2C). *M. euphorbiae* (the most abundant species from traps) and *A. solani* were also collected but the latter species was very rare (Table 2). The populations of *M. persicae* and *M. euphorbiae* in unsprayed plots grew steadily from the first to the seventh and eighth weeks, respectively, before declining. *A. solani* appeared from the fourth week onwards (Figure 2C).

A. gossypii and *A. nusturtii* were absent from plants for all the nine weeks of sampling (Table 2 and Figure 2C).

The occurrence of potato infesting aphids in sprayed plots sharply contrasted between Namulonge (NAARI) and Kalengyere. At Namulonge, during the 1994SR, there was differential aphid incidence on dimethoate sprayed potatoes. On these plants, there was a disproportionately high occurrence of *M. persicae* compared to other aphid species. For example, the mean occurrence of *M. persicae* for the nine weeks of sampling was 44.5% while the next abundant (*A. nusturtii*) was only 3.6% (Table 2). This sharply contrasts with the potatoes that were not treated with the aphicide. The trend in the increase of populations of different aphid species showed that there was a steady rise in the number of *M. persicae* and a gradual decline of other aphid species over the period of sampling in sprayed plots (Figure 2D). Dimethoate seemed to kill other potato infesting aphid species except *M. persicae*. A similar trend was observed at Namulonge in the 1995LR (Figure 2E).

At Kalengyere, there was no differential incidence of potato infesting aphids in sprayed potato. All potato infesting aphids were equally affected by the insecticide (Figure 2F). The mean proportion of individual aphid species did not exceed 6.5% (Table 2) and the number of aphid per species per week were kept below 10 aphids in sprayed plots (Figure 2F).

Table 2: Relative occurrence (%) of potato infesting aphid species from dimethoate sprayed and unsprayed potato plants at Namulonge during the 1994 short rains (SR) and at Namulonge and Kalengyere during the 1995 long rains (LR).

Aphid species	N a m u l o n g e		K a l e n g y e r e	
	Sprayed	Unsprayed	Sprayed	Unsprayed
1994SR				
<i>M. persicae</i>	44.5±2.5	15.7±1.1	-	-
<i>M. euphorbiae</i>	0.5±0.1	1.1±0.6	-	-
<i>A. nusturtii</i>	3.6±1.2	20.2±6.4	-	-
<i>A. gossypii</i>	2.5±1.0	6.1±1.1	-	-
<i>A. solani</i>	0.6±0.1	3.0±0.8	-	-
1995LR				
<i>M. persicae</i>	57.4±2.7	52.9±3.0	2.3±0.8	37.5±2.3
<i>M. euphorbiae</i>	0.5±0.4	0.9±0.3	6.3±1.4	31.4±2.3
<i>A. nusturtii</i>	3.9±1.0	7.4±1.2	0.0±0.0	0.0±0.0
<i>A. gossypii</i>	5.2±1.4	11.0±1.4	0.0±0.0	0.0±0.0
<i>A. solani</i>	0.4±0.2	0.6±0.3	1.3±0.6	7.3±1.3

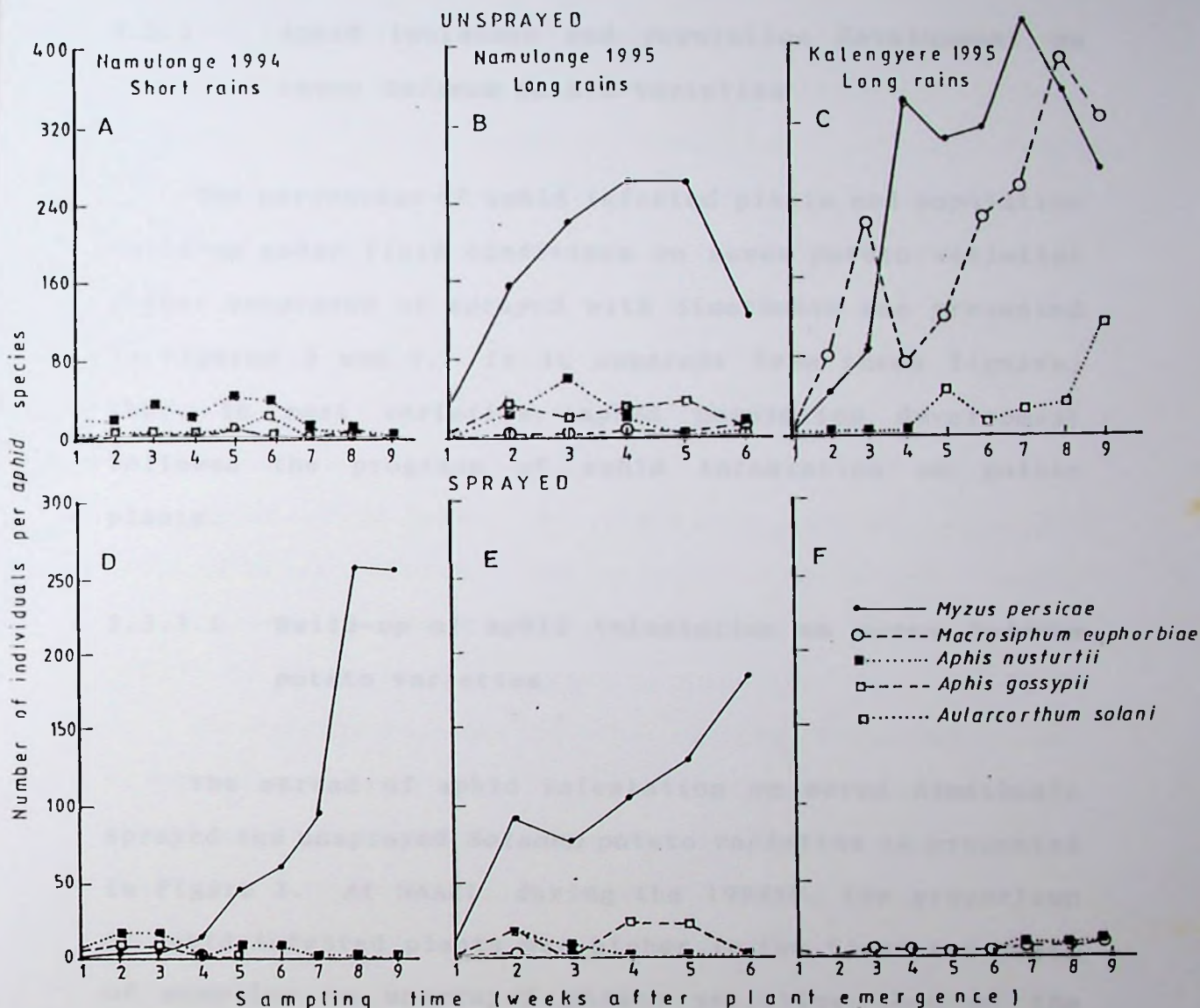


Fig. 2: Species abundances of *Solanum* potato infesting aphids in dimethoate treated and untreated plots at Namulonge and Kalengyere during the 1994 short rains and 1995 long rains.

3.3.3 Aphid incidence and population development on seven *Solanum* potato varieties

The percentage of aphid infested plants and population build-up under field conditions on seven potato varieties either unsprayed or sprayed with dimethoate are presented in Figures 3 and 4. It is apparent from these figures, that, in most varieties, aphid population development followed the progress of aphid infestation on potato plants.

3.3.3.1 Build-up of aphid infestation on seven *Solanum* potato varieties

The spread of aphid infestation on seven dimethoate sprayed and unsprayed *Solanum* potato varieties is presented in Figure 3. At NAARI, during the 1994SR, the proportion of aphid infested plants was higher in the first two weeks of sampling on unsprayed potato varieties than on the sprayed ones. In the third week, infestation on sprayed Rutuku and Kabale exceeded that in unsprayed controls. By the fifth week, however, the level of infestation in all sprayed potato had exceeded that in unsprayed plots (Figure 3). For all varieties, the percentage of aphid infested plants on unsprayed potato increased from the first to the fourth week of sampling. In the fifth week, infestation declined on unsprayed while it steadily rose on sprayed potato although no variety reached peak infestation.

In the 1995LR, aphid infestation at Namulonge was higher on unsprayed than sprayed potato varieties between the first and fifth weeks of sampling. Although aphid infestation on sprayed potato varieties was lower than in unsprayed ones, it rose steadily over the study period. The increase in the level of infestation on unsprayed potatoes was sharp between the first and fourth weeks of sampling. In the fifth week, aphid infestation crashed. By the sixth week, the trend of infestation was similar to what was observed during the 1994SR being higher in sprayed than unsprayed potato. The greatest infestation during this season at Namulonge was recorded on the varieties 382171.4, Victoria and Sangema (Figure 3).

At Kalengyere, during the 1995LR, infestation was higher in unsprayed than in sprayed plots as expected. By the first week of sampling, infestation was evident on all unsprayed potato except on Rutuku, 381403.1 and Sangema (Figure 3). The progress of infestation on these varieties was unstable between the first and fifth weeks of sampling. From the sixth week of sampling, however, the rise in infestation was similar to that in the rest of unsprayed potato varieties. By the seventh week, more than 75% of the plants in unsprayed potatoes were infested by aphids, and by the ninth week all plants of the varieties 381403.1 and Sangema were infested. On the rest of the potato varieties, infestation ranged between 90 and 98% by the ninth week.

In sprayed potatoes at Kalengyere, dimethoate effectively controlled aphid infestation and kept it at levels below 10% in all the weeks of sampling, except on Kisoro and 381403.1 where infestation only exceeded 10% during the seventh week of sampling (Figure 3).

3.3.3.2 Aphid population development on potato

The number of aphids per plant on the seven sprayed and unsprayed *Solanum* potato varieties at Namulonge during the 1994SR, 1995LR, and at Kalengyere during the 1995 long rains are presented in Figure 4.

At Namulonge, during the short rains of 1994, the number of aphids per plant was low in all the potato varieties with or without insecticide treatment between the first and fourth weeks of sampling (Figure 4). On Rutuku, Kisoro, Kabale and Victoria, however, the density of aphids was higher on sprayed than unsprayed potatoes. On the other varieties, the number of aphids per plant was either higher on unsprayed potato than sprayed ones or the aphid population density increased at the same rate. In the fifth or sixth week, the number of aphids per plant on all sprayed varieties increased tremendously and exceeded those on unsprayed plots. By the ninth week, the highest aphid density was recorded on sprayed 382171.4, Kabale and 381403.1, all late maturing varieties. The least infested variety was Rutuku although it is one of the late maturing varieties. Aphid population densities on Kisoro, Victoria,

