INTEGRATED MANAGEMENT OF GROUNDNUT ROSETTE DISEASE

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DECLARATION

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

Signed..... Date.10/08/09.....

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This thesis has been submitted for examination with our approval as university supervisors from the Department of Plant Science and Crop Protection.

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DEDICATION

To my parents, Samuel Karanja and Irene Wairimu for their moral support and care all my life.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
CP	Coat Protein
DMP	Disease management practice
GRAV	Groundnut Rosette Assistor Virus
GRD	Groundnut rosette disease
GRV	Groundnut Rosette Virus
Ep	Early planting
FAO	Food and Agriculture Organization
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICTV dB	International Committee on Taxonomy of Viruses database
KARI	Kenya Agricultural Research Institute
Lp	Late planting
MOA	Ministry of Agriculture
sat RNA	Satellite Ribonucleic acid
SSA	Sub-Saharan Africa
SAT	Semi-arid tropics

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ABSTRACT

Groundnut is an important food, feed and cash crop in sub-Saharan Africa. This crop suffers greatly from a viral disease; groundnut rosette (GRD) vectored by an aphid cause 100% yield loss if it occurs before flowering. Management strategies for the disease include reduction of vector populations using pesticides, cropping practices to delay onset and spread of both vector and the disease and growing groundnut varieties resistant to the virus and the vector. The objective of this study was to assess the effectiveness of selected cultural practices, chemical pesticide and host plant resistance in the management of groundnut rosette disease. Field experiments were conducted between March 2007 and February 2008 at Siaya Agricultural Training Centre (Siaya district) and Kenya Agricultural Research Institute, Alupe sub station (Teso district) in Western Kenya.

The cultural disease management strategies included alteration of time of planting (early planting at the onset of rains and late planting one month later), host plant resistance, use of trap crops (cowpea and sesame), vector control using a chemical insecticide (dimethoate) and roguing. The experimental design used was randomized complete block laid out as a split-plot and replicated three times. The disease management practices and groundnut varieties were allocated to main plots and sub-plots respectively.

The time of planting significantly influenced aphid population and groundnut rosette disease incidence. High aphid population and GRD incidence was observed in late-planted than in early-planted groundnut. Late planting reduced groundnut yield by 48-71%. Application of dimethoate lowered vector population and reduced GRD

incidence by 85-94%. Cowpea and sesame trap crops reduced the disease incidence by 56-76% while roguing reduced the disease incidence by 30-44%. Groundnut yield increased by 167-255% where insecticide and trap crops were applied. Planting of varieties resistant to the virus (ICGV-SM 90704) and the vector (ICGV 12991) reduced the disease incidence by 46-61%. *Aphis craccivora* Koch was the most abundant of the aphid species. This study recommends early planting in addition to combination of host plant resistance with other protective measures such as cultural practices for effective management of groundnut rosette disease. There is however, a need to undertake further studies in order to establish economic injury levels and action thresholds to guide in integrated management of groundnut rosette disease and its vectors.

CHAPTER ONE

1.0 INTRODUCTION

1.1 The groundnut crop

1.1.1 Origin and distribution of the groundnut crop

Groundnut (*Arachis hypogaea*) also known as earthnut, monkeynut and peanut is the 13th most important food crop and 4th most important oilseed crop of the world (FAO 2006). It originated in the central part of Brazil or Northeastern Paraguay (Simpson *et al.*, 2001). It was distributed to Indonesia, Western Pacific and China in the 16th century by Spanish explorers (Smith, 2002). Six centers of genetic diversity have been recognized in Southern America and Africa is considered as a secondary centre of genetic variation (Wynne *et al.*, 1991). Groundnut was probably reintroduced to South America from Africa (Simpson *et al.*, 2001).

It is cultivated in the semi arid, tropical and subtropical regions in more than one hundred countries in six continents between 40°N and 40°S (Nwokolo, 1996; Smith, 2002). Globally, twenty three million hectares are under groundnut cultivation with a total annual production of forty metric tons (FAO, 2006). Major groundnut producing countries are China (40%), India (16%), Nigeria (8%), United States of America (6%) and Indonesia (4%). Other important countries for production are Sudan, Senegal, Indonesia, Myanmar, Ghana, Chad, Vietnam, Democratic Republic of Congo, Burkina Faso, Argentina, Cameroon, Mali, Guinea, Egypt, Brazil and Zimbabwe in decreasing order (FAOSTAT, 2003-2006).

In Kenya, groundnuts are grown by small-scale farmers and its cultivation is small compared with that of other crops. Groundnut production is mainly concentrated in warm, humid areas, particularly along the coastal and lake regions – Western and

Nyanza provinces (MOA, 2004a; MOA, 2004b). It is also an important cash crop in the Rift Valley particularly in West Pokot, Trans Nzoia, Uasin Gishu and Keiyo districts. There are scattered pockets of production in Eastern Provinces (Kamidi *et al.*, 2005). Groundnut varieties commonly grown in Western Kenya include Homa Bay, Uganda red and Red Valencia. The major producing areas are at an altitude of 1000 to 1500 m above sea level with a mean temperature of 21-24°C. The crop is also grown at an altitude of less than 400 m at the coast province with temperatures of 24-27°C (MOA, 2004b).

1.1.2 Nutritional quality

Groundnut seeds (kernels) contain 10-20% carbohydrate, 40-50% oil, 20-50% digestible protein, vitamins (vitamin E, niacin, riboflavin, thiamine and falacin) and minerals (calcium, phosphorus, magnesium, zinc, iron and potassium) (Oumarou *et al.*, 2005). The oil contains higher levels of mono- and polyunsaturated fatty acids than soybean and corn oil but relatively lower compared to sunflower oil. Peanut oil is low in cholesterol and contains mixed glycerides and a high proportion of unsaturated fatty acids especially oleic acid (50-65%), linoleic acid (18-30%) and 1% palmitic acid (Jonnala *et al.*, 2005). When it is included in a diet groundnut oil lowers triglyceride levels (Maguire *et al.*, 2004).

Raw groundnuts have most of the antinutritional factors found in soybean but at very low levels. They contain antinutritional compounds such as trypsin inhibitors and lectins. The testa of peanut contain goiterogenic factor and saponin-like compounds which are bitter tasting have been identified in the germ. Peanut also have atherogenic property which is regarded as an antinutritional effect (Ejigui *et al.*, 2005; Fasoyiro *et al.*, 2006).

1.1.3 Utilization of groundnut

About two thirds of world groundnut production is crushed for oil. The cake is high in protein and is used as livestock feed. The oil is preferred in deep-frying industries since it has a high smoke point of 229.4°C compared to the 193.5°C of extra virgin olive oil (Dean, 2004; Maguire *et al.*, 2004). The oil is also used to make margarines and mayoinnase (Hui, 1996; Sanders *et al.*, 2003).

Young pods may be consumed as vegetables, while young leaves and tips are utilized as a cooked green vegetable. The kernel is used for human consumption as raw, boiled or roasted nuts or made into paste and eaten with sweet potatoes, cassava and bananas. Scorched seeds may serve as a coffee substitute (Bryan, 2006).

Groundnut is used to make non food products such as soaps, medicines, cosmetics, pharmaceuticals, emulsions for insect control, lubricants and fuel for diesel engines (Yaranal *et al.*, 2005). The haulms are high in protein and are used as hay and shells may be used for fuel, as soil conditioner, filler material in cattle feed, raw source of organic chemicals, as an extender of resin, as a cork substitute and in production of blocks or hardboards. The haulms are either fed to livestock or used in compost or left in the fields as crop residue (Hill, 2002).

Groundnut is also used as medicine for aphrodisiac purposes, inflammation, cholecystosis, nephritis and decoagulant. In China, the oil is taken with milk for gonorrhea, and used externally for rheumatism, while in Zimbabwe it is used in folk remedies for plantar warts (Bryan, 2006).

Groundnut plays a major role in improvement of diet and income among small-scale farmers in Kenya and is sold in the local markets as boiled, unshelled roasted nuts while some is sold in the confectionery trade (Hilderbrand and Subrahmanyan, 1994, Demese *et al.,* 1997). It is also pounded and used as a vegetable oil for cooking, or made into paste and eaten with sweet potatoes, cassava and bananas (Kamidi *et al.,* 2005). As a legume, it improves soil fertility in the farming systems by fixing atmospheric nitrogen and it is also a trap crop in the management of striga weed in cereal crop (MOA, 2004a).

1.1.4 Groundnut production constraints in Kenya

Groundnut is grown in smallholder farms under low input rain fed conditions and is mainly intercropped with cereals such as maize and sorghum. The crop is grown either once or twice in a year depending on rainfall patterns. It is planted during the long rains (March-April) as well as short rains (September-October). Due to lack of appropriate mechanization technologies, groundnut production in Kenya is labor intensive on farm and during harvesting and shelling. Fertilizer, pesticides and rhizobial inoculation are not generally applied to the crop for improved production (MOA, 2004a).

Production decline has been attributed to factors such as drought, pests, diseases, inappropriate cultural practices, unavailability of healthy and improved varieties, unstable government policies that hinder procurement of inputs and poor market infrastructure (Rop *et al.,* 1996). Abiotic stresses affecting groundnut productivity include drought, unsuitable pH and temperature. These are common in Africa, Asia and America and occur in various combinations. Although the crop is tolerant to

drought, inadequate moisture coupled with unreliable and poorly distributed rainfall is the most critical climatic factor limiting yield in the semi arid regions (Nigam *et al.*, 2001). In the tropics, low pH fixation and calcium deficiency can be important limiting factors in groundnut productivity especially in highly weathered soils. Low pH negatively impacts the nitrogen fixing bacteria that help groundnut to use biologically fixed nitrogen. Leaching in sandy soils and inadequate moisture availability during pod filling may limit calcium availability (Nigam *et al.*, 1997).

Biotic stresses include insect pests, fungi, bacteria, viruses and nematodes. These agents are known to cause considerable yield losses in groundnut (Kokalis-Burelle *et al.*, 1997). Globally, fungal diseases like leafspots caused by *Cercospora arachidicola* (Hori) and *Cercospora personatum* (Berk. and Curt) and rust caused by *Puccinia arachidis* are the most destructive pathogens of groundnut accounting for up to 70% yield losses (Kishore *et al.*, 2005).

Groundnut is also attacked by several virus diseases. These diseases are an important constraint to groundnut production (Horne, 2005). Soilborne pathogens also attack groundnut pods and roots during early stages of growth. The crown area of the plant stem is also subject to attack by insects and various microorganisms. Important soilborne diseases include crown rot caused by *Aspergillus* spp., collar rot caused by *Diplodia gossypina*, stem rot caused by *Sclerotium rolfisii*, pod rot caused by *Pythium myriotylum* and dry rot caused by *Neocosmospora vasinfecta* (Shokes *et al.*, 1997). Groundnut rosette disease is the most destructive viral disease of groundnut in Africa. The disease is endemic to sub-Saharan Africa and its off-shore islands (Naidu *et al.*, 1991, Subrahmanyam *et al.*, 1997). Rosette disease outbreaks are sporadic and

unpredictable but when the disease occurs in epidemic proportions, yield losses are high. Rosette epidemic of 1975 in Nigeria destroyed an estimated 0.7 million hectares of groundnut worth US $ 250 million (Yayock *et al.,* 1976). In Malawi the total area under groundnut production fell from 92, 000 ha in 1994/95 to 65, 000 ha in 1995/96 due to destruction of the crop as a result of rosette epidemic. In the same year losses estimated at US $ 5 million were incurred in Eastern Zambia as a result of a rosette epidemic (Anon, 1996; Subrahmanyam *et al.,* 1997).

In Africa yield loss due to rosette disease was estimated at about US $ 156 million per annum (ICRISAT 2005). Potential yield gain estimated at about US $ 121 million can be realized through proper management of the disease (Kimmins *et al.,* 1999). Rosetted plants produce significantly lower kernel yields (34–90%) depending on the severity of the disease and often very severely infected plants do not produce any pods at all (Kannaiyan, 1993).

1.2 Problem statement and justification

Groundnut production trend in Kenya over the past decade has been on the decline with farmers realizing less than 50% of the yield potential. Farmers obtain low yields with an average of 0.5 ton ha^{-1} compared to on-station yields of 3.5 ton ha^{-1}. Due to pressure on arable land, the extent of fallowing and crop rotation is limited. Consequently soil nutrients are rapidly depleted and most often are not replaced by application of inorganic fertilizers. The farmers do not have access to improved, high-yielding, disease-resistant seed hence they grow traditional landraces saved from their own seed that are adapted to local environments, have low yield potential and are susceptible to drought, pests and diseases. Foliar diseases such as leaf spots and groundnut rosette disease are generally considered a major constraint to increased groundnut production. These diseases cause 60-100% yield losses in groundnut

production. Groundnut farmers incur huge losses due to attack by groundnut rosette disease and thus compromising their economic advancement and even food security at the household level.

Increasing groundnut production has the potential to improve food and nutrition security of the rural households in groundnut growing areas. Being a popular commodity that is widely traded in local and regional markets, groundnuts can also be an important source of income for farmers. Good crop husbandry practices and tolerant varieties to rosette are cheap, affordable and can improve productivity of groundnut. Disease management strategies such as early planting, planting rosette resistant groundnut varieties, roguing, judicious use of insecticides, trap cropping provides the most appropriate means of containing groundnut rosette, being easily incorporated into farmers' operations at little extra cost.

1.3 Objectives

The overall objective was to develop integrated disease management practices that can control groundnut rosette disease.

The specific objectives were to evaluate:

1. Effect of planting time and varietal resistance on aphid population, groundnut rosette disease incidence and yield.
2. Effects of integrated disease management practices on aphid population, groundnut rosette disease incidence and yield

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Groundnut botany

Groundnut (*Arachis hypogaea* L.) belongs to the family *Leguminosae,* subfamily *Papilionidae,* tribe *Aeschnomeneae,* sub-tribe *Stylosanthinae,* genus *Arachis* and species *hypogaea.* The genus *Arachis* is derived from a-arachis; a Greek name meaning without spine with regard to its absence of erect branches. Although the genus *Arachis* has 70 species, only one species, *hypogaea* is of significant economic importance (Coffelt and Simpson 1997). The species name *hypogaea* originates from hupo-ge; a Greek name meaning below the earth and is associated with gynophore (flower stalk or peg) that grows downward into the earth so that the pod develops underground (Pattee and Stalker, 1995).

Subspecific and varietal classifications are based on location of flowers on the plant, patterns of reproductive nodes on branches, number of trichomes and pod morphology. There are two major subspecies of *Arachis hypogaea* that mainly differ in their branching pattern. These are subspecies *hypogaea* with alternate branching and subspecies *fastigiata* with sequential branching. Within the *hypogaea* subspecies are two botanical varieties; var. *hypogaea* (Virginia and runner types) and var. *hirsuta* (Peruvian humpback and Chinese dragon). Subspecies *fastigiata* is divided into botanical varieties *fastigiata* (Valentia type) and *Vulgaris* (Spanish type) (Simpson *et al.,* 2001). *Arachis hypogaea* ssp. h*ypogaea* have a low growth habit (runner types) with a growth period of four to five months or more. The seeds are generally used for direct consumption and confectionery purposes and exhibit marked dormancy. Examples of this subspecies include Virginia and the Peru types (Simpson *et al.,* 2001).

Arachis hypogaea ssp. *fastigiata*, for instance, Valencia and Spanish types have an erect growth habit (bunch type) with a growth period of three to four months. The seeds have no dormancy. They are generally grown for oil extraction (De Waele and Swanevelder, 2001).

The cultivated groundnut (*Arachis hypogaea* L.) is diploid with forty chromosomes. It was first described in 1753 by Linnaeus as an allotetraploid species native to South America. All other species of the genus *Arachis* are wild, perennial and they are mostly used for grazing (Simpson *et al.*, 2001).

2.2 Climatic and soil requirements of groundnut

Groundnut requires abundant sunshine and warmth for normal development. It is not sensitive to day-length although more flowers are produced under long day conditions (Stalker, 1997). Although the plant is day neutral, its growth is adversely affected by low light intensity. Bunchy types are generally vulnerable to climatic variation than runner types (Weiss, 2000). The rate of development and growth of groundnut is highly influenced by temperature. The optimum range for vegetative and reproductive growth is between 25°C and 30°C. It requires an average annual rainfall of 500 mm-1200 mm for commercial production (Kees and Orivaldo, 2006).

Groundnut is grown mostly on light-textured soils ranging from coarse and fine sands to sandy clay loams with moderately low amounts of organic matter (1-2%) and good drainage. The light soils help in easy penetration and development of pegs into the soil and their harvesting (Weiss, 2000). Occurrence of rainfall after pod maturity unfavorably affects the crop since some cultivars have short dormancy and germinate under suitable conditions. Groundnut responds unpredictably to fertilizer applications

(Kees and Orivaldo, 2006). However, it requires considerable amounts of nutrients for high yields. The productivity of groundnut is higher in soils with pH between 6.0 and 6.5 (Weiss, 2000).

2.3 Pests and diseases of groundnut

Pests and diseases are a major constraint to groundnut production since they cause quality and yield losses (Pretorius, 2005). Insect pests damage almost every part of the plant. They can be classified as foliage feeders, intracellular feeders, root and pod feeders and stored-product feeders. Foliage feeders include groundnut leaf miner (*Aproaerema modicella*), red necked peanut worm (*Stegasta bosqueella),* corn earworm (*Helicoverpa zea),* army worms (*Spodoptera* spp.*),* bollworm, earworm (*Helicoverpa zea*), velvet bean caterpillar (*Anticarsia gemmatalis*) and hairy caterpillars (*Amsacta* spp.) (Thomas *et al.,* 2004, Hagan *et al.,* 2005).

Intracellular feeders include leafhoppers (*Empoasca spp),* tobacco thrips (*Franklineilla fusca, Thrips palmi, Scirtothrips dorsalis),* groundnut aphid (*Aphis craccivora),* two-spotted spider mite *(Tetranychus urticae*) and white flies (*Bemicia tabaci*) (Weeks, 2006).

Root and pod feeders include lesser cornstalk borer (*Elasmopalpus lignosellus),* southern corn rootworm *(Diabortica undecimpunctata howardi*), white grub (*Lachnosterna* spp., *Adoretus* spp., *Anomala* spp., *Leucophilis* spp.), termites (*Odontotermes* spp., *Microtermes* spp.), wireworm (*Conoderus* spp.), and millipedes (*Peridontopyge* spp.). Stored-product feeders include Indianmeal moth (*Plodia interpunctella*), rice moth (*Corcyra cephalonica*), flour beetles (*Tribolium castaneum,*

T. confusum), groundnut bruchid (*Caryedon serratus*) and pod sucking bug (*Elasmolomus sordidus*).

Aphids, thrips, jassids and leafminers are the most important pre- and postharvest insect pests that cause significant economic losses in groundnut worldwide. Poor control of weeds early in the season can cause great yield reduction (CAB International, 2004, Hagan *et al.*, 2005).

A large number of fungal, viral, nematode, and bacterial diseases have been reported. Foliar diseases such as early leaf spot and late leaf spot can occur either individually or in combination, and cause considerable yield loss. Early leaf spot caused by *Cercospora arachidicola* (Hori) is the most destructive groundnut disease in Southern and Eastern Africa. Epidemics occur in many countries, causing yield losses of up to 50 percent in some regions. Late leaf spot caused by *Cercosporidium personatum* (Berk. and Curt) is also widely distributed mainly in low-altitude areas (Van Wyk and Cilliers, 2000).

Other fungal diseases of groundnut include anthracnose (*Colletotrichum mangenoti*, C. *arachidis, and C. dematium*), aspergillus crown rot (*Aspergillus niger, A. pulverulentus*), black hull (*Chalara elegans*), botrytis blight (*Botrytis cinerea*), Charcoal rot (*Macrophomina phaseolina*), cylindrocladium black rot (*Cylindrodium crotalariae*), diplodia collar rot (*Diplodia gossypina*), Fusarium wilt (*Fusarium* spp.), foot rot (*Neocosmospora vasinfecta*), peanut pod rot (*Pythium myriotylum, Rhizoctonia solani, Fusarium solani*), powdery mildew (*Oidium arachidis*), verticillium wilt (*Verticillium dahliae*), sclerotinia blight (*Sclerotinia minor*), stem rot (*Sclerotium rolfsii*), web blotch (*Phoma arachidicola*), yellow mold and aflatoxin (*Aspergillus flavus, A. parasiticus*) (Kokalis-Burelle *et al.*, 1997).

