

MAKERERE



UNIVERSITY

**INFLUENCE OF AGRO-ECOLOGY AND FARMERS' PRACTICES ON THE
OCCURRENCE AND SEVERITY OF GROUNDNUT ROSETTE VIRUS
DISEASE IN UGANDA**

BY

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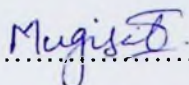
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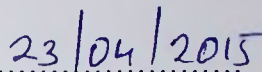
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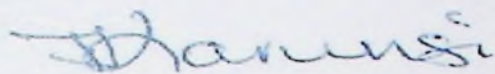
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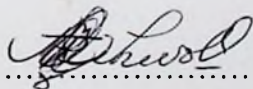
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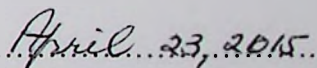
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DEDICATION

This thesis is dedicated to my dear mother, Mrs. Franchesca Otwoda Bichendi, who sacrificed everything to ensure that her children got an education.

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I start by thanking the Almighty God, - who gave me the grace to come this far in my education and enabled me to complete this project. Surely- "Nothing is impossible with God!" - Luke 1:37.

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ABSTRACT

Groundnut rosette virus disease (GRVD) is the most destructive disease of groundnut (*Arachis hypogaea*) in Uganda and across sub-Saharan Africa. Epidemics are sporadic and unpredictable, causing substantial losses which significantly reduce groundnut production and can potentially cripple the rural economy. The disease is principally transmitted by aphids (*Aphis craccivora* Koch.). There has been an increase in understanding of GRVD since its discovery in 1907. However, gaps still remain in the available knowledge on key epidemiological aspects of the disease. This study was aimed at establishing the influence of ambient ecology and farmers' practices on the incidence and severity patterns of GRVD in Uganda.

Trials were established for three planting seasons (1st and 2nd season 2011 and 2nd season 2012) in four groundnut growing locations each situated in different agro-ecological zones in Uganda. Four groundnut genotypes (2 susceptible and 2 resistant to GRVD) were used as treatments in a randomized complete block design that had four replicates. Disease progress was assessed at 4, 8 and 12 weeks after planting. Data on environmental factors; particularly rainfall, temperature and wind speed were obtained from standard meteorological stations located at/near the study sites. Aphid populations were assessed at regular intervals during the trial. Soil samples and yield data were also obtained for each planting season at each location. The study revealed that GRVD incidence and severity were significantly affected by season, location and variety as well as their three way interactions ($P \leq 0.05$). This was also true for groundnut yields. Levels of GRVD infection were found to be influenced by rainfall and wind speed. Disease incidence, severity and AUDPC values were generally higher in conditions of lower rainfall and wind speeds. The Pearson's two tailed correlation between total rainfall and GRVD incidence for all trial sites in all the three seasons was negative and highly significant ($r = -0.280$, $P \leq 0.01$; $N=144$). This was also true for wind speed and GRVD incidence ($r = -0.476$, $P \leq 0.01$; $N=48$). However, there was no conclusive trend between temperature and GRVD incidence with the Pearson's two tailed correlation showing significantly positive and negative trends depending on location. The rate of GRVD development was also observed to be different for the four groundnut varieties, the three seasons and the different locations.

A survey was also conducted within five major agro-ecological zones in Uganda. In this survey, 105 farmers were interviewed using a structured questionnaire with the aim of obtaining information on the various practices they employed in the field. Disease severity was scored in each farmer's field. Results of the survey showed that farmers were employing a range of practices in groundnut production, including: early sowing, intercropping, use of improved groundnut genotypes, crop rotation; and uprooting and burning diseased plants among others. However, only two management practices: early sowing and use of improved varieties were found to significantly ($P \leq 0.05$) reduce rosette severity in groundnut fields. It can be concluded, therefore, that ecological factors (such as rainfall, temperature, wind speed and soil), farmers' practices and their consequential interactions, are ultimately the main influencing factors of GRVD severity in groundnut fields. This knowledge will guide the future development and promotion of more sustainable integrated GRVD management packages within the different agro-ecologies of Uganda.

CHAPTER ONE

INTRODUCTION

1.1 Background

The groundnut (*Arachis hypogea* L.), also known as peanut, is a cultivated annual or semi perennial herb grown in many tropical and sub-tropical countries and in continental parts of temperate countries (Cummins, 1986). It is a member of the family Leguminosae, subfamily Papilionoidae, tribe Aeschynomeneae and subtribe Stylosanthinae (Polhil and Raven, 1981). Groundnut is thought to have originated from South America, in the region of Southern Bolivia and Northern Argentina (Gregory *et al.*, 1980, Krapovickas and Gregory, 1994; Kochert *et al.*, 1996). The crop is believed to have been introduced into Uganda by early traders and travelers around 1862 after its introduction into East Africa by Portuguese explorers during the 16th century (Tiley, 1972; Nalyongo and Emeetai-Areke, 1987; Naidu *et al.*, 1999). This was followed by slow spread and adoption of this new crop. Between 1920 and 1930; more groundnut varieties were introduced into the country by the Agriculture Department (Nalyango, 1987). By the early 1990's, the crop had become a popular crop in Uganda especially in the Eastern and Northern regions of the country where it became part of the people's culture (Mahmoud *et al.*, 1991). Today, groundnut is the second most produced food legume after beans (*Phaseolus vulgaris* L.) in Uganda (UBOS, 2013).

Groundnuts are cultivated on over 25.4 million hectares globally, with annual production (groundnuts with shell) estimated at 45.2 million metric tons worldwide (FAO, 2013). The Asian continent produces the highest quantities of groundnuts totaling to 29.9 million metric tons annually, followed by Africa which produces an estimated 11.5 million metric tons annually. Among the various regions of Africa, East Africa comes third after West Africa (48.9%) and North Africa (17.6%), accounting for 17% of total groundnut production in the African continent. Uganda is currently the second largest producer of groundnuts in East Africa after Tanzania (FAO, 2013). Annual groundnut production in Uganda is currently estimated at 244,683 metric tons, harvested from 345,232 hectares (UBOS, 2013).

Groundnuts are an important crop throughout Sub-Saharan Africa which comprises 40% of the world's groundnut harvested area, but only contributes 26% of the world's groundnut production (ICRISAT, 2012). Groundnut seeds contain 40-50% fat, 20-50% protein and 10-20% carbohydrate, depending on the variety. They are also a nutritional source of vitamin E, niacin, calcium, folacin, phosphorous, magnesium, zinc, iron, riboflavin, thiamine and potassium (Savage and Keenan, 1994). The seeds are utilized as whole seeds (raw, boiled, or roasted) or may be ground after roasting to form peanut butter. Groundnut oil, a non-drying oil, is used in cooking, manufacture of margarine, and as a lubricant. High quality groundnut oil is used in pharmaceutical industries whereas poor quality oil is used in the manufacture of soap. Groundnuts are also important as animal feeds in the form of pressings, seeds, green haulms (used to make fodder and hay) and straw (FAO, 2003). The groundnut crop is used as a rotation crop because it improves soil fertility by fixing nitrogen into the soil through a symbiotic association with rhizobium, thereby improving productivity particularly of cereal cropping systems (Smart, 1994).

1.2 Problem statement

Groundnut yields at farmer level in Uganda are extremely low, averaging 0.8 tons per hectare of dried pods (Okello *et al.*, 2010). This is in contrast to yields as high as 2.5 – 3.0 tons per hectare reported at research stations in Uganda and other countries with developed agriculture (Busolo-Bulafu, 2004). The low yields at farmer level in Uganda have been attributed to several factors including pests and diseases, unreliable rains with recurrent droughts, poor agronomic practices, lack of high yielding cultivars, shortage of good planting seed and low level of input use (Mahmoud *et al.*, 1992; Adipala *et al.*, 1998).

Pests and diseases have been found to cause the greatest economic damage to groundnut production in Uganda (Busolo-Bulafu, 1990). Major pests include: aphids (*Aphis craccivora* Koch), thrips (*Thrips palmi* Karny, *Frankliniella schultzei* Trybom, *Scirtothrips dorsalis* Hood and *Caliothrips indicus*) and termites (Isoptera); whereas important diseases include: groundnut rosette virus disease (GRVD), leaf spots and rusts (Okello *et al.*, 2010). Of these diseases, the most important is groundnut rosette virus disease, which is transmitted by the groundnut aphid

(*Aphis craccivora* Koch) and is known to sometimes cause total crop failure (Bonabana-Wabbi *et al.*, 2008). GRVD has been identified by researchers as the major constraint to increased groundnut production in Uganda (Okello *et al.*, 2010). Epidemics of groundnut rosette virus disease (GRVD) in Sub-Saharan Africa are reported to be unpredictable, causing devastating losses in some years while others are relatively unaffected (Naidu *et al.*, 1998). This poses a great threat to groundnut production in the country. In Eastern Uganda, for instance, where groundnut is a major crop, varieties such as 'Red beauty' that were previously preferred by the local market for confectionery purposes because of high oil content, have been abandoned because of their high susceptibility to the disease (Mr. David Kalule Okello, Plant Breeder, Groundnut Improvement Program, NaSARRI; Personal communication).

Uganda has known GRVD hotspots where total crop loss has been observed (Okello *et al.*, 2010). These hotspots include; the National Semi Arid Resources Research Institute (NaSARRI) in Serere district, Nakabango in Jinja district and Iki-Iki in Pallisa district (Okello *et al.*, 2010). Apart from these hot spots, it has also been observed that different regions in the country have varying GRVD incidences. However, information on GRVD incidence and severity in the different agro-ecologies of Uganda is not documented and the reasons for the differing disease patterns remain unknown. This information is relevant to researchers and extension workers who may need it as a guide or reference while developing, recommending and disseminating disease management packages within these groundnut producing agro-ecological zones. The lack of or limited knowledge on this could also potentially exacerbate yield losses due to disease outbreaks.

1.3 Justification

Plant virus epidemics are multi-component systems resulting from interactions between the virus (es), vectors and host plant(s), influenced by the environment (Thresh, 1983). A better understanding of the relationship between the incidence and severity of GRVD and agro-ecological factors (such as weather and soil) is critical for the successful development of sustainable disease management strategies and could possibly facilitate the future development of disease forecasting methods for the groundnut crop.

In the past, attention has been given to the control and management of GRVD on groundnut (Thresh, 2003). There is abundant evidence of the importance of management practices in determining disease prevalence and a wide range of management options are available. These include the use of management practices to delay onset and spread of the vector and disease. These management practices would involve early sowing, removal of wild hosts and use of recommended plant populations; pesticide application to reduce vector aphid populations and host plant resistance (Thresh, 1982; Naidu *et al.*, 1999). However, challenges remain in adoption of these practices by farmers. For instance, early sowing may not be adopted by some farmers who give priority to sowing their main staple food crops such as maize and sorghum. The use of chemical pesticides may also be an unlikely control measure for many smallholder farmers due to financial constraints (Naidu *et al.*, 1999). The disease therefore continues to cause yield losses whenever the crop is grown. Thresh (2003), emphasized that more detailed research and a thorough knowledge of farming practices is required before an effective integrated virus disease management programme can be developed and promoted. This study was therefore implemented in different agro-ecological zones in the country to establish the effect of diverse ecological aspects and management practices on the dynamics of GRVD and its principal aphid vector in Uganda. This information will guide the future development, promotion and dissemination of sustainable integrated GRVD management strategies in the country.

1.4 Study objectives

The overall purpose of this study was to contribute to better management of GRVD in Uganda by generating knowledge on pertinent factors that influence the spread of the disease.

Specific research objectives included:

1. To establish the influence of agro-ecology on the occurrence and severity of GRVD in Uganda.
2. To evaluate the effect of farmers' management practices on the severity of GRVD on groundnut in Uganda.

1.5 **Research hypotheses**

- 1. Incidence and severity of GRVD in groundnut farmers' fields are influenced by differences in weather and soil characteristics at the different locations.
- 2. Severity levels of GRVD vary with farmers' management practices.

CHAPTER TWO

LITERATURE REVIEW

2.1 History of groundnut rosette virus disease in Sub-Saharan Africa

Groundnut rosette virus disease was first reported in 1907 in Tanganyika (Zimmermann, 1907), now called Tanzania, and has since been reported in several other countries in sub-Saharan Africa (SSA). Epidemics of GRVD in SSA often significantly reduce groundnut yields and can cripple the rural economy. In 1975, an epidemic in northern Nigeria destroyed approximately 0.7 million ha of groundnuts, with an estimated loss of \$250 million (Yayock *et al.*, 1976). Recurrent epidemics have limited production to below the pre-1975 yields. Similarly, the epidemic that occurred in 1995 in eastern Zambia affected approximately 43,000 ha, causing an estimated loss of \$4.89 million (Naidu *et al.*, 1999). In the following year, in the central region of neighboring Malawi, groundnut production was reduced 23% by GRVD (Anonymous, 1996). Pioneering work on GRVD was done in South Africa more than 70 years ago when it was demonstrated that it was caused by a virus transmitted by the aphid *Aphis craccivora* (Koch) (Storey and Ryland, 1955). Many studies focused on breeding for resistance, insect vector control through chemical sprays, and modification of cultural practices such as date of sowing and plant densities (Evans, 1954, Saunger *et al.*, 1954, Davies, 1975 and Farrell, 1976). Despite these efforts, many of the recommendations to reduce the risk of GRVD were not adopted by smallholder farmers because crucial socioeconomic factors were not considered by researchers (such as quality and duration of resistant varieties and labor constraints) (Naidu *et al.*, 1999). By the early 1990s, it was established that GRVD had a complex etiology involving three disease causing agents: groundnut rosette assistor luteo-virus (GRAV), groundnut rosette umbra-virus (GRV), and a satellite RNA (satRNA) of GRV. However, the lack of diagnostic tools for the three agents was a major constraint in understanding the epidemiology of and in developing management strategies for the disease (Naidu *et al.*, 1999).