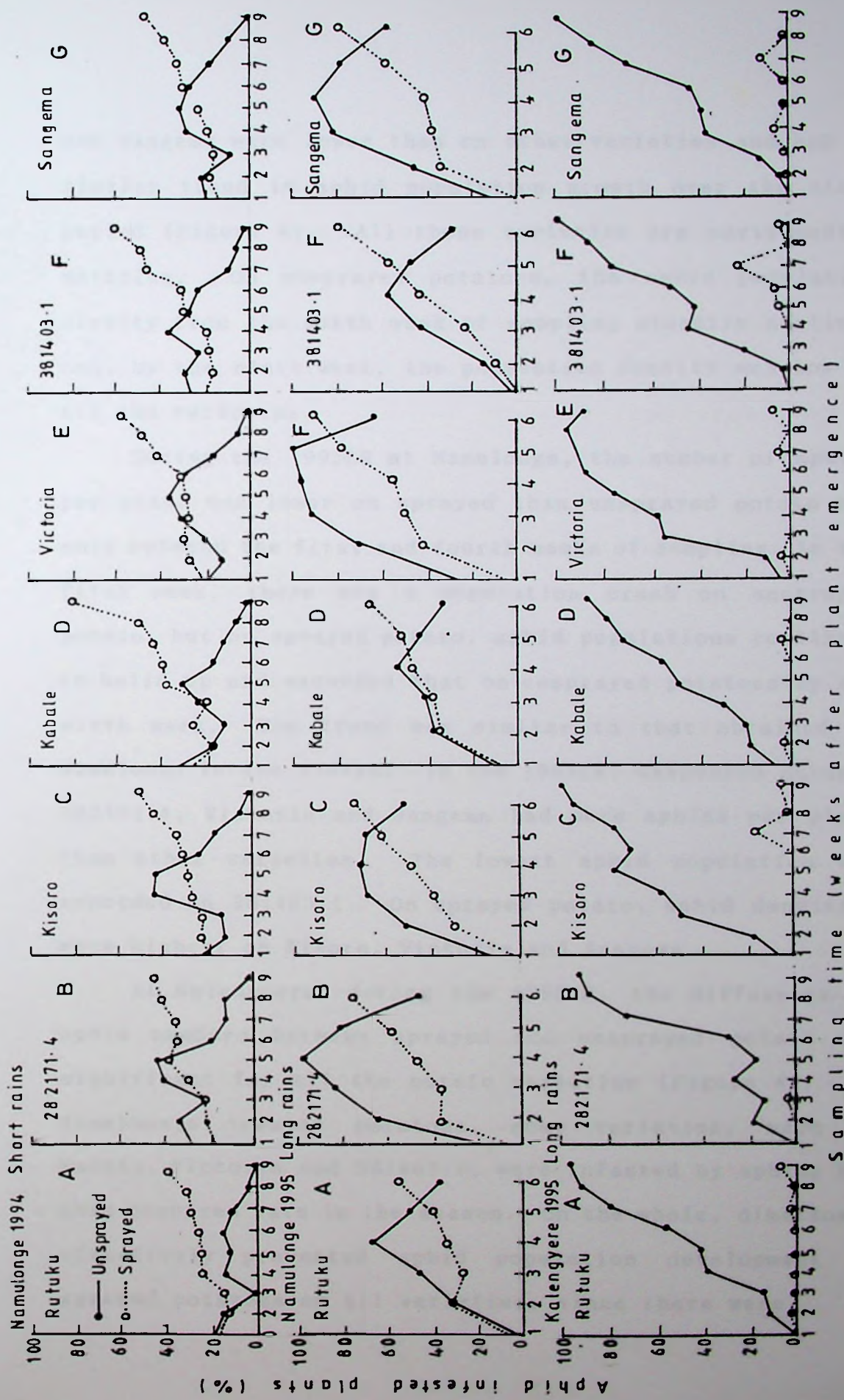


Fig. 3 : Build-up of aphid infestation on Dimethoate sprayed and unsprayed seven *Solanum* potato varieties at Namulonge during the 1994 short rains and at Namulonge and Kalengyere in the 1995 long rains.

and Sangema were lower than on other varieties and had a similar trend in aphid population growth over the study period (Figure 4). All these varieties are early-medium maturing. On unsprayed potatoes, the aphid population density from the sixth week of sampling steadily declined and, by the ninth week, the population density was low on all the varieties.

During the 1995LR at Namulonge, the number of aphids per plant was lower on sprayed than unsprayed potato but only between the first and fourth weeks of sampling. In the fifth week, there was a population crash on unsprayed potato, but on sprayed potato, aphid populations continued to build up and exceeded that on unsprayed potatoes by the sixth week. The trend was similar to that obtained at Namulonge in the 1994SR. In the 1995LR, unsprayed Rutuku, 382171.4, Victoria and Sangema had more aphids per plant than other varieties. The lowest aphid population was recorded on 381403.1. On sprayed potato, aphid densities were highest on Kisoro, Victoria and Sangema.

At Kalengyere, during the 1995LR, the difference in aphid numbers between sprayed and unsprayed potato was significant for all the potato varieties (Figure 4). On dimethoate treated potatoes, some varieties, such as Rutuku, Victoria and 381403.1, were infested by aphids but this occurred late in the season. On the whole, dimethoate effectively prevented aphid population development on sprayed potatoes on all varieties, since there were

no aphids recorded on sprayed plots of most varieties during most of the weeks of sampling.

On unsprayed potatoes at Kalengyere, the number of aphids per plant was low between the first and fifth weeks of sampling. From the sixth week, there was a sharp rise in aphid populations on all the varieties. The highest aphid population was recorded on Rutuku and Sangema while the lowest was on 382171.4. Aphid population growth on Kisoro, Kabale, Victoria, 381403.1 and Sangema, all early-medium maturing varieties except Kabale, showed a similar trend. The on-set of a steady rise in aphid population on these varieties was in the second or third weeks of sampling. Aphid population development, however, delayed on late maturing varieties, such as Rutuku, 382171.4, and 381403.1. On these varieties, a sharp rise in aphid population growth occurred during the fifth and sixth weeks of sampling (Figure 4).

For all the potato varieties used in this study, there seemed to be limited resistance to aphid attack although there was delayed aphid establishment on late maturing varieties compared to early-medium maturing ones. However, towards plant maturity, all the potato varieties were heavily infested especially at Kalengyere where dimethoate did not have differential effects on various potato aphid species.

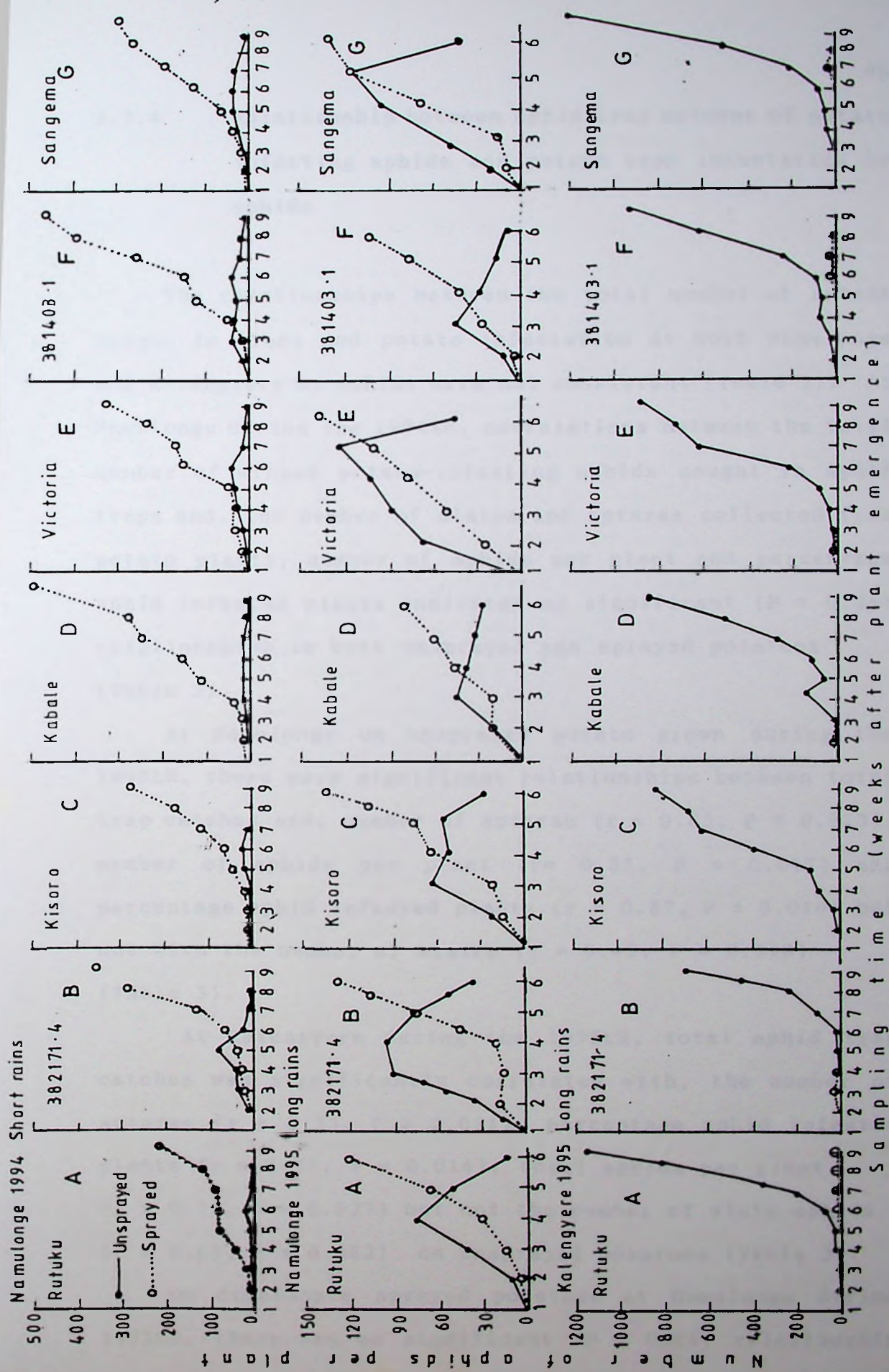


Fig. 4: Aphid population development (aphids per plant) on Dimethoate sprayed and unsprayed seven *Solanum* potato varieties at Namulonge during the 1994 short rains and at Namulonge and Kalengyere in the 1995 long rains.

3.3.4 Relationship between aphid trap catches of potato infesting aphids and potato crop infestation by aphids

The relationships between the total number of aphids caught in traps and potato infestation at both Namulonge and Kalengyere by aphids were not consistent (Table 3). At Namulonge during the 1994SR, correlations between the total number of winged potato-infesting aphids caught in aphid traps and, the number of alates and aptarae collected from potato plants, number of aphids per plant and percentage aphid infested plants indicated no significant ($P = 0.05$) relationships in both unsprayed and sprayed potatoes (Table 3).

At Namulonge on unsprayed potato grown during the 1995LR, there were significant relationships between total trap catches and, number of aptarae ($r = 0.85$, $P = 0.023$), number of aphids per plant ($r = 0.85$, $P = 0.017$) and percentage aphid infested plants ($r = 0.87$, $P = 0.016$) but not with the number of alates ($r = 0.42$, $P = 0.398$) (Table 3).

At Kalengyere during the 1995LR, total aphid trap catches was significantly correlated with, the number of aptarae ($r = 0.73$, $P = 0.021$), percentage aphid infested plants ($r = 0.77$, $P = 0.014$), total aphids per plant ($r = 0.72$, $P = 0.027$) but not the number of alate aphids ($r = 0.63$, $P = 0.062$) on unsprayed potatoes (Table 3).

On dimethoate sprayed potatoes at Numulonge during 1995LR, there was no significant ($P = 0.05$) relationship

between total trap catches and, number of alates and aptarae, number of aphids per plant, and percentage of potato plants infested by aphids (Table 3). In sprayed potatoes at Kalengyere, total aphid trap catches was only significantly correlated with percentage aphid infested plants ($r = 0.80$, $P = 0.008$) (Table 3). Although no particular trend in relationships could be discerned between aphid trap catches and potato crop infestation parameters at the two locations in both seasons, pooled data indicated that in the absence of human intervention, the percentage of aphid infested plants was significantly correlated ($r = 0.45$, $P = 0.029$) with the number of alate aphids caught in traps (Table 3).

Direct aphid counts from potato plants indicated that at Namulonge, during the 1994SR, percentage aphid infested plants in unsprayed potato was significantly correlated ($r = 0.75$, $P = 0.05$)) with the number of aptarae aphids (Table 4). In the 1995LR, the percentage of plants infested by aphids on unsprayed potatoes was also significantly correlated ($r = 0.96$, $P \leq 0.01$) with the number of aptarae aphids (Table 4).

In unsprayed potatoes at Kalengyere, during the 1995LR, percentage aphid infested plants was significantly correlated with both alate ($r = 0.91$, $P = 0.01$) and aptarae aphids ($r = 0.89$, $P = 0.01$) (Table 4).

In sprayed potatoes at Namulonge during both seasons, the percentage of potato plants infested by aphids was significantly correlated with the number of aptarae aphids

Table 3: Correlation coefficients obtained when the total number of aphids trapped per week were related to the total number of alates, aptarae, aptarae, aphids per plant and percent aphid infested plants in sprayed and unsprayed potatoes at Namulonge (NAARI) during the short rains (SR) of 1994 and at Namulonge and Kalengyere (KRS) in the long rains (LR) of 1995.

Site	Un - s p r a y e d P o t a t o			S p r a y e d P o t a t o		
	³ No. Alates	³ No. Aptarae	Total aphids plant ⁻¹	Infested plants %	No. Alates	No. Aptarae
NAARI 1994SR	-0.24	-0.36	-0.38	-0.43	-0.30	0.51
NAARI 1995LR	0.42	0.85 [†]	0.85 [†]	0.87 [†]	0.61	0.17
KRS 1995LR	0.63	0.73 [†]	0.72 [†]	0.77 ^{††}	0.23	0.28
Pooled data ^b	0.12	0.27	0.33	0.45 [†]	0.12	0.19
					0.35	0.50

[†], ^{††} indicate significant at an alpha level of 0.05 and 0.01, respectively.

^a Total number of aphids from 20 plants per plot per week.

^b Data were pooled for nine and six weeks at Namulonge during 1994SR and 1995LR, respectively, and for nine weeks at Kalengyere during the 1995LR.

($r = 0.91$, $P \leq 0.01$ in 1994SR and in 1995LR, $r = 0.94$, $P = 0.01$) but not the number of alates in both seasons (Table 4). At Kalengyere in sprayed potatoes, percentage aphid infested plants was significantly correlated ($r = 0.82$, $P = 0.05$) with the number of alates but not significantly ($P = 0.05$) correlated with the number of aptarae aphids ($r = 0.32$) (Table 4).