Diseases caused by bacteria include bacterial leaf spot (*Pseudomonas* spp) and bacterial wilt (*Ralstonia solanacearum*). Diseases caused by nematodes include root knot nematodes (*Meloidogyne* spp), root lesion nematodes (*Pratylenchus brachyurus*), sting nematodes (*Belonolaimus* spp), ring nematodes (*Criconemella ornate*) and peanut pod nematodes (*Ditylenchus africanus*) (Melouk *et al,* 1995; Hagan *et al.,* 2005).

Groundnut is also attacked by several virus diseases. They include stripe caused by peanut stripe virus, mottle caused by peanut mottle virus (PeMoV) genus Potyvirus, stunt caused by peanut stunt virus, tomato spotted wilt caused by tomato spotted wilt virus (TSWV) genus Tospovirus, groundnut streak necrosis caused by sunflower yellow blotch virus genus Umbravirus (SuYBV), cowpea mild mottle caused by Cowpea mild mottle virus genus Carlavirus (CPMMV), clump caused by Peanut clump virus (PCV) genus Furovirus, and groundnut rosette. Virus diseases which are common in Africa include clump, mottle, groundnut streak necrosis, cowpea mild mottle and groundnut rosette disease (CAB International, 2004, Olorunju and Ntare 2002).

2.4 Groundnut rosette disease (GRD)

Groundnut rosette disease was first reported in Tanzania by Zimmerman in 1907 (Gibbons, 1977). It has since been reported in other countries in sub-Saharan Africa (SSA). It causes greater yield loss to farmers in the semi-arid tropics than any other virus disease affecting groundnut (Naidu *et al.,* 1999).

Since groundnut rosette disease is limited to SSA and its offshore islands, it is likely that groundnut, after its introduction into the continent, was infected by a pathogen

endemic to SSA (Subrahmanyam *et al.,* 1998). It is therefore an example of the new-encounter phenomenon which occurs when a crop has been introduced into a new geographical region and pests and/or pathogens that evolved with other host species attack the newly introduced crop (Naidu and Kimmins, 1999).

The major areas of rosette disease occurrence include Burkina Faso, Ghana, Nigeria, Malawi, Mozambique, Mali, Niger Republic, Uganda, Kenya and Tanzania (Olorunju, 2001). Chlorotic rosette is widely distributed while mosaic rosette has been reported in East Africa (Storey and Ryland, 1957). Green rosette has been reported in West Africa, Uganda, Northern Malawi, Angola and Swaziland (Subrahmanyam and Mamba, 1993; Subrahmanyam and Chiyembekeza, 1995).

Rosette disease outbreaks are sporadic and unpredictable but when the disease occurs in epidemic proportions, yield losses are high. Rosette epidemic of 1975 in Nigeria destroyed an estimated 0.7 million hectares of groundnut incurring a loss of nearly US $ 250 million (Yayock *et al.,* 1976). In Malawi the total area under groundnut production fell from 92, 000 ha in 1994/95 to 65, 000 ha in 1995/96 due to destruction of the crop as a result of rosette epidemic. In the same year, losses estimated at US $ 5 million were incurred in Eastern Zambia as a result of a rosette epidemic (Anon, 1996; Subrahmanyam *et al.,* 1997).

In Africa yield loss due to rosette disease was estimated at about US $ 156 million per annum (ICRISAT 2005). Potential yield gain estimated at about US $ 121 million can be realized through proper management of the disease (Kimmins *et al.,* 1999). Rosetted plants produce significantly lower kernel yields (34–90%) depending on the

severity of the disease and often very severely infected plants do not produce any pods at all (Kannaiyan, 1993).

2.4.1 Biology of groundnut rosette disease

Okusanya and Watson (1966) were the first to report that groundnut rosette disease is caused by a complex of two agents: *Groundnut Rosette Assistor Virus,* genus *Luteovirus* (GRAV) and *Groundnut Rosette Virus* (GRV) genus *Umbravirus*. Murant *et al. (*1988) later reported that the disease is caused by the complex of two viruses and a satellite RNA (sat RNA). This was later confirmed by various studies by Murant and Kumar (1990), Blok *et al.* (1994), and Taliansky *et al* (2000).

Diagnostic plants for GRV include *Arachis hypogaea*, *Nicotiana clevelandii,* and *Chenopodium amaranticolor. Nicotiana clevelandii* exhibits nectrotic rings, systematic curling and malformation while *Chenopodium amaranticolor* shows chlorotic lesions (Kumar *et al.,* 1991). GRV has been transmitted to several other species of Leguminosae (*Glycine max, Indigofera nummularifolia, Macrotyloma uniflorus, Phaseolus vulgaris, Stylosanthes gracilis*, *S. guayensis, S. mucronata*, *S. juncea, S. sundaica*, *Tephrosia purpurea, Trifolium incarnatum*, *Trifolium repens* and *Vigna gracilis*). It is also transmitted to a few species in the Amaranthaceae (*Gomphrena globosa*), Chenopodiaceae (*Chenopodium amaranticolor, C. murale, C. quinoa*, *Spinacia oleracea*) and Solanaceae (*Nicotiana benthamiana, N. clevelandii, N. debneyi, N. occidentalis*, *N. rustica*, *N. tabacum*) (Okusanya and Watson, 1966; Kumar *et al.* 1991).

GRV is a member of the genus *Umbravirus*. Umbraviruses alone cannot be transmitted by aphids. They are transmissible when co-infected with suitable

luteoviruses that act as helper viruses (Taliansky *et al.*, 2003). The RNA of an umbravirus can be encapsidated by the coat protein of the assistor virus. The assembled virion is readily acquired by the vector aphid together with the plant sap and transmitted between plants (Syller J., 2000). GRV has a replicating single-stranded, positive sense RNA (ssRNA) genome of 4019 nucleotides and contain four open reading frames (ORF). It does not encode for a coat protein and therefore has no conventional particles (Taliansky *et al.*, 2000).

GRV structures occur in vacuoles of infected cells. Virions contain one molecule of linear positive-sense single stranded RNA and are enveloped in vesicles. Genome nucleic acid is infectious and replicates in cytoplasm. It is transmitted by a vector in a persistent (circulative, non-propagative) manner (Watson and Okusanya, 1967). It is also transmitted by mechanical inoculation, and grafting. GRV is neither transmitted by contact between plants nor by seed (Brunt *et al.*, 1996). It neither multiplies in the vector nor is it transmitted congenitally to the progeny of the vector. The virus is retained when the vector moults. For vector transmission, it requires a helper virus (ICTV dB, 2006).

Infective ssRNA of GRV has not been obtained free from host plant RNA. However, infected plants yield abundant double stranded RNA (dsRNA). Electrophoretic analysis revealed three major dsRNA species of molecular weight approximately 3 x 10^6 and 0.9 x 10^6, not present in healthy plants species (Reddy *et al.*, 1985; Murant *et al.*, 1988; Murant, 1998). The largest of them, dsRNA-1 (approx. 4.6 kbp), was presumed to be the double-stranded form of the single-stranded genomic RNA of GRV; dsRNA-2 (approx. 1.3 kbp), which has at least some sequences in common with dsRNA-1 (Deom *et al.*, 2000), may represent the dsRNA form of a subgenomic

RNA species. DsRNA-3 (approx. 0.9 kbp) has been shown to represent a satellite RNA, which is largely responsible for the symptoms of rosette disease (Murant *et al.*, 1988).

The ten sat RNA variants are 895 to 903 nt long and are at least 87% identical (Blok *et al.*, 1994). The sat RNA variants contain up to five potential open reading frames (ORFs) in either positive or negative sense. The ORFs of sat RNA are not required for disease or symptom development. The role of sat RNA in groundnut rosette disease is therefore RNA mediated. Variants of Sat RNA are primarily responsible for different symptoms of groundnut rosette disease (Murant and Kumar, 1990).

GRAV is a member of *Luteoviridae,* the family grouping viruses that are readily transmitted by aphids, but cannot be transmitted mechanically by rubbing healthy plants with extracts made from virus infected plants (Herrbach E., 1999). *Luteoviruses* assist aphid transmission of other viruses and viroid (Falk and Tian, 1999; Querci *et al.*, 1997). The virus has isometric particles about 28 nm with hexagonal outlines. It contains a single nucleic acid species presumed to be RNA of molecular weight approximately 2.09 x 10^6. It causes symptomless infection in several species of Leguminosae and a few other families. It is transmitted in a persistent circulative manner by aphids (*Aphis craccivora* Koch) (Okusanya and Watson, 1966). It is not transmitted by inoculation of sap or through seed (ICTV dB, 2006). GRAV acts as a helper virus for aphid transmission of GRV and sat RNA. Unlike sat RNA and GRV, GRAV is phloem limited (Casper *et al.*, 1983; Reddy *et al.*, 1985; Murant, 1990).
GRAV, GRV and sat RNA are dependent on each other, and all the three agents play a crucial role in the biology and perpetuation of the disease. GRV RNA and sat RNA are packaged in the coat protein of GRAV to form virus particles that can be

transmitted by aphids. The sat RNA depends on GRV for replication and GRV depends on sat RNA for aphid transmission, that is, for GRAV-dependent transmission of GRV, sat RNA must be present in the source plants (Taliansky *et al.*, 2000; Taliansky *et al.*, 2003). Sat RNA is necessary for encapsidation of GRV RNA into the coat protein of GRAV (Murant, 1990; Robinson *et al.*, 1999). GRAV and GRV contribute little to disease symptoms in groundnut apart from yield loss (Taliansky *et al.*, 2000).

2.4.2 Disease symptoms

Disease symptoms are exhibited in three distinct forms; chlorotic, green and mosaic rosette. Chlorotic and green rosette symptoms were first observed by Hayes (1932). Different strains of the virus, its assistor luteovirus and satellite RNAs cause different forms of the disease (Murant and Kumar, 1990). Chlorotic rosette is exhibited by bright chlorosis of the leaves usually with a few green islands, faint mottling of youngest leaflets, yellowing, curling and malformation of leaflets, vein banding and blotching. The chlorosis may affect the whole plant, or only some shoots or parts of shoots. Plants that are infected early are stunted, with small, curled and puckered leaflets (Murant and Kumar, 1990).

Green rosette is characterized by mild mottling and flecking, but mostly dark green, severe stunting, while mosaic rosette involve green blotching and severe chlorosis but less severe rosetting than with chlorotic rosette. The leaves are very dark green, or show a light green and dark green mosaic, and are much reduced in size. Infected leaves have their margins rolled downwards. Some leaves show a light green and a dark green mosaic (Murant and Kumar, 1990).

Chlorotic and green rosettes are the two predominant symptom forms of GRD in SSA (Naidu *et al.* 1998). Chlorotic rosette is apparently ever-present in SSA whereas green rosette has been reported only from West African countries and from Uganda, Northern Malawi, Swaziland and Angola and confirmed in East Africa (Subrahmanyam and Mamba, 1993; Subrahmanyam and Chiyembekeza, 1995; Wangai, 2001; Naidu and Kimmins, 2007).

Mosaic symptom of the disease was reported only in East Africa by Subrahmanyam in 1992. Mosaic form of the rosette is caused by a GRV containing a mixture of chlorotic satellite variant and a mottle variant. The striking bright yellow symptom is caused by a yellow blotch satellite variant (Murant and Kumar, 1990). Variability in disease symptom could also be attributed to variety response, variable climatic conditions, and mixed infections with other viruses (Naidu *et al.*, 1999).

The infection of young plants with rosette disease affects the entire plant and causes severe stunting due to shortened internodes and reduced leaf size leading to a bushy appearance. Plants infected late in their growth stage may show symptoms only in some branches or parts of branches. Regardless of the type of rosette, early infection causes severe or total yield loss (Naidu *et al.*, 1999).

2.4.3 Effects of rosette disease on groundnut yields

Losses in yields due to groundnut rosette disease depend on the growth stage of the plant when infection occurs. A 100% loss in pod yield due to different forms of the disease may result if infection occurs before flowering. Yield loss is variable if infection occurs between flowering and pod maturing stage. Later infections cause insignificant effects. Unlike other members of the family *Luteoviridae,* which often

cause yellowing, reddening and/or stunting of the host plant, GRAV or GRV infection alone is asymptomatic in groundnut (Ansa *et al.,* 1990; Olorunju *et al.,* 1991). However, GRAV contributes to yield losses by reducing total dry mass of the plant and seed weight (Naidu *et al.,* 2007).

2.4.4 Diagnosis of rosette disease

Groundnut rosette disease can be diagnosed in the field based on the characteristic symptoms or by mechanical inoculation onto a suitable indicator host such as *Chenopodium amaranticolor.* Necrotic lesions are produced on leaves four days after inoculation (Kumar, 1991). Symptom development on indicator plants indicates the presence of GRV, but this test is not always reliable when the indicator plants are subjected to temperature fluctuations in the field. Improved diagnostic methods include a triple antibody sandwich enzyme-linked immunosorbent assay (TAS-ELISA) for detection of GRAV (Casper *et al.,* 1983; Rajeshwari and Murant, 1988; Scott ***et al.,*** 1996). GRV and sat RNA cannot be detected by TAS-ELISA since they do not have a coat protein. A dot blot hybridization (DBH) is used for detection of GRV and sat RNA (Blok *et al.,* 1995) and reverse transcription polymerase chain reaction (RT-PCR) that allows detection of each of the three agents in diseased plants and viruliferous aphids (Naidu *et al.,* 1998). Symptoms and aphid transmission procedures can also be used in diagnosis of GRD. However, these procedures are labor intensive and time consuming. Advantages of improved diagnostic methods are sensitivity, speed and ability to assay many samples concurrently (Naidu *et al.,* 1998).

2.5 The aphid vector

Aphis craccivora Koch (Homoptera: Aphididae) is the only aphid vector that can transmit groundnut rosette disease agents efficiently (Hull, 1964; Haciwa, 1990).

Aphis gossypii (Glover) has also been reported to transmit the disease but inefficiently (Adams, 1967). *Aphis craccivora* (Koch) has a wide distribution in many countries around the world. Females reproduce parthenogenetically throughout the year. The adults have a black shiny body with a prominent tail-end and are either winged (alatae) or wingless (apterae) (Blackman and Eastop, 2000).

Tactile stimulation, host plant quality, and climatic conditions influence development of these morphs. Alatae produce only about half the progeny produced by apterae. The nymphs undergo four nymphal stages before developing into adults. Nymphs are light yellowish green or greenish black or brownish (Dixon 1985). When conditions are favorable, the development of one generation takes 6 to 8 days (an average of 5.5 days). An adult can produce larvae for 6 to 7 days at the rate of 2 to 3 per day or a total fertility of 13 to 14 descendants. The rate of reproduction is largely dependent on climatic factors, especially temperature and the nutritional status of the host plant (Millar 1994).

Aphis craccivora Koch infests many plant species in many plant families. It however has a strong preference for members of Leguminosae which account for 47% of the known host species (Blackman and Eastop, 2000). During the dry season, *Aphis craccivora* has been found to survive in leguminous hosts such as *Dolichos malosanus* (Bak.), *Eriosema affine* (De Wild), *Eriosema psoraleoides* (Lam.) G Don, *Eminia antennulifera* Baker (Taub.) and *Adenodolichos punctarus* (Micheli) Harms., *Vigna* spp., *Millettia* spp. and *Lonchocarpus* spp. Aphids also survive on shrub and tree species common in groundnut growing regions of Africa and produce flushes of new growth before onset of rains (Blackman and Eastop, 2006).

2.5.1 Taxonomic characters of *Aphis craccivora* Koch

Wingless adult females have shiny black body with large black patch on dorsum of the abdomen. Legs are strikingly white with black 'knees' and 'ankles', especially hind legs. Immatures are often covered with grayish wax. The aphids have rounded body measuring 1.4-2.0 mm long. Frontal tubercles are not well developed. Antenna segments are six and terminal process more than twice length of the base of the sixth antennal segment. The third antennal segment lack secondary sensorial. They have black cylindrical cornicles more than three times as long as wide, black cauda with 2-4 (usually 3) pairs of lateral setae and one dorsal pre-apical seta (Blackman and Eastop, 2000).

Winged adult female have similar taxonomic characteristics but differ in that the dorsum of the abdomen have black lateral areas and variable bands. The body measures 1.4-2.1m in length. The third antennal segment has four to seven secondary sensorial, one noticeably longer than the others (Manya *et al.,* 1996; Blackman and Eastop, 2000).

2.6 Disease-vector relationship

Vector transmission characteristics of GRD are influenced by GRAV but not by GRV or sat RNA (Taliansky *et al.,* 2000 and 2003). Since GRV and its sat RNA do not depend on GRAV for replication, spatial and temporal separation of GRAV from the other two agents can occur under natural conditions in groundnut, depending on the feeding behavior of the aphid-vector. Studies have shown that a single vector aphid does not always transmit the acquired three agents together into the inoculated plants resulting in separation of groundnut rosette disease agents in time and space (Naidu *et al.,* 1999). Viruliferous aphids can either transmit GRAV alone, groundnut rosette

virus with its satellite RNA or all three agents together (Naidu *et al.,* 1999; Naidu *et al.,* 2007).

All virus particles whether GRAV RNA, GRV RNA or sat RNA, are acquired by the aphid vector from the phloem sap. The acquisition period is usually longer than four hours and the virus persists for more than ten days and through the insects' moult. The virus is transmitted by all developmental stages of the aphid but nymphs are more efficient transmitters than apterae (Missari *et al.,* 1988). Different races of *A. craccivora* vary in their inherent efficiency of transmission. Once acquired, the aphid can transmit virus particles for up to 14 days and possibly for life. Infection by GRV and sat RNA can occur if the aphid vector makes brief probes into mesophyll cells but GRAV must be inoculated into phloem cells (Naidu *et al.,* 1999).

2.7 Epidemiology of Groundnut rosette disease

Groundnut plants that survive between cropping seasons and alternative hosts form possible sources of inoculum for disease spread. There could be native African plants from which the disease spreads into groundnut as groundnut rosette disease is endemic to SSA and its off-shore islands (Alegbejo *et al.,* 2002). The vector, *Aphis craccivora is* polyphagous, and can survive on as many as 142 plant species in 23 families in addition to groundnut. Eighty three of these species are in leguminosae and thus indicates that *A. craccivora* has a strong preference for legume hosts. One or more of these 142 plant species could be the source of the rosette complex (Blackman and Eastop, 2006). Host plants for GRAV and/or GRV and sat RNA have been identified under experimental conditions but groundnut is the only known natural host for the entire rosette complex (Naidu and Bottenberg, 1998).

Groundnut rosette is a polycyclic disease as each infected groundnut plant acts as a source for initiating subsequent spread in the field (Naidu *et al.*, 1999). Primary infection can only be introduced into the crop by viruliferous aphids since the viral agents of the disease are not seedborne (Murant, 1998). Plants that show disease symptoms but lack GRAV are not important in disease spread since the CP of GRAV is needed for encapsidation and transmission of GRV and sat RNA. The number of plants containing all the three agents therefore plays a major role in secondary spread of the disease in the field. Yield is however determined by the total number of plants infected by GRV, GRAV or both (Olorunju *et al.*, 1991).

GRD epidemics are also influenced by host plant preferences and transmission efficiency of various clones of *Aphis craccivora* Koch. There are various factors that can influence the nature and pattern of disease spread (Millar, 1994). These include plant age, crop density, timing and efficiency of transmission by viruliferous aphid vectors that reach the crop, proximity to the source of inoculum, climatic factors, and predators and parasitoids of vector population within the crop (Naidu *et al.*, 1999).

2.8 Management of groundnut rosette disease

Plant virus diseases cause serious losses in yield and quality of cultivated crops worldwide. Aphid-transmitted viruses account for 50% of the 600 known viruses with an invertebrate vector (Jeger, 2004). Viral plant diseases are not curable and therefore prevention remains the most viable strategy for their control. Controlling epidemics involve use of measures that minimize virus infection sources or suppress virus spread (Roger, 2004). Chemotherapy, thermotherapy and meristem-tip culture can be

successful, but they cannot be used on a large scale. Consequently, the main approach has been to prevent or delay virus infection or to improve its effects.