2.2 Etiology of groundnut rosette virus disease

2.2.1 Causal agents of GRVD

Groundnut rosette virus disease is caused by a complex of three agents, namely, groundnut rosette virus (GRV), its satellite RNA (satRNA) and groundnut rosette assistor virus (GRAV).

GRV is mechanically transmissible and replicates independently in plants, whereas the satRNA depends entirely on GRV for its replication (Murant *et al.*, 1988; Blok *et al.*, 1994). The satRNA is largely responsible for the different types of rosette symptoms. Variants of satRNA were shown to cause the chlorotic and green forms of the disease, while other variants induce mild or no symptoms in groundnut. In nature, individual plants may contain a mixed population of satRNA variants (Murant *et al.*, 1988; Murant and Kumar, 1990).

The inter-dependence and interactions among the three agents of the rosette disease are complex. GRAV replicates autonomously in plants and is transmitted by the groundnut aphid *Aphis craccivora* (Koch.). By contrast, satRNA depends on GRV for replication and GRV depends on satRNA for aphid transmission. Both, in turn, depend on GRAV for their packaging in GRAV coat protein and subsequent transmission by an aphid vector (Murant, 1990).

2.2.2 Transmission of GRVD

GRVD is transmitted efficiently in nature by the groundnut aphid in a persistent and circulative manner (Storey and Bottomley, 1928; Storey and Ryland, 1955; Hull, 1964). Another aphid species, *Aphis gossypii* (Glov) was reported to be an inefficient vector (Adams, 1967) but this has not been confirmed. Okusanya and Watson (1966) first reported that aphids failed to transmit GRVD from plants that had been infected mechanically by sap inoculation. This is now known to be because GRAV is not mechanically transmissible and only GRV and its satRNA establish and multiply in manually inoculated plants (Murant *et al.*, 1988). Aphids can acquire and transmit GRAV irrespective of the presence of GRV and its satRNA. The transmission characteristics of GRVD by the vector are therefore influenced by GRAV (Fig. 1) but not by either GRV or satRNA as they are encapsulated within the GRAV particles (Naidu *et al.*, 1999).

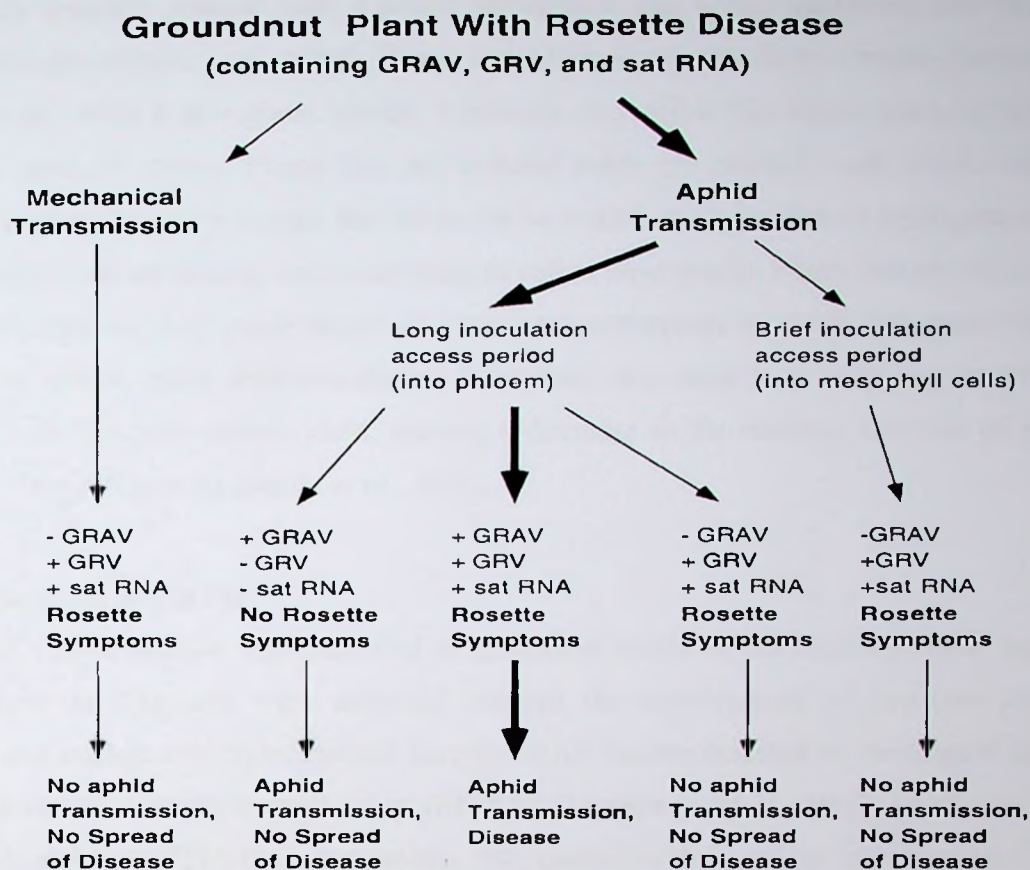


Figure 1. Separation of groundnut rosette disease agents in time and space during mechanical or aphid inoculations. + indicates replication, – indicates no replication (Source: Naidu *et al.*, 1999).

2.2.3 Symptoms of GRVD

Groundnut rosette virus disease occurs in sub-Saharan Africa as two predominant symptom forms: “chlorotic” and “green” rosette (Gibbons, 1977; Murrant and Kumar, 1990). Chlorotic rosette is the most prevalent and widely distributed symptom type in eastern, central and southern Africa including countries such as Kenya, Uganda, Somalia, Tanzania, Zambia, Congo, Malawi, Zimbabwe, and South Africa (Wangai *et al.*, 1999). On the other hand, distribution of green rosette has primarily been reported in western and southern Africa. Symptoms vary depending on the type of rosette. Generally, however, plants affected either by green or chlorotic

rosettes are severely stunted with a bushy appearance due to the shortened inter-nodes and reduced leaf size (Naidu *et al.*, 1998). Plants with chlorotic rosette show a bright chlorosis of the leaves, usually with a few green islands. 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. In green rosette, the leaves are very dark green or show a light green and dark green mosaic, reduced in size, with their margins rolled downwards. Plants that are infected early are severely stunted, with much shortened internodes, and appear as small dark green bushes. In all types of rosette, early infection (before flowering) can cause total crop loss in susceptible varieties. Late infection affects yield, causing a decrease in the number and size of pods and subsequently small kernels (Naidu *et al.*, 1997).

2.2.4 Diagnosis of GRVD

In the past, rosette disease was identified in groundnut solely on the basis of visual symptoms, but advances in diagnosis were achieved through the development of accurate serological detection and nucleic acid hybridisation assays. GRAV can be detected by serological tests such as enzyme-linked immune-sorbent assay (ELISA) (Rajeshwari *et al.*, 1987; Scott *et al.*, 1996). Since GRV and its satRNA lack coat protein, they cannot be detected by such tests but GRV can be detected by manual inoculation to suitable test (indicator) plants (*Nicotiana benthamiana* or *Chenopodium amaranticolor*). Both agents can be detected in dot-blot hybridization assays by using nucleic acid probes specific to either GRV or sat RNA (Blok *et al.*, 1995). All the three disease causing agents can be detected by reverse transcription-polymerase chain reaction (RT-PCR) with specific primers (Naidu *et al.*, 1998). Although TAS-ELISA and RT-PCR are currently used to detect all three pathogens, this approach is time-consuming, expensive and not easily amenable to high throughput. A multiplex PCR-based approach was recently developed to detect all three pathogens at once, reducing diagnostics costs and time by two thirds (Anitha *et al.*, 2014)

2.3 Spatial spread of disease

Groundnut rosette virus disease is transmitted by an insect vector and has not been reported to be seed-borne. Primary infection is influenced by the number, timing and infectivity of aphids moving into the groundnut crop (Naidu *et al.*, 1999). Once groundnut seedlings emerge,

viruliferous winged immigrants alight within the field and establish randomly distributed primary inoculum sources, and consequently, spread of the disease from plant to plant within the field (Davies, 1976, Naidu *et al.*, 1999). Disease spread in groundnut crops does not, therefore, occur until inoculum is introduced from other sources. Field spread is largely determined firstly, by the nature and distribution of the initial sources of infection from which spread occurs and secondly, by the extent to which the incoming aphids and their progeny survive and multiply on such plants. The initial sources may be alternate host plants in areas where the cropping season is followed by a long dry season. Alternatively, source plants may be volunteers and/or overlapping groundnut crops in areas of bimodal annual rainfall (Naidu *et al.*, 1999).

Rosette is regarded as a typical polycyclic disease because it spreads from sources of inoculum whose number increases during the growing season as progressively increasing numbers of plants become infectious (Thresh, 1983b). Secondary disease spread often occurs within the crop around these initial foci of infection to give clusters of infected plants. This leads to a change over time from an initial random to a clumped distribution of infection (Farrell, 1976a). Disease progress curves based on symptom development are typically sigmoid and reach maxima 45-55 days after primary infection occurs (Sauger and Catherinet, 1954; Catherinet *et al.*, 1955). However, detailed information is not available on the time taken for symptoms to develop in relation to environmental conditions, and the age and variety of groundnut.

2.4 Virus-vector-host plant interactions

2.4.1 Virus host range

Since GRV is mechanically transmissible and GRAV is not, many host range studies relate to GRV and not to GRAV. GRV has been transmitted to a limited range of species in the Leguminosae, Chenopodiaceae or Solanaceae families (Okusanya and Watson, 1966; Adams, 1967; Hull and Adams, 1968; Dubern, 1980; Reddy *et al.*, 1985). In host assays, *Chenopodium amaranticolor* has been identified as a good local lesion assay host, whereas *Nicotiana benthamiana* is a systemic host suitable for virus propagation. SatRNA was found to multiply in all hosts of GRV that were tested. Under experimental conditions, GRAV has been transmitted to: *Pisum sativum*, *Stylosanthes gracilis*, *S. hamata*, *S. mucronatu*, *S. sundaica*, *Trifolium incarnatum*, *T. pretense*, *Capsella bursa-pastoris*, *Gomphrena globosa*, *Montia pefoliata* and

Spinacia oleracea (Okusanya and Watson, 1966; Adams, 1967; Hull and Adams, 1968; Murant, 1989). Of these, only *C. bursa-pastoris* showed symptoms (generalized chlorosis) when infected. Adams (1967) and Hull and Adams (1968) reported *T. incarnatum*, *S. mucronata* and *S. sundaica* as hosts for the GRVD complex under experimental conditions. However, groundnut is the only naturally infected host known to contain the entire disease complex (Naidu *et al.*, 1999).

2.4.2 Aphid vector host range

The host range of *Aphis craccivora* has been studied extensively in an effort to explain the seasonal survival of aphid populations. *Aphis craccivora* infests many plant species in many families, but has a strong preference for members of the Leguminosae family (Eastop, 1981). Millar (1994), in a catalogue of the aphids of Sub Saharan Africa, listed 142 plant species in 23 families as hosts of *Aphis craccivora*, of which 83 are in Leguminosae. Adams (1967) listed 31 leguminous and 9 non-leguminous species as hosts in Malawi. Groundnut was the main host in the growing season, while during the dry season prominent alternate hosts comprised of: *Dolichos malosan* (Bak.), *Eriosema affine* (De Wild), *Eriosema psoraleoides* (Lam.) G Don, *Eminia antennulifera* Baker (Taub.) and *Adenodolichos punctatus* (Micheli) Harms, all of which belong to Leguminosae. *Euphorbia lzirta* L. was found to be the main dry season host in Nigeria (Booker, 1963). In Tanzania, Evans (1954) found that *Vigna* spp., *Milletia* spp. and *Lonchocarpus* spp. were the major dry season hosts, but considered self-sown groundnut 'volunteers' to be important in the seasonal survival of aphids. In the Central Province of Malawi, Nutman *et al.* (1964) and Hildebrand *et al.*, (1991) found no evidence that volunteer groundnuts played any role in vector and/or virus survival. It was suggested that aphids survived on a succession of dry season hosts, particularly shrub and tree species that were common in the groundnut growing regions of Africa and that produced flushes of new growth before the onset of the rains (Adams and Farrell, 1967; Bock, 1985).

Host plants that support aphid colonization and multiplication may also be reservoir hosts for rosette disease. Because several hours are needed for virus acquisition, the source must also be a good host plant for the aphid. However, as successful inoculation can occur within minutes, plant species that are not preferred by the aphids may still become infected during brief penetrations provided they are hosts for components of the disease complex (Naidu *et al.*, 1998). Such plants

may support replication only of GRV and its satRNA and would not be sources for further transmission. Alternatively, all three components may replicate, but the plants may be poor sources for subsequent spread because of the need for extended acquisition feeding.

2.5 Management of groundnut rosette virus disease

The different methods that have been investigated to manage GRVD include pesticides to reduce aphid vector populations, cropping practices to delay onset and spread of both vector and disease, and breeding for virus and vector resistance.