The graphical representation of the above relationships are given in Figure 5. The correlation between the percentage potato plants infested by aphids and the number of aptarae aphids at Namulonge during the 1994 short rains, were given by the equations, $Y = 9.2 + 0.64X$, ($r^2 = 0.566$, $P = 0.05$) for the potatoes in unsprayed plots and $Y = 19.7 + 0.15X$, ($r^2 = 0.826$, $P = 0.05$) for sprayed potatoes (Figure 5A).

At Namulonge, in the 1995 long rains, the function for percentage aphid infested plants was given by the equation; $Y = 23.0 + 0.73X$, ($r^2 = 0.914$, $P < 0.01$) for unsprayed potatoes while for sprayed potato, it was $Y = 17.3 + 1.25X$, ($r^2 = 0.882$, $P = 0.01$) (Figure 5B).

At Kalengyere, on the other hand, potato plants infestation by aphids as a function of alate aphids for unsprayed potatoes was given by the equation $Y = 30.8 + 2.16X$ ($r^2 = 0.826$, $P = 0.01$) and for sprayed potatoes, infestation was given by equation $Y = 1.7 + 3.1X$, ($r^2 = 0.677$, $P = 0.05$) (Figure 5C). These relationships indicate that at Namulonge, a higher number of aptarae aphids in a potato crop resulted in

Table 4: Correlation coefficients between percentage aphid infested potato plants and number of alate and aptarae aphids at Namulonge (NAARI) during the 1994 short rains (SR) and at Namulonge and Kalengyere Research Stations (KRS) during the 1995 long rains (LR).

	Percentage aphid infested plants					
	Non S p r a y e d			S p r a y e d		
	NAARI 1994SR	NAARI 1995LR	KRS 1995LR	NAARI 1994SR	NAARI 1995LR	KRS 1995LR
Alates	0.65 ^{ns}	0.57 ^{ns}	0.91 ^{††}	0.26 ^{ns}	0.51 ^{ns}	0.82 [†]
Aptarae	0.75 [†]	0.96 ^{†††}	0.89 ^{††}	0.91 ^{†††}	0.94 ^{††}	0.32 ^{ns}

† , †† , †††

Significant at alpha level of 0.05, 0.01 and <0.01, respectively.

^{ns}

Non significant at P = 0.05.

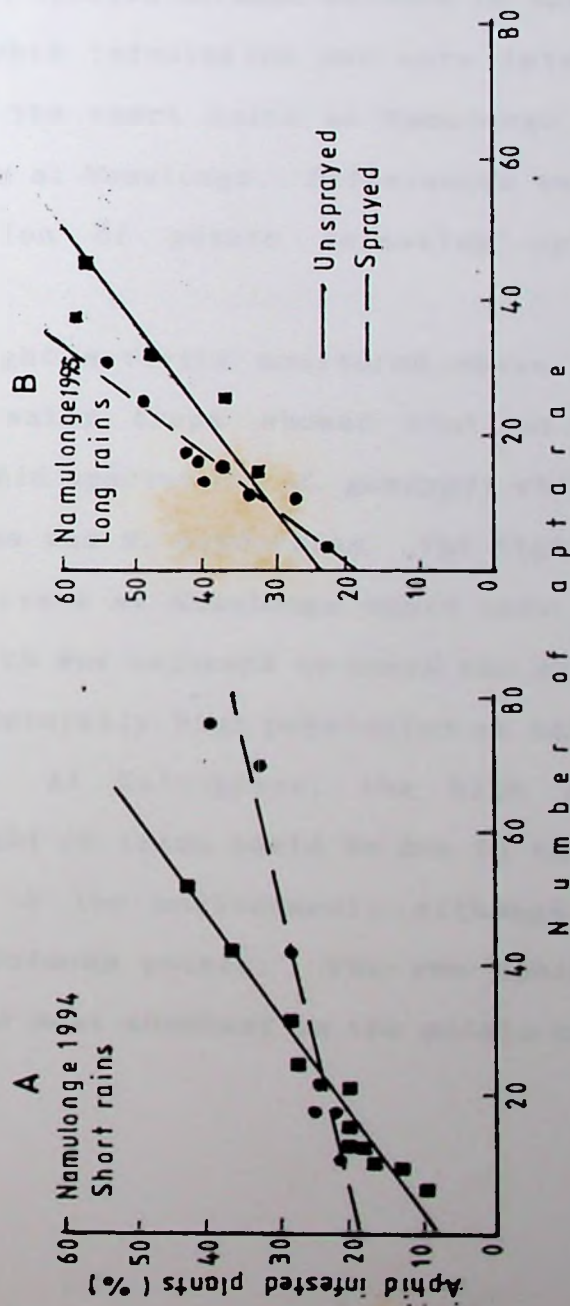


Fig. 5: Regression relationship between aphid infested plants(%) and number of aptarae aphids at Namulonge in the 1994 short rains, 1995 long rains and number of alate aphids at Kalengyere in the 1995 long rains.

great infestation by aphids while at Kalengyere a high number of alates aphids led to a high proportion of plants getting infested by aphids.

3.4 DISCUSSION

The results obtained during this study showed that there are variations in the occurrence and abundance of potato infesting aphid species between seasons in both Kalengyere and Namulonge. Aphid infestation was more intense in the long rains than in the short rains at Namulonge and, greater at Kalengyere than at Namulonge. Differences were also observed in the reaction of potato infesting aphid species to dimethoate.

Aphid flight activity monitored above the potato crop using yellow water traps showed that at Namulonge, the predominant aphid species was *A. gossypii* while at Kalengyere the main species was *M. euphorbiae*. The high abundance of *A. gossypii* from traps at Namulonge could have been due to the cotton crop which was adjacent to where the experiment was set or there is a naturally high population of this aphid species at Namulonge. At Kalengyere, the high incidence of *M. euphorbiae* caught in traps could be due to this species being more abundant in the environment, although it was a poor coloniser of *Solanum* potato. The two aphid species were, however, not the most abundant on the potato crop. Samples of

aphids collected from potato plants revealed that *M. persicae* was the most abundant aphid species on potato at both Kalengyere and Namulonge.

Evaluation of aphid infestation on different potato varieties showed that infestation and aphid population development set in earlier in early-medium maturing than late maturing potato varieties. There was a tendency for aphid infestation in potato to increase sharply between the fifth and sixth weeks after plant emergence in sprayed potatoes at Namulonge and unsprayed potato at Kalengyere. Towards potato maturity, however, all the potato varieties were heavily infested by aphids. This indicated that all varieties used were susceptible to aphid infestation, and therefore needed to be protected with regular insecticide sprays.

In unsprayed potato at Namulonge, infestation tended to decline between the fifth and sixth week of sampling. By the ninth week, infestation was at a minimum in unsprayed potato but maximum in sprayed varieties. The decline in aphid infestation in the fifth week in unsprayed potato at Namulonge could have been due to setting-in critical densities of aphids and aphid disease epizootics which caused the aphid population to collapse.

In sprayed potatoes at Namulonge, the sharp increase in aphid density and plant infestation in the sixth week could have been due to the failure of dimethoate to control *M. persicae*. It is possible that *M. persicae* has developed

resistance to dimethoate since reports of its resistance to organophosphates are common (Furk, 1986; Devonshire, 1989; Quaglia *et al.*, 1993). Alternatively, the effectiveness of this insecticide could have been reduced by environmental or plant growth factors unique to the this area (Broadbent, 1957; Devonshire, 1989; Atiri and Jimoh, 1990).

At Kalengyere, dimethoate effectively controlled all potato-infesting aphid species. No differential aphid species' occurrence was observed in sprayed or unsprayed potato. However, only *M. persicae*, *M. euphorbiae* and *A. solani* were collected from potato plants although trap catches indicated the presence of other potato-infesting aphid species at this site. As expected, minimum infestation was observed in sprayed potato and maximum in the unsprayed plots. The onset of a sharp rise in infestation in unsprayed potatoes, like at Namulonge, was between the fifth and sixth weeks of sampling but, unlike Namulonge, there was no population decline on unsprayed potato in the sixth week of sampling.

The onset of heavy aphid infestation coincided with potato flowering and tuberisation. Differences in the on-set of high aphid infestation between early and late maturing varieties was probably due to the different varieties reaching their prime stages of growth at different times. The heavy aphid infestation at this stage could have been related to two main factors; (i) the aphids may have established a minimum population density that was not suppressed by natural external

processes in the presence of adequate food supply; (ii) the plants at this stage were more nutritious to aphids (Beukema and van der Zaag, 1990) and were therefore suitable for rapid aphid multiplication. Both of these factors could have contributed to a rapid aphid population build-up towards plant maturity.

The level of plant infestation by aphids at Namulonge was higher in the 1995LR than the 1994SR, although the aphid population densities were to an extent similar in both seasons. This probably means that, in the 1994SR, the aphids were more dispersed than in the 1995LR and therefore more plants were infested. A comparison of data for Kalengyere and Namulonge showed that, in the absence of external pressure, infestation of potato by aphids is higher at Kalengyere than at Namulonge. The difference in the levels of infestation in sprayed and unsprayed potato at Namulonge and Kalengyere means that different strategies have to be adopted for controlling aphids in potato. Thus, the low aphid pressure and the rare occurrence of alate potato aphids at Namulonge implies that this area probably has a low pressure of aphid-borne *Solanum* potato viruses.

At Kalengyere, potato infestation by aphids was correlated with the number of alate aphids collected from both sprayed and unsprayed potatoes, although aptarae aphids also had a significant input to infestation in unsprayed potatoes. The dependence of the level of infestation by aphids in a crop

on the number of alates aphids was also reported by Oonyu (1992) on beans. The absence of a significant correlation between aphid infested plants and number of aptarae at Kalengyere in sprayed potatoes means that dimethoate spray completely prevented establishment of aphid population in the in the insecticide treated plots.

In contrast, aphid infestation in field grown potato at Namulonge was a function of aptarae aphid population. Thus, at both Namulonge and Kalengyere, the level of potato infestation by aphids can be appreciably predicted from aptarae aphid counts monitored from potato plants than yellow water aphid traps. At Kalengyere, however, alate aphids from both traps and plants had a significant input to the proportion of plants infested by aphids. In the absence of human intervention (non-spray) data for the two locations revealed that total trap catches influenced percentage aphid infested. This can be attributed to the random landing of alate aphids, and their redistribution and reproduction after crop colonisation (van Emden *et al.*, 1969; Heathcote, 1972) in the absence of external pressure.

CHAPTER 4

EFFECTIVENESS OF WEEKLY SYSTEMIC INSECTICIDE SPRAY AGAINST THE INFECTION OF *SOLANUM* POTATO WITH APHID-BORNE VIRUSES

4.1 INTRODUCTION

Aphids are the main natural vectors of most plant viruses (Hooker, 1982), and the spread of aphid-borne viruses is related to the size of aphid populations (Raman, 1985). Aphids will spread viral diseases either if they are virus infected and feed on a healthy host, or if non-viruliferous individuals feed on infected hosts or both (Jayasinghe, 1988). In all cases, the scale of virus infection within a crop will be increased.

The principle sources of virus infection in a virus-free crop are insect vectors. However, the presence of plants with secondary infection or alternate weed or crop plant hosts of both the aphid and viruses greatly increases the chance of virus spread (Auclair, 1989; Harrewijn, 1989). Thus, if a field is initially planted with virus-free seed potato, virus infection will be introduced in it by infective alate aphids. On the other hand, if alate aphids are virus-free and if they invade a field with some few virus infected plants, they will spread infection to formerly healthy plants.

Potato plants which are fed on by virus infected aphids late in the season may not show viral infection symptoms in the current season (Knutson and Bishop, 1964; Clarke *et al.*, 1980). There is need, therefore, to test seed potato tubers for virus latent infection before they are planted next season otherwise they are likely to be a source of infection to other healthy potato crops (Mih *et al.*, 1993).

In certified seed, the number of infection sources may be low or absent, especially where seed plots are isolated from ware potato crops (Raman, 1985; Jayasinghe, 1988). The presence of aphids, even if they were virus-free, will greatly facilitate virus spread if a crop had some few latently infected seed tubers. In a crop obtained from healthy seed, the strategy is to reduce the number of virus vectors within the crop (Gibson and Rice, 1989). This can be achieved by use of aphicides, especially systemic ones. Secondly, aphicides will prevent aphid population development which would otherwise facilitate further virus spread (Schepers, 1972). If systemic insecticides are combined with initial virus-free seed stocks, virus spread by aphids in a potato crop can be reduced or completely eliminated.