2.8.1 Chemical control of the vector

Insecticides have been proved useful in controlling *Aphis craccivora* Koch and to reduce or prevent spread of rosette disease in the field. To decrease rosette incidence, the first spray is applied early and before symptoms appear. The timing, dosage interval and the type of insecticide are crucial for successful reduction of the vector populations (Perring *et al.,* 1999). Monitoring of the vector migration into the crop should be done early in the season. Chemicals are useful to large scale growers because labor required for maintaining cultural practices are minimized thus lowering the cost of production (Naidu *et al.,* 1999).

2.8.2 Cultural practices

Cultural practices aim at reducing the population of *Aphis craccivora* Koch in a groundnut field leading to reduction of rosette disease. Manipulation of the crop by planting early and at close spacing reduces the chance of aphids invading and multiplying within the crop. Early planting of groundnuts creates temporal desynchronisation between the crop and aphid vector (Farrel, 1976). Early planting produces older, less attractive plants at the time of aphid invasion thus reducing disease incidence (A'Brook, 1964). It also reduces the extent of rosette spread due to less aphid colonization at plant maturity. Absence of new leaf production suppresses symptom expression owing to cessation of vegetative growth. The early sown crops cover the ground before the aphids' main period of flight activity. Early sown crop

largely escapes infection because aphids prefer younger crops and often alight preferentially on widely spaced plants (Naidu *et al.*, 1998).

It is also important to ensure that nuts from an infected crop are not used for seed and that all nuts are removed from the field during harvesting. Diseased seeds left in the soil will germinate and form volunteers or groundkeepers that provide an early food source for invading alate aphids. Field sanitation is therefore of great importance in reducing disease spread (Termorshuizen, 2002).

A. craccivora can live through the dry season in East Africa in the common weeds like *Euphorbia hirta* and *E. prostrate* and other legumes. Weed species should be controlled both during the time the crop is growing and when the land is fallow between crops. Weeds and volunteers should be totally eradicated before new crops are planted. Weed hosts are often symptomless carriers of viruses over successive seasons. Their destruction has been demonstrated as contributing to a reduced incidence of diseases (Hunter, 2005).

Trap crops are plant stand that are grown to attract insects or other organisms like nematodes to protect the target crops from pest attack (Shelton *et al.*, 2006). The principle of trap cropping rests on the fact that virtually all pests show a distinct preference to certain plant species, cultivars or a certain crop stage (Ciancio and Murkeji, 2007). The trap crops are deployed based on inherent characteristics of a trap crop which include differential attractiveness to oviposition and feeding. Trap crops have other attributes that enable the trap crop to serve as sinks for insects or the pathogens they vector (Shelton and Badenes-Perez, 2006). Trap crops is a common

cultural practice in many countries. Among its potential advantages are effects on the population dynamics of pests which may minimize crop damage. Effects of trap crops include initial colonization of crops and feeding, reproduction and dispersal of pests within the crop (Perrin and Phillips, 2006). Other attributes of trap crops may be due to host volatiles, leaf morphology and color or a combination of these factors, total leaf area, leaf shape or plant architecture. Trap crops are planted with early or late crop and can be of the same cultivar as the main crop or a completely different plant species (Javaid *et al.,* 1995; Badenes-Perez *et al.,* 2004).

Trap crops are commonly grown to restrict vector populations and virus sources to refuge host plants which are usually insusceptible to infection. Trap cropping generally involves early planting of border strips of a particular crop to attract insects where they may be destroyed by insecticide. Trap cropping also has a potential to control other crop pests. It can minimize the use of insecticides and can be integrated with other IPM tactics. Protection may be achieved either by preventing the pests from reaching the crop or by concentrating them in a certain part of the field where they can economically be destroyed, for example, in soybeans one can attract 70-85% of the stink bug population to a trap crop that covers only 1-10% of the total crop area (Sastawa, 2003).

2.8.3 Host plant resistance

About 100 long duration Virginia types and 15 early maturing Spanish types have a high level of resistance to GRV and its satellite RNA but not to GRAV (Olorunju *et al.,* 1991; Subrahmanyam *et al.,* 1998). In all tested rosette resistant varieties, resistance is to GRV. Resistance to GRV provides indirect resistance to sat RNA and

hence such varieties do not develop symptoms (Bock *et al.*, 1990). Resistance to GRV does not however result to immunity and can be overcome under high inoculum level or unfavorable environmental conditions (Bock *et al.*, 1990).

Early maturing Spanish cultivars (*Arachis hypogaea* subsp. *fastigiata* var. *vulgaris*) have been found to have resistance against both chlorotic and green rosette. This resistance is governed by two independent recessive genes (Nigam *et al.*, 1990). Sources of resistance to groundnut rosette incidence has also been identified in groundnut land races of late maturing Virginia type (*Arachis hypogaea* subsp. *Hypogaea* var. *hypogaea*) (Catharinet *et al.*, 1954). The resistance in races of the Virginia type contributed to the development of several disease resistance cultivars such as RMP 12, RMP 11, KH 241-D and RG 1 (Gibbons, 1977).

Several wild *Arachis* species or accessions have been screened and found resistant to GRAV (Subrahmanyam *et al.*, 2001). The accessions belong to *Arachis diogoi, A. hoehnei, A. Kretschmeri, A. cardenasii, A. villosa, A. pintoi, A. kuhlmanui, A. stenosperma.* Some accessions in *A. appressipla, A. diogoi, A. stenosperma, A. decora, A. triseminata, A. kretschmeri, A. kuhlamannui* and *A. pintoi* were found to be resistant to all the three components of groundnut rosette diseases (GRAV, GRV and its sat RNA). This immunity can be transferred to cultivated groundnut through biotechnological approaches. Mechanisms of resistance include resistance to initial infection, restriction of virus movement, and restricted production of sat RNA which induces rosette symptoms in the plant.

Resistance in groundnut landraces is effective against both chlorotic and green rosette and is governed by two independent recessive genes (Berchoux 1960; Nigam and Bock, 1990; Olorunju *et al.*, 1992; Olorunju *et al.*, 2001). Over 12, 600 groundnut germplasm lines have been screened and identified to be field resistant to groundnut rosette disease (Subrahmanyam *et al.*, 1998). These germplasm lines have shown resistance to GRAV. Resistance in these lines is therefore not absolute as a small proportion of plants or a few branches in most resistant genotypes show rosette symptoms (Subrahmanyam *et al.*, 1998). Such plants act as sources of inoculum for the vector. This leads to spread and survival of the disease. A high percentage of these germplasm lines may not show visible symptoms in the field but yield reduction in such is substantial under rosette epidemic situations due to their susceptibility to GRAV (Naidu *et al.*, 2006).

Arachis accessions (ICGs 8946, 8128, 8186, 8904, 8970 and 11557) have been shown to be resistant to GRAV (Murant *et al.*, 1991; Subrahmanyam *et al.*, 2001). Absence of GRAV limits transmission and hence accessions resistant to GRAV can contribute to disease control. Some accessions (ICGs 13187 and 14862) though susceptible to GRAV have showed a low level of virus accumulation (Subrahmanyam *et al.*, 2001). This is possibly due to presence of quantitative resistance to GRAV multiplication. Plants having such resistance are poor sources of virus acquisition by aphids. Resistance to the aphid vector has been identified in genotypes such as EC 36892 and ICGV 12991. On such plants prolonged phloem feeding by aphids is not maintained. This results in a short feeding period and presumably the aphid-resistance phenotypes (Naidu *et al.*, 1999 and van der Merwe *et al.*, 2002).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study area

The study was carried out in two groundnut growing regions of Western Kenya, namely, Alupe and Siaya. The study was carried out at Kenya Agricultural Research Institute Alupe sub station and Siaya Agricultural Training Centre (Siaya ATC) from March 2007 to January 2008 during the long rain and short rain seasons. Alupe is in Teso district of Western Province and has an altitude of 1128 m to 1500 m above sea level. The mean annual rainfall ranges from 600 to 2030 mm. The region lies between latitude 0°6'N and longitude 34°32'E. Mean annual temperatures range between 14 and 37°C. According to FAO Classification the soils are ferralo-orthic acrisols with a pH of 5.4.

Siaya ATC is in Siaya district of Nyanza province and has an altitude of 1128 to 1500 m above sea level and a mean annual rainfall of 800 to 2000 mm. Mean temperatures ranges from 15°C to 30°C. Siaya ATC lies between latitude 0°4'N and longitude 34° 18'E. The soil class is sandy clay loam and classified as a Ferralsol with a pH of 6.3 (FAO Classification).

3.2 Description of test groundnut varieties

Three rosette resistant varieties, which had been released to farmers in Malawi, were tested for resistance to groundnut rosette disease in Kenya at Siaya and Alupe. These were ICGV 12991, ICGV-SM 99568 and ICGV-SM 90704. JL-24 and Etesot were used as susceptible and local checks respectively.

JL-24, a Spanish type is early maturing and a high yielding variety. It has a bunch growth habit, matures in 90-110 days, drought-tolerant, has no seed dormancy. Seeds

are tan and have a 100 seed mass of 50 g and 48% oil content. It is susceptible to groundnut rosette disease (Freeman *et al.*, 2002).

ICGV 12991 is a short duration (90 to 110 days to maturity), drought-tolerant, Spanish-type peanut. It has a bunch growth habit and a high level of field resistance to groundnut rosette disease. This variety is resistant to the aphid vector (Naidu *et al.*, 1999; Subrahmanyam *et al.*, 2000). Seeds are tan, have a 100 seed mass of 33.9 g with 43% oil and have no fresh seed dormancy (Deom *et al.*, 2006).

ICGV-SM 99568 is a short duration rosette resistant variety belonging to Spanish botanical group. It matures in 90 to 105 days after sowing. It has a tan colored seed coat, 100 seed mass of 40 g and 46% oil content. It has no fresh seed dormancy. It is moderately resistant to groundnut rosette disease (Deom *et al.*, 2006).

ICGV-SM 90704 is a medium duration Virginia type, has a spreading bunch growth habit, matures in 120 to 140 days, is resistant to rosette, and has a tan seed with 45-48% oil content. ICGV-SM 90704 is resistant to groundnut rosette virus (Freeman *et al.*, 2002).

Etesot is a local landrace, a Virginia type. It has a spreading bunch growth habit, matures in 120–140 days. It has large, tan-colored seeds. This variety has not been screened for resistance but it is known to be moderately resistant to groundnut rosette disease.

3.3 Field preparation and fertilizer application

The land was ploughed to a fine tilth and plots measuring 4 m x 4 m were then marked out and separated from each other by alleys of 1 m wide to minimize interplot effects. Blocks were separated from each other by a path measuring 2 m in width.

Furrows were made using a hand hoe at a spacing of 45cm. The experimental design for each trial was randomized complete block design laid out as a split plot. A band application of diammonium phosphate (18% N, 46% P_2O_5) at 50 kg ha^{-1} was included in all treatments.

3.4 Planting and weeding

For erect varieties (ICGV 12991, ICGV-SM 99568 and JL-24) a spacing of 45 cm by 10 cm (inter and intra-row respectively) was used to give a plant population of 451 plants per plot (185 000 plants per hectare). For spreading bunch varieties (Etesot and ICGV-SM 90704) a spacing of 45 cm by 15 cm (inter and intra-row respectively) was used to give a total population of 308 plants per plot (108 000 plants per hectare). All the seeds were pretreated with Thiram (3 g kg^{-1} seed) and one seed was hand sown per hole at a depth of five to ten centimeters. All seeds for sowing were obtained from International Crops Research Institute for the Semi arid Tropics (ICRISAT), Nairobi. There was 100% germination and therefore no gapping was done.

Weeding was done three times. The first weeding was done when the crop was 3 weeks old, second weeding was done six weeks after planting. First and second weeding was done using a hand hoe. The third weeding was done at the pegging stage by hand pulling to avoid disturbance of developing pods. This was followed by earthing up. The trials were rainfed and were left for natural pest and disease development.

CHAPTER FOUR

4.0 EFFECT OF PLANTING TIME AND VARIETAL RESISTANCE ON APHID POPULATION, GROUNDNUT ROSETTE DISEASE INCIDENCE AND YIELD

4.1 Introduction

Many insect pests cause groundnut damage in the semi arid tropics (SAT) region. These include soil inhabiting pests, storage pests and foliage feeders, which vector disease causing agents. Among the foliage feeders, aphids play a significant role in virus transmission and account for transmission of 50% of the insect-vectored viruses (Brunt *et al.*, 1997). Aphids reproduce asexually and their populations can therefore increase at a very high rate. They can therefore cause disease epidemics through short- and long-distance spread of viruses (Hull, 2002).

Aphids are globally distributed and there are more than 200 vector species identified (Brunt *et al.*, 1997; Blackman and Eastop, 2000; Hull, 2002). The majority of aphid vectors belong to the subfamily aphidinae (order: Homoptera) (Blackman and Eastop, 2000). The success of aphids as vectors of plant viruses can be attributed to their polyphagous nature that allow them to feed on a wide variety of plant hosts, this is important for the dissemination of viruses that infect a large number of plant species, ability to undergo parthenogenetic reproduction thus rapid production of large quantities of offspring and possession of a needle-like stylet capable of piercing plant cell walls and delivering viruses into a host cell (James *et al.*, 2004). The role of aphids as vectors is facilitated by their piercing and sucking mouthparts that can make easy delivery of virions into plant cells. Groundnut aphids transmit viral diseases such as peanut stripe virus (*Aphis craccivora* Koch and *Aphis citricola* van der Goot),

groundnut eyespot virus (*Aphis craccivora* Koch), groundnut chlorotic spotting virus (*Aphis craccivora* Koch and *Aphis spiraecola* Patch) and groundnut rosette viral complex which is transmitted by *Aphis craccivora* Koch (Singh *et al.*, 1992). Apart from transmitting viruses, aphids cause direct injury to the host plant by sucking the plant sap from young foliage and growing tips which contains essential food materials that promote plant growth. This results in chlorotic patches and leaf curl. As flowering starts, aphids infest flower stalks and pegs which result in poor pod formation. This plant sap is rich in sugars and amino acids which aphids need for growth. Much of the sap that is sucked by the aphids is excreted as honey dew. When aphid populations are extremely large, this sugar rich honeydew covers the leaf surface forming an ideal substrate for the growth of sooty mold fungi (Hail, 2007). The fungi and honeydew reduce the efficiency of respiration and photosynthesis of the plant and consequently final yields (Peterson, 2004; CAB International, 2004).

Groundnut rosette disease, transmitted by an aphid, *Aphis craccivora* Koch is the most destructive virus disease in groundnut growing regions of sub-Saharan Africa (Naidu *et al.*, 1999). In groundnut growing regions of Kenya, groundnut rosette incidence ranges from 24 to 40% in Western and 30% in Rift Valley provinces (Wangai *et al.*, 2001). With the high population growth rate in Western Kenya and the decreasing farm size per head (MOA, 2004b), there is a need therefore to maximize the yield in smallholder farmers' fields by managing this disease and providing an environment for increased productivity. Growing varieties that are resistant to groundnut aphid and viruses, with good crop husbandry practices like right sowing date are some of the major cost-effective strategies for managing groundnut rosette disease especially for resource poor smallholder farmers (Olorunju and Ntare, 2002).

The objective of the study was to assess the effectiveness of early and late planting and host plant resistance in management of groundnut rosette disease and its vectors and also to assess populations of aphid species from the selected groundnut varieties.

4.2 Materials and methods

A field experiment was set up at Siaya and Alupe to evaluate the effects of planting time and varietal resistance on aphids, groundnut rosette disease incidence and yield. The experiment was set up in a split plot randomized complete block design with three replications. Time of planting (early and late planting) was allocated to the main plots and the varieties to the subplots. Each main plot measured 20 by 4 m^2 and a subplot 4 by 4 m^2 with 1m and 2m paths between subplots and main plots respectively. Three rosette resistant varieties (ICGV 12991, ICGV-SM 99568 and ICGV-SM 90704), a susceptible check (JL-24) and a local check (Etesot) were sown at two different dates: at the onset of rains (early planting) and one month later (late planting).

Data on aphid population (*Aphis craccivora* Koch) and groundnut rosette disease incidence was collected fortnightly at 2, 4, 6, 8, 10, and 12 weeks after planting (WAP). Aphids were counted on three leaflets from the base, middle and top on each 10 randomly selected plants from five middle rows per plot. The aphids were dislodged from their host with a fine hair brush soaked in dilute soap solution and were collected in a vial containing 70% alcohol and thereafter counted in the laboratory without separating the different morphs from the population. Aphids were collected early in the morning when they were less active. Visual assessment of groundnut rosette disease incidence was done from five middle rows each measuring

three meters in each plot and the number of diseased plants recorded. The disease was assessed in all plots and symptom expression observed during the assessment included leaf chlorosis, distorted, and folded leaflets together with stunting. Groundnut rosette incidence was recorded as the number of the diseased plants and expressed as a percent of the total number of plants sampled in the five rows. The experiment was done during the long rain season (March – May, 2007).

During the short rain season (October – December, 2007) another experiment was set up at the onset of rains (early planting) at Alupe to assess other aphid species in order to investigate possibility of GRD transmission by other aphid species. The experiment was set up as randomized complete block design with three replicates, with each variety representing a replicate. Individual experimental plots measured 4 by 4 m^2 with 1m path between them and 2m alleys between blocks. The GRD incidence was assessed fortnightly as described above throughout the season from 2 weeks after planting. Aphid assessment was on ten groundnut plants which were randomly selected from each plot and three leaves picked from top, middle and bottom of each plant. The leaves from each plant were put in separate labeled paper bags and stored at 4^0C until aphids were counted and identified at the Entomology Laboratory of the Department of Plant Science and Crop Protection of the University of Nairobi.

Taxonomic characteristics, pictorial and dichotomous keys were used in identification of aphids (Martin, 1983; Blackman and Eastop, 2000). Characters were seen with a dissecting microscope with a magnification power of at least one hundred and twenty. The taxonomic characters used were: *Aphis craccivora* Koch: In life body shiny black with large black patch on dorsum of abdomen, legs strikingly white with black

"knees" and "ankles," especially hind legs; immatures often covered with grayish wax. Small aphids (1.4-2.0 mm long), body rounded. Frontal tubercles not well developed and antenna 6-segmented. Terminal process more than twice length of base of antennal segment VI, antennal segment III without secondary sensoria. Cornicle cylindrical, more than 3 times as long as wide, black. Cauda with 2-4 (usually 3) pairs of lateral setae and 1 dorsal preapical seta, black.

Aphis fabae Scopoli: In life body shiny black, but may appear dull black due to waxy covering; immatures often covered with wax. Small aphids (1.5-3.1 mm long), body rounded. Frontal tubercles not well developed. Antenna 6-segmented, terminal process 2 1/2-4 times length of base of antennal segment VI, antennal segment III without secondary sensoria. Cornicle cylindrical, two and a half to four times as long as wide, black. Cauda with 3-4 pairs of lateral setae and 2-3 dorsolateral setae, black.

Aphis gossypii Glover: In life body color varies from blackish green to green to pale yellow to almost white. Small aphids (1.3-2.1 mm long), size apparently influenced by crowding, temperature, and host; body rounded. Frontal tubercles not well developed. Antenna 6-segmented; terminal process 3-4 times length of base of antennal segment VI; antennal segment III without secondary sensoria. Cornicle cylindrical, 4-9 times as long as wide, black. Cauda usually with 2-4 (usually 2-3) pairs of lateral setae, pale to dusky.

Yield data was taken on five middle rows at the end of each experiment. To check whether the plants were ready and mature for harvesting, 5 plants were pulled up from the guard rows and the pods removed and shelled. The insides of shells were examined and if the majority of pods (over 70%) had dark markings and the seeds

were plump and had the correct color for the variety, then the plants were considered ready for harvesting. A hoe fork was used to lift plants out of the soil from five rows per plot. The erect varieties were harvested 16 weeks after planting while the spreading bunch varieties were harvested 20 weeks after planting. Fresh pod mass per plot was determined. The pods were left to dry in the sun to 7% moisture content, this was determined using a moisture meter. Total yield per plot before and after shelling was then taken. A sample of 500g was drawn from the total yield of each plot and shelled to determine shelling percentages (grain mass/pod mass). Seed size was determined as the weight of 100 seeds measured in grams (100 seed wt). Shell mass per plot was also taken. The variables (total dry weight, 100 seed mass, shell mass, pod mass) were used to calculate total yield (kg ha^{-1}). Data collected on aphid population, GRD incidence and yield was subjected to analysis of variance by use of Genstat software and means compared by least significant difference at 5 % probability level.