2.5.1 Cultural practices

Studies carried out where a single groundnut crop alternates with a long dry season, indicate that early sowing and maintaining a uniformly dense stand of groundnut greatly reduces the incidence of GRVD (A'Brook, 1968; Davies, 1976; Farrell, 1976a). The early sown crops cover the ground before the aphids' main period of flight activity. Such crops largely escape infection because aphids prefer younger crops and often alight preferentially on widely spaced plants. However, these practices are seldom adopted by traditionally conservative smallholder farmers because they prefer sowing their main staple food crops (for instance maize and sorghum) first. Groundnut, provided sufficient seed is available, is left until later in the season or until the second rains. In many countries, farmers do not remove volunteer groundnuts and groundkeepers that start growing with the first rains. This permits aphid vectors to colonize and infect such plants, which in turn serve as primary sources of inoculum for the subsequently sown crops. In addition, early sowing may not be effective in areas with overlapping groundnut crops where the vector and disease agents perpetuate throughout the year. Many times, early sown crops must be harvested during wet weather, causing problems of drying and predisposition to fungi, which may result in the accumulation of mycotoxins (Diener *et al.*, 1982; Wilson, 1995; Wilson and Payne, 1994). Furthermore, weeding of groundnut fields is often delayed due to labor constraints and, in many cases, due to the preoccupation of farmers with other priority food and cash crops (Busolo-Bulafu, 1990), resulting in poor plant growth and yield. However, intercropping groundnuts with beans or sorghum was reported to be effective in reducing the disease incidence because they affect aphid colonization, movement and behavior within crops, thereby reducing disease incidence (Farrell, 1976; Alegbejo, 1997).

2.5.2 Chemical control

Organo phosphorous pesticides have been used to control aphid vector populations to minimize spread of GRVD in the field. The timing, dosage, and type of insecticidal applications are critical for effectively diminishing the vector population and require an early forecast of vector migration into the crop. However, chemical pesticides are not economically feasible for smallholder farmers. In addition, improper use of these potent chemicals might alter the delicate balance between aphid vectors and their natural enemies, and possibly result in the development of insecticide-resistant biotypes (Naidu *et al.*, 1999).

2.5.3 Host resistance

Genetic resistance offers a promising approach to management of GRVD. It offers the cheapest option for control of GRVD by the farmer (NARO, 2001). Several GRVD resistant groundnut genotypes in Uganda have previously been developed through the groundnut breeding programme at NaSARRI. These include the Serenut series (Serenut 1R, 2R, 3R, 4T, 5R, 6T). However; some of these cultivars such as Serenut 4T and Serenut 3R are currently succumbing to the disease (Mr. David Kalule Okello, Plant Breeder, Groundnut Improvement Program, NaSARRI; Personal communication). Breeding for durable resistance for GRVD management therefore still remains a challenge in Uganda.

2.6 Effect of environmental factors on the spread and intensity of GRVD and its aphid vector

Climatic factors have been reported to influence the secondary spread of GRVD by affecting the nature and pattern of disease spread by aphids away from the initial foci of the disease (Naidu *et al.*, 1999). Among the different environmental factors, higher temperatures and sun shine hours have been reported to be positively correlated with aphid population build up. On the other hand, lower temperature, relative humidity and wind speed were negatively correlated with aphid population build up (Hassan *et al.*, 2009). The optimal development time of *A. craccivora* in experimental studies occurs around 65% relative humidity and in temperatures between 24-28.5°C (Mayeux, 1984). High rainfall is not favourable to *A. craccivora* populations since it can destroy aphid colonies on young plants, where foliage is not plentiful enough to protect them (Mayeux, 1984). This in turn leads to lower GRVD levels.

This study will provide information on the levels of GRVD incidence and severity in the selected groundnut producing agro-ecological zones of Uganda. It will give insight on the effect that agro-ecological factors have on GRVD incidence and severity. Information on the current practices being employed by groundnut farmers in GRVD management and their effect on reduction of the disease will be also elucidated.

CHAPTER THREE

INFLUENCE OF AGRO-ECOLOGY ON OCCURRENCE AND SEVERITY OF GROUNDNUT ROSETTE VIRUS DISEASE IN DIFFERENT AGRO-ECOLOGIES OF UGANDA

3.1 Introduction

Groundnut rosette virus disease (GRVD) is the most destructive disease of groundnut (*Arachis hypogaea*) in Uganda and across Sub-Saharan Africa (Naidu *et al.*, 1999). The disease is principally transmitted by the groundnut aphid (*Aphis craccivora* Koch.). Epidemics of GRVD are sporadic, with devastating losses recorded in some years while others are relatively unaffected. The unpredictability of outbreaks thus poses a great threat to groundnut production in Uganda. Although GRVD has been studied for several years, gaps still remain in the available knowledge particularly on epidemiological and ecological aspects of the disease. For instance, there is limited information on disease occurrence and severity in relation to environmental conditions and variety of groundnut.

Naidu *et al.*, (1998), highlighted the importance of detailed studies on the pattern of GRVD spread at a representative range of sites in different agro-ecologies and under different cropping systems over a period of several years. Three GRVD hotspots are reported to exist in Uganda including NaSARRI (Serere district), Nakabango (Jinja district) and Iki-Iki (Pallisa district) where total crop loss has been observed in unsprayed susceptible varieties (Okello *et al.*, 2010). It has also been noted that in any given growing season, disease levels vary in different agro-ecological zones within Uganda. The reasons for this occurrence remain unclear since no studies have been documented in this area. The main objective of this experiment was to establish how ecological factors such as wind, rainfall, temperature and soil influence the incidence and severity of groundnut rosette virus disease in different agro-ecologies of Uganda.

3.2 Materials and Methods

3.2.1 Study Area

Field trials were conducted for three planting seasons: first growing season 2011 (2011A), second growing season 2011 (2011B) and second growing season 2012 (2012B) at research stations located in four groundnut producing areas, each representing a different agro-ecological zone within Uganda (Fig. 2). These areas fell in the districts of Sironko (Buginyanya Zonal Agricultural Research and Development Institute), Lira (Ngetta Zonal Agricultural Research and Development Institute), Jinja (Nakabango Varietal Trial Centre) and Mbarara (Mbarara Zonal Agricultural Research and Development Institute) districts (marked with a star) representing the Highland ranges (X), North Eastern Savannah Grasslands (II), Lake Victoria Crescent (VI), and Southern Western Farmlands (IX) (MAAIF, 2010) respectively.

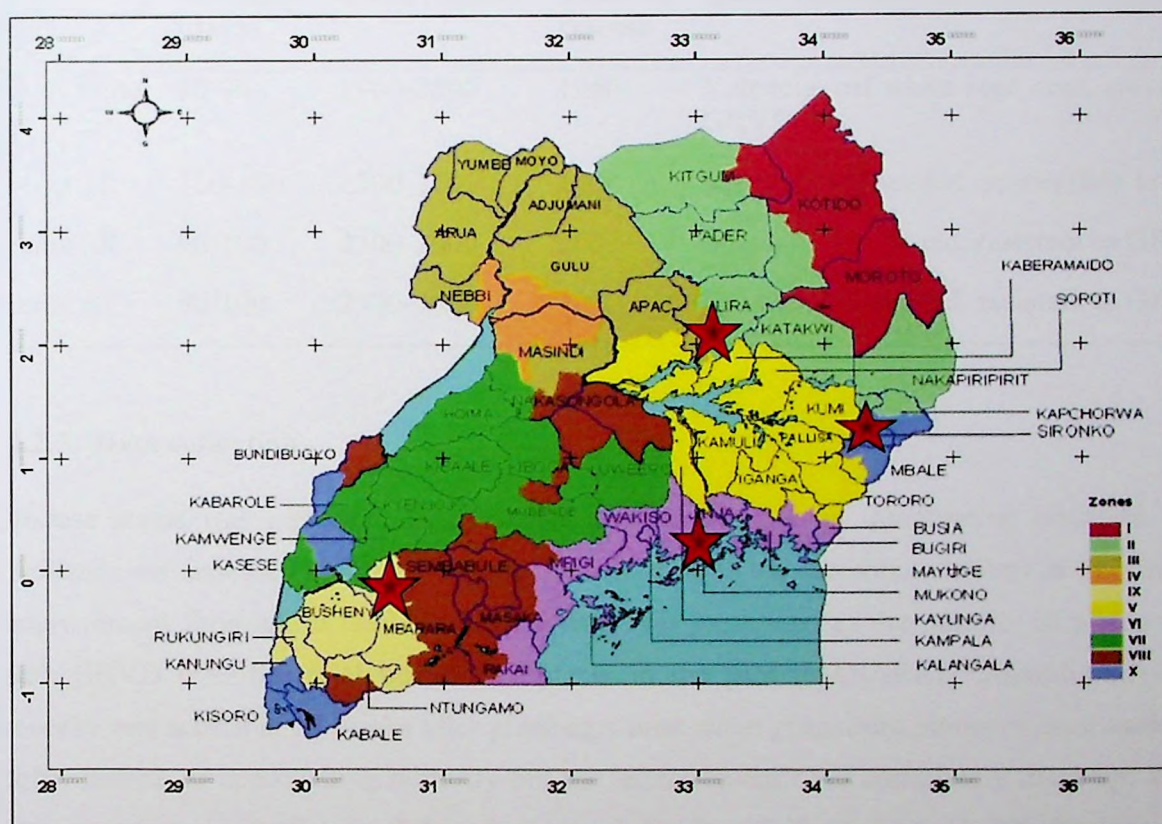


Figure 2. Map of Uganda showing zones according to MAAIF. I: North Eastern Dry lands, II: North Eastern Savannah Grasslands, III: North Western Savannah Grasslands, IV: Para Savannah, V: Kyoga Plains, VI: Lake Victoria Crescent, VII: Western Savannah Grasslands, VIII: Pastoral Rangelands, IX: Southern Western Farmlands, and X: Highland Ranges

3.2.2 Experimental design and agronomic practices

In each of the four locations, four groundnut genotypes were studied as treatments; two susceptible varieties, Serenut 1R and Acholi white; and two resistant varieties, Serenut 6T and Serenut 3R (Table 1). All germplasm were kindly provided by Mr. David Kalule Okello of the Groundnut Improvement Program at the National Semi Arid Resources Research Institute (NaSARRI) in Serere. Field trials were established as a randomized complete block design (RCBD) with 4 replicates. Each experimental unit measured 3m x 3m and a plant spacing of 45cm x 15cm was used. No fertilizers, pesticides or herbicides were applied in the fields. Hand-weeding was done thrice during each growing season.

Table 1. Characteristics of groundnut varieties used in field trials

Variety	Maturity (days)	Yield (kg/ha)	Year of release	Other remarks
Acholi white	80-90	1900-2500	1966	Valencia, off white seed coat, susceptible to GRVD
Serenut 1R	100-110	2500-3700	1998	Virginia, red seeded, susceptible to GRVD
Serenut 3R	90-100	2500-2900	2002	Spanish, red seeded, resistant to GRVD
Serenut 6T	90-100	2500-3000	2010	Spanish, tan-seeded, resistant to GRVD

3.2.3 Data collection

Disease status was measured as incidence and severity, using quantitative methods. Rosette incidence was assessed at 4, 8 and 12 weeks according to the recommendations of the Groundnut Improvement Program at NaSARRI. Incidence was expressed as the number of plants infected with GRVD over the total number of plants in the plot (NASARRI, Unpublished) Disease severity was scored at 12 weeks after planting a time when groundnut plants of most varieties are either mature or approaching maturity but the leaves haven't yet completely dried up. This was done using a scale of 1 to 9 based on the intensity of disease attack (Okello *et al.*, 2014). According to the scale:

1-3= Low GRVD severity (Resistant)

4-6= Moderate GRVD severity (Moderately resistant)

7-9= High GRVD severity (Susceptible)

In order to determine aphid populations, 10 plants were randomly selected per plot and the numbers of adult aphids on each plant were counted. However, this information was obtained from only two districts, Mbarara and Sironko during two planting seasons (2011A and 2011B). Results for aphid population dynamics for Jinja and Lira were not included because no aphids were found at the time of data collection. This was because of heavy rains which often washed away the aphids in many cases prior to data collection.

Data on environmental factors including rainfall, temperature and wind speed were obtained from meteorological stations located at or near the trial sites. Information on rainfall and temperature was obtained from all the trial sites whereas wind speed data was obtained from only two sites, Jinja and Lira during 2011A and 2011B.

Soil samples were also obtained from each of the experimental trial sites and analyzed to determine their chemical characteristics (pH, organic matter and percentage nitrogen), base mineral elements (potassium, calcium, magnesium and phosphorus) and textural class (sand, clay or silt) in the Soil and Plant Analytical Laboratories at the National Agricultural Research Laboratories (NaRL) in Kawanda in order to determine their general characteristics.

3.3 Data analysis

Incidence data was used to compute the area under disease progress curve (AUDPC) as described by Campbell and Madden (1990) as;

$$AUDPC = \sum_{i=1}^n [(X_{i+1} + X_i)/2][t_{i+1} - t_i]$$

Where:

X_i = disease incidence at the i^{th} observation

t_i = time (days) at the i^{th} observation

n = total number of observations

Data on disease incidence, severity, AUDPC's, yield and aphid infestation were entered into an Excel program (Microsoft Office, 2007) and exported into GenStat computer package (13th edition, Release 13.3; VSN International Ltd, 2010) to generate analyses of variance (ANOVA). Analysis was done using the general treatment structure (in randomized blocks) design. For the treatments showing significant 'F' statistics, the means were separated using SED (the standard error of the difference between two sample means, $SED \times 1.96 = LSD_{5\%}$). The Pearson's two tailed correlation analysis was used to assess the strength of association between weather variables and GRVD incidence (Cohen and Cohen, 1983).

3.4 Results

3.4.1 Incidence and severity of GRVD

Groundnut rosette virus disease occurred in all locations in the three growing seasons and was observed on all the four varieties. Significant differences were, however, observed in GRVD incidence across season, variety and location at the 5% confidence level (Appendix 1). In addition, the two-way interactions of season x location and location x variety, and the three-way interaction of season x location x variety significantly ($p \leq 0.05$) affected disease incidence (Appendix 1).