One of the aphicides that has been used to curtail the spread of aphid-borne viruses in *Solanum* potato is dimethoate (Kibata, 1982; Raman and Radcliffe, 1992). This insecticide is reported to have both contact and systemic properties (Matthews, 1984). It has also been shown to reduce the number

of short trial probes by *Myzus persicae* (Sulz.) and *Aphis fabae* (Scop.) on various hosts (Gibson and Rice, 1989). These attributes of dimethoate probably reduce the chances of transmission of non-persistent viruses and completely stop infection of potato with persistently transmitted viruses.

In this regard, a study was undertaken to assess the effectiveness of dimethoate (a systemic insecticide) in preventing or reducing the spread of aphid-borne viruses in virus-indexed certified seed potato tubers. Attention was paid to potato leaf roll virus (PLRV), potato virus Y (PVY) and potato virus S (PVS) which are aphid-borne. Potato virus X (PVX) which is only transmitted by contact was also included because its presence in some *Solanum* potato varieties increases their susceptibility to infection by other potato viruses especially potato leaf roll virus.

4.2 MATERIALS AND METHODS

This study formed part of the same field studies reported in Chapter 3. The same *Solanum* potato varieties and experimental plots that were used in studies for potato aphid infestation assessment were also used to assess the effectiveness of dimethoate at preventing infection of field grown *Solanum* potato with aphid-borne viruses. The study was conducted at Namulonge Agricultural and Animal Production Research Institute (NAARI) during the 1994 short rains (SR)

and at both NAARI and Kalengyere Research Station (KRS) in the 1995 long rains (LR).

4.2.1 Seed-borne potato virus latent infection indexing before planting

Before planting the seed potatoes in each season, their virus infection status was first established. Ten medium sized (100-120 g) seed tubers from each of the seven potato varieties; Rutuku, 382171.4, Kisoro, Kabale, Victoria, 381403.1 and Sangema, that were used in the studies reported in Chapter 3 were selected and induced to sprout using Rindite (7:3:1 parts of; ethylene chlrohydrin, ethylene dichloride and carbon tetrachloride, respectively) (Burton, 1966). Three weeks after treatment with rindite, all the seed tubers had sprouted. The tubers were numbered and from each tuber a sprout together with part of the tuber flesh from the heel end was scooped out and put in numbered polythene bags corresponding to the number on the tuber. The tubers were then indexed for latent infection with potato leaf roll virus (PLRV), potato virus Y (PVY), potato virus X (PVX) and potato virus S (PVS) using the Direct Double Antibody Sandwich Immunosorbent Assay (DAS-ELISA) as described by Converse and Martin (1993).

The virus antigen-antibody reaction for each of the above viruses was detected using the respective virus antibodies

conjugated to a phosphatase enzyme. The enzyme substrate used was P-nitrophenyl phosphate adjusted to pH 9.8 in 10% diethanolamine stock solution (Converse and Martin, 1993). The respective antigen-antibody reaction for each virus was quantified using the Multiskan Plus ELISA plate reader (Version 2.03) through a 405 nm wavelength light filter. The positive-negative threshold (cut-off value for infected and healthy samples respectively) for each virus was set at the mean absorbance value of ten healthy (control) samples plus three standard deviations (Satula *et al.*, 1986; Flanders *et al.*, 1990). Any sample whose absorbance value was greater than the threshold value for a particular virus was declared to be infected with that virus. The mean absorbance values for seed potato of each variety in both seasons of acquiring seed from Kalengyere were worked out and tabulated.

4.2.2 Virus incidence and severity in field grown *Solanum* potatoes

From the seven potato varieties subjected to the insecticide spray treatment as reported in Chapter 3, Section 3.2.2, two fully expanded apical leaflets (Flanders *et al.*, 1990) were picked from each of the plants in the middle two rows per plot, at 75 days after planting (DAP) and bulked.

The composite leaf samples were collected in numbered polythene bags corresponding to the field plots. The samples

were taken to the laboratory and tested for the presence of PLRV, PVY, PVX and PVS using DAS-ELISA protocol as described by Converse and Martin (1993). The virus antigen-antibody reactions were quantified using a Multiskan Plus (Version 2.03) ELISA plate reader at a wave-length of 405 nm. Virus infection quantification was on the principle that the intensity of yellow colour of the virus antigen-antibody reaction is proportional to the virus antigen concentration (Salazar, 1983; Converse and Martin, 1993), and therefore, to the severity of virus infection. The negative-positive thresholds for healthy and infected samples, respectively, were set at the mean absorbance of ten healthy controls plus three standard deviations. Differences between treatments were tested using ANOVA and the means were compared using the Least Significant Difference (LSD) test at the appropriate alpha level.

4.2.3 Effect of dimethoate spray on the performance of field grown *Solanum* potato

The potato varieties that were used for the assessment of aphid infestation (Section 3.2.2) and virus infection were also used to assess the effect of dimethoate spray on the field performance of current season potato receiving the insecticide treatment. The differences in infection with aphid-borne viruses, and fresh tuber yield due to variety and

insecticide treatments, were tested using ANOVA. Means of significantly different factors were compared using the Least Significant Difference (LSD) test at an appropriate alpha level. Fresh potato tuber yield (MT ha^{-1}) of different potato varieties were individually correlated with the levels of virus infection where applicable.

4.3 RESULTS

4.3.1 Seed potato tubers latent virus infection indexing before planting

Virus indexing of potato seed tubers obtained from Kalengyere during the 1994SR and 1995LR and tested for virus latent infection before they were planted in the same seasons either at Namulonge or Kalengyere indicated that all the varieties were free from potato leaf roll virus (PLRV), potato virus Y (PVY) and potato virus S (PVS), their mean absorbance values being less than the negative-positive thresholds for the respective viruses (Table 5). All the potato viruses named above are aphid-borne although the latter can also be spread by contact (Hooker, 1981; 1982). Seed tubers used in this study were therefore free from these viruses at planting.

Three cultivars; Rutuku, Kabale and Sangema obtained from Kalengyere in both seasons were latently infected with potato virus X (PVX), their mean Multiskan absorbance values were

greater than the negative-positive threshold for PVX in both seed sets of the two seasons (Table 5). In the case of Rutuku, for example, obtained from Kalengyere during the 1994SR its mean absorbance value for PVX was 0.520 which is greater than the threshold value (0.143) for PVX for this potato seed set. The mean absorbance value for Rutuku seed tubers in the 1995LR (0.255) was also a higher than that of Sangema (0.190). Rutuku therefore, was more infected with PVX than Sangema (Table 6). In the 1994SR, among the seed tubers obtained from Kalengyere, Rutuku had the highest rate of infection with PVX (100%) while Kabale had the least (10%) (Table 6). In the 1995LR, seed tuber indexing indicated that 90% of the seed samples of Sangema, 70% of Rutuku, and 10% of Kabale were latently infected with PVX (Table 6). So the seed tubers of some varieties obtained from Kalengyere were infected with PVX but at different levels.

4.3.2 Virus incidence and severity on field grown potatoes

Virus indexing, at 75 days after planting, of potatoes grown at Namulonge during the 1994SR and subjected to the insecticide sprays as earlier described, indicated no significant ($P = 0.05$) differences in infection with potato leaf roll virus, potato virus Y and potato virus S among varieties, and sprayed and unsprayed potatoes (Table 7). However, significant ($P = 0.05$) differences among varieties were observed for PVX infection (Table 7).

Table 5: Mean^a Multiskan Plus values (Relative virus antigen titre) for virus indexing of seed potato tubers before planting for latent virus infection of seven *Solanum* potato varieties obtained from Kalengyere in the 1994 short rains (SR) and planted at Namulonge during the 1994SR and seed tubers obtained from Kalengyere and planted at both Kalengyere and Namulonge in the 1995 long rains (LR).

Variety	Potato leaf roll virus (PLRV)	Potato virus Y (PVY)	Potato virus X (PVX)	Potato virus S (PVS)
(a) 1994SR				
Rutuku	0.207±0.01	0.115±0.00	0.520±0.02	0.187±0.06
382171.4	0.205±0.02	0.118±0.01	0.124±0.05	0.178±0.00
Kisoro	0.201±0.00	0.122±0.01	0.122±0.00	0.176±0.01
Kabale	0.207±0.01	0.118±0.00	0.195±0.08	0.181±0.01
Victoria	0.190±0.02	0.118±0.00	0.111±0.00	0.158±0.00
381403.1	0.201±0.01	0.119±0.00	0.116±0.07	0.174±0.01
Sangema	0.204±0.01	0.117±0.01	0.531±0.01	0.184±0.01
Threshold ^b	0.225	0.133	0.143	0.203
(b) 1995LR				
Rutuku	0.089±0.01	0.089±0.01	0.255±0.05	0.070±0.01
382171.4	0.084±0.01	0.084±0.01	0.079±0.01	0.071±0.01
Kisoro	0.091±0.00	0.091±0.00	0.076±0.01	0.073±0.01
Kabale	0.082±0.01	0.082±0.01	0.107±0.02	0.087±0.01
Victoria	0.078±0.01	0.078±0.01	0.070±0.01	0.067±0.01
381403.1	0.085±0.01	0.085±0.01	0.072±0.01	0.075±0.01
Sangema	0.077±0.01	0.072±0.01	0.190±0.02	0.062±0.01
Threshold ^b	0.154	0.160	0.117	0.126

^a Mean of ten tubers per variety.

^b Cut-off values for positive (infected) and negative (healthy) samples which are means of 10 healthy samples plus 3 standard deviations for each virus in each seed set in the two seasons.

Table 6: Percentage of seed tubers per variety obtained from Kalengyere in the 1994 short rains (SR) and the 1995 long rains (LR) latently infected with potato virus X in seven *Solanum* potato varieties^a.

Variety	Percentage Potato virus X infection	
	1994SR	1995LR
Rutuku	100.0	70.0
382171.4	0.0	0.0
Kisoro	0.0	0.0
Kabale	20.0	10.0
Victoria	0.0	0.0
381403.1	0.0	0.0
Sangema	80.0	90.0

^a Each sample per variety consisted of ten tubers.

Table 7: Mean squares from ANOVA tables of Multiskan Plus ELISA plate reader values for four viral infections in seven *Solanum* potato varieties under two insecticide spray treatments at Namulonge Research Station during the short rains of 1994.

Source of variation	Df	Potato Leaf roll virus	Potato virus Y	Potato virus X	Potato virus S
Replication	2	0.003	0.222	0.004	0.002
Spray (A)	1	0.002	1×10^{-5}	0.001	0.002
Error	2	0.003	5×10^{-4}	5×10^{-4}	3×10^{-4}
Variety (B)	6	0.001	3×10^{-4}	0.189**	4×10^{-4}
AB	6	0.003	2×10^{-5}	0.003	1×10^{-4}
Error	24	0.0004	8×10^{-5}	0.002	2×10^{-4}
C.V. (%)	-	7.62	6.20	19.01	8.15

** significant at $P = 0.01$

At Kalengyere in the 1995LR, no significant differences were observed between sprayed and unsprayed insecticide treatments, and among varieties, for PLRV, PVY, and PVS. As in Namulonge in the 1994SR, significant ($P = 0.01$) differences were observed among varieties for PVX infection (Table 8).

At Namulonge in the 1995LR, no significant ($P = 0.05$) effects between insecticide treatments was observed for all the potato viruses under study (Table 9) but, like in the 1994SR, highly significant differences were observed among the varieties for PVX infection. When seed potato produced at Namulonge during the 1994SR were planted again at this location during the 1995LR, significant differences ($P = 0.05$) were observed among varieties and between seed tuber produced at Namulonge and those freshly obtained from Kalengyere for PLRV infection (Table 9). Significant differences were also observed in PVX infection among varieties ($P = 0.01$), seed tuber generation ($P = 0.01$), and variety by seed generation interactions were also significant ($P = 0.01$). No significant ($P = 0.05$) differences were observed among varieties, spray treatments nor were, spray by variety interactions significant for both PVY and PVS infection (Table 9).

Virus testing of composite leaf samples from each plot showed that at Namulonge in the 1994SR, all the potato varieties irrespective of the insecticide treatment were infected with PLRV (Table 10). During the 1995LR, the same

Table 8: Mean square values from Multiskan Plus ELISA plate reader values for virus screening of seven potato varieties at Kalengyere Research Station during the 1995 long rains.