Infestation by aphids in both experiments was dependent on natural conditions. All the normal agronomic practices used in groundnut production were followed during crop growth as described in chapter three.

4.3 Results

4.3.1 Aphid population

Aphid population varied with time and was significantly higher in late planted groundnuts than in early planted crop at Siaya and Alupe (Figure 1). Averaged across the sampling time and varieties, the aphid population was 30% higher at Alupe compared to Siaya. Aphid populations increased by the fourth week after planting in

both early and late planted groundnuts but declined by the sixth week then increased between the 8th and 10th week (Figure 1) and declined by the 12th week at both sites.

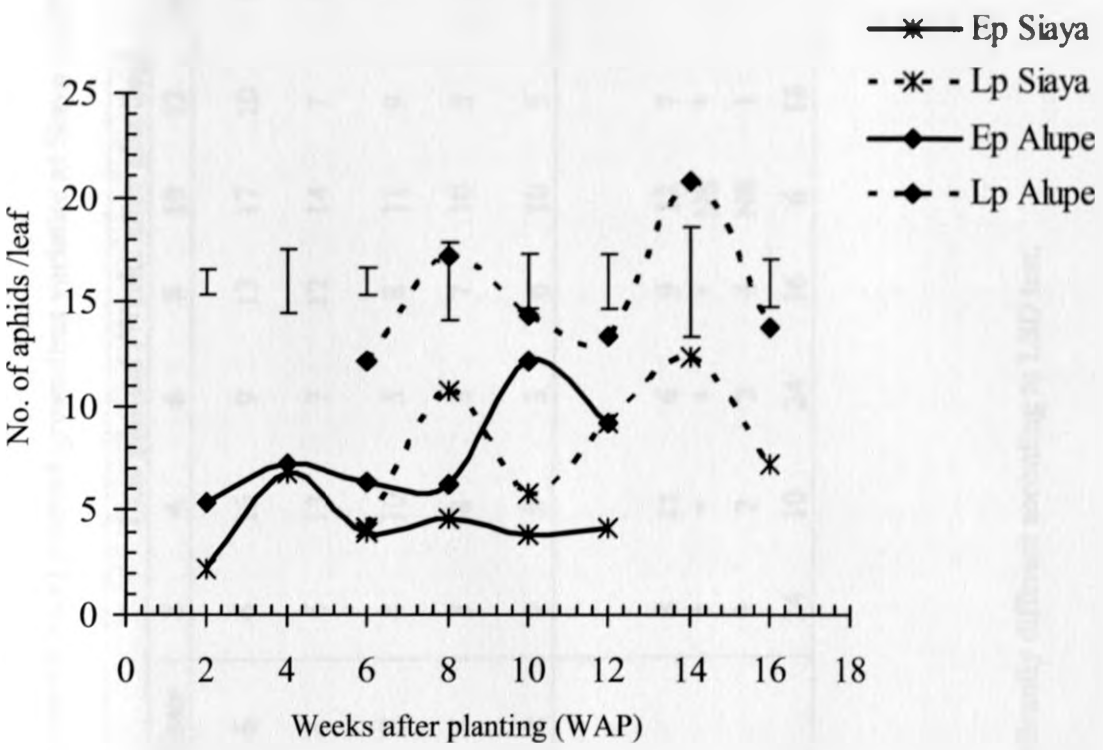

Figure 1 Aphid population over time in early and late planted groundnut varieties at Siaya and Alupe during the long rain season, 2007 (LSD bars inserted).

Ep Siaya=Early planting at Siaya; Lp Siaya=Late planting at Siaya; Ep Alupe= Early planting at Alupe; Lp Alupe – Late planting at Alupe

Among the early planted groundnut varieties in Siaya, there was no significant difference in aphid counts between rosette resistant varieties and the local and susceptible checks (Table 1). At Siaya, late planted rosette resistant varieties had significantly lower aphid counts than JL-24 and Etesot. ICGV-SM 90704 and ICGV 12991 had comparable populations which were significantly lower than ICGV-SM 99568 (Table 1).

Table 1 **Aphid population (no. of aphids/leaf) in early and late (4 weeks later) planted groundnut varieties at Siaya in 2007**

	Early planted (Weeks after planting)							Late planted (Weeks after planting)						
Variety	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**
JL-24	3	5	8	9	6	7	**6**	6	15	9	13	17	10	**12**
Etesot	4	5	2	6	3	5	**4**	6	13	7	12	14	7	**10**
ICGV-SM 99568	3	9	5	5	4	5	**5**	4	10	5	8	11	9	**8**
ICGV 12991	1	8	3	2	4	3	**4**	3	8	5	7	10	5	**6**
ICGV-SM 90704	0	7	2	1	2	1	**2**	2	8	3	6	10	5	**6**
Mean	**2**	**7**	**4**	**5**	**4**	**4**		**4**	**11**	**6**	**9**	**12**	**7**	
P<0.05	*	NS	*	**	NS	*		*	*	*	*	NS	*	
LSD (5%)	1	NS	1	3	NS	2		1	2	2	4	NS	1	
CV (%)	24	25	10	27	38	31		24	10	24	16	6	18	

** P≤0.001

* P≤0.05

NS Not significant

Values followed by the same letter within a column are not significantly different according to LSD test.

There was no significant difference in aphid population among the late and early planted varieties in Alupe (Table 2). On average however, the rosette resistant varieties had lower aphid counts than Etesot and JL-24. JL-24 had higher aphid counts than Etesot (Table 2).

There was no significant interaction between site and varieties (Appendix 1). Averaged across sites the aphid population varied significantly among varieties and was highest and lowest on JL-24 and ICGV-SM 90704, respectively. The aphid counts were low among the rosette resistant varieties (ICGV-SM 90704, ICGV 12991 and ICGV-SM 99568) and higher on Etesot and JL-24 (Tables 1 and 2).

There were three aphid species that were recorded in low counts throughout the sampling period at Alupe during the short rain season. These are *Aphis gossypii* Glover, *Aphis fabae* Scopoli and *Aphis craccivora* Koch. *Aphis craccivora* Koch was the most abundant species (average of 1-3 aphids/plant), followed by *Aphis fabae* Scopoli (average of 1 aphid per plant). The populations of *Aphis fabae* Scopoli and *Aphis gossypii* Glover did not differ significantly and were significantly low throughout the sampling period (Table 3).

Table 2 **Aphid population (no. of aphids/leaf) in early and late (4 weeks later) planted groundnut varieties at Alupe in 2007**

Variety	Early planted (Weeks after panting)							Late planted (Weeks after planting)						
	2	4	6	8	10	12	Mean	2	4	6	8	10	12	Mean
JL-24	8	4	11	9	19	14	**14**	16	22	20	16	29	18	**20**
Etesot	7	9	7	7	12	10	**9**	16	18	18	15	22	16	**18**
ICGV-SM 99568	4	5	5	6	15	10	**8**	10	15	12	12	17	12	**13**
ICGV 12991	5	7	6	5	11	8	**7**	11	20	13	14	25	13	**16**
ICGV-SM 90704	3	11	3	4	4	4	**5**	8	11	9	10	11	10	**10**
Mean	**5**	**7**	**6**	**6**	**12**	**9**		**12**	**17**	**14**	**13**	**21**	**14**	
P<0.05	*	NS	*	*	NS	*		*	*	*	NS	*	*	
LSD (5%)	1	NS	4	2	NS	2		2	3	3	NS	6	1	
CV (%)	24	32	17	19	6	10		26	11	20	32	16	26	

** P≤0.001

* P≤0.05

NS Not significant

Values followed by the same letter within a column are not significantly different according to LSD test.

Table 3 **Aphid population (no. of aphids/leaf) in early planted groundnut varieties at Alupe during the short rain season in 2007**

	Weeks after planting						
Variety	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**
ICGV-SM 90704	0	3	0	0	0	1	**1**
ICGV-SM 99568	0	3	3	0	0	3	**2**
ICGV 12991	2	5	0	12	0	0	**3**
Etesot	0	2	0	1	0	0	**1**
JL-24	0	3	0	0	1	1	**1**
Mean	**0**	**3**	**1**	**3**	**0**	**1**	
P<0.05	NS	NS	NS	NS	NS	NS	
LSD (5%)	NS	NS	NS	NS	NS	NS	
CV (%)	14.2	37.4	15.2	10.0	39.3	24.6	

NS Not significant

4.3.2 Groundnut rosette disease incidence

Groundnut rosette disease (GRD) manifestation in the field was mainly in the form of chlorotic rosette symptoms at both sites (Plate 1). Groundnut rosette incidence was 37% higher at Alupe compared to Siaya. Disease incidence was significantly higher in late- (47%) than in early-planted groundnut varieties in both sites (Figure 2; Table 4). It increased rapidly within the first two weeks (3.5 to 5 fold at Siaya and Alupe, respectively) with minor variation thereafter, irrespective of planting time (Figure 2). Disease incidence increased by 43-159% in rosette resistant varieties and 23-33% in local and susceptible checks due to late planting (Table 4).

1a. Chlorotic rosette

1b. Green rosette

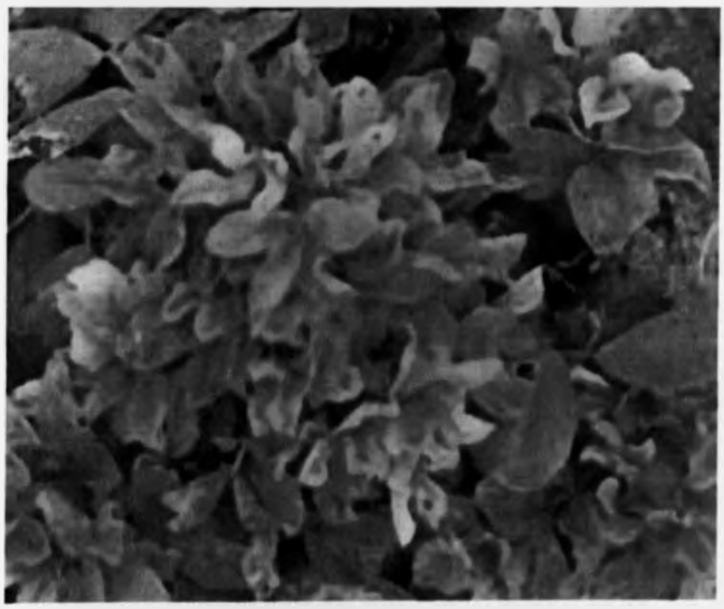

Plate 1 **Groundnut rosette disease symptoms in the field.**

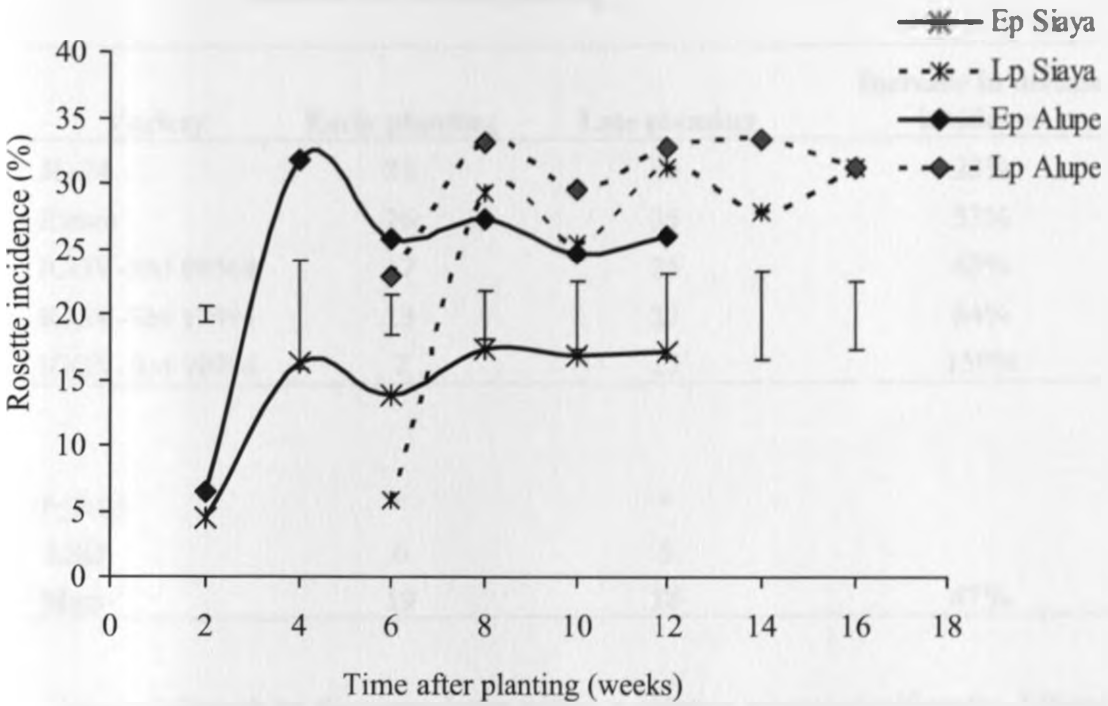

Figure 2 **Groundnut rosette incidence in early planted (Ep) and late planted (Lp) groundnut varieties at Siaya and Alupe during the long rain season, 2007 (LSD bars inserted).**

Key:

Ep Siaya	Early planting at Siaya
Lp Siaya	Late planting at Siaya
Ep Alupe	Early planting at Alupe
Lp Alupe	Late planting at Alupe

Table 4 **Percentage increase in disease incidence among groundnut varieties due to late planting**

Variety	Early planting	Late planting	Increase in disease incidence
JL-24	33	40	23%
Etesot	26	35	33%
ICGV-SM 99568	17	25	43%
ICGV-SM 12991	13	23	84%
ICGV-SM 90704	7	17	159%
P≤0.05	*	*	
LSD	6	5	
Mean	**19**	**18**	**47%**

Values followed by the same letter within a column are not significantly different according to LSD test.

In general there was significant interaction among varieties in the two sites. Rosette resistant varieties (ICGV-SM 90704, ICGV 12991 and ICGV-SM 99568) had significantly lower disease incidence than the local (Etesot) and susceptible (JL-24) checks (Tables 5 and 6). Disease incidence in ICGV-SM 90704 and ICGV 12991 was comparable but was higher in ICGV-SM 99568 (Table 5 and Table 6). JL-24 had the highest incidence even compared with Etesot. Averaged across sampling times and sites, disease incidence in the improved Spanish types (ICGV 12991 and ICGV-SM 99568) was 82% higher compared to ICGV-SM 90704 and 194% in Etesot. The latter two are Virginia types.

Table 5 Groundnut rosette incidence in early and late planted (4 weeks later) groundnut varieties at Siaya in 2007

	Early planted (Weeks after planting)							Late planted (Weeks after planting)						
Variety	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**
JL-24	8	18	28	32	41	36	**27**	10	42	43	46	38	46	**38**
Etesot	8	24	20	27	21	24	**21**	8	38	41	39	37	39	**34**
ICGV-SM 99568	3	18	11	16	13	14	**13**	5	26	14	28	23	29	**21**
ICGV-12991	3	9	10	9	7	8	**8**	4	25	19	29	25	28	**22**
ICGV-SM 90704	0	13	1	3	3	3	**4**	2	16	9	15	17	15	**12**
Mean	**4**	**16**	**14**	**17**	**17**	**17**		**6**	**29**	**25**	**31**	**28**	**31**	
P<0.05	**	NS	**	*	*	**		**	**	*	*	NS	*	
LSD (5%)	1	NS	7	11	5	7		2	3	8	7	NS	6	
CV (%)	28	14	2	17	21	16		12	8	25	3	12	12	

** P≤0.001

* P≤0.05

NS Not significant

Values followed by the same letter within a column are not significantly different according to LSD test.

Table 6 Groundnut rosette incidence in early and late planted (4 weeks later) groundnut varieties at Alupe in 2007

Groundnut rosette incidence over time (Weeks after planting) at Alupe														
	Early planted							Late planted						
	2	**4**	**6**	**8**	**10**	**12**	**Mean**	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**
JL-24	10	21	42	61	47	54	**39**	15	50	44	45	54	45	**42**
Etesot	8	46	39	35	27	31	**31**	11	40	34	40	40	37	**34**
ICGV-SM 99568	5	48	20	19	21	20	**22**	7	25	30	24	25	27	**23**
ICGV-12991	6	27	16	13	24	19	**18**	9	30	25	31	29	28	**25**
ICGV-SM 90704	4	18	12	8	6	7	**9**	5	22	16	24	21	20	**18**
Mean	**7**	**3**	**26**	**27**	**25**	**26**		**9**	**33**	**30**	**33**	**34**	**31**	
P<0.05	NS	NS	*	*	*	*		**	*	*	*	*	*	
LSD (5%)	NS	NS	13	12	10	10		2	6	4	6	7	8	
CV (%)	21	2	11	22	11	8		15	8	13	13	10	3	

** P≤0.001

* P≤0.05

NS Not significant

Values followed by the same letter within a column are not significantly different according to LSD test

4.3.3 Kernel yield

Siaya had significantly higher kernel yield than Alupe (Table 7). Groundnut kernel yield was significantly lower in late-planted crop in all varieties at the two sites. There was no significant interaction between site and planting time. Averaged across varieties and sites, late-planted groundnut had approximately 61% less yield than early-planted crop (Table 7). Averaged between sites and among varieties, kernel yield was 154% higher in early-planted groundnut varieties compared to late planted crop (Table 7; Appendix III) and 27% higher at Siaya than Alupe. Yield varied significantly among varieties; ICGV-SM 90704 and JL-24 had the highest and lowest yields respectively. Etesot had higher yields than JL-24. On average the kernel yield of Etesot, ICGV-SM 99568, ICGV-12991 and ICGV-SM 90704 was 37%, 78%, 94% and 159% respectively that of JL-24 (Table 7).

There was significant interaction between planting time and variety (Appendix III). Early planted rosette resistant varieties had significantly higher yield than JL-24 and Etesot. ICGV-SM 90704 had significantly higher yield than ICGV 12991 which in turn had significantly higher yield than ICGV-SM 99568. Late planted ICGV 12991 and ICGV-SM 99568 had comparable yield which was significantly lower than that of ICGV-SM 90704. Etesot had significantly higher yield than JL-24 when planted early and late (Table 7).

Kernel yield did not vary significantly among groundnut varieties planted during the short rain season at Alupe. On average however, ICGV-SM 90704 had the highest yield followed by ICGV 12991 and ICGV-SM 99568 respectively. Etesot had higher yield than JL-24 (Table 7).