The overall mean GRVD incidence was highest in 2011A (35.99%), followed by 2011B (11.87%) and least in 2012B (4.64%) (Table 2). Local variety Acholi white had the highest average disease incidence (20.74%) across all seasons followed by Serenut 1R (19.51%), then Serenut 6T (16.96%) and Serenut 3R had the lowest GRVD incidence (12.8%). Jinja district had the highest average GRVD incidence for all seasons (37.21%) followed by Sironko (20.21%), Mbarara (7.42%) and lastly Lira (5.17%) (Table 2). Generally, GRVD came in early in the fields and incidence increased with time.

The rate of disease development was different for the four groundnut varieties, the three seasons and the different locations (Figs. 3 and 4). Generally for all sites and seasons, varieties that had the highest rates of disease development were Acholi white and Serenut 1R. Serenut 3R had the lowest rate of disease development. Considering location, the rate of disease development was

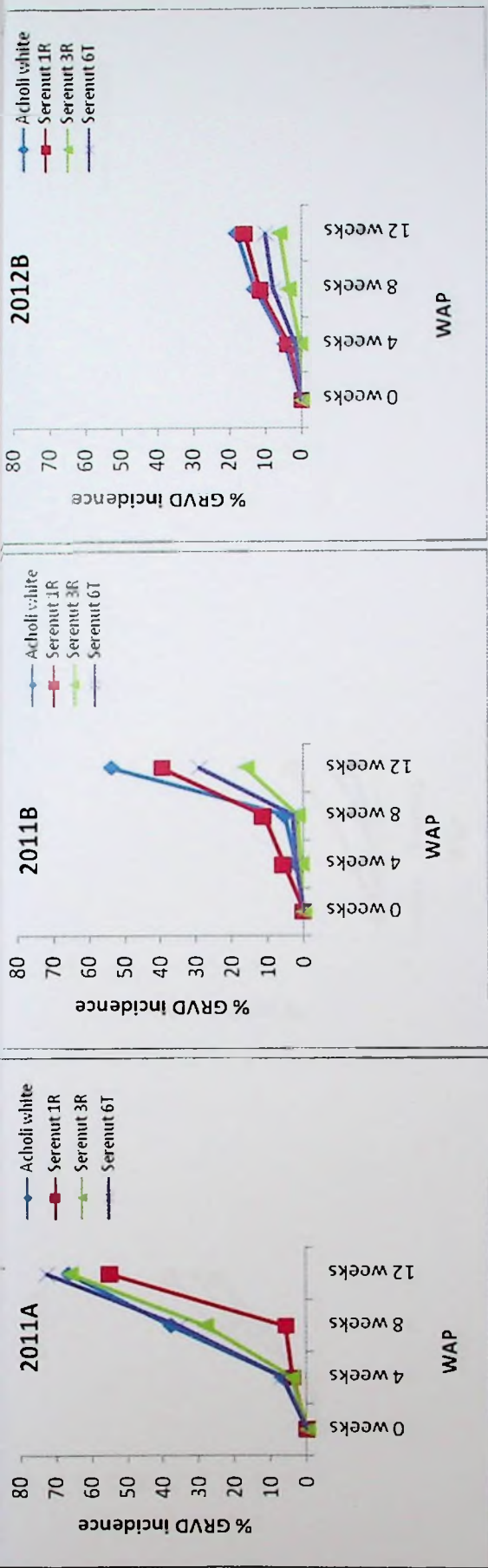
generally highest in Jinja followed by Sironko, Lira and Mbarara respectively. Season 2012B was observed to have the lowest rate of disease development whereas season 2011A had the highest. No disease was observed on Serenut 3R at Mbarara trial site during season 2011B.

Season, location and variety significantly affected the severity of GRVD (Appendix 2; Fig. 5). The interaction between season x location also significantly affected disease severity (Appendix 2). All the other interactions were not significant ($P \leq 0.05$). Trends in GRVD severity were similar to those of GRVD incidence. Jinja district had the highest mean disease severity (5.3), followed by Sironko (3.2), Mbarara (2.7) and Lira (2.6), respectively (Fig. 5). Disease severity was highest during 2011A (5.07) and was significantly lower during 2011B (3.2) as well as 2012B (2.98). Severity data also showed that the variety Acholi white was the most severely affected by GRVD (mean severity 4.54) followed by Serenut 1R (4.35), Serenut 6T (3.39) and Serenut 3R (2.73) respectively.

Table 2. Influence of season, location and variety on GRVD incidence (%)

		Incidence (%)					
		Variety					
		1	2	3	4		
Season	Location	Acholi White	Serenut 1R	Serenut 3R	Serenut 6T	Mean	s.e.d
2011A	Jinja	66.30	55.00	66.09	72.61	65.00	8.4
	Lira	16.52	15.00	4.78	7.61	10.98	
	Mbarara	17.17	25.22	20.87	16.52	19.95	
	Sironko	52.39	57.83	30.22	51.74	48.04	
	Mean	38.10	38.26	30.49	37.12	35.99	
	s.e.d					4.23	
2011B	Jinja	53.48	39.57	16.09	28.91	34.51	3.5
	Lira	3.70	5.65	1.30	1.96	3.15	
	Mbarara	1.96	3.70	0.00	1.09	1.68	
	Sironko	10.87	10.65	3.04	8.04	8.15	
	Mean	17.50	14.89	5.11	10.00	11.87	
	s.e.d					1.75	
2012B	Jinja	18.00	14.50	6.00	10.00	12.12	1.8
	Lira	1.50	2.00	1.50	0.50	1.37	
	Mbarara	0.50	0.50	0.50	1.00	0.62	
	Sironko	6.50	4.50	3.25	3.50	4.44	
	Mean	6.62	5.37	2.81	3.75	4.64	
	s.e.d					0.9	

2011A= 1st rains (March-June) of 20112011B= 2nd rains (September-December) of 20112012B=2nd rains (September-December) of 2012



Lira

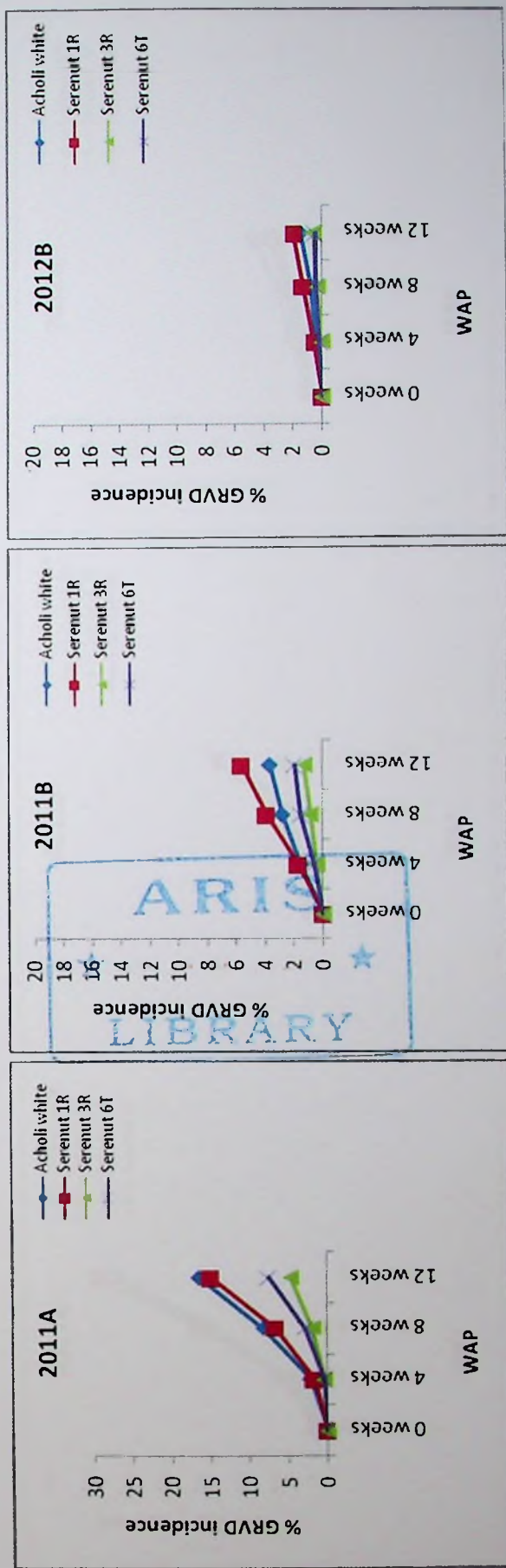


Figure 3. Disease progress curves of GRVD in Jinja and Lira districts for three growing seasons

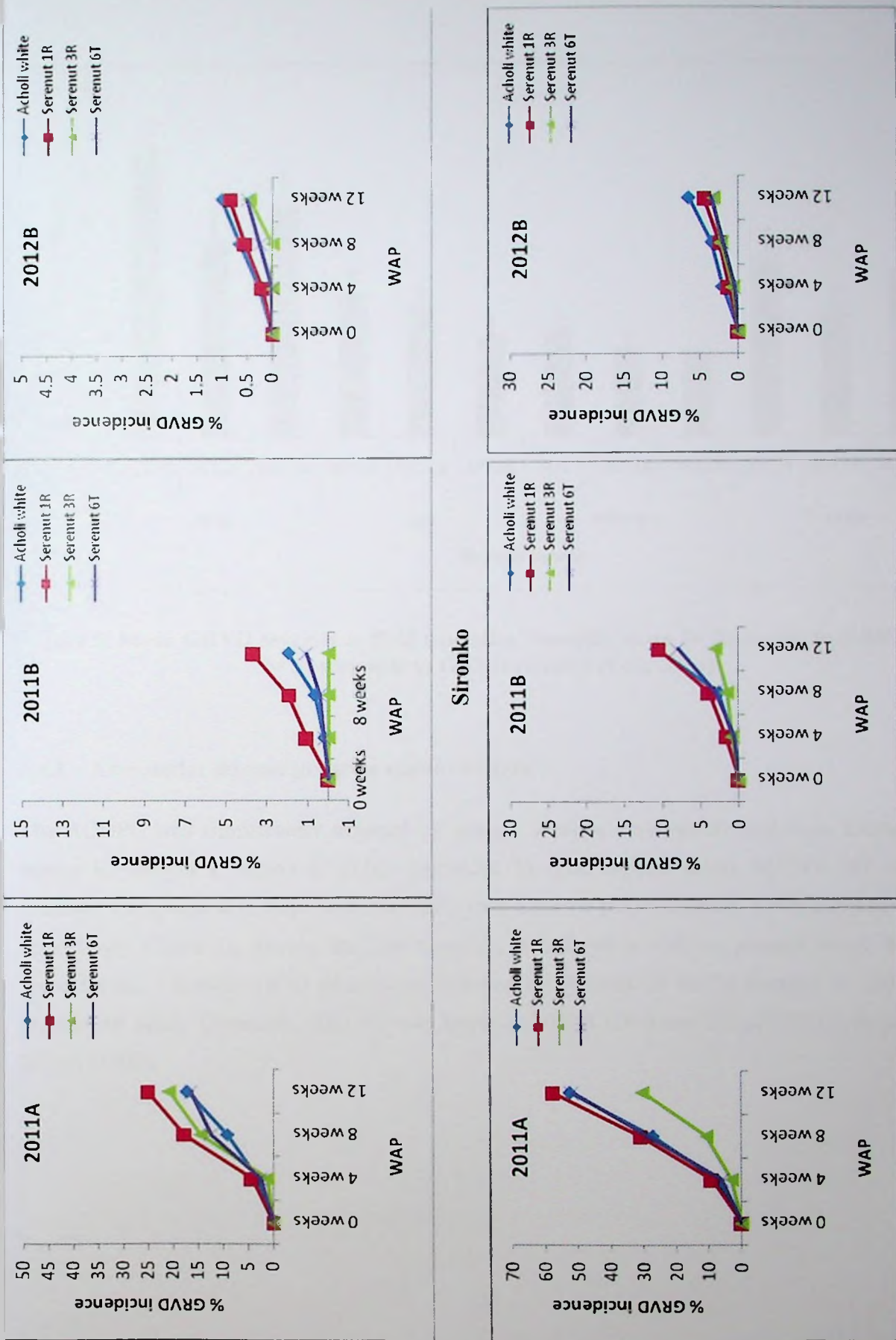


Figure 4. Disease progress curves of GRVD in Mbarara and Sironko districts for three growing seasons