Source of variation	Df	Potato leaf roll virus (PLRV)	Potato virus Y (PVY)	Potato virus X (PVX)	Potato virus S (PVS)
Replication	2	0.00001	0.001	0.0001	0.00001
Insecticide Spray (A)	1	0.0005	0.00001	0.001	0.0001
Error	2	0.0003	0.00005	0.005	0.00004
Variety (B)	6	0.001	0.001	0.098**	0.006
AB	6	0.001	0.0002	0.008	0.00071
Error	24	0.001	0.001	0.008	0.00009
C.V. (%)		36.6	35.0	41.2	34.2

** Significant at (P = 0.01)

Table 9: Mean square values of Multiskan Plus ELISA plate reader values for virus screening of seven *Solanum* potato varieties: Seed tubers obtained from Kalengyere and grown at Namulonge in the 1994 short rains (SR), progeny of 1994 short rains (SR) at Namulonge in 1995 long rains (LR) and materials freshly obtained from Kalengyere in 1995LR and grown at Namulonge during the 1995LR.

Source of variation	Df	Potato leaf roll virus	Potato virus Y	Potato virus X	Potato virus S
Replication	2	0.045	0.001	0.030	0.003
Spray (A)	1	0.039	0.002	0.005	0.001
Error	2	0.009	0.002	0.008	0.001
Variety (B)	6	0.017 [*]	0.001	0.134 ^{**}	0.001
AB	6	0.006	0.001	0.009	0.003
Generation (C)	1	0.115 [*]	0.010	0.129 ^{**}	0.003
AC	1	0.009	0.0005	0.016	0.0001
BC	6	0.029	0.001	0.024 ^{**}	0.0001
ABC	6	0.017	0.001	0.002	0.001
Error	52	0.016	0.001	0.006	0.001
C.V.		21.6	26.4	32.60	20.3

* and ** Significant at (P = 0.05) and (P = 0.01), respectively.

trend of potato infection with PLRV, PVY and PVS as for 1994SR were also obtained (Table 10). In this context, weekly dimethoate spray failed to prevent the spread of PLRV at Namulonge in both seasons.

At Kalengyere, all potato varieties were free from PLRV, PVY, and PVS whether they were sprayed with dimethoate or not (Table 10). As in Namulonge, PVX was confined to Rutuku, Kabale and Sangema whose seed was latently infected with this virus during both seasons although at this site cultivar 382171.4 got infected by this virus during field growth in the 1995LR (Table 10).

4.3.2.1 Potato leaf roll virus infection severity in field grown *Solanum* potato

Comparison of mean values for ELISA plate absorbance readings revealed that in the 1994SR at Namulonge, Victoria had the highest PLRV antigen concentration while Kisoro had the least (Table 11). The 1994SR seed potato progeny grown in 1995LR at Namulonge showed that the PLRV antigen titre had increased.

There was higher PLRV antigen concentration in 381403.1 than in any other variety for seed potatoes produced at Namulonge in the 1994SR and grown at the same site in the 1995LR. The absorbance values of materials freshly obtained from Kalengyere in the 1995LR and grown at Namulonge adjacent

Table 10: Mean Multiskan Plus values (Relative virus antigen concentrations) for Potato leaf roll virus (PLRV), Potato virus Y (PVY) and Potato virus S (PVS) infection in field grown *Solanum* potato 75 days after planting at Namulonge during the 1994 short rains and, at Namulonge and Kalengyere during the 1995 long rains.

Variety	Mean absorbance values (Relative virus titre)					
	U n s p r a y e d			S p r a y e d		
	PLRV	PVY	PVS	PLRV	PVY	PVS
(a) Namulonge 1994 Short rains						
Rutuku	0.258	0.139	0.212	0.256	0.127	0.200
382171.4	0.256	0.128	0.201	0.252	0.127	0.186
Kisoro	0.237	0.126	0.195	0.235	0.127	0.195
Kabale	0.263	0.132	0.205	0.249	0.134	0.205
Victoria	0.278	0.126	0.198	0.248	0.122	0.193
381403.1	0.251	0.126	0.202	0.237	0.126	0.213
Sangema	0.256	0.127	0.192	0.242	0.124	0.207
LSD (0.05)	0.034	0.015	0.037	0.034	0.015	0.037
Threshold ^a	0.178	0.147	0.235	0.178	0.147	0.235
(b) Namulonge 1995 Long rains						
Rutuku	0.611	0.157	0.143	0.578	0.160	0.183
382171.4	0.577	0.141	0.176	0.461	0.133	0.150
Kisoro	0.610	0.160	0.174	0.569	0.139	0.159
Kabale	0.645	0.150	0.158	0.614	0.147	0.169
Victoria	0.586	0.149	0.169	0.611	0.152	0.169
381403.1	0.675	0.160	0.169	0.595	0.149	0.169
Sangema	0.600	0.166	0.183	0.577	0.132	0.128
LSD (0.05)	0.147	0.037	0.036	0.147	0.037	0.036
Threshold ^a	0.184	0.246	0.245	0.184	0.246	0.245
(c) Kalengyere 1995 Long rains						
Rutuku	0.076	0.074	0.071	0.047	0.053	0.061
382171.4	0.038	0.056	0.051	0.073	0.072	0.070
Kisoro	0.087	0.091	0.134	0.089	0.097	0.126
Kabale	0.094	0.094	0.137	0.089	0.093	0.115
Victoria	0.069	0.080	0.121	0.085	0.094	0.106
381403.1	0.090	0.093	0.123	0.089	0.099	0.109
Sangema	0.073	0.077	0.110	0.088	0.095	0.132
LSD (0.05)	0.053	0.041	0.016	0.053	0.041	0.016
Threshold ^a	0.103	0.105	0.144	0.103	0.105	0.144

^a Cut-off values for healthy and infected samples.

to the 1994SR seed progeny in the same season had mean absorbance values close to that of seed generated at Namulonge in the 1994SR (Table 11). This probably indicates that PLRV infection was spread from the 1994SR progeny to the new crop adjacent to it and whose seed, obtained from Kalengyere in the 1994SR, was initially free from potato leaf roll virus.

Although all potato varieties were susceptible to PLRV infection, they showed differences in PLRV antigen titre as shown by differences in Multiskan absorbance values, thus indicating the ability of PLRV to multiply differently in various potato varieties. For example, in the 1994SR at Namulonge, Victoria had the highest absorbance value, and therefore the highest PLRV infection. With seed stocks freshly obtained from Kalengyere in the 1995LR and grown at Namulonge in the same season, Sangema had the highest PLRV infection while Rutuku had the least in (Table 11).

4.3.2.2 Incidence and severity of Potato virus X in field grown *Solanum* potatoes

Evaluation of *Solanum* potato grown in the field in the 1994SR and 1995LR seasons at Namulonge, revealed that PVX infection was confined to varieties whose seed tubers were latently infected before planting except 382171.4 during the 1994SR (Table 12). It was also evident that PVX originated from Kalengyere as earlier observed in seed tuber indexing

Table 11: Mean Multiskan values (levels of virus antigen concentration) for Potato leaf roll virus (PLRV) of seven *Solanum* potato varieties at Namulonge Research Station during 1994 short rains (SR) and 1995 long rains (LR).

Variety	Mean absorbance values		
	1994 SR [*]	Progeny of 1994SR [*] in 1995LR	1995LR*
Rutuku	0.255 ³	0.642 ^{ab}	0.565 ⁵
382171.4	0.246 ⁶	0.529 ^b	0.509 ⁷
Kisoro	0.243 ⁷	0.653 ^{ab}	0.525 ⁵
Kabale	0.256 ²	0.667 ^{ab}	0.592 ²
Victoria	0.358 ¹	0.647 ^{ab}	0.550 ⁴
381403.1	0.247 ⁵	0.746 ^a	0.524 ⁶
Sangema	0.253 ⁴	0.500 ^c	0.629 ¹
Threshold**	0.178	0.184	0.184
LSD	0.032	0.147	0.147
P-value	0.01	0.05	0.05

^{*}Seeds freshly obtained from Kalengyere.

^{**}Negative-positive threshold of infected and healthy samples.

^{1,2,...7} Decreasing level of antigen concentration.

since varieties grown at Namulonge for the first season were not infect by this virus except 382171.4. The cultivar 382171.4 should have got infected in the field during growth. When seed potatoes generated at Namulonge in 1994SR were planted again in 1995LR, PVX was detected in all varieties except Victoria. Potato virus X infection could have been spread during seed storage or at planting during the 1995LR since it is spread by contact.

The potato grown at Kalengyere in 1995LR behaved the same way as that freshly introduced at Namulonge in the 1995LR. Potato virus X was only detected in Rutuku, Kabale, and Sangema which were formerly latently infected with this virus. No variety other than those that were latently infected with this virus got infected in the field during vegetative growth at Kalengyere.

4.3.3: Effect of dimethoate spray on the field performance of seven potato varieties

Summaries of analyses of variance of data on the effect of applied systemic insecticide on the performance of *Solanum* potato are presented in Tables 13 and 14. The insecticide treatment did not significantly ($P = 0.05$) affect the field performance of the potato varieties at both Namulonge and Kalengyere. However, the performance of the potato varieties at both locations varied significantly ($P = 0.01$) for number

Table 12: Potato virus X infection (relative virus antigen concentrations) in field grown *Solanum* potato at Namulonge during the 1994 short rains (SR) and at Namulonge and Kalengyere in the 1994 long rains (LR).

Variety	Namulonge 1994SR [*]	Progeny of 1994SR in 1995LR	Namulonge 1995LR [*]	Kalengyere 1995LR
Rutuku	0.517 ^a	0.554 ^a	0.295 ^a	0.346 ^{ab}
382171.4	0.165 ^b	0.238 ^c	0.180 ^{ab}	0.068 ^d
Kisoro	0.119 ^b	0.302 ^b	0.174 ^b	0.136 ^{cd}
Kabale	0.114 ^b	0.242 ^c	0.236 ^a	0.260 ^{bc}
Victoria	0.113 ^b	0.141 ^d	0.135 ^b	0.170 ^{cd}
381403.1	0.123 ^b	0.163 ^d	0.161 ^b	0.130 ^{cd}
Sangema	0.457 ^a	0.487 ^a	0.297 ^a	0.406 ^a
Threshold ^{**}	0.152	0.220	0.220	0.220

^{*}Seeds freshly obtained or grown at Kalengyere.

^{**}Cut -off values for infected and healthy samples.

Means followed by same letters are not significantly different at ($P = 0.01$).

$LSD_{0.05}$ between varieties during the 1994SR = 0.072.

$LSD_{0.05}$ between varieties during the 1995LR = 0.120.

of tubers plant per plant, mean tuber weight (g) and fresh tuber yield (MT ha^{-1}).

When fresh tuber yield (MT ha^{-1}) at Namulonge for the 1994SR, and of the 1994SR progeny from Namulonge in 1995LR were analysed, significant ($P = 0.01$) differences were obtained among varieties, seasons and, variety by season interactions were also significant (Table 13). The differences observed between potato varieties were therefore due to genetic and environmental factors rather than the insecticide treatments. When potato yields at Namulonge in 1994SR and at Kalengyere in 1995LR were compared, significant ($P = 0.01$) differences were also observed among varieties, location and, variety by location interactions were again also significant (Table 14).

A comparison among potato varieties for their mean fresh tuber yield (MT ha^{-1}) at Namulonge in 1994SR and its progeny in 1995LR showed a yield decline of the cultivars in the successive season (Table 15). The highest yield decline occurred in cv. Kabale while the least decline was in cv. Sangema. In the short rains of 1994 at Namulonge, the highest yielding variety was Sangema, however, its yields were depressed by 66.4% when used again as seed at Namulonge in the 1995LR. The least yield decline was in Kisoro although it was not among the best yielding varieties in the 1994 short rains (Table 15).

Table 13: Mean squares of yield and yield components of seven potato varieties at Namulonge Research Station during the short rains (SR) of 1994 and long rains (LR) of 1995.

Source of variation	Df	No. of tubers plant ⁻¹	Mean tuber weight (g)	Yield (MT ha ⁻¹)
Replications	2	1.66	864.66	31.68
Season (A)	2	322.7 ^{**}	19792.56 ^{**}	25.89 [*]
Error	4	1.04	54.57	6.49
Spray (B) schedule	1	1.68	48.38	5.80
AB	2	0.76	124.49	1.71
Variety (C)	6	83.08 ^{**}	4329.39 ^{**}	120.1 [*]
AC	12	12.11 ^{**}	1764.74 ^{**}	27.86 [*]
BC	6	1.40	353.14	3.39
ABC	12	3.42	324.52	6.28
Error	78	3.61	351.88	6.79
C.V (%)		44.50	48.9	66.7

* and ** Significant at (P = 0.05) and (P = 0.01), respectively.

Table 14: Means squares for yield and yield components of seven *Solanum* potato varieties at Namulonge during the 1994 short rains and Kalengyere Research Station during the 1995 long rains.