Table 7 **Kernel yield (kg ha^{-1}) among groundnut varieties planted during the short and long rain seasons (early and late planted groundnut).**

	Groundnut kernel yield (kg ha^{-1})									
	Early-planted				Late-planted					
Variety	Alupe SR	Alupe LR	Siaya LR	**Mean**	Alupe LR	Siaya LR	**Mean**	**Mean yield**	% Reduction in yield due to late planting	% Yield compared to JL-24
ICGV-SM 90704	2588	2546	3001	**2774**	1163	1541	**1352**	**2063**	51%	159%
ICGV 12991	2373	2107	2602	**2355**	676	814	**745**	**1550**	68%	94%
ICGV-SM 99568	2243	2006	2384	**2195**	500	789	**645**	**1420**	71%	78%
Etesot	1613	1358	1763	**1561**	492	765	**629**	**1095**	60%	37%
JL-24	1047	897	1203	**1050**	476	610	**543**	**797**	48%	
Mean	**1973**	**1783**	**2191**	**1987**	**661**	**904**	**783**		61%	
Fp	NS	*	NS		*	*				
LSD (5%)	NS	647	NS		454	438				
CV (%)	12	6	9		19	15				

* $P \leq 0.05$

LR - Long rain season; SR - Short rain season

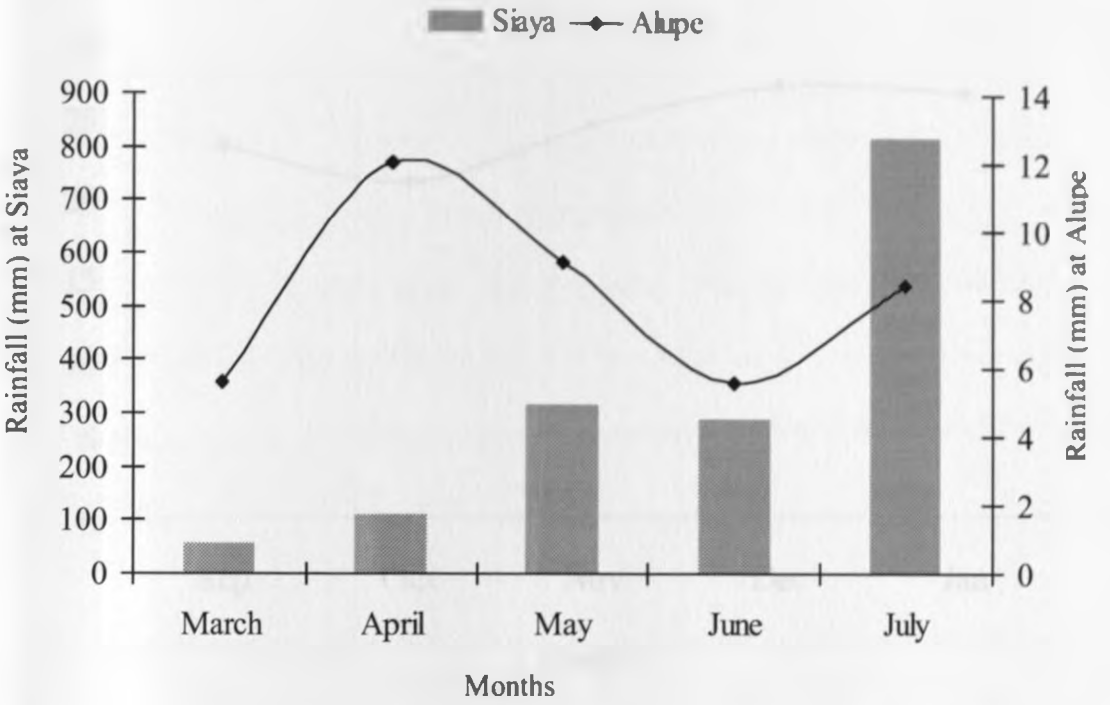

Figure 3 **Rainfall (mm) at Siaya and Alupe during the long rain season, 2007**

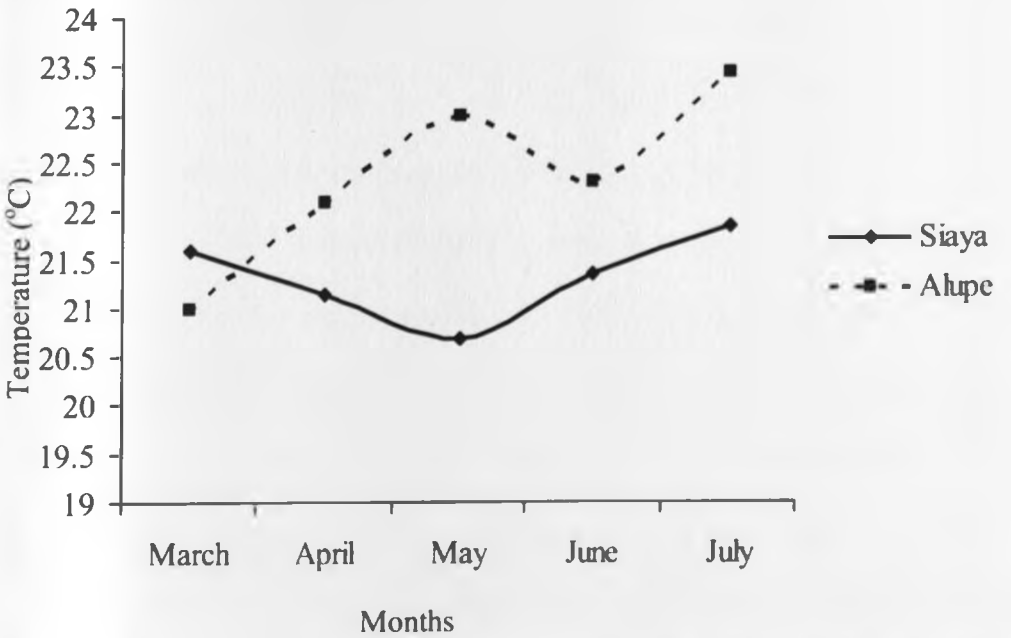

Figure 4 **Temperature (°C) at Siaya and Alupe during the long rain season, 2007**

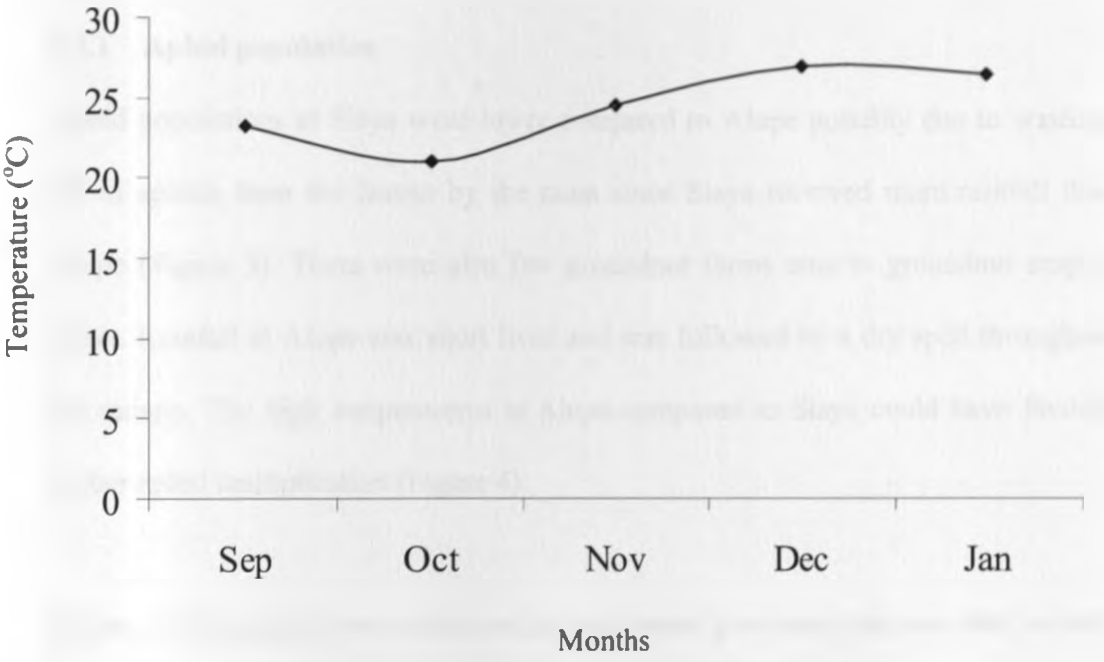

Figure 5 **Temperature (°C) at Alupe during the short rain season, 2007**

(Source: Kenya Agricultural Research Institute Alupe substation)

4.4 Discussion

4.4.1 Aphid population

Aphid populations at Siaya were lower compared to Alupe possibly due to washing off of aphids from the leaves by the rains since Siaya received more rainfall than Alupe (Figure 3). There were also few groundnut farms next to groundnut crop at Siaya. Rainfall in Alupe was short lived and was followed by a dry spell throughout the season. The high temperatures at Alupe compared to Siaya could have favored higher aphid multiplication (Figure 4).

Higher aphid numbers were observed in late-planted groundnut varieties than in early planted ones. The late-planted crop was established in an environment with high aphid population, possibly higher viral load and low rainfall. Low soil moisture due to low rainfall in the season reduces leaf growth. This may have encouraged movement of aphids from the older early-planted crop to the younger late-planted crop. An early-planted crop is able to establish rapidly because it utilizes available water and nutrients with low competition from weeds. Rapid establishment of ground cover early in the season reduces available landing spaces for aphids because they prefer light airy conditions. Sastawa (2005) also showed late-planted groundnut had higher population of *Aphis craccivora* Koch. Similar studies by Adipala *et al.*, 2001 demonstrated that late planted groundnut had higher aphid populations and higher rosette incidence compared to early planted crop. Bringing forward sowing dates has been shown to allow the soybean crop to establish before pest populations reach their peak (Sastawa *et al.*, 2003). Planting early in the season has also been shown to reduce infestation of cowpea by *Aphis craccivora* Koch (Karungi *et al.*, 2002). This is

attributed to the lower populations early in the season, which progressively build up as the season progresses.

There was significant variation in aphid species among different varieties during the short rain season. Temperature range during the sampling period was between 21-27°C (Figure 5). Low populations of *Aphis gossypii* Glover and *Aphis fabae* Scopoli were observed. This could be attributed to the effect of temperature on development of nymphs. Studies by Shahzad *et al.,* (2003) showed that the population of *Aphis gossypii* Glover decreased with increasing temperature. Studies by Zamani *et al.* (2006) also showed that higher temperatures delay prolonged development, increase mortality of immature stages, shortened adult longevity and reduced fecundity of *Aphis gossypii.* Studies by Mustafa *et al.,* (2005) showed that high temperatures, above 19°C had a drastic effect on fecundity of *Aphis fabae* Scopoli. The high population of *Aphis craccivora* Koch may be attributed to low mortality and its higher fecundity and readiness to settle and feed on the host plant (William *et al.,* 1998). Earlier studies have shown that large number of aphids of the same species infesting a plant can be due to a positive feed back for the population (William *et al.,* 1998). Earlier studies reported that the population of *Aphis craccivora* Koch is positively correlated with temperature (Nandagopal *et al.* 2004).

4.4.2 Groundnut rosette incidence

The rosette resistant varieties showed significant variation in groundnut rosette disease incidence. ICGV-SM 90704 had the lowest GRD incidence compared to ICGV 12991, ICGV-SM 99568, Etesot and the susceptible check (JL-24). Earlier studies by Merwe *et al.,* (2001) and Naidu (2007) showed that ICGV-SM 90704 was

more resistant to accumulation of GRAV than ICGV 12991 and JL-24. The GRAV component is needed for aphid transmission and hence further spread of the disease (Taliansky, 2003). ICGV 12991 had lower aphid GRD incidence compared to JL-24. Earlier studies showed that ICGV 12991 is resistant to the aphid vector responsible for transmission of disease agents unlike JL-24, which is susceptible to the disease agents, as well as the aphid vector (van der Merwe *et al.,* 2002). Early-planted groundnut had lower rosette incidence compared to late-planted crop. This could be attributed to low populations of the aphid vector due to washing away of aphids by rains and good ground cover and hence low inoculum. This is in agreement with studies by Mukankusi *et al.,* (1999), Adipala *et al.,* (2001) and Subrahmanyam *et al.,* 2002 who showed that late-planted groundnut had higher rosette incidence compared to early-planted crop.

4.4.3 Groundnut kernel yield

The higher yields observed at Siaya than Alupe could possibly be due to favorable environmental conditions especially high rainfall that caused reduction in aphid population and hence retarded disease development. Late planted groundnut had significantly higher GRD incidence and lower kernel yields than early-planted crop. Osiru *et al* (2007) also reported reduction in kernel yield due to high GRD incidence. This implies that rosette incidence significantly decrease kernel yields possibly due to impairness of plant performance through limitation of photosynthate production thereby causing reduction in growth and interruption of the supply of assimilates to pod and seed development. The results are also in agreement with earlier findings by Mukankusi *et al.,* 1999 and Adipala *et al.,* (2001) who observed higher yield in early-planted groundnut compared to late-planted crop.

Higher yields were obtained from early-planted rosette resistant varieties compared to late-planted crop. Subrahmanyam *et al* (2001) also observed higher yields when resistant varieties (ICGV-SM 90704 and ICGV 12991) were sown early. This can be attributed to low rosette incidence and also a combination of climatic factors such as availability of enough soil moisture for growth and biotic factors which play a crucial role in determination of yield performance of varieties.

Higher yields were observed among late-planted rosette resistant varieties compared to the local and susceptible checks. These results are comparable to those of Ntare and Olorunju (2001) who observed that even under high disease situations rosette resistant varieties ICGV 12991 and ICGV-SM 90704 gave the highest yields.

The rosette resistant varieties gave lower yields when planted late. This could be explained by the fact that the varieties used in this study are susceptible to GRAV as reported by Subrahmanyam *et al.*, (1998), Olorunju *et al.*, (1991) Olorunju *et al.*, (2001). Earlier reports have indicated that GRAV infection without GRV and sat RNA affect plant growth and contribute to yield losses in groundnut (Naidu *et al.*, 2007).

CHAPTER FIVE

5.0 EFFECTS OF INTEGRATED DISEASE MANAGEMENT PRACTICES ON APHID POPULATION, GROUNDNUT ROSETTE DISEASE INCIDENCE AND YIELD

5.1 Introduction

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop and food legume grown on 25.2 million hectares in warm, tropical and subtropical areas throughout the world with a total production of 35.9 million metric tons (FAO, 2006). Groundnut is attacked by various pests and diseases, which cause significant reduction in yield and quality (Pretorius, 2005). Farmers incur heavy financial losses due to yield losses. Groundnut suffers from various diseases such as leaf spots, anthracnose, aspergillus crown rot, botrytis blight, powdery mildew, web blotch and yellow mold (Hagan *et al.,* 2005). Among the diseases that attack the crop, groundnut rosette disease (GRD) caused by a viral complex is an important constraint to production in sub-Saharan Africa with epidemics often resulting in 100% yield losses (Naidu *et al.,* 1999). Yield losses are substantial when the viral complex which is spread by an aphid vector (*Aphis craccivora* Koch) causes high incidences of infection within the crop. In Kenya, the disease has been estimated to cause 60-100% yield losses in the groundnut growing areas (MOA, 2004a; MOA, 2004b).

Various control measures have been used in management of groundnut rosette disease. These include crop hygiene, roguing, changes in cropping practices, use of pesticides to control vectors, and the deployment of resistant varieties. When these measures are used singly, they yield only small benefits and they may become ineffective over the long term. When the various control measures are used in combination they make use of synergistic interactions and yield complementary

effects, which are more effective (Cerruti *et al.*, 2006). Therefore this study was set up to evaluate a combination of sustainable management practices such as use of trap crops, chemical control, roguing and use of resistant varieties on disease incidence and aphid population. The aim of the study was to come up with sustainable management practices for groundnut rosette disease and its vector in order to protect farmers from economic hardship that arises as a result of groundnut rosette disease epidemics.

5.2 Materials and methods

A field experiment was set up at Siaya and Alupe to evaluate effect of integrated disease management practices on aphids, groundnut rosette disease and yield. The experiment was set up in a split plot randomized complete block experiment with three replications. Disease management strategies were allocated to the main plots and two rosette resistant varieties namely (ICGV 12991 and ICGV-SM 90704) and a susceptible check, JL-24 to the sub plots. Only three varieties were selected due to unavailability of ICGV-SM 99568 and Etesot seeds during the time of experiment. Each main plot measured 320 m by 4 m and a subplot 4 m by 4 m with 1m and 2m paths between plots and blocks respectively. The selected disease management practices were trap cropping with cowpea (*Vigna unguiculata* Linn.) and Sesame (*Sesamum indicum* Linn.), pesticide application and rouging. Cowpea and sesame are common crops grown by farmers in the area and are known to be preferred by aphids to groundnut.

Perimeter trap cropping of 3 by 1.6 m^2 plot of groundnut with sesame (var. ICEASE 0020) and cowpea (var. M66) was done during the long rain season. Two cowpea seeds were sown per hole at a spacing of 30 cm by 20 cm. Sesame was sowed by seed

drilling in rows at the rate of 5 Kg ha^{-1} with spacing of 30 cm between rows, which were later thinned to 15 cm between plants at two weeks after emergence.

A chemical insecticide, dimethoate (40 EC; 250 g a.i/ha) was applied at the recommended rate of 1.5-2 L ha^{-1} in 750-1000 L of water using a knapsack sprayer. The sprayer used a hydraulic (cone) nozzle with a flow rate of 0.5 L min^{-1}. Polyethylene sheets were used to shield off unsprayed plots and 2m alleys were left between sprayed and unsprayed plots to prevent pesticide drift and interplot interference. Four preventative sprays were done at an interval of two weeks. Roguing was done as soon as visual symptoms appeared in the field and thereafter after every 14 days. No management practices were carried out in control plots.

The experiment was conducted during the long rain season. All the normal agronomic practices used in groundnut production were followed during crop growth as described in chapter three. Infestation by aphids was dependent on natural conditions throughout the season. Yield data was taken at the end of the experiment.

Data on aphid population (*Aphis craccivora* Koch) and groundnut rosette incidence was collected fortnightly at 2, 4, 6, 8, 10, and 12 weeks after planting (WAP). Aphids were counted on three leaflets from the base, middle and top on each 10 randomly selected plants from five middle rows per plot. The aphids were dislodged from their host with a fine hair brush soaked in dilute soap solution and were collected in a vial containing 70% alcohol and thereafter counted in the laboratory without separating the different morphs from the population. Aphids were collected early in the morning when they were less active.

Visual assessment of groundnut rosette disease incidence was done from five middle rows each measuring three meters in each plot and the number of diseased plants recorded. The disease was assessed in all plots and symptom expression observed during the assessment included leaf chlorosis, distorted, and folded leaflets together with stunting. Groundnut rosette incidence was recorded as the number of the diseased plants and expressed as a percent of the total number of plants sampled in the five rows. The experiment was done during the long rain season (March-May, 2007).

Yield data was taken on five middle rows at the end of each experiment. To check whether the plants were ready and mature for harvesting, 5 plants were pulled up from the guard rows and the pods removed and shelled. The insides of shells were examined and if the majority of pods (over 70%) had dark markings and the seeds were plump and had the correct color for the variety, then the plants were considered ready for harvesting. A hoe fork was used to lift plants out of the soil from five rows per plot. The erect varieties were harvested 16 weeks after planting while the spreading bunch varieties were harvested 20 weeks after planting. Fresh pod mass per plot was determined. The pods were left to dry in the sun to 7% moisture content, this was determined using a moisture meter. Total yield per plot before and after shelling was then taken. A sample of 500g was drawn from the total yield of each plot and shelled to determine shelling percentages (grain mass/pod mass). Seed size was determined as the weight of 100 seeds measured in grams (100 seed wt). Shell mass per plot was also taken. The variables (total dry weight, 100 seed mass, shell mass, pod mass) were used to calculate total yield (kg ha^{-1}). Data collected on aphid population, GRD incidence and yield was subjected to analysis of variance by use of Genstat software and means compared by least significant difference at 5 % probability level. Profitability test of each control option was determined by

calculating the various costs associated with the different control measures (Table 8). Marginal returns were estimated as income of yield gain divided by the cost for control option as illustrated by Evans, (2005). Marginal return values of less than unity indicated that increase in yield did offset the cost of control.

Table 8 Costs used in calculating marginal returns

Technology	Item	Description	Costs ha^{-1}
Chemical spray	Dimethoate	4 sprays, 1.5 l ha^{-1} @ 1200/L	7200
	Knapsack sprayer	20 l capacity	5000
	Labor for spraying	4 sprays, 4 man day @ 200	3200
	Labor for harvesting and shelling extra pods	30 man 2 day @ 200	12000
	Total		27400
Cowpea trap crop	Cowpea seed	40 Kg ha^{-1} @150	6000
	Labor for planting	30 man day @ 200	6000
	Labor for weeding	30 man day @ 200	6000
	Labor for harvesting and threshing extra cowpea grain	30 man day @ 200	6000
	Labor for harvesting and threshing extra pods	30 man 2 day @ 200	12000
	Total		36000
Sesame trap crop	Sesame seed	5 Kg ha^{-1} @ 150	750
	Labor for planting and thinning	30 man day @ 200	6000
	Labor for weeding	30 man day @ 200	6000
	Labor for harvesting and threshing	30 man day @ 200	6000
	Labor for harvesting and shelling extra pods	30 man 2 day @ 200	12000
	Total		30750
Roguing	Labor for removal and destruction of diseased materials	10 times, 10 man day @ 200	20000
	Labor for harvesting and shelling extra pods	30 man 2 day @ 200	12000
	Total		32000

5.3 Results

5.3.1 Aphid population

Averaged over time, Alupe had significantly more aphids (1.5 times) compared to Siaya (Figure 6). Aphid population at Alupe increased with time and was highest at 10th week after planting. At Siaya the population increased rapidly between the 4th and 6th week after planting with little variation thereafter (Figure 6). Averaged across sites and varieties, the disease management practices varied significantly in aphid population (Table 9, Appendix IV). Insecticide applied plots had the lowest aphid populations followed by cowpea and sesame trap crops (Plate 2), and rouging respectively. Control plots had significantly higher populations compared to all the other plots with different management practices (Table 9).