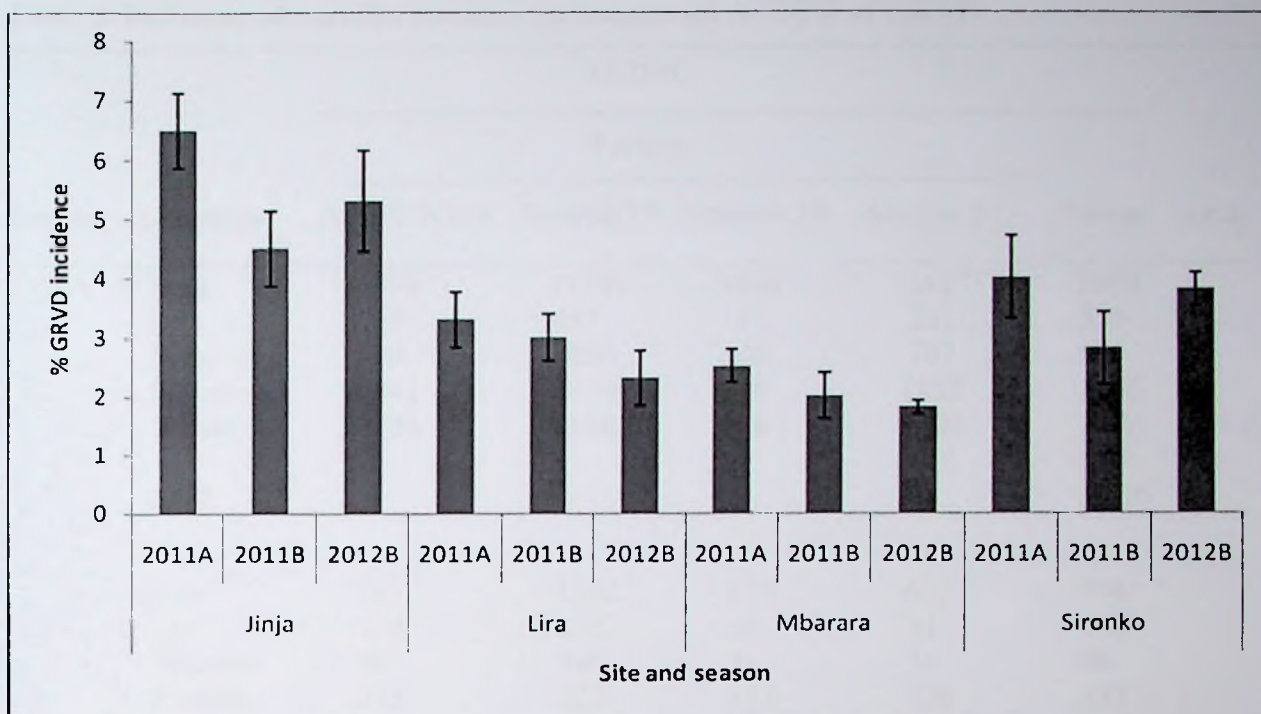


Figure 5. Mean GRVD severity at field trial sites. Severity score 1= Resistant to GRVD and 9= Susceptible to GRVD (Okello *et al.*, 2014)

3.4.2 Area under disease progress curve (AUDPC)

The AUDPC was significantly affected by season, location and variety and their interactions, except for season x variety ($P < 0.05$; Appendix 3). The highest mean AUDPC for all four varieties was obtained in Jinja district (1096), then Sironko (685), Mbarara (293) and Lira (181), respectively (Table 3). Among the four varieties, Acholi white had the greatest mean AUDPC value for the 3 seasons (666) which was followed by Serenut 1R (627), Serenut 6T (562) and Serenut 3R (400). Generally, AUDPC was lower in 2012B (183) and 2011B (303) compared to 2011A (1205).

Table 3. Influence of variety, location and season on AUDPC of GRVD

AUDPC							
Season	Location	Variety				Mean	s.e.d
		Acholi White	Serenut 1R	Serenut 3R	Serenut 6T		
2011A	Jinja	2398	1138	2044	2422	2000	295.2
	Lira	567	487	147	221	355	
	Mbarara	620	1050	826	707	801	
	Sironko	1841	2079	886	1855	1665	
	Mean	1356	1188	976	1301	1205	
	s.e.d					147.6	
2011B	Jinja	1071	1092	329	605	774	90
	Lira	175	245	56	91	142	
	Mbarara	56	140	0	35	58	
	Sironko	273	326	112	238	237	
	Mean	394	451	124	242	303	
	s.e.d					45	
2012B	Jinja	721	721	203	409	514	84.6
	Lira	49	74	60	7	47	
	Mbarara	7	18	14	39	19	
	Sironko	217	158	119	112	151	
	Mean	248	242	99	142	183	
	s.e.d					42.3	

2011A= 1st rains (March-June) of 2011

2011B= 2nd rains (September-December) of 2011

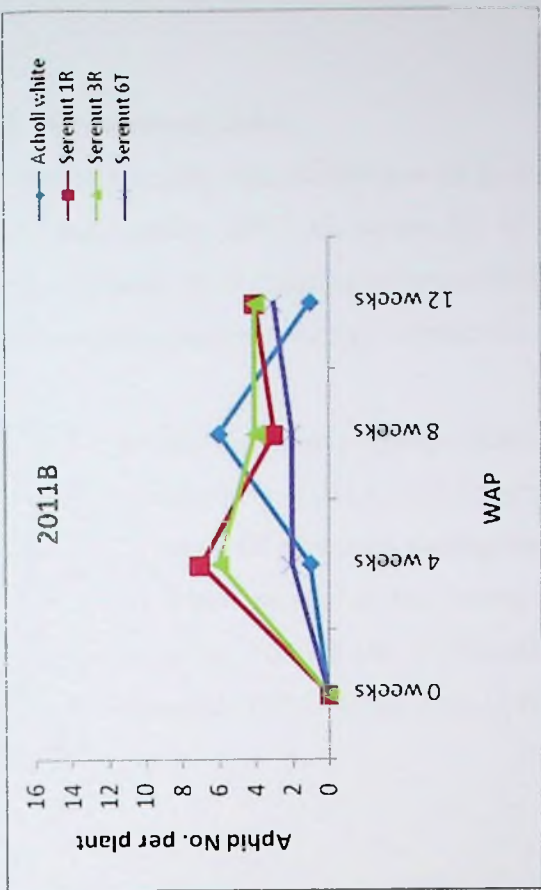
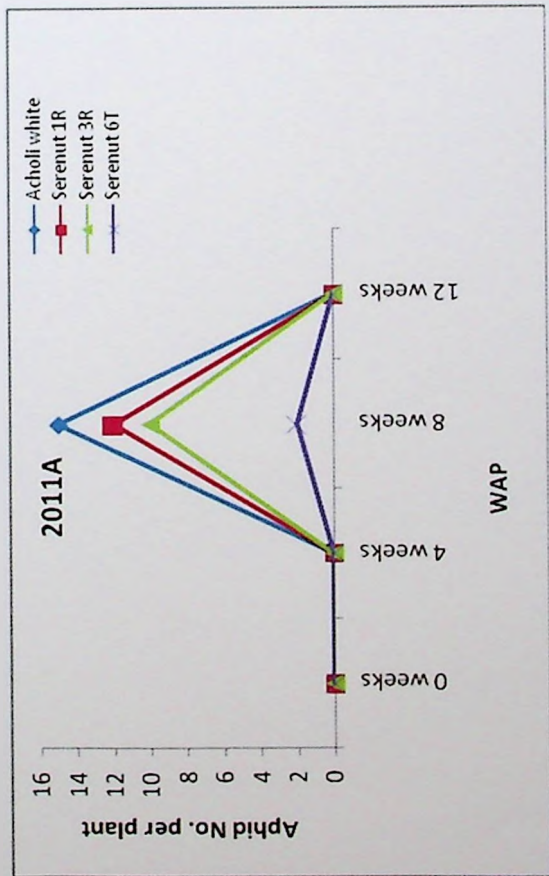
2012B=2nd rains (September-December) of 2012

3.4.3 Aphid populations

Results for aphid populations in the two districts sampled (Mbarara and Sironko) revealed no significant differences in mean aphid numbers per plant among the four varieties and the 2 seasons (2011A and 2011B) ($P>0.05$; Appendix 5). There was a very weak effect of the interaction between location x variety on aphid numbers/plant (Appendix 5). Mean adult aphid

numbers per plant were: Mbarara (5.25), Sironko (3.75) during 2011A; Sironko (4.75), and Mbarara (3.75) in 2011B (Table 5). Variety Serenut 6T had marginally higher mean aphid numbers per plant for both seasons in the 2 locations (6), followed by Acholi white (4.5), Serenut 1R (4.25) and Serenut 3R (2.75). Generally in both locations and for both seasons, average aphid populations increased up to 8 WAP after which their occurrence decreased (Fig. 6) with the exception of Serenut 1R in 2011B. Data on aphid populations was only obtained for adult aphids because it was the winged individuals that were mostly encountered during data collection.

Sironko



Mbarara

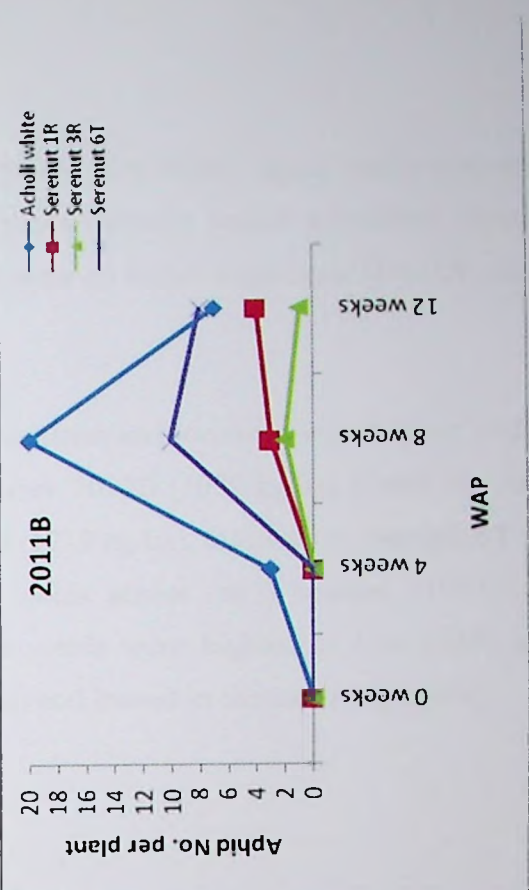
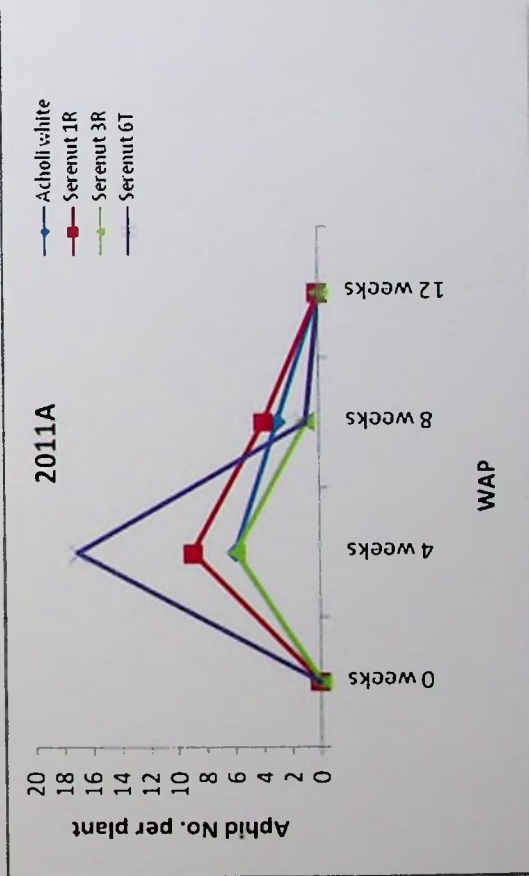


Figure 6. Variation of average aphid numbers on groundnut in Sironko and Mbarara districts plotted against time (wks)

3.4.4 Groundnut yields

The results revealed that differences in groundnut yields were highly significant across season, variety and location ($P < 0.05$; Appendix 4). Interactions between season x location, location x variety x season, site x location on groundnut yields were all highly significant ($P < 0.05$) with the exception of the season x variety interaction.

Generally in all the 3 seasons, average yields in all varieties and locations were highest in 2011B (1665 kg/ha) followed by 2011A (1522 kg/ha) and then 2012B (1079 kg/ha) (Table 4). Among the varieties, Serenut 1R produced the highest yields (1719 kg/ha), followed by Serenut 6T (1595 kg/ha). Acholi white produced the lowest mean yields across the 3 seasons (1077 kg/ha). Considering location, for all the 3 seasons, mean yields were highest in Lira (2313 kg/ha) followed by Mbarara (1475 kg/ha), Jinja (1417 kg/ha) and lowest in Sironko (482 kg/ha).

Table 4. Influence of variety, location and season on groundnut yields (kg/ha)

		Groundnut yields (kg/ha)					
		Variety					
Season	Location	Acholi White	Serenut 1R	Serenut 3R	Serenut 6T	Mean	s.e.d
2011A	Jinja	561	3069	903	1194	1432	489.5
	Lira	2250	2750	2696	3042	2684	
	Mbarara	1425	1089	903	1769	1296	
	Sironko	195	111	264	2139	677	
	Mean	1108	1755	1191	2036	1522	
s.e.d						244.8	
2011B	Jinja	1272	3130	1444	1336	1796	288.4
	Lira	1408	2588	2521	2258	2194	
	Mbarara	2067	1467	1483	3330	2087	
	Sironko	458	250	1292	333	584	
	Mean	1301	1859	1685	1815	1665	
s.e.d						144.2	
2012B	Jinja	835	1107	1459	694	1024	289.4
	Lira	1542	2944	1735	2024	2061	
	Mbarara	760	1888	646	877	1043	
	Sironko	154	239	210	145	187	
	Mean	823	1545	1012	935	1079	
s.e.d						144.7	

2011A= 1st rains (March-June) of 2011

2011B= 2nd rains (September-December) of 2011

2012B=2nd rains (September-December) of 2012

3.4.5 Influence of rainfall, temperature and wind speed on the incidence and severity of GRVD

Weather characteristics (rainfall, temperature and wind speed) at the four study sites (Table 5; Appendices 6-9) were found to influence GRVD incidence and severity in different ways during the three seasons. Taking rainfall for instance, there was generally less average rainfall (83.9 mm) in 2011A in all sites compared to 2011B (163.1 mm). Highest mean rainfall was obtained in

2012B (226.4mm). Among the trial sites, Jinja had the highest mean rainfall during the 2 seasons of the trial (217.4mm), followed by Lira (174.8mm), Sironko (140mm) and finally Mbarara (99mm). General trends of rainfall versus GRVD incidence for all locations showed that high amounts of total rainfall generally corresponded to less GRVD incidence (and vice versa) for all the four varieties during all the three seasons (Fig. 7). In fact, the correlation between total rainfall and GRVD incidence for all trial sites in all the three seasons was negative and significant ($r = -0.280$, $P \leq 0.01$; $N=144$).