Source of variation	Df	No. of tubers plant ⁻¹	Mean tuber weight (g)	Yield (MT ha ⁻¹)
Replications	2	5.38	2999.0	140.56
Location (A)	1	6.16	133385.0 ^{**}	2835.75 ^{**}
Error	2	2.52	447.8	23.64
Spray (B) schedule	1	0.557	150.7	8.03
AB	1	0.348	224.2	5.59
Variety (C)	6	20.86 ^{**}	3548.2 ^{**}	48.19 ^{**}
AC	6	4.70 [*]	3062.1 ^{**}	48.36 ^{**}
BC	6	3.89	338.8	3.92
ABC	6	1.55	143.6	4.16
Error	52	2.49	396.0	6.38
C.V. (%)		21.85	19.39	23.90

* and ** Significant at (P = 0.05) and (P = 0.01), respectively.

Table 15: Yield (MT ha⁻¹) of seven *Solanum* potato varieties grown at Namulonge during the 1994 short rains (SR) and the progeny of 1994SR in the 1995 long rains (LR).

VARIETY	Short rains of 1994 (SR [*])	Progeny of 1994SR in 1995LR	Yield decline (%): 1994SR [*] to 1995LR
Rutuku	3.61	0.434	88.0
382171.4	5.47	0.412	92.5
Kisoro	3.90	3.48	0.1
Kabale	4.85	0.00	99.8
Victoria	6.67	1.77	73.5
381403.1	2.69	0.699	74.0
Sangema	6.14	2.06	66.4

Data were combined across seasons

LSD(0.05) between varieties = 3.00 for all the seasons.

*Seed freshly obtained from Kalengyere research station.

When potato yields at Namulonge in the 1994SR and at Kalengyere in the 1995LR were compared, there was generally higher yields at Kalengyere than at Namulonge (Table 16). Victoria and Sangema, which are early maturing varieties, had the highest yields at Namulonge during the 1994SR (Table 16). Low yields at the same site were registered by late maturing varieties such as Rutuku, Kabale and 381403.1 at the same location (Table 16).

At Kalengyere on the other hand, the highest yield was from 382171.4, a late maturing variety, and lowest yield was from Sangema (Table 16). The yields of Sangema, Victoria and Kisoro which are early/mid-early maturing varieties were expected to have very small differences in yield. Also, the yields of Rutuku, Kabale, 382171.4 and 381403.1 (late maturing varieties) were expected to fall within the same range but this was not the case. Other factor(s) could have influenced potato yields because some cultivars such as Sangema had unexpectedly low yields at Kalengyere compared to other varieties in the same category (Table 16).

The potato yields seemed to be influenced by varietal differences and infection with PVX (Table 17), which was detected in some of the seed potatoes obtained from Kalengyere during both the 1994SR and 1995LR, and probably PLRV infection in field grown potatoes at Namulonge. For instance the absorbance value of Sangema for PVX infection at both Kalengyere and Namulonge during the 1995LR was greater than

Table 16: Yield (MT ha⁻¹) of seven *Solanum* potato varieties grown at Namulonge during the 1994 short rains (SR) and at Kalengyere during the 1995 long rains (LR).

Variety	Namulonge 1994SR	KaLengyere 1995LR
Rutuku	3.61	15.67
382171.4	5.47	21.31
Kisoro	3.90	17.01
Kabale	4.85	18.84
Victoria	6.67	17.89
381403.1	2.69	15.01
Sangema	6.14	9.28
L.S.D. (0.05)	2.58	3.90
C.V. (%)	66.70	42.31

the negative-positive threshold for PVX; thus Sangema was infected with PVX. Sangema also had a relatively high PVX absorbance value, hence a high PVX infection and correspondingly low yields (Table 17). A similar observation was made in the yields for Rutuku which was also infected with PVX during the 1995LR at both Kalengyere and Namulonge (Table 17).

Analysis of the relationships between fresh tuber yield (MT ha^{-1}), PVX and PLRV infection for each variety indicated significant correlations between yield and PVX infection for those varieties that had tested positive for PVX infection (Table 18). A highly significant and negative correlation ($r = -1.0$, $P \leq 0.01$) was obtained between potato yield and PVX infection for Rutuku while significant ($P = 0.05$) and negative correlations were obtained for 382171.4, Kabale, and Sangema (Table 18). A significant correlation ($r = -0.98$, $P = 0.05$) was also obtained between yield and PLRV infection but only in Rutuku (Table 18). These results indicate yield depressing effects of potato virus infections.

The effects of initial PVX infection on the performance and susceptibility of *Solanum* potato to PLRV was depicted by Rutuku. In this variety, there was a strong relationship between potato yield and PVX infection ($r^2 = 1.0$) and, potato yield and PLRV infection ($r^2 = 0.96$). Thus, double infection by PVX and PLRV may have caused drastic yield decline in Rutuku (Table 18).

Table 17: Potato yield (MT ha⁻¹) and Potato virus X (PVX) infection (relative virus antigen concentration) of seven potato varieties at Namulonge and Kalengyere during 1994 shot rains (SR) and 1995 long rains (LR).

Variety	Namulonge 1994SR		Namulonge 1995LR		Kalengyere 1995LR	
	PVX	Yield	PVX	Yield	PVX	Yield
Rutuku	0.517	3.61	0.554	0.434	0.346	15.67
382171.4	0.165	5.47	0.238	0.412	0.068	21.31
Kisoro	0.119	3.90	0.302	3.48	0.136	17.01
Kabale	0.114	4.85	0.242	0.01	0.260	18.48
Victoria	0.113	6.67	0.141	1.77	0.170	17.89
38140.31	0.123	2.69	0.163	0.699	0.130	15.01
Sangema	0.457	6.14	0.487	2.06	0.406	9.28
Threshold*	0.152	-	0.219	-	0.220	-
LSD (0.05)	0.072	3.90	0.120	3.00	0.120	3.00
C.V. (%)	32.6	23.9	19.0	66.7	32.6	23.9

* Cut-off values for PVX infected and healthy samples.

Table 18: Correlation^d coefficients between potato yield (MT ha⁻¹) potato virus X (PVX) and, potato leaf roll virus (PLRV) infections (relative virus antigen titre) in field grown *Solanum* potatoes at Namulonge during the 1994 short rains (SR) and at Namulonge and Kalengyere in the 1995 long rains(LR).

VARIETY	Yield against PVX	Yield against PLRV	PVX against PLRV
Rutuku	-1.00 ^{***}	-0.98 [*]	0.94 [*]
382171.4	-0.98 [*]	0.22	-0.02
Kisoro	-0.45	0.19	0.79
Kabale	-0.37 [*]	0.10	0.96
Victoria	0.67	-0.11	0.65
381403.1	-0.49	-0.07	0.91
Sangema	-0.63 [*]	0.39	-0.47
Pooled data ^b	-0.07	0.17	0.23

* and *** Significant at $P = 0.05$ and $P \leq 0.01$, respectively.

^a Data pooled for each variety across locations and seasons.

^b Data for all varieties across seasons and locations.

4.4 DISCUSSION

The results obtained from this study showed that the original seed tubers obtained from Kalengyere were free from aphid-borne viruses. The use of dimethoate at Namulonge did not deter the spread of PLRV and did not influence the field performance of the current season crop.

The indexing of seed potatoes, obtained from Kalengyere before planting for latent virus infection indicated the probable absence or rare occurrence of PLRV at Kalengyere. This virus was last detected at this site in 1990 in only four samples (Anon., 1993a).

The absence of PVY is not surprising because it has not been detected at Kalengyere since 1988 while PVS was last detected in 1989 (Anon., 1993a). The seed tubers from three of the seven varieties obtained from Kalengyere in both the 1994SR and 1995LR tested positive for PVX infection. This virus has been commonly detected at Kalengyere (Anon., 1993a). The seed potatoes obtained from Kalengyere were therefore free from aphid-borne viruses. The insect-transmitted viral infections that were detected in field grown potatoes at Namulonge could not therefore have been seed-borne. They must have been introduced by virus arthropod vectors.

At Namulonge, dimethoate did not prevent the infection of potato with PLRV despite the low aphid pressure. Both the sprayed and unsprayed crops were infected with PLRV. This

implies that there is a high virus infection pressure in the area. In addition to this, the failure of dimethoate to suppress *M. persicae* the principle vector of PLRV, could have further contributed to the of this virus in Namulonge.

At Kalengyere, no aphid-borne viruses were detected in both sprayed and unsprayed field grown potatoes in spite of the high aphid pressure. In addition, dimethoate effectively controlled aphid colonisation and infestation, thus increasing the deterrent effects to virus spread by killing the virus vectors. Although there was heavy aphid infestation in unsprayed potato at Kalengyere as seen in the previous Chapter, it did not result in infection of field grown potatoes with aphid-borne viruses. This implies that there is a low virus infection pressure at Kalengyere. The low virus pressure at Kalengyere and, the effectiveness of dimethoate at controlling aphid infestation in potato could have prevented the spread of potato leaf roll virus.

Virus screening of field grown potatoes at Namulonge indicated that all the varieties used were susceptible to PLRV. However, Rutuku and Kabale seemed to be the most susceptible. This could be due to their initial infection with PVX because potato cultivars that are infected with PVX are more susceptible to PLRV than those that are PVX-free (Jayasinghe *et al.*, 1989).

Dimethoate spray did not have any significant effect on potato fresh tuber yield at both Kalengyere and Namulonge.

Differences in yield between varieties were mainly due to genetic and location/site effects. The different potato varieties had higher yields at Kalengyere than at Namulonge. However, at Namulonge, early-medium (80 - 100 days) maturing varieties, such as Sangema and Victoria, performed better than late (>100 days) maturing ones, such as Rutuku, 38171.4 and Kabale. The reverse was observed at Kalengyere where late maturing varieties had better yields. This was expected since *Solanum* potato is more adapted to temperate conditions and yields are usually higher in cool (high altitudes) than in warm climates (Sikka, 1982; Sikka *et al.*, 1992). At high altitudes, the cool environment provide a longer growing period compared to warm lowland tropics where the hot dry season sets in before the late maturing varieties have exhausted their bulking potentials (Beukema and van der Zaag, 1990). The high and stable temperatures in the lowlands all the year round in addition reduces the partitioning the assimilates to the tubers thus leading to low yields (Manrique, 1993).

The field performance of some *Solanum* potato varieties also seemed also to have been affected by infection with potato viruses, especially PVX. The yields of a number of varieties at Namulonge may have been further depressed by double infection with PVX and PLRV. This is because yield depression is greater in multiple than single virus infections (Reestman, 1972; Jayasinghe *et al.*, 1989; Beukema and van der

Zaag, 1990; Mih *et al.*, 1993). The unexpectedly low yields of Sangema, Rutuku and Kabale at Kalengyere could have been probably due to infection with PVX. Correlation analysis showed strong negative relationship between yield and PVX infection in those varieties that were PVX-positive. Greater yield depression was observed in Rutuku which was infected with both PVX and PLRV.

The danger of continuous use of seed potato without replenishment is highlighted by PVX infection at Namulonge. In the 1994SR, only four variety were infected with PVX. When seed potato generated from this crop was used in 1995LR all the varieties except Victoria were infected with this virus. The antigen titre in samples tested in the 1995LR had also increased in comparison with the materials that were infected in the 1994SR. Thus, virus infection pressure is likely to increase if seed potatoes are used without being replenished (Omer and El-Hassan, 1992).

The study has shown that, a high aphid pressure may not necessarily result in virus spread, especially in an area of low virus infection pressure. According to Powell and Mondor (1973), a large number of aphids in a potato field without a source of virus infection causes little or no danger of virus spread compared with few aphids on or from virus infected plants. This may have been the case for Kalengyere. The absence of PLRV infection or any aphid-borne viruses, despite the high aphid abundance in the area in contrast with

Namulonge, may account for the absence of aphid-borne virus infections in field grown potatoes at Kalengyere. There is need therefore for stringent measures to enforce the flush out system that will always ensure seed flow from high to low elevations but not the other way round. This will prevent the build up of virus infection pressure in areas with high aphid pressure and ensure the supply of virus-free seed potato from the highlands to potato farmers else-where. Production of seed potato from lowland areas should be discouraged or reduced to only one season of seed production generation.

CHAPTER 5

ASSESSMENT OF ONSET OF MATURE PLANT RESISTANCE TO APHID-BORNE VIRUSES IN *SOLANUM* POTATO

5.1 INTRODUCTION

The control of aphids using insecticide on calendar-based spray schedules has a tendency of encouraging aphid resistance to insecticides (DiFonzo et al., 1994; Sekamate, 1994). Continuous use of insecticides, especially foliar sprays, also harm beneficial arthropods such as predators, parasitoids, and pollinators (Broadbent, 1957; Powell and Mondor, 1973; Oonyu, 1992). To reduce these risks, therefore, foliar spray applications on *Solanum* potato should be carried out when the plants are most susceptible to virus infection, especially when they are still young. Thereafter insecticide spray frequency could be reduced or sprays stopped altogether (Knutson and Bishop, 1964; Beukema and van der Zaag, 1990).