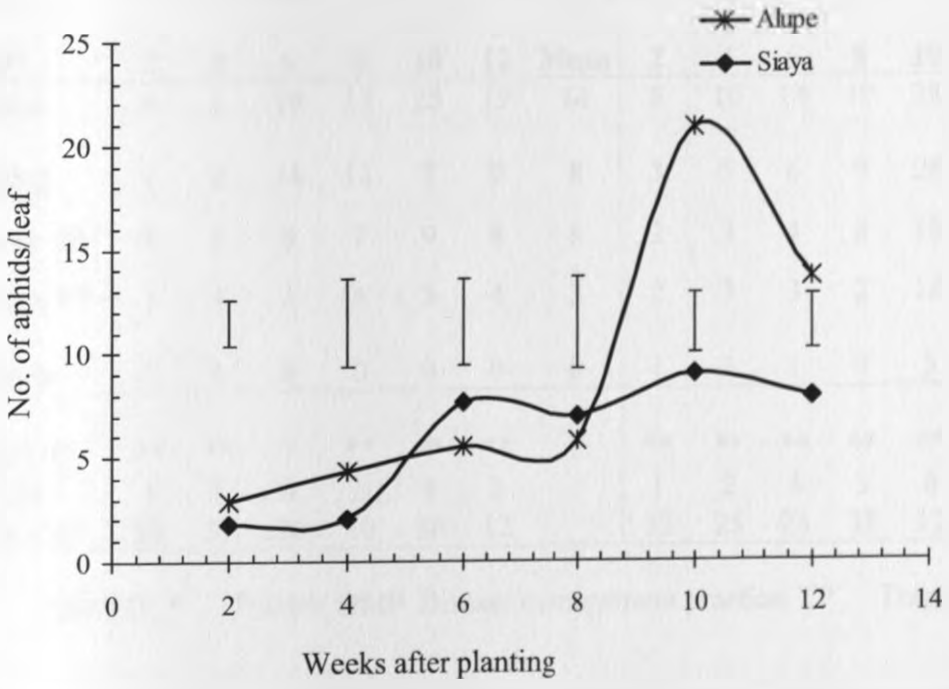

Figure 6 **Mean aphid population over time at Siaya and Alupe during the long rain season, 2007 (LSD bars inserted).**

There was significant interaction between site and disease management practices only at 4 weeks after planting at both sites (Appendix IV). At Alupe, control plots had significantly higher aphid counts than all other treatments. Sesame and cowpea treatments were comparable but significantly less than rouging and higher than pesticide treatments (Table 9). During the same period at Siaya, aphid population in cowpea, sesame and insecticide treatments was comparable and significantly less compared to plots where roguing was done (Table 9).

Table 9 **Aphid population (no. of aphids/leaf) in various disease management practices at Siaya and Alupe during the long rain season, 2007.**

	Number of aphids per plant (Weeks after planting)													
	Siaya							Alupe						
DMP	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**
Control	4	5	16	13	25	19	**14**	6	10	14	10	38	24	**17**
Rouging	2	2	14	11	7	9	**8**	3	5	6	9	28	18	**12**
Sesame TP	1	1	6	7	9	8	**5**	2	3	4	8	18	15	**8**
Cowpea TP	1	1	3	4	3	4	**3**	2	3	3	2	16	9	**6**
Pesticide	1	1	0	0	0	0	**0**	1	1	1	0	5	3	**2**
P<0.05	**	**	*	**	**	**		**	**	**	**	**	**	
LSD	1	1	6	3	4	3		1	2	4	3	6	6	
CV (%)	28	28	36	10	38	12		32	25	23	35	17	18	

** P≤0.001; * P≤0.05; DMP Disease management practice; TP Trap crop

There was a significant interaction between disease management strategies and varieties at 2 and 8 weeks after planting (Appendix IV). Variation in aphid population at 2 weeks after planting among insecticide, roguing, cowpea and sesame trap crop

treatments was not significant in all varieties but in control plots, ICGV 12991 had significantly higher aphid counts compared to ICGV-SM 90704 and JL-24 (Table 10).

In both sites and at 8 weeks after planting, aphid counts among the varieties differed significantly in sesame trap-cropped plots with ICGV-SM 90704 having the lowest and JL-24 the highest aphid population. There was no significant variation in aphid population among the varieties due to insecticide and cowpea treatments whereas where roguing was done, JL-24 and ICGV 12991 had comparable populations but ICGV-SM 90704 had significantly lower populations than the two (Table 10).

Table 10 Aphid counts/leaf in various disease management practices per variety

	2 weeks after planting			8 weeks after planting		
	ICGV 12991	ICGV SM 90704	JL 24	ICGV 12991	ICGV-SM 90704	JL 24
C	7	5	8	13	12	14
R	3	2	4	9	5	13
Se TP	2	1	2	7	3	12
CP TP	2	1	2	3	2	3
P	0	1	2	0	0	0
P<0.05	*			P<0.05	*	
LSD	3			LSD	7	
CV (%)	25			CV (%)	10.8	

Values followed by the same letter within a column are not significantly different according to LSD test

$P \leq 0.05$

Note: C – Control, R – Roguing, Se TP – Sesame trap crop, CP TP – Cowpea trap crop, P – Pesticide application

2a. Cowpea trap crop

2b. Sesame trap crop

Plate 2: **Cowpea and sesame trap crops.**

5.3.2 Groundnut rosette disease incidence

Groundnut rosette disease was evaluated as described in section 5.2. There was significant variation in rosette incidence across sites over time and incidence was higher at Alupe than at Siaya (Figure 7). In both sites, disease incidence increased to a maximum by 4th week after planting and then decreased by 6th week after planting and did not vary significantly thereafter (Figure 7).

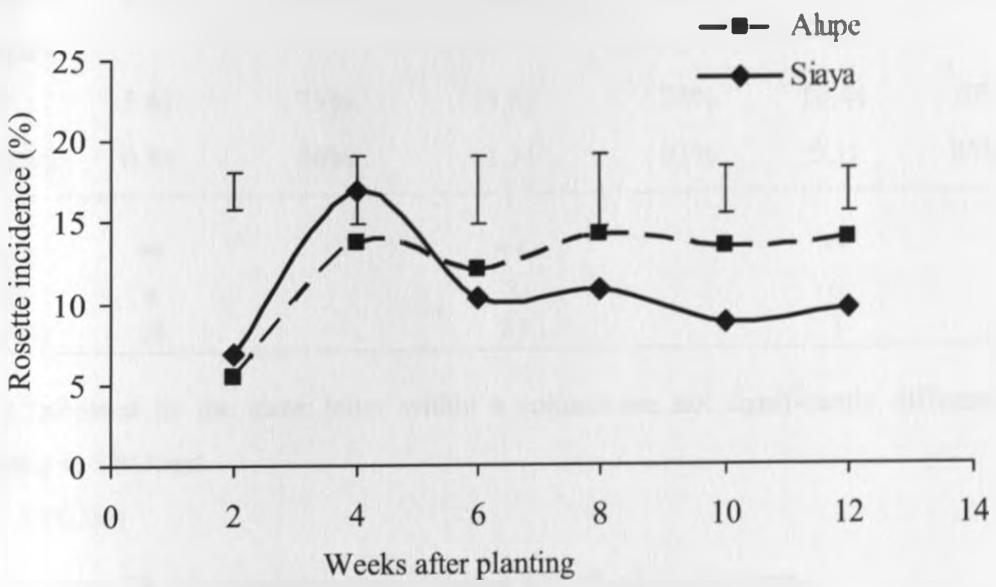

Figure 7 **Groundnut rosette incidence over time during the long rain season, 2007 (LSD bars inserted).**

Dimethoate reduced GRD incidence in the susceptible variety (JL-24) by 85% compared to the trap crops (61-70%) and roguing (32%) whereas in rosette resistant varieties insecticide treatment reduced the incidence by 93-96%. Cowpea and sesame caused 60-78% reduction in GRD incidence in rosette resistant varieties compared to roguing (35-48%) (Table 11).

Table 11 Percentage reduction in GRD incidence in groundnut varieties due to different disease management practices

	ICGV 12991	Reduction in GRD incidence	ICGV-SM 90704	Reduction in GRD incidence	JL-24	Reduction in GRD incidence
Control	20.43		16.14		34.89	
Roguing	13.32	35%	8.43	48%	23.71	32%
Sesame TP	8.11	60%	5.56	66%	13.69	61%
Cowpea TP	5.61	73%	3.62	78%	10.44	70%
Insecticide	0.85	96%	1.11	93%	5.31	85%
P≤0.05	**		**		**	
LSD	4		3		6	
CV (%)	10		23		3	

Values followed by the same letter within a column are not significantly different according to LSD test

** P≤0.001

Note: Cowpea TP – Cowpea trap crop, Sesame TP – Sesame trap crop

Groundnut rosette incidence varied significantly among management strategies and varieties in both sites (Appendix V). Averaged across varieties, incidence at Alupe was comparable between cowpea and sesame trap crops but higher and lower than where roguing and pesticide application respectively, was done. At Siaya, cowpea and pesticide treatments were comparable throughout the sampling period (Table 12). Averaged across sites and varieties, the disease management practices varied significantly in rosette incidence. Insecticide applied plots had the lowest incidence

followed by cowpea and sesame trap crops respectively. Control plots had significantly higher incidence compared to where rogued plots (Table 12).

Table 12 Groundnut rosette incidence (%) across varieties over time in various disease management practices in Siaya and Alupe during the long rain season, 2007

	Groundnut rosette disease (Weeks after planting)													
	Siaya							Alupe						
DMP	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**	**2**	**4**	**6**	**8**	**10**	**12**	**Mean**
Control	9	32	28	26	16	21	**22**	11	23	30	29	26	27	**24**
Roguing	5	16	13	14	13	14	**13**	7	15	20	20	20	20	**17**
Sesame trap crop	2	11	6	7	11	8	**8**	4	15	5	15	11	14	**11**
Cowpea trap crop	2	15	3	5	3	4	**5**	4	14	5	6	9	8	**8**
Pesticide	2	11	2	2	2	2	**4**	2	2	1	2	2	2	**2**
P<0.05	**	*	**	**	**	**		**	**	**	**	**	**	
LSD	2	9	3	6	3	3		2	5	5	9	7	6	
CV (%)	30	16	26	27	14	13		30	6	32	21	39	21	

DMP Disease management practice

** P≤0.001

* P≤0.05

5.3.3 Kernel yield

Yield among management practices were comparable at the two sites. In both sites, highest and lowest yields were obtained in spray and control plots respectively. The yield in groundnut surrounded by cowpea and sesame trap crops was comparable but was significantly lower than where insecticide was sprayed at both sites. Averaged across sites and varieties, yield where roguing was done increased by 42% and 167-255% where insecticide and trap crops were planted (Table 13). The yield in insecticide plots was 20 and 34% higher compared to cowpea and sesame trap crops respectively (Table 13).

There was no significant difference between rouging and control in all varieties at both sites. In ICGV 12991 pesticide, cowpea and sesame treatments were comparable at Alupe but sesame treatment had significantly lower yield than pesticide and cowpea treatment in the same variety at Siaya (Table 14). Pesticide, cowpea and sesame treatments compared well in ICGV-SM 90704 at both sites. In JL-24, pesticide, cowpea and sesame treatments were comparable at Siaya but at Alupe, pesticide had significantly higher yield than all the other treatments (Table 14).

Insecticide application was more profitable since it had the highest marginal return (Table 13). Sesame and cowpea trap crop application were equally profitable since they had equal marginal returns. Roguing had a marginal return less than unity and hence not profitable.

Table 13 **Mean kernel yield, % yield gain and marginal returns of groundnut in response to different disease management practices at Siaya and Alupe**

Treatment	Kernel yield (Kg ha^{-1})	Yield gain	Income of yield gain	Total variable costs	Marginal returns	Yield gain (%)
Control	786					
Pesticide	2791	2005	160400	27400	6	255%
Cowpea trap crop	2330	1544	123520	36000	3	196%
Sesame trap crop	2088	1302	104160	30750	3	165.6%
Roguing	1116	330	26400	32000	0.8	42%

Value of groundnut at the prevailing time was KShs. 80 Kg^{-1}

Table 14 **Groundnut kernel yield (Kg ha^{-1}) response to disease management practices at Siaya and Alupe, during the long rain season, 2007**

	Siaya (Kg ha^{-1})			Alupe (Kg ha^{-1})		
Treatment	ICGV-SM 90704	ICGV 12991	JL-24	ICGV-SM 90704	ICGV 12991	JL-24
Pesticide	2910	2764	3007	3089	2258	2720
Cowpea trap crop	2714	2662	2411	2506	2039	1647
Sesame trap crop	2701	1600	2083	2971	2068	1102
Roguing	1238	1526	784	1136	1254	758
Control	1170	1083	386	941	595	543
P<0.05	<.001	<.001	<.001	<.001	<.001	<.001
LSD (5%)	460	600	604	623	311	557
CV (%)	6	10	12	3	9	2

Values followed by the same letter within a column are not significantly different according to LSD test

5.4 Discussion

Aphid population at Alupe increased with time and was highest at 10 weeks after planting. This was due to low rainfall and high temperature that prevailed during that time thus favoring aphid multiplication (Figures 4 and 5). At Siaya the population increased between 4th and 6th week with little variation thereafter. During this period dry weather prevailed but this was followed by reduction in temperature and increase in the amount of rainfall received (Figures 4 and 5). Rain water washes away aphids from plants thus reducing their multiplication.

In both sites low aphid populations and groundnut rosette disease incidence were observed in spray treatments throughout the sampling period. This is probably due to the fact that dimethoate is systemic and kills all developmental stages of the vector in the whole plant (Gallo and Lawryk, 1991). Low GRD incidence observed could be attributed to reduction in vector numbers and thus lower rate of virus transmission. Studies done by Subrahmanyam *et al.,* (1997), Kyamanywa *et al.,* (1999) and Adipala *et al.,* 2001 showed that application of dimethoate was effective in reduction of aphid infestation and groundnut rosette disease thus resulting to high yields. Their results also showed that three or four dimethoate sprays were economical (had a high marginal rate of return). Studies by Verghese *et al.,* (2007) showed that dimethoate effectively controls *Aphis craccivora* Koch in pawpaw thus delaying the onset of papaya ring spot.

Low aphid populations and groundnut rosette incidence were recorded on groundnut plants surrounded by cowpea and sesame trap crops. This could probably be due to relatively lower temperatures and increased interplant humidity (Nampala *et al.,*

2000). This gave the aphids less chance of residing and multiplying within the crop. Cowpea and sesame could also have acted as alternative hosts and thus reduced chances of groundnut infestation by aphids. Studies by Singh *et al.,* (1991) also showed that sesame reduced aphid infestation in groundnut. This was explained by the fact that sesame has a natural differential attractiveness for oviposition and feeding and is also appealing to aphid landing and attractive to their natural enemies. Sesame could have also acted as a barrier crop since it is taller than groundnut crop. This could have reduced the number of aphids landing on groundnut crop.

Earlier studies showed that when cowpea is attacked by aphids, it responds with a temporal increase in attractivity (Petterson *et al.,* 2003). This probably explains the reduction in aphid population in groundnut surrounded by cowpea. Studies by Sastawa *et al.,* (2005) showed that cowpea effectively controls *Aphis craccivora* Koch in groundnut fields.

Roguing of diseased plants was the least effective strategy in management of aphids and groundnut rosette incidence and had a marginal rate of return less than unity. This is probably because it targets the inoculum source and not the vectors. Ineffectiveness of roguing in management of groundnut rosette disease could also be attributed to disease development of latent infected plants. Studies have shown that roguing is less effective in controlling viruses of hop in Australia unless management options to reduce spread within the field are incorporated (Pethybridge, 2005).

Roguing has also been found ineffective in management of *Plum pox virus* strain M in orchards (Sylvie *et al.,* 2004). This was attributed to exogenous sources of

inoculum as well as infected plants overlooked during visual surveys. Besides, there is the risk of spreading the disease by shaking off aphids or by mechanical spread (Kucharek and Purciful, 2001).

Higher yields were observed in groundnut where disease management strategies reduced aphid populations and groundnut rosette incidence. This is possibly due to lowering of aphid numbers and consequently GRD incidence until the crop became established. This caused a delayed onset of infection and lower rate of disease transmission. On the contrary low yields were obtained from groundnut plots where roguing of plants was done. This is possibly due to presence of inoculum in asymptomatic plants, which resulted in low yields. All the disease management strategies apart from roguing were profitable since each disease management strategy had a marginal rate of return greater than unity.

CHAPTER SIX

6.0 GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1 General discussion

Time of planting had significant effect on aphid populations and GRD incidence and kernel yield. Early planting reduced aphid population, groundnut rosette and increased kernel yields in all groundnut varieties used in this work. This could be due to early crop establishment and ground cover before aphids' invasion. Studies done by Sastawa *et al.,* (2005) also showed that early planting of groundnut reduces aphid infestation. Plant resistance also reduced rosette disease and increased yield. Rosette resistant varieties such as ICGV 12991 and ICGV-SM 90704 showed marked resistance to groundnut rosette disease especially when early planted. Studies done by van der Merwe *et al.,* (2002) showed that ICGV 12991 is resistant to the vector while those done by Naidu *et al.,* (2007) showed that virus accumulation in ICGV-SM 90704 is low. Higher yields were obtained from late-planted rosette resistant varieties compared to susceptible and local checks. Studies by Ntare and Olorunju (2002) also showed that resistant varieties (ICGV-12991 and ICGV-SM 90704) had higher yields even in high disease situation.

Insecticide application effectively controlled aphids and groundnut rosette disease in all varieties even in susceptible ones such as JL-24 and Etesot. This is probably due to reduction in vector numbers and hence groundnut rosette incidence. The results are in agreement with earlier studies done by Adipala *et al.,* (2001) who observed low groundnut rosette incidence in susceptible variety (Etesot) sprayed with dimethoate. Trap crops effectively managed aphid population and groundnut rosette disease in all varieties. There was variability in the effectiveness of trap crops between sites.

Cowpea trap crop was the most effective in Siaya and sesame at Alupe. Groundnut rosette incidence was comparable where insecticide application and trap cropping with cowpea and sesame was done. Trap cropping with plants that are more attractive to the vector than groundnut can therefore be a suitable strategy for resource poor farmers. Although roguing was less effective compared to insecticide and trap crops, it increased yields by 42% in rosette resistant varieties and hence its effectiveness is enhanced when combined with resistant varieties.

Aphid populations were higher at Alupe than at Siaya, possibly because of relatively dry conditions experienced at Alupe at 4 and 6 weeks after planting. *Aphis craccivora* Koch was the most abundant aphid species at Alupe. This is probably due to high temperatures that prevailed during the season. High temperature is positively correlated with fecundity of *Aphis craccivora* Koch (Nandagopal *et al.*, 2004).

6.2 Conclusion

- Groundnut rosette disease can effectively be managed by use of resistant varieties such as ICGV 12991, ICGV-SM 99568 and ICGV-SM 90704. This option is the least expensive and hence very beneficial to resource poor farmers.
- Resistant varieties should be planted early to minimize infestation by groundnut aphid, the vector of groundnut rosette disease.
- Combination of host resistance and minimal sprays when aphid populations are highest and other disease management strategies such as trap crops minimize groundnut rosette disease and increase groundnut yields even in rosette susceptible varieties such as JL-24 and Etesot.
- Use of host plant resistance as a primary component of an integrated disease management strategy is the most practical approach for small-scale farmers.