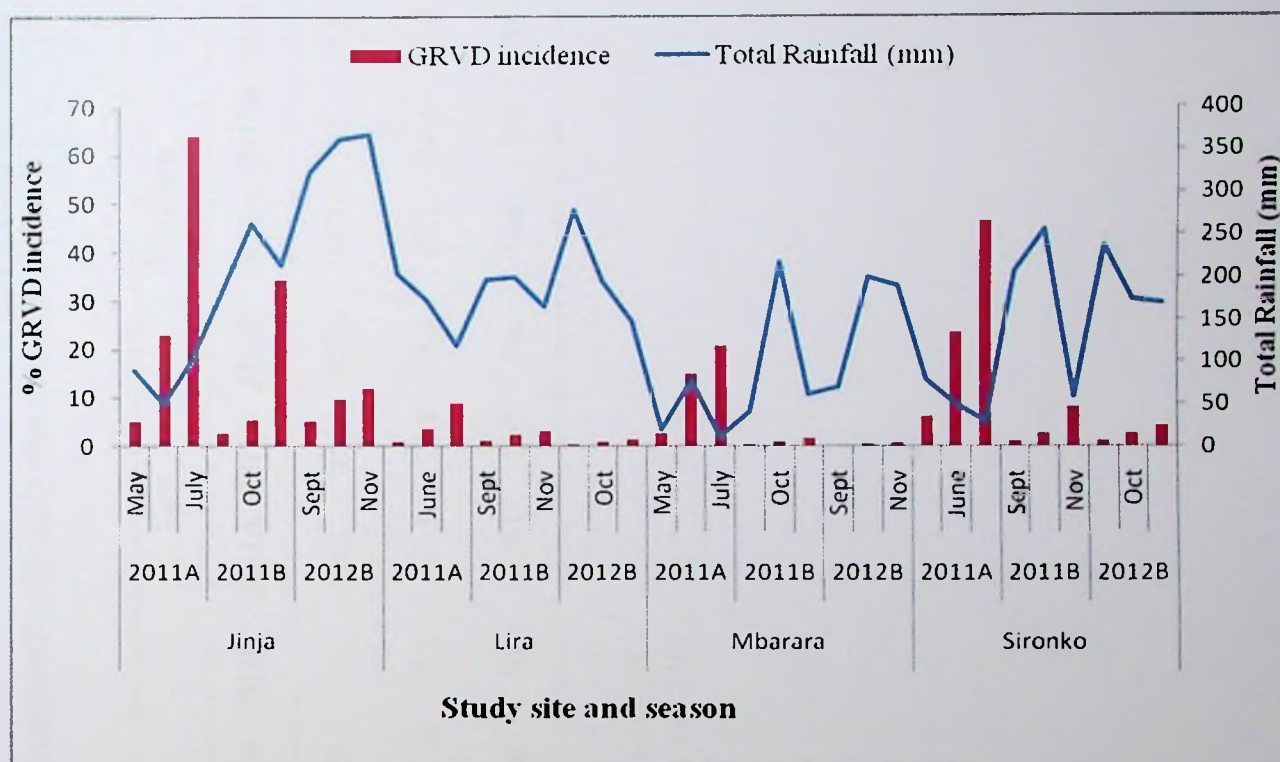


Figure 7. Trends of GRVD incidence vs total rainfall amounts at the four trial sites during three growing seasons

Table 5. Summary of weather characteristics for the study sites during planting seasons 2011A, 2011B and 2012B

Season	Jinja			Lira			Mbarara			Sironko		
	2011A	2011B	2012B	2011A	2011B	2012B	2011A	2011B	2012B	2011A	2011B	2012B
Mean Rainfall (mm)	81.2	220	351	165	152	207.6	36.7	107	153.5	53	173.6	193.5
Mean Temperature (°C)	22.9	22.6	28.1	22.8	26.8	26.1	25.7	24.1	25.4	21.6	21.8	21.9
Mean Wind speed (km/hr)	3.4	3.0	Na	59.4	116	Na	Na	Na	Na	Na	Na	Na

2011A= 1st rains (March-June) of 2011
2011B= 2nd rains (September-December) of 2011
2012B=2nd rains (September-December) of 2012
Na = Information not available

Average temperatures were highest in 2012B (25.3°C) and lowest in 2011A (23.2°C) across all locations. Highest mean temperatures were recorded in Lira district (25.2°C), followed by Mbarara (25.0°C), Jinja (24.5°C) and Sironko (21.7°C). The trend for temperature and GRVD incidence was not very distinct (Fig. 8) with the correlation showing positive and negative trends depending on location. There was a highly significant positive relationship between GRVD incidence and average temperatures at the Mbarara site ($r = 0.444$, $P \leq 0.01$; $N=36$) whereas the Lira site showed a significant negative relationship between GRVD incidence and average temperatures ($r = -0.470$, $P \leq 0.01$; $N=36$). There was no significant relationship between GRVD incidence and average temperatures at the Jinja and Sironko sites.

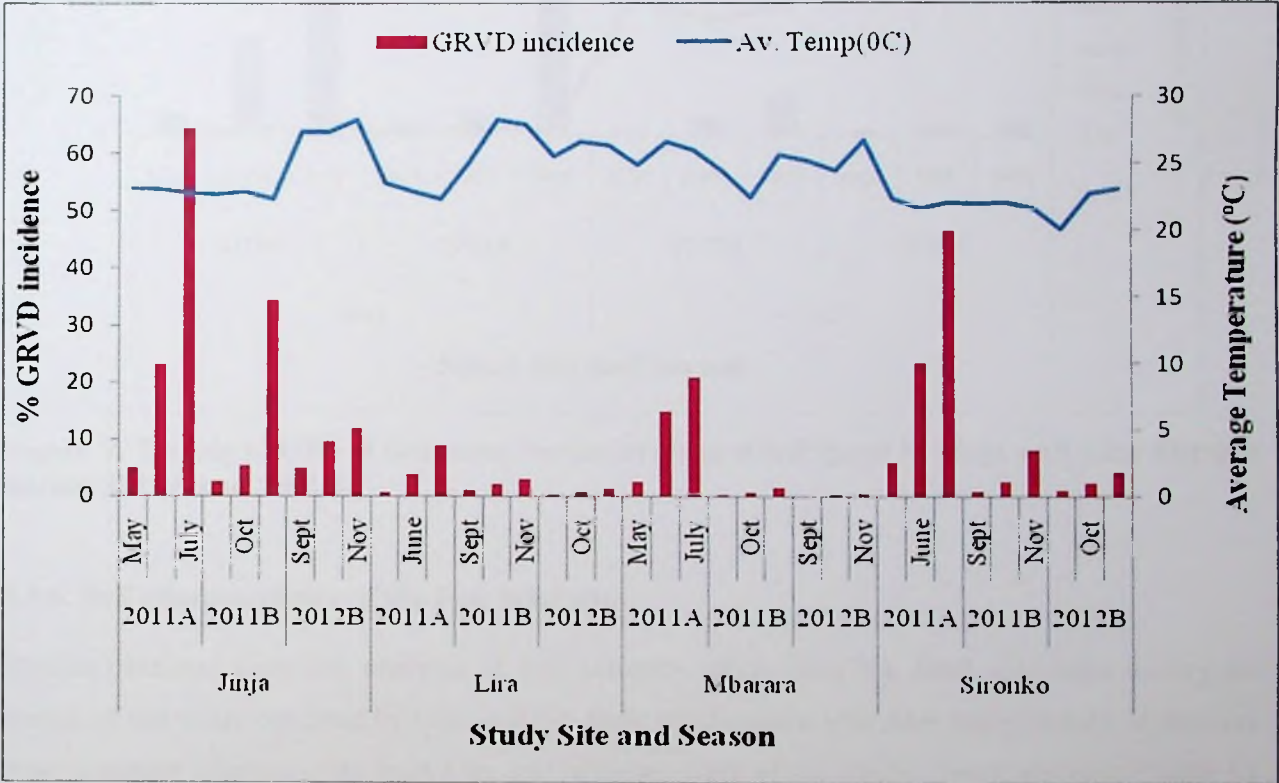


Figure 8. Trends of GRVD incidence vs temperature at the four trial sites during three growing seasons

In the 2 districts sampled for wind speed (Jinja and Lira), average wind speeds recorded were highest in 2011B (59.5 km/hr) and lowest in 2011A (31.4 km/hr), with Lira having much higher wind speeds (3.2 km/hr) than Jinja (86 km/hr) (Fig. 9). The correlation between wind speed and GRVD incidence showed that there was a highly significant negative relationship between wind speed and GRVD incidence ($r = -0.476$, $P \leq 0.01$; $N=48$).

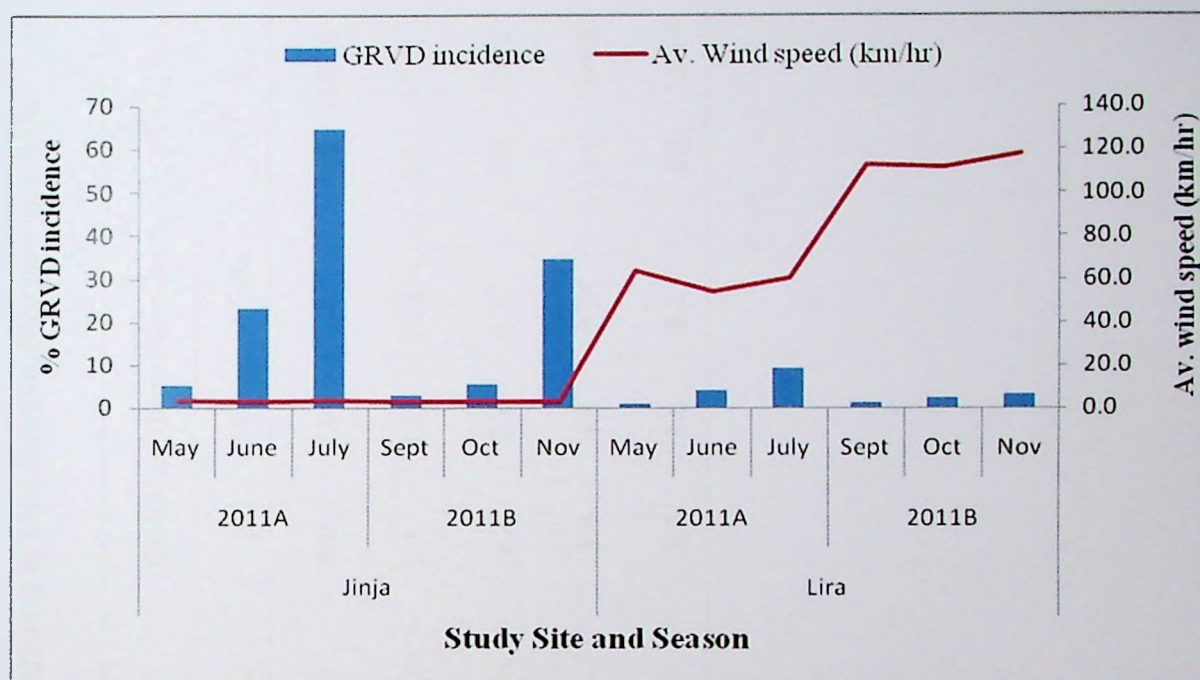


Figure 9. Trends of GRVD incidence versus average wind speed in Jinja and Lira districts during 2011A and 2011B

3.4.6. Soil characteristics of the four trial sites

Results obtained from the analysis of soil samples taken from the field trial sites during the course of the study revealed that the soils in Jinja and Sironko trial sites were mainly of the clay type in nature whereas soils from Lira and Mbarara were of the sandy-clay-loam-type (Table 6). Soils from Jinja and Sironko generally had higher pH, more organic matter, soil nitrogen, calcium, magnesium, potassium, clay and silt compared to soils from Mbarara and Lira sites. However, the two sites (Jinja and Sironko) also had the lowest levels of sand. Generally, soils from all the trial sites were found to have very low levels of phosphorus, which were much lower

Table 6. Summary of soil characteristics for the study sites in Lira, Sironko, Mbarara and Jinja

District	% Texture			Chemical characteristics				Base, m.e./100g (ppm)		
	Sand	Clay	Silt	Textural class	pH	%O.M	%N	P	Ca	Mg K
Jinja	18.4	71.0	10.6	Clay	6.0	7.0	0.31	0.8	1189.6	608.3 441.2
Lira	60.4	31.0	8.6	Sandy-clay-loam	5.8	3.1	0.18	0.9	709.2	232.1 312.8
Mbarara	66.4	27.0	6.6	Sandy-clay-loam	5.2	2.7	0.17	2.0	526.2	232.1 397.7
Sironko	20.4	65.0	14.6	Clay	5.9	4.8	0.24	0.9	999.0	453.9 795.5
Critical levels					5.2	3.0	0.2	90	350.0	100.0 150.0

Note: O.M= Organic matter

than the critical level of 90. Mbarara was the only site that had percentage organic matter content (2.7%) below the critical level (3%). Lira (0.18%) and Mbarara (0.17%) sites were also found to have nitrogen levels which were below the critical level (0.2%).