Most *Solanum* potato cultivars, including those highly susceptible to potato viruses, exhibit mature plant resistance as they grow older (Kolbe, 1970; DiFonzo et al., 1994), i.e., feeding on maturing potato plants by viruliferous aphids may not necessarily result in virus infection. Knutson and Bishop (1964) reported that infection of *Solanum* potato with potato leaf roll virus (PLRV) decreases as the potato plants approach flowering. Thus, insecticide sprays can be limited to the period

before flowering and the frequency of the sprays be scaled down or stopped thereafter. This strategy would reduce the cost of seed potato production and provide cheap virus-free seed potato to farmers. The experiment reported in this chapter was, therefore, conducted to establish the onset of mature plant resistance in some of the established *Solanum* potato cultivars in Uganda.

5.2 MATERIALS AND METHODS

The study was carried in a screen house at Namulonge Agricultural and Animal Production Research Institute (NAARI) in 1995 using potted potato plants. The seven *Solanum* potato varieties used in earlier studies (Chapter 3, Section 3.2.2) and indexed against potato leaf roll virus (PLRV), potato virus Y (PVY), potato virus S (PVS) and potato virus X (PVX) (Chapter 4, Section 4.2.1) were evaluated in this study. Twenty four tubers of each variety were individually planted in circular plastic pots (top diameter 30 cm) filled with steam sterilised soil. The seed tubers were planted on 27th April 1995, and within fifteen days all had germinated.

At twenty days after planting (DAP), or five days after emergence (DAE), four pots per variety were transferred to a separate section of the screen house. On each potted plant, ten viruliferous aphids raised on PLRV infected potato plants and previously starved for two hours were put to feed on the plants for one day in the screen

house. Thereafter, the plants were taken outside for more exposure to virus vector pressure. The other five groups of each variety were similarly infected with the virus at ten day intervals until 55 DAE. The plants' phenological stages at each infection date were recorded.

At 60 DAE, two leaflets from the top fully expanded leaves, one from the middle and another from the bottom were collected from each potted plant in numbered polythene bags. The samples were tested for the presence of two aphid-borne viruses, PLRV and PVY, using direct Double antibody Sandwich Immunosorbent Assay (DAS-ELISA). No tests were done for PVX because it is mechanically transmitted (Schepers, 1972). Potato virus S was also not tested for because it can be transmitted by both contact and arthropod vectors (van der Wolf, 1964; Hooker, 1981; Khalil Shalla, 1982).

The virus antigen-antibody reactions were read 45 minutes after the last incubation stage. The reactions were quantified using the Multiskan Plus (Version 2.03) ELISA plate reader at a wavelength of 405 nm. The negative-positive thresholds that were used to determine healthy and infected samples for each virus were set at the mean absorbance value of 10 healthy samples plus three standard deviations. Differences due to treatments were determined using analysis of variance (ANOVA). The means for factors that were significantly different were compared using the Least Significant Different (LSD) test at an appropriate alpha level.

5.3 RESULTS

Data on the exposure of seven potato varieties to viruliferous aphids at ten day intervals are presented in Tables 19 and 20 while the trend in infection of sample inoculated at different dates and their absorbance values are presented in Figure 6. All the plant materials under study were free from PVY but were infected with PLRV. There were highly significant ($P \leq 0.01$) differences in PLRV level among varieties and plant age at inoculation. However, there was no significant ($P = 0.05$) variety by plant age interaction observed on the level of PLRV infection (Table 19).

All potato plants exposed to viruliferous aphids before 35 DAE were infected with PLRV (Table 20 and Figure 6). This indicated that all the varieties were susceptible to PLRV. However, at 45 DAE, only 28.6% of the samples tested positive for PLRV infection (Table 20 and Figure 6). At this inoculation date, it was Rutuku and Victoria that got infected with PLRV. The level of infection in the two varieties was within the same range; the mean absorbance value of Rutuku being 0.227 and Victoria 0.224 while the negative-positive threshold value was 0.216 (Table 20). Potato plants exposed to aphids at 55 DAE were free from PLRV infection (Table 20 and Figure 6).

The absorbance values for each variety decreased with increasing plant age at the time of inoculation (Table 20 and Figure 6). This indicated that the PLRV probably

Table 19: Mean squares for potato leaf roll virus (PLRV) and potato virus Y (PVY) from analyses of variance tables of seven *Solanum* potato varieties exposed to virus infected aphids at ten-day intervals for six dates.

Source of variation	Virus infection		
	Df	PLRV	PVY
Plant age (A)	5	0.356 ^{**}	0.0002
Variety (B)	6	0.022 ^{**}	0.001
AB	30	0.006	0.001
Error	42	0.004	0.001
C.V. (%)		18.2	31.45

^{**} Significant at ($P \leq 0.01$).

multiplies in the plant host and plants infected with PLRV late in the season have a low virus concentration. Thus, if seed potato are used without being replenished, virus infection pressure is likely to build up with time and adversely affect yield in subsequent seasons.

The varieties had different absorbance values, probably indicating the different levels of susceptibility to PLRV in the potato cultivars. For example, the absorbance values for Rutuku, Victoria and 381403.1 were more often than not higher on the various inoculation dates than for other varieties (Table 20).

The reduction in the number of clones with virus infection in plants inoculated at 45 DAE and the total absence of infection in plants inoculated at 55 DAE (Table 20) indicated the setting in of mature plant resistance to PLRV infection. Thus, if potato plants are protected before this period in an area of low vector pressure, few seed tubers are likely to be infected with PLRV and the incidence of this virus in the next season's crop is therefore likely to be low.

The setting in of apparent resistance to PLRV infection seems to have occurred in most varieties at about the flowering stage (40-50 DAE) (Appendix 1). After this growth stage, potato plant leaves started to fall. Plants which were inoculated after complete flower drop (55 DAE) were free from PLRV, implying that even the varieties which were highly susceptible to potato leaf roll virus had acquired resistance to this virus.

Table 20: Potato leaf roll virus (PLRV) infection (Relative virus concentration) in seven potato varieties 60 days after plant emergence (DAE[†]) for plants inoculated at ten day intervals.

Variety	Plant age (DAE [†]) at inoculation					
	5	15	25	35	45	55
Rutuku	0.639	0.476	0.494	0.449	0.227	0.157
382171.4	0.477	0.378	0.385	0.301	0.145	0.138
Kisoro	0.477	0.429	0.299	0.228	0.159	0.099
Kabale	0.544	0.503	0.476	0.285	0.159	0.120
Victoria	0.517	0.484	0.450	0.346	0.224	0.137
381403.1	0.468	0.516	0.510	0.226	0.143	0.152
Sangema	0.458	0.500	0.561	0.230	0.191	0.127
Threshold ^a	0.220	0.220	0.220	0.216	0.216	0.216
Infection (%)	100.0	100.0	100.0	100.0	28.6	0.0

[†]Days after plant emergence

^aThe negative-positive threshold for virus inoculation at 5, 15 and 25 days was 0.220 and that at 35, 45, and 55 inoculation dates was 0.216.

LSD_{0.01} between varieties along the columns = 0.106

LSD_{0.01} between inoculation dates along rows = 0.104

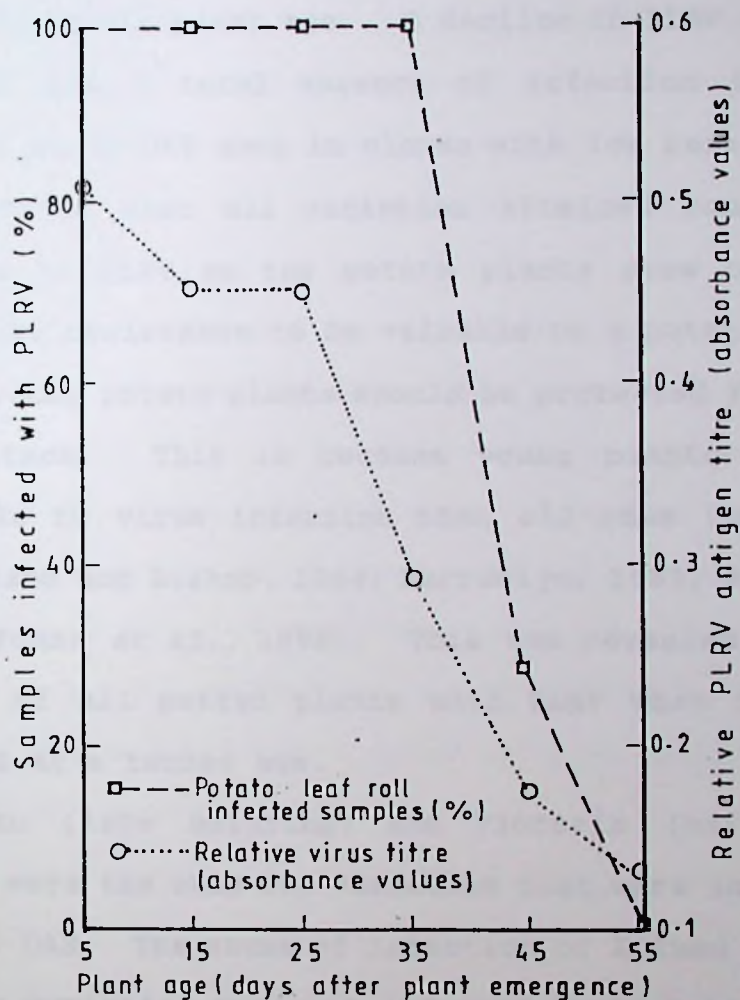


Fig. 6: Effect of plant age (days after plant emergence) on infection of *Solanum* potato with potato leaf roll virus (PLRV) in potato plants inoculated at 10-day intervals.

5.4 DISCUSSION

The results generated from this study revealed that susceptibility of *Solanum* potato to PLRV decreases with increase in potato plant age. A decline in PLRV infection at 45 DAE and a total absence of infection in plants inoculated at 55 DAE even in clones with low resistance to PLRV indicated that all varieties attained considerable resistance to PLRV as the potato plants grew old. For mature plant resistance to be valuable to a potato grower, however, young potato plants should be protected from early vector attack. This is because young plants are more susceptible to virus infection than old ones (Broadbent, 1957; Knutson and Bishop, 1964; Harrewijn, 1989; Sylvester, 1989; DiFonzo et al., 1994). This was revealed by total infection of all potted plants with PLRV when they were inoculated at a tender age.

Rutuku (late maturing) and Victoria (early-medium maturing) were the only two varieties that were infected by PLRV at 45 DAE. The cause of infection of Rutuku at 45 DAE when other varieties were not infected could have been due to this variety being still vegetative when other clones had stopped growing. Rutuku could have been therefore, easier to probe and allowed free movement and multiplication of PLRV (Auclair, 1989; DiFonzo, 1994). In the case of Victoria, infection with PLRV at an advanced age (45 DAE) could be due to this variety having very low resistance to PLRV. The setting-in of mature plant resistance seemed to occur at a stage of potato plant flowering.

CHAPTER 6

GENERAL DISCUSSION AND CONCLUSION

This study has documented the presence of *Myzus persicae*, (Sulz.), *Macrosiphum euphorbiae* (Kalt.), *Aphis nusturtii* (Kalt.), *Aphis gossypii* (Glov.) and *Aulacorthum solani* (Kalt.) on *Solanum* potato in Uganda. However, the occurrence of the aphid species and their attack on potato varied between the lowland (Namulonge) and highland (Kalengyere) eco-climatic zones.

Aphid flight activity monitored using yellow water traps indicated that the most abundant aphid species in the lowlands was *A. gossypii*. In the highlands, the predominant aphid species was *M. euphorbiae*. However, the predominant aphid species caught from traps were not necessarily the most abundant aphid species infesting the potatoes, and aphid flight activity did not reflect aphid crop activity. In both locations, the most abundant aphid species infesting *Solanum* potato was *M. persicae*.

The application of dimethoate to *Solanum* potato to control aphid infestation was more effective at Kalengyere than at Namulonge. The low effectiveness of dimethoate at Namulonge seemed to be due to its poor control of *M. persicae*. This was manifested by the heavy infestation and simultaneous predominance of *M. persicae* in sprayed plots at Namulonge. At

Kalengyere, all potato infesting aphids were equally controlled by the insecticide.