6.3 Recommendations

- Aphid populations were high during the long rain season and lower during the short rain season at Alupe and therefore short rain season is a better season to plant short duration resistant varieties such as ICGV 12991.
- ICGV-SM 90704 is a long duration (120-140 days) tolerant variety to groundnut rosette disease and is suitable during the long rain season.
- For rosette susceptible varieties such as JL-24 and Etesot, protective measures such as trap cropping with cowpea and sesame and minimal sprays should be considered in order to minimize disease incidence and increase yield.
- Though ICGV 12991 is resistant to the aphid vector, its resistance is broken down when aphid populations are very high e.g. when it is late planted. This variety should therefore be planted early when the vector populations are low.

6.4 Further research

Further studies need to be undertaken in order to establish economic injury levels and action thresholds to guide in integrated management of groundnut rosette disease and its vectors. This is necessary to avoid improper use of chemicals which might alter the balance between aphid vectors and natural enemies which can result in development of insecticide resistant biotypes and environmental pollution. It is also necessary to establish resistance levels of the groundnut varieties to other pests and diseases which greatly reduce yield e.g. leaf miners and leaf spots. Other trap crops should also be evaluated. Studies to determine the incidence of latent form of groundnut rosette disease infection should also be carried out. Studies should be carried out to determine presence of biotypes of *Aphis craccivora* Koch that may be responsible for resistance breakdown in ICGV 12991.

REFERENCES

A'Brook, J. 1964. The effects of planting date and spacing on the incidence of groundnut rosette disease and of the vector, *Aphis craccivora* Koch, at Mokwa, Northern Nigeria. Annals of Applied Biology 54:199-208.

Adipala, E., Ogenga-Latigo, M.W., Kyamanywa, S., Nabirye, J., Wilson, H., Odeke, V. and Iceduna, C. 2001. Integrated Management of Groundnut Insect Pests and Diseases. *In* abstracts of the eighth annual report of the integrated pest management collaborative research support program (IPM CRSP), 28-29 September 2001, Uganda.

Alegbejo, M.D. and Abo, M.E. 2002. Etiology, ecology, epidemiology and control of groundnut rosette disease in Africa. Journal of Sustainable Agriculture 20:17.29.

Ansa, O.A., Kuhn, C.W., Misari, S.M., Demski, J., W., Casper, R. and Breyel, E. 1990. Single and mixed infections of groundnut (peanut) with Groundnut rosette virus and Groundnut rosette assistor virus (Abstr.). Peanut Research Education Society 22:40.

Anonymous, 1996. SADC/ICRISAT Groundnut Project Annual Progress Report for 1996. Chitdze Research Station, PO Box 1096, Lilongwe, Malawi.

Badenes-Perez, F., Shelton, R., Anthony, M. and Brian, A. 2004. Evaluating Trap Crops for Diamondback Moth, Plutella xylostella (Lepidoptera: Plutellidae). Journal of economic entomology. 97:1365-1372.

Blackman, R.L. and Eastop, V.F. 2000. Aphids on the World's crops: An identification and information guide, 2nd edn. Wiley, Chichester, 466 pp.

Blackman, R.L. and Eastop, V.F. 2006. Aphids on the World's herbaceous plants and shrubs. Wiley, Chincheser, 1439pp.

Blok, V.C., Ziegler, A., Robinson, D.J. and Murant, A.F. 1994. Sequences of 10 variants of the satellite-like RNA-3 of groundnut rosette virus. Virology 202:25-32.

Bock, K.R., Murant, A.F. and Rajeshwari, R. 1990. The nature of the resistance in groundnut to rosette disease. Annals of Applied Biology 117:379-384.

Brunt, A.A, Crabtree, K., Dallwitz, M.J., Gibbs, A.J., Watson, L., Zurcher, E.J. and editors. 1996. Plant Viruses Online: Descriptions and Lists from the VIDE Database. Version: 20th August. http://biology.anu.edu.au/Groups/MES/vide.

Bryan, M., That's not just peanuts. 2006. The Peanut Institute, Virginia Carolina Peanuts Website about Peanuts, Texas AG experimental station. http://www.medicinalfoodnews.com/vol07/issue4/peanuts

CAB International. 2004. Crop Protection Compendium, Global Module, 2004 Edition. CABI Publishing, Wallingford, UK.

Casper, R., Meyer, S., Lesemann, D.E, Reddy, D.V.R., Rajeshwari, R., Misari, S.M, and Subbarayudu, S.S. 1983. Detection of a luteovirus in groundnut rosette diseased groundnuts by enzyme-linked immunosorbent assay and inimunosorbent assay and ininiunoelectron microscopy. Phytopathologische Zeitschrift 108:12- 17.

Cerruti, R.R. and Alberto, F. 2006. Protecting crops from non-persistenttly aphid-tranmsitted viruses: A review on the use of barrier plant as a management tool. 2006. Virus Research 120:1-16

Ciancio, A., Mukerji, K. G. 2007. Integrated Management Of Insect Borne Viruses By Means Of Transmission Interference As An Alternative To Pesticides. General Concepts in Integrated Pest and Disease Management 11:269-293.

Coffelt, T. A. and Simpson, C. E. 1997. Taxonomy of the genus *Arachis*. Pages 2-3 *In*: Compendium of Peanut Diseases, Second Edition.

De Waele, D. and Swanevelder, C. J. 2001. Crop Production in Tropical Africa: 747-762.

Dean, J. 2004. Smoke point of olive oil. www.oliveoilsource.com/olive_oil_smoke_point.htm

Demese, C., Rop, I.K. and Maritim, H.K. 1997. Vegetable Oils/Protein Production to Consumption System Analysis in Kenya. Workshop. *Proceedings on Vegetables* Oil/*Protein System,* 29th -30th April .1997. Egerton University, Njoro.

Deom, C. M., Naidu, R. A., Chiyembekeza, A. J., Ntare, B. R. and Subrahmanyam, P. 2000. Sequence diversity within the three agents of groundnut rosette disease. Phytopathology 90:214-219.

Deom, C. M, Kapewa, T. C., Busolo-Bufalu, M., Naidu, R. A., Chiyembekeza, A. J. , Kimmins, F. M., Subrahmanyam, P. and Van Der Merwe, P. J. A. 2006. Registration of ICGV 12991 Peanut germplasm line. Crop Science. 46:481.

Dixon, A. F. G. 1985. Structure of aphid populations. Annual Review of Entomology 30:155-174.

Evans, Edward. 2005. Marginal Analysis: An Economic Procedure for Selecting Alternative Technologies/Practices. Available online at www.cimmyt.org.

Ejigui, J., Savoie, L., Marin, J. and Desrosiers, T. 2005. Influence of traditional processing methods on the nutritional composition and antinutritional factors of red peanuts (*Arachis hypogaea*) and small red kidney beans (*Phaseolus vulgaris*). Journal of Biological Sciences 5:597–605.

Farrell, J. A. K. 1976. Effects of groundnut sowing date and plant spacing on rosette virus disease in Malawi. Bull. Entomological Research 66:159-171.

Falk, B. W., Tian, T. Vector–virus interactions: transcapsidation interactions and dependent aphid transmission among luteoviruses, and luteovirus-associated RNAs. 1999. *In*: Smith HG, Barker H. editors. The Luteoviridae. Wallingford, the United Kingdom: CAB International; p. 125–34.

FAO 2006. FAO Production Yearbook, Vol.60, Rome, Italy.

FAOSTAT. 2003-2006. www.faostat.org.

Fasoyiro, S.B., Ajibade, S.R., Omole, A. J., Adeniyan, O.N. and Farinde, E. O. 2006. Proximate, minerals and antinutritional factors of some underutilized grain legumes in south-western Nigeria. Journal of Nutrition & Food Science 36: 18-23.

Freeman, H.A., van der Merwe, P.J.A., Subrahmanyam, P., Chiyembekeza, A.J. and Kaguongo, W. 2002. Assessing adoption potential of new groundnut varieties in Malawi. Working Paper Series no. 11. Socioeconomics and Policy Program, International Crops Research Institute for the Semi-Arid Tropics. 16 pp.

Gallo, M. A. and Lawryk, N. J. 1991. Organic phosphorus pesticides. In Handbook of Pesticide Toxicology. Hayes, W. J., Jr. and Laws, E. R., Jr., Eds. Academic Press, New York, NY, 5-3.

Gibbons, R.W. 1977. "Disease, Pests and Weeds in Tropical Crops: Groundnut Rosette Virus." In J. Cranz, J. Schutter, and W. Koch, eds. Diseases of Tropical Crops. Berlin: Verlag Paul Parey, pp. 19–21.

Haciwa, H. C. and Kannaiyan J. 1990. Prevalence of groundnut diseases and extent of yield losses due to leaf spot diseases in Zambia. Pages 93–97 *in* Proceedings

of the 4th Regional Groundnut Workshop for Southern Africa, 19–23 March 1990, Arusha, Tanzania. ICRISAT, Patancheru, India.

Hagan, A.K., Weeks, J.R. and Hartzog, D. 2005. Peanut. Insect, disease, nematodes and weed control recommendations. http://www.aces.edu/pubs/docs/A/ANR-0369.pdf

Hail K. Shannag (Jordan). 2007.Effect of black bean aphid, Aphis fabae, on transpiration, stomatal conductance and crude protein content of faba bean. Annals of Applied Biology 15: 183-188.

Herrbach, E. 1999. Vector-virus interactions: Introduction. In: Smith HG, Barker H, editors. The Luteoviridae. Wallingford, The United Kingdom: CAB International; p. 5–8.

Hilderbrand, G. L., Subrahmanyan, P. 1994. Genetic Enhancement of Groundnuts: Its role in sustainable Agriculture. Seminar proceedings on sustaining soil productivity in intensive African Agriculture 15-19 November 1993, Accra, Ghana, Technical Center for Agricultural and rural crop, The Netherlands, pp 5-12.

Hill, G.M. 2002. Peanut by-products fed to cattle. Veterinary Clinics of North America - Food Animal Practice 18:295.315.

Horne, C.W. 2005. Peanut disease control alternatives – a guide for producers. The Texas Agricultural Extension Service. The Texas A& M University System. Texas.

Hui, Y.H. 1996. Peanut oil. Bailey's Industrial Oil and Fat Product 2:337-392.

Hull, R., 1964. Spread of Groundnut rosette virus by *Aphis craccivora* (Koch). Nature 202:213–214.

Hunter, D.G., 2005. Nonpesticide Methods for Sustainable Crop Disease Management in the Asia-Pacific Region: Present Status, Issues and Strategies Nonpesticide Methods for Controlling Diseases and Insect Pests Bulletin 92-833-7037-6.

International Crop Research Institute for Semi-Arid Tropics, (ICRISAT). 2005. "Management of Groundnut Rosette: Past, Present, and Future." http://www.icrisat.org/text/research/grep/homepage/grephomepage/archives/rosette.html.

ICTV dB Management (2006). 00.078.0.01.005. Groundnut rosette virus. In: *ICTVdB - The Universal Virus Database*, version 4. Büchen-Osmond, C. (Ed), Columbia University, New York, USA

James, C. K., Keith, L., Perry, N. G. 2004.Transmission of plant viruses by aphid vectors. Molecular Plant Pathology. 5: 505 - 511

Javaid, I., Joshi, J. M.1995. Trap Cropping in Insect Pest Management. Journal of Sustainable Agriculture 5: 117-136.

Jeger, M. J. 2004. Analysis of disease progress as a basis for evaluating disease management practices. Journal of Annual Review of Phytopathology 42: 61-82.

Jones, M G. 1967. Observations on two races of the groundnut aphid, *Aphis craccivora*. Entomologia Experimentalis et Applicata 10:3 1-38.

Jonnala, R.S, Dunford, N.T. and Dashiell, K.E. 2005. New higholeic peanut cultivars grown in the Southwestern United State. Journal of the American Oil Chemists' Society 82:125–128.

Julia, M.F., Roberts, G. and Thottappily, C.J. 2008. The ability of *Aphis craccivora, A. gossypii* and *A. citricola* to transmit single and mixed viruses to cowpea. Journal of Phytopathology 138: 164-170.

Kannaiyan, J. and Haciwa, H.C. 1993. Diseases of food legume crops and the scope for their management in Zambia. FAO Plant Protection Bulletin 412:73–90.

Kamidi, M., Wanjekeche, E., Omamo, B., Okumu M. and Wanyonyirr M. 2005. 'Grow and eat groundnuts'. Kenya Agricultural Research Institute Bulletin.

Karungi, J. 2002. Pest management in cowpea. Influence of planting time and plant density on cowpea field pests infestation in Eastern Uganda. Crop protection 19:231-236.

Kees, S. and Orivaldo, B. 2006. Agrometeorology and groundnut production. Journal of agronomy 52: 112-115

Kersting, U., Satar, S., Uygun, N. 1999. Effect of temperature on development rate and fecundity of apterous Aphis gossypii Glover Glover (Hom., Aphididae) reared on Gossypium hirsutum L. Journal of Applied Entomology, 123: 23–27.

Kimminis, F., M., Naidu, R., A., van der Merwe, P., J., Minja, E., Subhahmanyam, P. 1999. Groundnut disease: a virus disease affecting the sustainability of groundnut production in sub-Saharan Africa. Plant Disease 83: 700-709

Kishore, G. and Pande, S. 2005. Integrated management of late leaf spot and rust diseases of groundnut (*Arachis hypogaea* L.) with *Prosopis juliflora* leaf extract and chlorothalonil. International Journal of Pest Management 51:327–334.

Kokalis-Burelle, N., Porter, D.M., Rodriguez-Kabana, R., Smith, D.H. and Subrahmanyam, P. 1997. Compendium of peanut diseases. APS PRESS. The American Phytopathological Society, Minnesota, USA.

Kumar, I., Murant, A., F. and Robinson, D. J. 1991. A variant of the satellite RNA of groundnut rosette virus that induces brilliant yellow blotch mosaic symptoms in Nicotiana benthamiana. Annals of Applied Biology 118:555-564.

Kyamanywa, Mukankusi, C., Adipala, E., G., Epieru, V., Odeke, H. L., Warren, H. R., Wilson. 1999. Efficacy and economic benefit of different chemical spray regimes on the management of the major pests and diseases of groundnut in Eastern Uganda. African Journal of Plant Protection 9: 69-81.

Maguire, L.S., O'Sullivan, S.M., Galvin, K., O'Connor, T.P. and O'Brien, N.M. 2004. Fatty acid profile, tocopherol, squalene and phytosterol content of walnuts, almonds, peanuts, hazelnuts and the macadamia nut. International Journal of Food Sciences and Nutrition. 55:171–178.

Manya, B., Gary, L., Miller, Patti, J. and O'Brien, J.B. 1996. Aphids (Homoptera: Aphididae) colonizing cotton in the United States. Florida Entomologist 79:2.

Marion, A., Watson, Bolajoko, A.M., Okusanya. 2008. Studies on the transmission of groundnut rosette virus by *Aphis craccivora* Koch. Annals of applied biology 60: 199-208.

Martin, J. H. 1983. The identification of common aphid pests of tropical agriculture. Tropical pest management 29:395-411.

Melouk, Hassan, Frederick and Shokes, (eds.) 1995 Peanut Health Management. St. Paul, Minnesota: APS Press.

Merwe, van der, P.J.A., Subrahmanyam, P., Kimmins, F.M. and Willekens, J. (2001). Mechanisms of resistance to groundnut rosette. International Arachis Newsletter 21: 43-45.

Ministry of Agriculture. 2004b. *Annual report 2004*, Nyanza Province. Kisumu, Kenya.

Ministry of Agriculture. 2004a. *Annual report 2004*, Western Province. Kakamega, Kenya.

Mukankusi, C., Adipala, E., Kyamanywa, G., Epieru, V., Odeke, H. L., Warren, H. R., Wilson. 1999. Effect of host genotype, time of planting and spacing on epidemics of groundnut rosette and Cercospora leaf spot diseases in Eastern Uganda. Plant Protection 9: 37-53

Murant, A. F., Rajeshwari, R., Robinson, D. J., Raschke, J. H. 1988. A satellite RNA of groundnut rosette virus that is largely responsible for symptoms of groundnut rosette disease. Journal of General Virology 69:1479-1486.

Murant, A.F. 1990. Dependence of groundnut rosette virus on its satellite RNA as well as on groundnut assistor Luteovirus for transmission by *Aphis craccivora.* Journal of General Virology 719: 2163–2166.

Murant, A.F., Robinson, D.J., and Gibbs, M. J. 1995. Genus Umbravirus in: Virus Taxonomy—Classification and Nomenclature of Viruses. Sixth Rep. Int. Comm. Taxon. Viruses. F. A. Murphy, C. M. Fauquet, D. H. L. Bishop, S. A. Ghabrial, A. W. Jarvis, G. P. Martelli, M. A. Mayo, and M. D. Summers, eds. Springer-Verlag, Vienna. Pages 388-391

Murant, A.F., Robinson, D.J. and Taliansky, M.E. 1998. Groundnut rosette virus. AAB Descriptions of Plant Viruses No 355.

Murant, Kumar, Robinson, p.7, in: Groundnut Virus Diseases in Africa, Proc. 4th Meeting Consult. Gp Collab. Res. Groundnut Rosette Virus Disease, Montpellier, France 1990, ICRISAT, 1991.

Murant, A.F., Kumar, I.K, Robinson D.J. 1991. Current research on groundnut rosette at SCRI. In Groundnut Virus Diseases in Africa: Summary Proceedings of the Consultative Group Meeting, 18-20 September 1990, Montpellier, France, pp. 7-8. Patancheru, Andhra Pradesh 502 324, India: ICRISAT.

Murant, A.F., Kumar, I.K. 1990. Different variants of the satellite RNA of Groundnut rosette virus are responsible for the chlorotic and green forms of groundnut rosette disease. Ann Appl Biol 117:85–92.

Mustafa, T., Samara, R. Y. 2005. Effect of temperature on the reproduction of the black bean aphid *Aphis fabae* Scopli (Homoptera: Aphididae). Arab Journal of Plant Protection 92: 147-156

Naidu, R.A., Kimmis, F.M., Deom, C.N., Subrahmanyam, P. and Thresh, J.M. 1998. Epidemiology of groundnut rosette virus disease: Current status and future research needs. Annals of the Applied Biology 132: 525-548.

Naidu, R.A., Kimmins, F.M., Holt, J., Robinson, D.J., Deom, C.M. and Subrahmanyam, P. 1999. Spatiotemporal separation of groundnut rosette disease agents. Phytopathology 89:934–941.

Naidu, R.A., Kimmins, F.M., Deom, C.M., Subrahmanyam, P., Chiyembekeza, A.J. and Van der Merwe, P.J.A. 1999. Groundnut rosette: a virus disease affecting groundnut production in sub-Saharan Africa. Plant Disease 83:700-709.

Naidu, R.A, Robinson, D.J, Kimmins, F.M. 1998. Detection of each of the causal agents of groundnut rosette disease in plants and vector aphids by RT-PCR. Journal Virology Methods 76:9–18.

Naidu, R.A., Kimmins, F.M., Robinson, D.J., Subrahmanyam, P. and van der Merwe, P.J.A. 1999. Plant age and inoculum dose dependent resistance in peanut cultivars to groundnut rosette virus disease and aphid vector. Phytopathology 89:55 (Abstract).

Naidu, R.A., Kimmins, F.M. 2007. The effect of groundnut rosette assistor virus on the groundnut performance of four groundnut (*Arachis hypogaea* L.) varieties. Journal of Phytopathology 155: 350–356.

Nandagopal, V., Gedia, M. V. and Makwana, A. D. 2004. Population dynamics of aphids (*Aphis craccivora* Koch and *Hysteroneura setariae* Thomes) in relation with weather parameters in groundnut, *Arachis hypogaea* L. Journal of Oilseeds Research 21:98–103.

Nigam, S.N., Dwivedi, S.L. and Gibbons, R.W. 1991. Groundnut breeding: Constraints, achievements and future possibilities. Plant Breeding Abstracts 61: 1127–1136.

Nigam, S. N., Nageswara Rao, R.C. and Wright, G.C. 2001. Breeding for increased water-use efficiency in groundnut. Pages 1–2 in Abstracts, New Millenium International Groundnut Workshop, 4–7 September 2001, Shandong, China. Qingdao, China: Shandong Peanut Research Institute.