3.5 Discussion and conclusions

The purpose of this study was to establish the influence of ambient ecology on the occurrence and severity of GRVD in different agro-ecologies of Uganda. Results of GRVD incidence, AUDPC and severity revealed that the disease was most prevalent during the first rains (2011A) as compared to the second rains (2011B; 2012B). This situation may be attributed to the weather characteristics during the three seasons; for instance, the highest rainfall amounts were received in 2012B (226.4 mm) compared to 2011B (163.1 mm) and 2011A (83.9 mm). The results of this study in 2011A from Lira are in line with previous research findings as they indicated a significant negative correlation between rainfall and GRVD incidence. Rainfall is known to have a negative influence on movement of aphids, which are the vectors of GRVD. Wightman *et al.*, (1990), reported that persistent rain dislodges aphids from plants onto the soil surface where they are subsequently exposed to predation or may be killed directly by soil particles splashed onto their colonies. Hasan *et al.*, (2009), in their study on aphid populations on the mustard crop, also noted that even slight rainfall amounts quickly lowered aphid populations from fields that were monitored at different times of the day.

This argument on effect of weather could be expanded to observations on aphid numbers with wind speed. Wind speeds recorded during the course of the study were generally higher in 2011B (mean 59.5 km/hr) compared to 2011A (mean 31.4 km/hr). Previous workers have reported that high wind speeds have a negative influence on population build up of aphids (Hasan *et al.*, 2009), causing them to be blown away, subsequently lowering their populations. This also proved to be the case in this study, where results showed that there was a significantly negative relationship between wind speed and GRVD incidence.

Furthermore, an increase in temperature has been reported to facilitate an increase in aphid populations (Bakhetia and Sindhu, 1983; Hasan *et al.*, 2009), which would lead to higher

incidence and severity of GRVD within the groundnut crop. In this study, higher temperatures corresponded to higher GRVD levels in Mbarara district ($r = 0.444$, $P \leq 0.01$; $N=36$) but this was not the case for Lira ($r = -0.470$, $P \leq 0.01$; $N=36$). Results showed that while there was a large difference between rainfall amounts received in Lira and Mbarara districts during the course of the study, temperature differences were minimal. It's therefore possible that the combined function of high rainfall amounts and minimal temperature increase in this case led to lower aphid populations (Inamullah *et al.*, 2004) since the temperature levels in Lira were within the optimum temperature ranges that favour aphid population build up (24°C - 28.5°C) (Mayeux, 1984).

The incidence and severity of GRVD varied across locations for all the three seasons. The highest mean scores of GRVD incidence were recorded in Jinja district (65%) and the lowest scores were recorded in Mbarara district (0.62%). This confirms with past reports that identified Jinja (Nakabango) as one of the hotspots for GRVD in Uganda (Okello *et al.*, 2010). However, the results on rainfall from Jinja indicate that though it received the highest rainfall amounts in 2011B and 2012B compared to the other three locations, GRVD incidence and severity was still highest in this district. This trend of GRVD incidence could partially be influenced by proximity to the sources of primary inoculum to the disease, thereby increasing subsequent occurrence levels given that groundnut is one of the major food crops in the district. Being a polycyclic disease, each infected plant would serve as a source for initiating subsequent spread in the field. Naidu *et al.*, (1999) concurs by identifying the role of volunteer plants and/or alternative hosts as possible sources from which GRVD could be spread.

In the past, some researchers have linked the nutritional status of soils to the levels of arthropod damage in a crop, with total nitrogen (N) being the most critical factor whose increase was associated with higher aphid and mite populations on a crop (van Emden, 1966; Slansky and Rodriguez, 1987; Duffield *et al.*, 2008). In this study, Jinja and Sironko, which had the highest amounts of nitrogen in their soils, also had the highest levels of GRVD incidence and severity. The reverse was true for Lira and Mbarara. The higher levels of GRVD incidence and severity could therefore also be partially attributed to higher nitrogen in the soils, which favored

vegetative growth of the groundnut crop, consequently leading to more build up in aphid populations hence more GRVD incidence and severity in Jinja and Sironko. However, results from the study showed that there was no significant difference in the number of aphids obtained in Mbarara and Sironko although mean aphid numbers were higher in Sironko compared to Mbarara district during 2011B.

Groundnut yields for all the three seasons were highest in Lira district (2313 kg/ha), followed by Mbarara (1475 kg/ha), Jinja (1417 kg/ha) and finally Sironko (482 kg/ha). The higher yields in Lira and Mbarara can be attributed to less GRVD incidence and severity in addition to having favourable soils for groundnut production. The reverse is true for Jinja and Sironko districts. Soil analysis results from the trial sites revealed that Lira and Mbarara had soils of the sandy-clay-loam textural class to which groundnut is best adapted being well-drained, loose, friable and medium textured soils (ICRISAT, 1995; FAO, 2009). Top soils that are loose allow the pegs, on which the fruits are formed, to enter the soil easily, thus promoting growth. Sironko district consistently had the lowest groundnut yields for all the three growing seasons. Apart from having high levels of GRVD incidence and severity (compared to Lira and Mbarara), it also turned out that the soils in Sironko district had much higher levels of potassium than the other districts. Very high amounts of potassium have been reported to lead to a decrease in groundnut yields (FAO, 2009) because of its antagonistic effect on the absorption of other nutrients like sodium.

Groundnut variety significantly influenced GRVD incidence and severity, with the varieties Acholi white and Serenut 1R sustaining the highest GRVD incidence and severity, compared to Serenut 6T and Serenut 3R. Serenut 3R proved to be the most resistant variety and had the lowest levels of GRVD in most cases. Even though Serenut 1R was more affected by GRVD compared to Serenut 3R, it yielded higher. This could be attributed to its large sized seeds which were heavier even when the crop was more affected by GRVD compared to the other varieties. When planted using recommended practices, Serenut 1R has been reported to yield between 2500-3700 kg/ha compared to Serenut 3R which yields between 2500-2900 kg/ha (Okello, 2010). Despite the reported resistance levels of Serenut 3R however, the variety succumbed much more to the disease when GRVD incidence was particularly very high (2011A). This could

imply the possibility of breakdown of resistance by this variety in situations of high disease pressure as it has been reported for previously released varieties of crops like maize (Erbaugh *et al.*, 2002). Serenut 6T, a tan seeded variety that was released eight years earlier than Serenut 3R, had much higher levels of disease incidence than Serenut 3R indicating faster breakdown in disease resistance.

This study has shown that rainfall, temperature, wind speed and soil factors play a role in influencing the occurrence and severity of GRVD in the different agro-ecological zones. However, differences in disease levels in different agro-ecologies cannot be attributed to only these factors. It has been reported that virus spread within a given crop is facilitated by some practices and impeded by others (Thresh, 2003). Therefore, attention has to as well be given to the management practices employed by farmers within the different agro-ecological zones which also affect disease levels in their fields and neighboring fields. The effect of management practices on GRVD was, thus, explored and is presented in the next chapter.

CHAPTER FOUR

EFFECT OF FARMERS' MANAGEMENT PRACTICES ON SEVERITY OF GROUNDNUT ROSETTE VIRUS DISEASE IN UGANDA

4.1 Introduction

Over the past years, a wide range of management options for GRVD have been developed and recommended for farmers in Uganda (NARO, 2001; Adipala *et al.*, 2001). These include the use of improved varieties, chemical control, and cropping practices that delay the onset and spread of GRVD such as early sowing, maintaining a dense uniform stand of groundnut, close spacing (45x15cm and 30x10cm) and removal of wild hosts. Relevant efforts have also been made by researchers from the Groundnut Improvement Programme (NaSARRI) and Makerere University in disseminating these research technologies to farmers in several parts of the country (Adipala *et al.*, 2002; NaSARRI report, unpublished). However, questions on the extent to which farmers are currently utilizing these technologies and their effectiveness in GRVD control remain unanswered. Thresh (2003), emphasized the need for much detailed research and a thorough knowledge of farming practices before an effective integrated virus disease management programme can be developed and promoted. This study was, therefore, conducted to establish the extent to which these practices being employed by farmers in GRVD management are influencing disease severity. Information obtained in this study will be important in the future development and promotion of sustainable integrated GRVD management strategies in Uganda.

4.2 Materials and Methods

A survey was conducted in 2012 that covered 5 major groundnut producing agro-ecological zones (AEZ) in 7 districts of Uganda (Table 7). In each district, sub counties and parishes were selected purposively based on production levels, giving preference to those which produced more groundnuts. Farmers that participated in the study were randomly selected with the help of district personnel based in the respective areas. No particular farmer categories were targeted. Farmers' fields were monitored over a period of two weeks and the level of GRVD severity in each entire field was assessed and recorded.

Table 7. Distribution and number of farmers interviewed during the survey

No.	Agro-ecological zone	Districts	No. of respondent farmers
1	Lake Victoria Crescent	Jinja and Kayunga	23
2	Kyoga Plains	Pallisa and Kumi	24
3	South Western Farmlands	Mbarara	22
4	North Eastern Savannah Grasslands	Lira	21
5	North Western Savannah Grasslands	Arua	15
Total			105

4.3 Data collection and analyses

A structured questionnaire was developed and used to obtain information on the current management practices employed by farmers in groundnut production (Appendix 12). In each farm, 10 plants were randomly selected. Severity of GRVD was scored using a similar scale as that used during the trials (Okello *et al.*, 2014) where:

1-3= Low GRVD severity (Resistant)

4-6= Moderate GRVD severity (Moderately resistant)

7-9= High GRVD severity (Susceptible)

The average severity score for each field was then computed. Data on farmers' management practices and severity for each field were entered and analyzed using the Statistical Package for Social Scientists, 15th edition (SPSS Inc., 2006). Regression analysis was carried out to establish the relationship between the management practices employed by farmers and GRVD severity. Linear regression was run with disease severity as the dependent variable and the management practices as the independent variables. Descriptive statistics such as frequencies and percentages were obtained for all continuous variables. Graphs and charts were also generated from the data using an excel program (Microsoft Office, 2007).

4.4 Results

4.4.1 General characteristics of respondent farms and practices used

Of the 105 farmers interviewed during this study, 44 (42%) were male and 61 (58%) were female. Farmers planted groundnuts on an average acreage of 0.58 acres, with the majority 85 farmers (81.6%) operating on acreages less than 0.5 acre. Only two farmers (1.8%) planted groundnuts on land exceeding 1 acre. The most dominant ploughing method used by groundnut farmers 98 (94%) was found to be using a hand hoe whereas eight farmers (7%) used tractors and five used oxen (4%) in their fields.

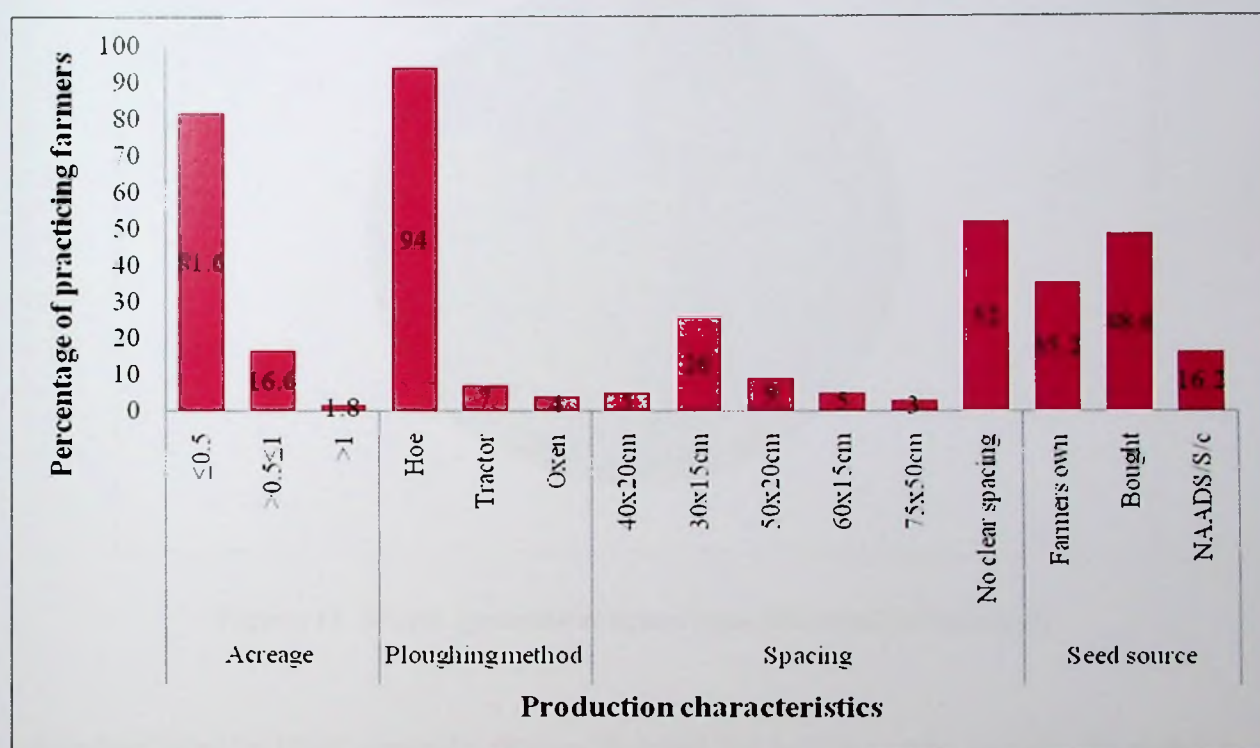


Figure 10. Groundnut production characteristics of farmers' fields visited during survey

Farmers in all the five agro-ecological zones used a wide range of plant spacings, ranging from 40 x 20cm to 75 x 50cm. However the majority (52%) of groundnut farmers did not use any particular spacing. Most of the farmers purchased their seeds from either the local market, input suppliers or from fellow farmers (48.6%) while 35.2% used seed they had saved from the

previous harvest. Some farmers (16.2%) obtained improved seed from either NARO or the NAADS sub county offices in the surrounding area (Fig.10).