The study also showed that there was a lower aphid pressure in the lowlands compared to the highlands as opposed to the commonly held view that highlands have a lower aphid pressure than lowlands (Horton, 1987; Beukema and van der Zaag, 1990). The study further showed that varietal differences influenced aphid infestation as reported elsewhere (Nderitu and Mueke, 1986; DiFonzo *et al.*, 1994). Early maturing varieties were heavily infested, and infestation occurred earlier in the season while, late maturing varieties were also heavily infested later in the season. It is therefore suggested that late maturing varieties should be given more insecticide sprays than early maturing ones if planted at the same time. This would prevent dispersal of aphids and probably virus spread from a diminishing food resource in early-medium maturing varieties to the more succulent late maturing ones.

At both Kalengyere and Namulonge, potato virus Y (PVY) and potato virus S (PVS) were not detected in both seed and field grown potatoes. This probably means the absence or very rare occurrence of these viruses. Indexing of seed and field grown potato for potato virus X (PVX) at Kalengyere showed that the virus was initially confined to three varieties namely, Rutuku, Kabale and Sangema. However, it spread to all varieties except Victoria when seed potato was generated from

Namulonge. Thus virus spread in the lowlands is very rapid compared to the highlands, and this is probably the cause of rapid degeneration of potato in low elevation agro-ecological zones.

The study also revealed a probable absence of *Solanum* potato aphid-borne viruses at Kalengyere despite the high aphid pressure. However, seed tuber indexing indicated the presence of PVX which is a contact virus. This suggests that unless strict phytosanitary measures are taken, Kalengyere can be a source of PVX or any other potato virus as long as this site is used as a source of seed potato.

In the lowlands, all the potato varieties were infected with potato leaf roll virus (PLRV), irrespective of the insecticide spray treatment and low aphid pressure, confirming the commonly held view that there is a higher virus infection pressure in lowlands than highlands (Raman, 1985; Jayasinghe, 1988; Harrewijn, 1989). There is need, therefore, to regularly replenish seed stocks in the lowlands in order to prevent the build-up of viral infection pressure on planting materials produced from this agro-ecological zone.

All potato varieties at Kalengyere, whether sprayed or not, were free from PLRV despite the high aphid infestation in unsprayed potatoes. In contrast, all potato varieties at Namulonge were infected with PLRV they were treated with the insecticide or not. This scenario implies that (i) there is very low incidence or a total absence of PLRV at Kalengyere,

(ii) a high aphid pressure does not necessarily lead to a high virus infection pressure, and (iii) a low aphid pressure in an area does not mean reduced threat of aphid-borne viruses (Powell and Mondor, 1973). It is therefore suggested that selection of seed potato growing areas should depend on the virus ("vector") pressure rather than aphid numbers. The absence of aphid-borne viruses and the effectiveness of dimethoate at Kalengyere against aphid infestation makes this location suitable for production of seed potato.

The absence of aphid-borne viruses in both seed and field grown potatoes from Kalengyere means that highlands should be protected against introduction of *Solanum* potato viruses from the lowlands by encouraging a potato flush-out system where potato (both ware and seed) only flow from high to low elevations although lowlands may produce ware potatoes.

From the study at Namulonge, it was evident that all the potato varieties used were susceptible to PLRV, although some varieties such as Sangema seemed to be less susceptible. However, as the potato plants grew older, their susceptibility to PLRV decreased particularly when infection occurred after the flowering stage. In an area of low vector pressure, therefore, early season spray application can supplement mature plant resistance and this would reduce potato infection with aphid-borne viruses. This observation means that insecticide use can be limited to critical potato plant growth periods after which aphid infestation control could be left to

natural processes. With this strategy, the cost of producing virus-free seed potato and, consequently the cost of ware potatoes can thus be reduced. This will make potato a cheaper food commodity in Uganda than it is today.

In conclusion, it is recommended that seed potato production systems utilising highland areas be developed for Uganda taking into consideration some of the findings reported in this study. Further studies should also be carried out to, (i) assess yield loss associated with heavy aphid infestation in potato crops, especially in out-of-season grown potatoes which is commonly grown by potato farmers in the highlands; (ii) establish the occurrence and infection pressure gradient of major potato viruses from the highlands (> 1700 m a.s.l.) to mid-elevations (1200-1600 m a.s.l.). This will be useful in determining how regularly seed stocks in a given locality should be replenished with fresh seed from the highlands; and (iii) investigate the cause of low effectiveness of dimethoate against *M. persicae* at Namulonge.

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APPENDIX

Appendix 1: Plant phenology of seven *Solanum* potato varieties at different growth ages^a in a screen house.

Variety	Plant age	Growth stage	Number of compound leaves	Plant Height (Cm)
Rutuku	5	V	6.9±0.5	21.4±1.4
	15	V	10.0±0.6	34.7±0.5
	25	V	15.0±0.7	58.3±2.8
	35	B	16.2±0.9	70.2±2.3
	45	F+T	16.8±10.	73.8±2.5
	55	F	14.0±1.4	72.9±3.0
382171.4	5	V	7.8±0.3	23.9±1.5
	15	V	9.2±0.4	48.3±2.6
	25	B+T	15.0±0.7	73.3±2.4
	35	F	17.6±0.6	88.3±3.6
	45	F.D	16.4±0.9	88.3±3.1
	55	L.D	9.7±0.7	88.2±3.1
Kisoro	5	V	9.8±0.7	30.1±1.8
	15	V	12.0±0.3	41.8±1.2
	25	B+T	15.6±0.3	56.0±2.8
	35	F	16.2±0.6	64.1±4.3
	45	F.D	17.4±0.7	65.1±4.1
	55	L.F	8.7±0.5	67.0±4.1
Kabale	5	V	9.3±0.4	25.1±1.6
	15	V	10.4±0.6	42.2±2.5
	25	V	15.1±0.4	57.0±2.8
	35	B+T	16.2±0.6	64.1±4.3
	45	F	13.4±0.9	65.9±2.2
	55	F	13.0±1.2	69.7±2.3

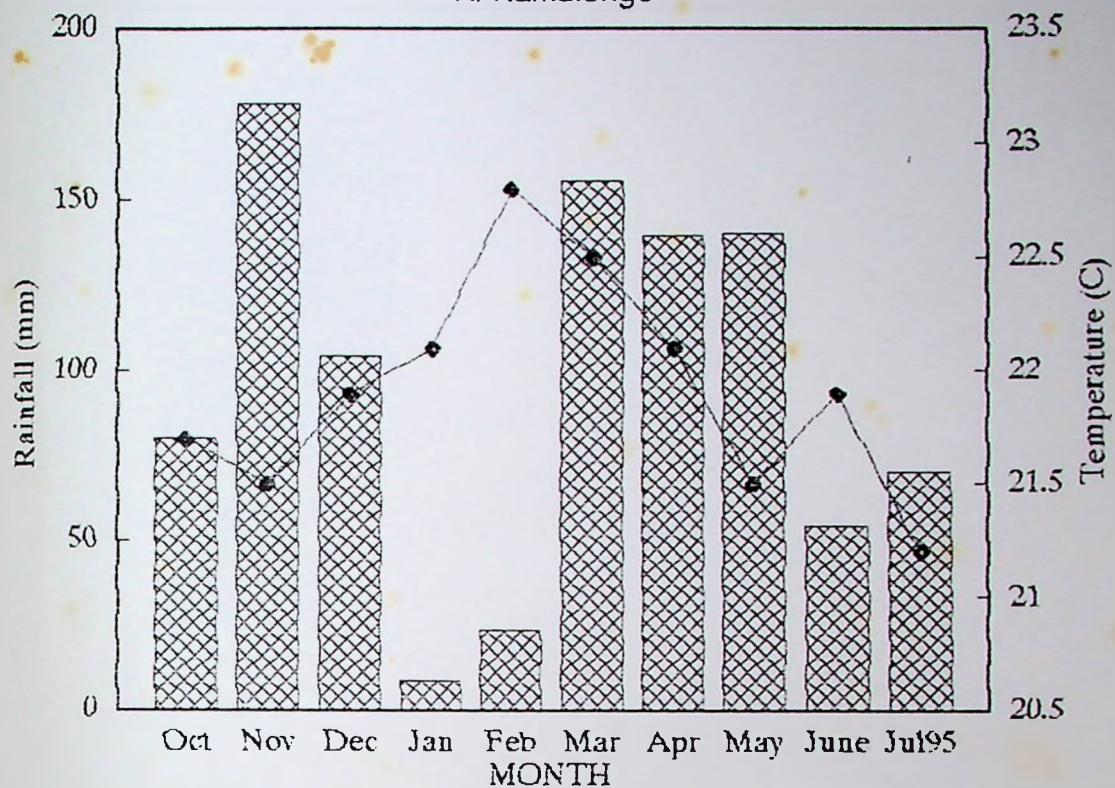
Appendix 1 cont'd

Victoria	5	V	10.2±0.4	23.9±1.6
	15	V	10.8±0.4	42.8±1.4
	25	B+T	16.0±0.5.	61.6±1.8
	35	F	17.0±0.5	73.2±2.9
	45	F.D	15.3±0.8	73.1±3.0
	55	L.D	11.6±1.0	73.0±2.2
381403.1	5	V	8.8±120.1	16.8±1.1
	15	V	9.4±0.3	37.9±1.1
	25	B+T	14.7±0.4	63.8±2.2
	35	F	15.2±0.5	79.9±3.0
	45	F	17.1±1.0	80.0±3.1
	55	F.D	12.8±0.6	79.9±2.7
Sangema	5	V	9.3±0.3	27.3±2.5
	15	V	9.6±0.5	47.8±2.6
	25	B+T	12.9±0.4	60.0±1.7
	35	F	13.6±0.5	69.6±2.0
	45	F.D	15.7±0.9	75.8±1.9
	55	L.D	11.2±0.6	76.0±1.1

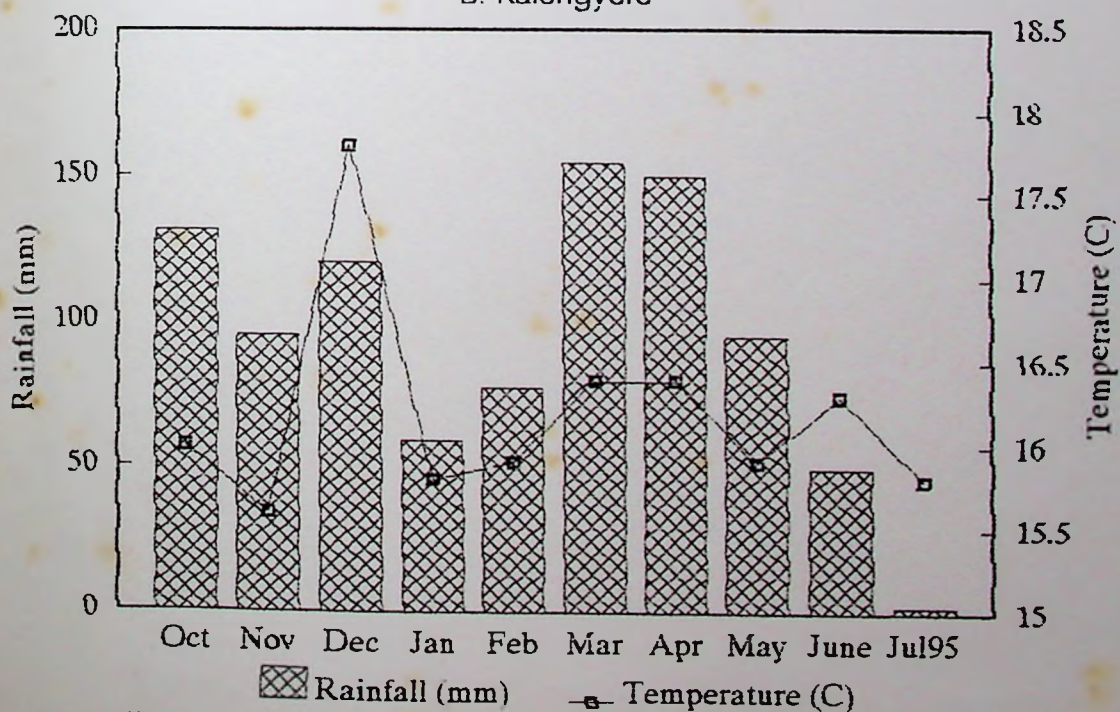
KEY

V = Vegetative
 B = Budding
 T = Tuberisation
 F = Flowering
 F.D = Flower drop
 L.F = Leaf drop

A. Namulonge



B. Kalengyere



Appendix 2 Weather data for Namulonge and Kalengyere Research Stations during the 1994 short rains and 1995 long rains.