Nwokolo, E., 1996. Peanut (*Arachis Hypogaea* L.). In Food and Fee from Legumes and Oilseeds. Nwokolo E. and Smartt J., eds. Pp. 49-63. New York: Chapman and Hall.

Ntare, B. R. and Olorunju, P. E. 2001. Variations in yield and resistance to groundnut rosette disease in early and medium maturing groundnut varieties in Nigeria. African Crop Science Journal 9:451–464.

Ntare, B. R., Olorunju, P. E. and Hildebrand, G. L. 2002. Progress in breeding early maturing peanut cultivars with resistance to groundnut rosette disease in West Africa. Peanut Science 29:17-23.

Nwokolo, E. and Smartt J. 1996. Peanut (*Arachis hypogaea* L.). *In*: Food and Fee from Legumes and Oilseeds., Eds. Pp. 49-63. New York: Chapman and Hall. ODA (Overseas Development Administration). 1984. Annual report no.13. Response of groundnut to the distribution of rainfall or irrigation. Nottingham, UK: University of Nottingham.

Okusanya, B.A.M, Watson, M.A. 1966. Host range and some properties of groundnut rosette virus. Annals of Applied Biology 58:377-387.

Oumarou, H., Ejoh, R., Ndjouenkeu, R., and Tanya, A. 2005. Nutrient content of complementary foods based on processed and fermented sorghum, groundnut, spinach, and mango. Food and Nutrition Bulletin 26:385–392.

Olorunju, P.E., Kuhn, C.W., Demski, J.W., Misari, S.M. and Ansa, O.A. 1991. Disease reaction and yield performance of peanut varieties grown under groundnut rosette and rosette-free field environments. Plant Disease 75:1269-1273.

Olorunju, P.E., Kuhn, C.W., Demski, J.W., Misari, S.M. and Ansa, O.A. 1992. Inheritance of resistance in peanut to mixed infections of groundnut rosette virus (GRV) and groundnut rosette assistor virus and a single infection of GRV. Plant Disease 76:95-100.

Olorunju, P.E., Ntare, B.R., Pande, S., and Reddy, S.V. 2001. Additional sources of resistance to groundnut rosette diseases in groundnut germplasm and breeding lines. Annals of Applied Biology 139: 259–268.

Olorunju, P.E. and Ntare, B.R. 2002. Combatting viruses and virus diseases of groundnut through the use of resistant varieties: A case study of Nigeria.

Osiru, M. O., Monyo, E. S., Waliyar, F. and Charlie, H. J. Screening groundnut varieties for resistance to the groundnut rosette disease. Abstract in 10th International plant virus epidemiology symposium: Controlling epidemics of emerging and established plant virus diseases – the way forward, 15-19 October 2007, ICRISAT, Pantacheru, India.

Pattee, H. and Stalker, H. T. 1995. Advances in peanut science. American Peanut Research and Education Society, Inc., Stilwater, OK 74078, USA.

Pettersson, J., Karunaratne, S., Ahmed, E., Kumar, V. 2003. The cowpea aphid, *Aphis craccivora,* host plant odours and pheromones. Entomologia Experimentalis et Applicata 88**:** 177–184.

Pethybridge, S. J. 2005. Epidemiology and management of viruses of hop in Australia. Acta Horticulturae. (ISHS) 668:131-142.

Perring, Thomas, M., Gruenhagen, Ned M., Farrar, Charles, A. 1999. Management of plant viral diseases through chemical control of insect vectors. Journal of Annual Review of Entomology 44:457-481.

Perrin, R. M., Phillips, M. L. 2006. Some effects of mixed cropping on the population dynamics of insect pests. Journal of Entomologia Experimentalis et Applicata 24 : 585-593.

Pretorius, A.E. 2005. ARC-GCI Groundnut Department Progress Report, Potchefstroom, South Africa.

Querci, M., Owens, R. A., Bartolini, I., Lazarte, V., Salazar, L. F. 1997. Evidence for heterologous encapsidation of potato spindle tuber viroid in particles of potato leafroll virus. Journal of General virology 78:1207.

Robinson, D.J., Ryabov, E.V., Raj., S.K., Roberts, I.M. & Taliansky, M.E. 1999. Satellite RNA is essential for encapsidation of groundnut rosette umbravirus RNA by groundnut rosette assistor luteovirus coat protein. Journal of virology 254: 105-114.

Roger, A.C. Jones. 2004. Developing integrated disease management strategies against non-persistently aphid-borne viruses: A model program. Journal of Integrated Pest Management Reviews: 6: 15-46.

Rop, I. K., Ouma, S. & Ogoye, H. 1996. Production Structure of Vegetable Oil crops in Kenya, final Report. Unpublished. VOPSK Project, Egerton University, Njoro.

Sanders, T. H., Caballero, B., Trugo, L. and Finglas, L. 2003. Groundnut oil. Encyclopedia of Food Science and Nutrition 2967-2974.

Sastawa, B. M., Lawan, M. & Maina, Y. T. 2003. Management of insect pests of soybean: effects of sowing date and intercropping on damage and grain yield in the Nigerian Sudan savanna. Crop Protection 23:155-161

Sastawa, B.M., Maina, Y.T. and Lawan, M. 2005. Effects of sowing date modification and intercropping on the distribution of *Aphis craccivora* Koch (Hemiptera: Aphididae) in groundnut (*Arachis hypogaea*) in the Nigerian Sudan Savanna and implications for management. International Journal of Agriculture and Biology 7:298–303.

Scott, K.P., Farmer, M..J, Robinson, D.J, Torrance, L., Murant, A.F. 1996. Comparison of the coat protein of groundnut rosette assistor virus with those of other luteoviruses. Annals of Applied Biology 81: 141-145

Simpson, C.E., Krapovickas, A., and Valls, J. F. M. 2001. History of *Arachis* including evidence of *A. hypogaea* L. progenitors. Peanut Science. 28:78-80.

Simpson, C.E., Higgins, D.L., Thomas, G.D., Howard, E.R., 1992. Catalog of passport data and minimum descriptors of *Arachis hypogaea* L. germplasm collected in South America, 1977–1986. Texas Agricultural Experiment Station, MP-1737.

Shahzad, M. K., Shah, Z. A., Anjum Suhail. 2003. Population dynamics of gram aphid (*Aphis craccivora*) and cotton aphid (*Aphis gossypii Glover*) in relation to climatic conditions. Pakistan Entomologist, 25: 77-84.

Shelton, A. M. and Badenes-Perez, F.R. 2006. Concepts and applications of trap cropping in pest management. Annual Review of Entomology Vol. 51: 285-308.

Shokes, F. M. and Culbreath, A. K. 1997. Early and late leaf spot. Compendium of Peanut Diseases 17-20.

Singh, T. V. K., Sing, K. M., Singh, R. N. 1991. Influence of intercropping. I. Incidence of major pests in groundnut (*Arachis hypogaea*) Linn. Indian Journal of Entomology 53: 18-44.

Singh, F., Oswalt, D. L., Nagur, T. 1992. Major diseases of groundnut. ICRISAT Human development program. Skills Development Series No. 1

Smith, A.F., 2002. Peanuts: The Illustrious History of the Goober Pea. Chicago: University of Illinois Press.

Stalker, H. T. 1997. Improvement in grain legumes. Field Crops Research. 53: 205-217.

Storey, H. H., Ryland, A. K. 1957. Viruses causing rosette and other diseases in groundnuts. Annals of Applied Biology 45:319-326.

Subrahmanyam, P, Hildebrand, G.L, Naidu, R.A., Reddy, L.J., Singh, A.K. 1998. Sources of resistance to groundnut rosette disease in global groundnut germplasm. Annals of Applied Biology 132:473-485.

Subrahmanyam, P. and Hildebrand, G.L. 1994. Integrated disease management: an important component in sustaining groundnut production in the SADC Region. In: Sustainable Groundnut Production in Southern and Eastern Africa: Proceedings of a Workshop, 5-7 July 1994. Mbabane, Swaziland.

Subrahmanyam P., van Wyk, P.S., Kisyombe, C.T., Cole, D.L., Hildebrand, G.L., Chiyembekeza, A. J., van der Merwe, P. J. A. 1997. Diseases of groundnut in the Southern African Development Community Region and their management. International Journal of Pest Management 43:261-273.

Subrahmanyam, P., Greenberg, D.C, Savary, S., Bosc, J.P. 1991. Diseases of groundnut in West Africa and their management: research priorities and strategies. Tropical Pest Management 37:259-269.

Subrahmanyam, P., Kannaiyan, J., Cole, D.L., Saka, V. W., Rao, Y. P. and Mphiri, M. G. 1992. Effects of cultural practices on diseases of groundnut. *In*: *Proceedings of the Fifth Regional Groundnut Workshop for Southern Africa.* 9-12 March 1992, Lilongwe, Malawi. Nageswara Rao, R.C. and Subrahmanyam, P. (Eds.), pp. 97-103, ICRISAT, Patancheru, Andhra Pradesh 502 324, India.

Subrahmanyam P., van Wyk P. S. , Kisyombe C. T., Cole D. L., Hildebrand G. L., Chiyembekeza A. J., van der Merwe P. J. A. 1997. Diseases of groundnut in the Southern African Development Community (SADC) region and their managementInternational journal of pest management. 43: 261-273

Subrahmanyam, P., van der Merwe, P. J. A., Reddy, L. J., Chiyembekeza, A. J., Kimmins, F.M., and Naidu, R. A. 2000. Identification of elite short-duration

rosette resistant lines in world germplasm collections. Int. Arachis Newsl. 20:46–50.

Subrahmanyam, P., Hildebrand, G. L., Naidu, R. A. and Reddy, J. L. 1998. Sources of resistance to groundnut rosette disease in global groundnut germplasm. Annals of Applied Biology 132: 473–485.

Subrahmanyam, P., van der Merwe, P.J.A., Chiyembekeza, A.J., Chandra S. 2002 Integrated management of groundnut rosette disease African Crop Science Journal 10:99-110

Syller, J. 2000. Heterologous encapsidation in transmission of plant viral particles by aphid vectors. Acta Microbiologica Polonica 49: 5–18.

Sylvie Dallot, Tim Gottwald, Gérard Labonne, and Jean-Bernard Quiot 2004. Factors Affecting the Spread of *Plum pox* virus Strain M in Peach Orchards Subjected to Roguing in France. Phytopathology 94:1390-1398

Taliansky, M. E., Robinson, D. J., and Murant, A. F. 1996. Complete nucleotide sequence and organization of the RNA genome of groundnut rosette umbravirus. Journal of General Virology 77:2335-2345.

Taliansky, M. E., Robinson D. J., Murant AF. 2000. Groundnut rosette disease virus complex: biology and molecular biology. Adv Virus Res 55:357–400.

Taliansky, M. E., Robinson, D. J. 2003. Molecular biology of umbraviruses: phantom warriors. Journal of General Virology 84:1951–1960.

Termorshuizen, A.J. 2002. In "Plant Pathologist's Pocketbook", pp. 318-327, eds, J.M. Waller, J.M. Lenné and S.J. Waller. (CAB International, Wallingford, UK).

Thomas, A., Lee Jr., Wendell Horne, C., and Mark C. B. 2004. Website resource: "Peanut Disease Atlas" website.

van der Merwe, P., Kimmins, F.M., Busolo-Bufalu, C., Naidu, R.A. and Subrahmanyam, P. (2002) Evaluation of Groundnut Rosette Resistant Varieties and Impact on Farmers' Livelihoods in the Teso System of Uganda pp. 47-48 In: Summary Proceedings of the Seventh ICRISAT Regional Groundnut Meeting for Western and Central Africa, 6-8 December 2000 Cotonou, Benin. Wailiyar, F. and Adomou, M. (Eds.).

van der Merwe, P.J.A., Subrahmanyam, Freeman, H.A., P., Chiyembekeza, A.J., and Kaguongo, W. 2002. Assessing adoption potential of new groundnut varieties in Malawi. Working Paper Series no. 11. P O Box 39063, Nairobi, Kenya: Socioeconomics and Policy Program, International Crops Research Institute for the Semi-Arid Tropics. 16 pp.

van Wyk, P. S. and Cilliers, A. J. 2000. Grondboonsiektes en –plae/Groundnut diseases and pests. ARC Grain Crops Institute, Potchefstroom, SA.

Verghese, A., Kalleshwaraswamy, C. M. and Anil Kumar, H. R. 2007. Pests of papaya and their management with special reference to aphid vectors. Acta Horticulturae. (ISHS) 740:259-264.

Wangai, A. W., Pappu, S. S., Pappu, H. R., Deom, C. M., and Naidu, R. A. 2001. Distribution and characteristics of groundnut rosette disease in Kenya. Plant Disease 85:470-474.

Watson, M. A., and Okusanya, B. A. M. 1967. Studies on the transmission of groundnut rosette virus by *Aphis craccivora* Koch Annals of Applied Biology. 60:199-208.

William, I. S., Dewar, A. M. & Dixon, A. F. G. 1998. The influence of size and duration of aphid infestation on host plant quality, and its effect on cowpea and groundnut. Entomologia experimentalis et applicata, 89: 25-33.

Weeks, J. R., Hagan, A. K., Hartzog, D., Everest, J. W., and Wehje G. 2006. Peanut insect, disease, nematode, and weed control recommendations. AL Coop. Ext. Sys. Cir. IPM: 360.

Weiss, E.A. 2000. Oilseed crops. London: Blackwell synergy.

Wynne, J. C., Beute, M. K., and Nigam, S. N. 1991. Breeding for disease resistance in peanut (*Arachis hypogaea* L.). Ann. Rev. Phyotpath. 29:279-303.

Yaranal, R. S. and Guruswamy, T. 2005. Performance of I.C. engine using blends of groundnut oil. Mysore Journal of Agricultural Sciences 39(3):294–299.

Yayock, J. Y., Rossel, H. W., and Harkness, C. 1976. A review of the 1975 groundnut rosette epidemic in Nigeria. Sumaru conference Paper 9. Institute of Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.

Zamani, A. A., Talebi, A. A., Fathipour, Y., Baniameri, V. 2006. Effect of temperature on biology and population growth parameters of *Aphis gossypii Glover* Glov. (Hom., Aphididae) on greenhouse cucumber. Journal of Applied Entomology, 130: 453–460.

APPENDICES

Appendix I. Analysis of variance of effect of planting time and varietal resistance on aphid population at Siaya and Alupe

	Mean sums of square											
	Early planting							Late planting				
	Weeks after planting							Weeks after planting				
Source of variation	df	2	4	6	8	10	12	2	4	6	8	10	12
Block	2	0.533	25.73	1.233	12.1	10.03	11.033	32.7	17.358	6.43	16.03	126.1	12.933
Site	1	83.333**	2.7	40.833	24.3*	554.7**	202.8**	496.133**	323.408**	554.7**	140.83*	529.2*	313.633**
Variety	4	20.783*	17.37	45.917*	39.533**	72.28*	50.45**	45.283*	71.429**	72.87*	37.08	124.47	37.154*
Site.Variety	4	1.917	16.7	5.917	3.3	22.12	2.633	7.717	17.179	6.2	3.42	44.53	9.279
Residual	168	2.793	18.14	5.307	1.581	17.14	4.57	6.737	7.794	10.4	23.4	50.88	9.841

df degrees of freedom

** $P \leq 0.001$

* $P \leq 0.05$

Appendix II. Analysis of variance of effect of planting time and varietal resistance on groundnut rosette incidence at Siaya and Alupe

		Mean sums of square					
		Weeks after planting					
Source of variation	**df**	**2**	**4**	**6**	**8**	**10**	**12**
Block	2	3.267	14.48	8.02	10.2	13.43	13.2
Site	1	1372.817**	192.6**	984.15**	495*	664.45*	288.94*
Planting time	1	1188.15**	683.44**	889.35*	1450.4**	1463.56**	1421.07**
Variety	4	204.9**	11.66	1815.9**	2154.7**	1913.53**	1596.1**
Site x Planting time	1	843.75**	133.5*	228.15	268.8	21.2	306.76*
Site x Variety	5	13.067	10.59	20.98	89.6	37.54	212.26*
Planting time x Variety	5	25.067*	77.14*	4.18	153.3	75.94	273.43*
Site x Planting time x Variety	5	139.333*	93.14	488.93	502.8	207.68	399.87
Residual	118	7.67	13.79	72.67	107.5	91.01	64.38

df degrees of freedom

** $P \leq 0.001$

* $P \leq 0.05$

Appendix III. **Analysis of variance of effect of planting time and varietal resistance on groundnut yield at Siaya and Alupe**

		Mean sums of square	
Source of variation	**df**	**Siaya**	**Alupe**
Block	1	0.1054	0.4263**
Planting time	1	12.4193**	9.4337**
Variety	5	1.562**	1.2065*
Planting time.Variety	5	0.3525*	0.325

Mgt prac=Disease management strategy; df=degrees of freedom, ** P≤0.001; * P≤0.05

Appendix IV. **Analysis of variance of effectiveness of disease management strategies on aphid population at Siaya and Alupe**

		Mean sums of square (Weeks after planting)					
Source of variation	**df**	**2**	**4**	**6**	**8**	**10**	**12**
Block	2	10.411	31.033	150.98	14.34	158.8	69.21
Site	1	24.544*	117.878**	100.28	31.21	3186.2**	764.17**
Mgt Prac	4	42.428**	102.889**	628.47**	438.25**	2051.6**	1064.31**
Variety	2	4.578	0.233	81.48	122.81*	722.2**	337.58**
Site x Mgt Prac	4	2.739	13.711*	50.64	15.41	148.6	29.44
Site x Variety	2	6.578	3.411	44.48	0.48	155	37.33
Mgt_Prac x Variety	8	6.536*	8.581	55.05	43.16*	191.5	49.96
Site x Mgt Prac x Variety	8	2.147	3.119	53.55	37.21	44	23.03

Mgt prac=Disease management strategy; df=degrees of freedom, ** P≤0.001; * P≤0.05

Appendix V. **Analysis of variance of effectiveness of disease management strategies on groundnut rosette disease incidence at Siaya and Alupe**

		Mean sums of square					
		Weeks after planting					
Source of variation	**df**	**2**	**4**	**6**	**8**	**10**	**12**
Block	2	113.2	90.6	87.5	170.4	326.29	21.84
Site	1	48.4	233.6	71.1	264.7	488.45*	1412.17*
Mgt Prac	4	465.96**	1067**	2346.6**	1853.4**	1063.68**	1291.84**
Variety	2	162.9*	1881.6**	457.7*	1251.2**	1357.45**	35.04**
Site x Mgt Prac	4	44.15	167.2	52.6	47.1	94.84	140.92
Site x Variety	2	20.63	166.7	138.4	282	16.13	117.03*
Mgt Prac x Variety	8	11.14	351.9*	69.5	178.2	121.99*	89.49*
Site x Mgt Prac x Variety	8	11.92	130.3	47.3	249.3*	31.74	39.61*

Mgt prac=Disease management strategy; df=degrees of freedom, ** P≤0.001; * P≤0.05

Appendix VI **Analysis of variance of effectiveness of disease management strategies on groundnut yield at Siaya and Alupe**

		Siaya	Alupe
Source of variation	**df**	**Mean sum of square**	**Mean sum of square**
Block	2	612913	59475
Planting time	1	6912854**	6001890**
Variety	2	639040*	2299323**
Planting time.Variety	2	342809*	434451**

df =degrees of freedom; ** P≤0.001; * P≤0.05

Appendix VII. Analysis of variance of aphid species at Alupe during the short rain season, 2007

		Mean sum of square					
		Weeks after planting					
Source of variation	**df**	**2**	**4**	**6**	**8**	**10**	**12**
Block	2	0.96	11	2.96	44.1	0.2	0.02
Aphid_sp	2	1.42	39**	2.96	115	0.47*	2.96*
Variety	4	0.42	5.5	1.92	64.3*	0.52**	1.37
Aphid sp x Variety	8	0.42	1.8	1.37	40.4	0.27**	1.32

df =degrees of freedom; ** $P \leq 0.001$; * $P \leq 0.05$

Appendix VIII. Analysis of variance of groundnut yield at Alupe during the short rain season, 2007

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block	2	643313	321656	1.93	
Variety	4	4791835	1197959	7.19	0.009
Residual	8	1333107	166638		

df =degrees of freedom; ss = sum of squares; ms =mean sum of square; v.r. = variance ratio; F pr = Fprobability