With regard to cropping system, 65% farmers intercropped groundnut with other crops including: Maize (42%), cassava (27%), perennials (21%) and legumes (7%) (Fig.11). Minor crops (3%) not indicated in the chart but found intercropped with groundnuts included: vegetables, sorghum, okra, potato, simsim and millet.

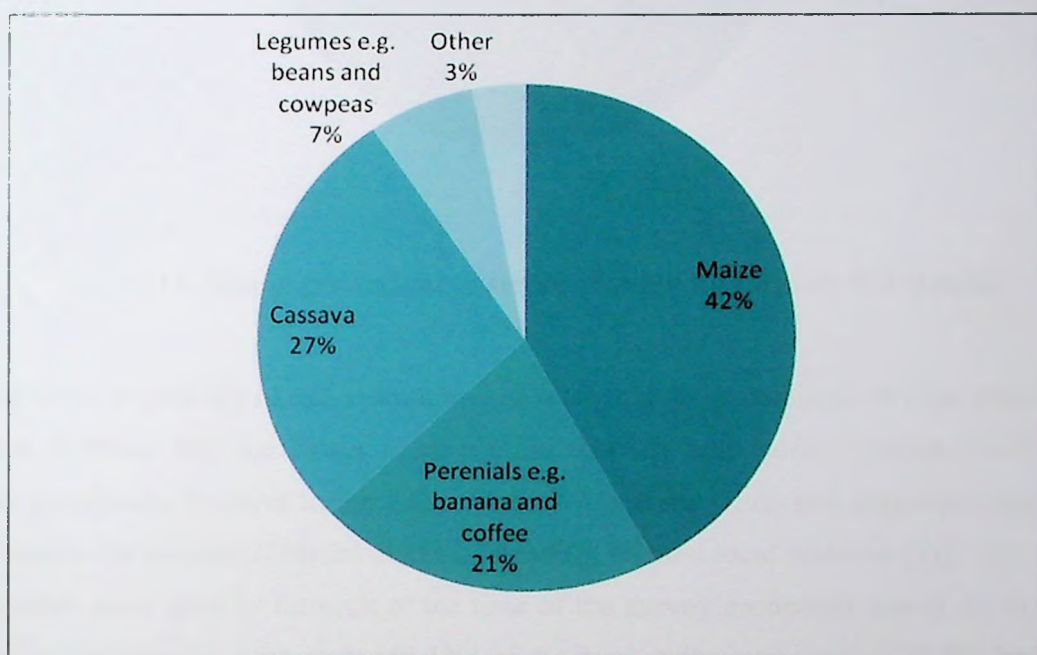


Figure 11. Major groundnut intercrops observed in the study

Groundnut varieties being grown by farmers included the Serenut series, specifically Serenut 1, 2, 3 and 4 (34%). The main local varieties grown by farmers included: Red beauty (21%) and Erudu (16%); others included Igola, Etesot, Egoromoit, Kabonge and Omgwere (Fig.12).

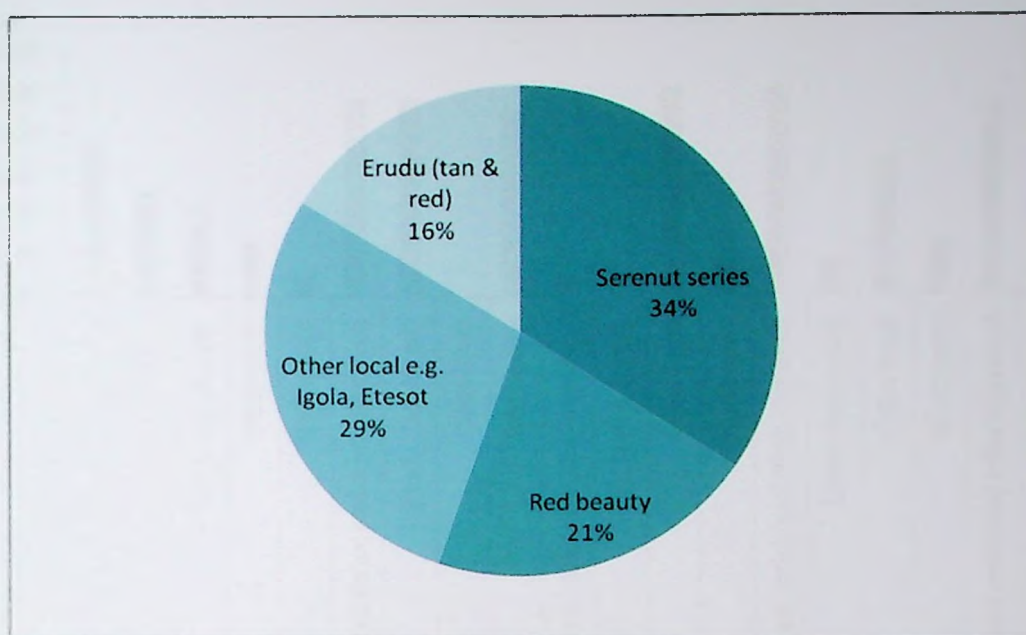


Figure 12. Major groundnut varieties planted by farmers in Uganda

Improved varieties (mainly of the Serenut series) were mainly grown in the Kyoga plains (Pallisa and Kumi districts) and the North Eastern (Lira district) and North Western (Arua district) savannah grasslands. Farmers in the Lake Victoria Crescent (Jinja and Kayunga districts) and South Western Farmlands (Mbarara district) primarily planted local varieties (Fig. 13). Different planting times were used by farmers; at the time of the survey groundnut was at different levels of physiological maturity with most (58.1%) of the crop at flowering stage, 23.8% had attained harvest maturity and 18.1% were in the pegging and pod filling stage (between flowering and maturity).

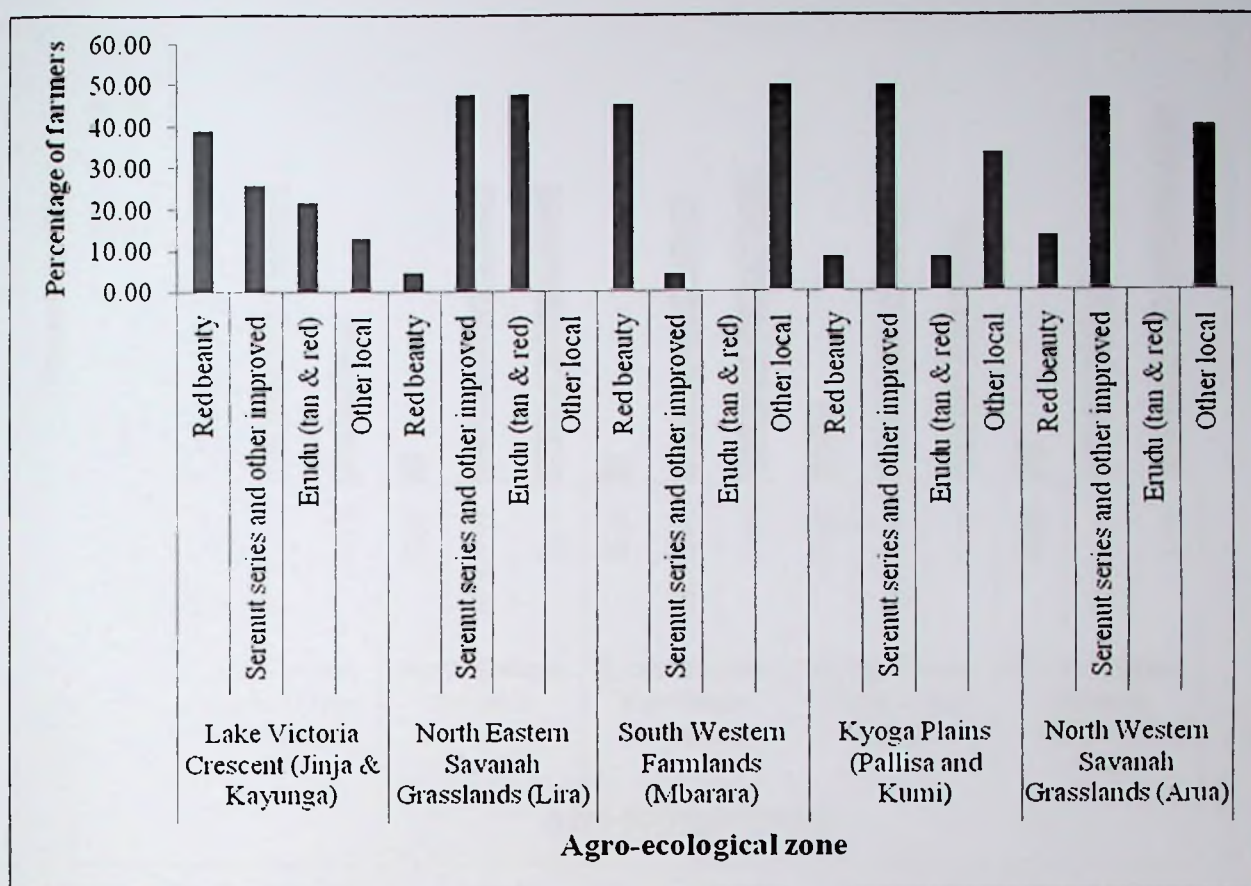


Figure 13. Groundnut varieties grown in the different agro-ecological zones

4.4.2 Trends of GRVD severity within five agro-ecological zones of Uganda

Results of the survey revealed that 41% of the fields visited had moderate levels of GRVD severity whereas 52.4% exhibited low levels of disease severity. Only 6.7% of the fields visited were severely affected by GRVD. Among the fields that were severely affected by GRVD, 50% were from the Lake Victoria Crescent agro-ecological zone, 25% from the Kyoga plains and only a few from the North Western Savannah grasslands (8.3%), North Eastern savannah grasslands (8.3%) and South Western Farmlands (8.3%) (Fig.14).

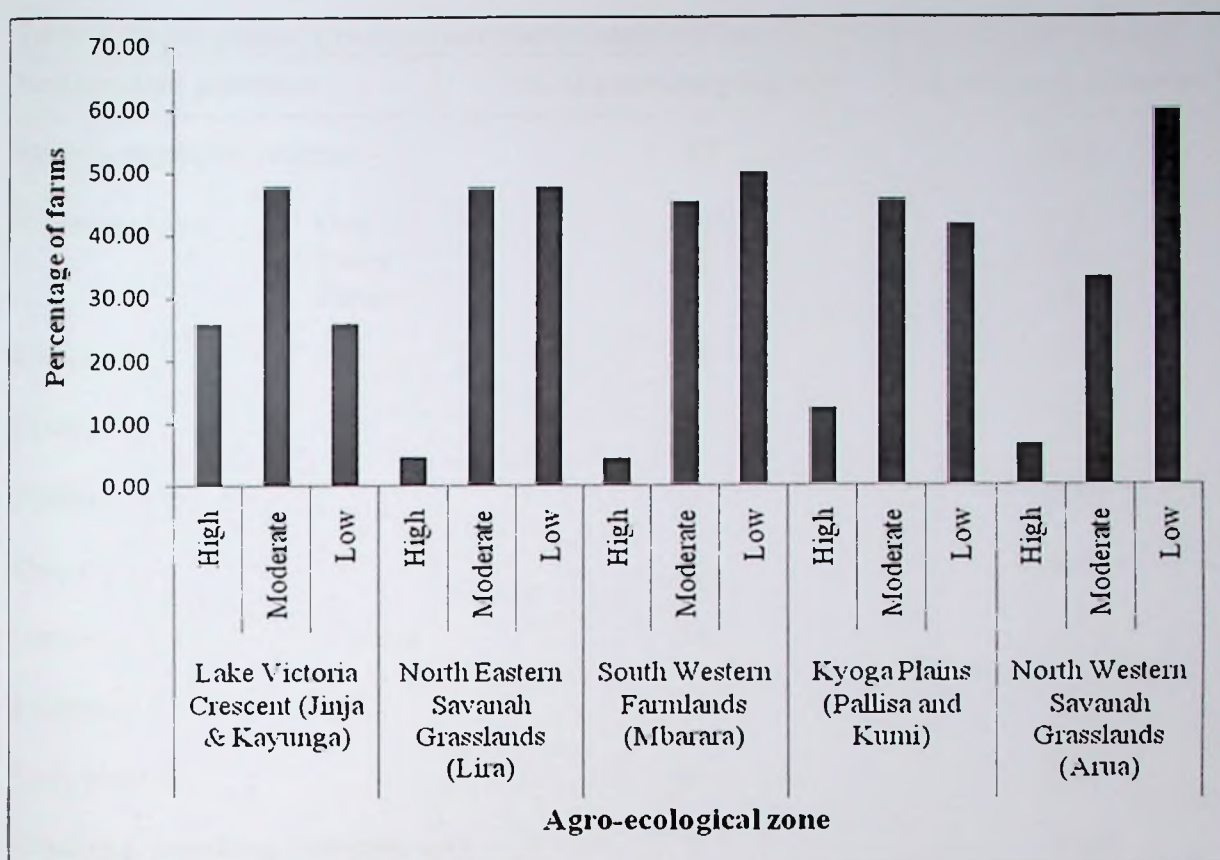


Figure 14. GRVD severity trends within five agro-ecological zones

4.4.3 Management practices employed by farmers in groundnut production

Farmers employed a range of practices in groundnut production which included: early planting, use of improved varieties, intercropping, pesticide application, crop rotation, uprooting and burning diseased plants and fallowing among others (Table 8). Among the recommended GRVD management practices, early sowing was the most common and was being practised by 80% of the farmers, the majority of whom were women (Fig. 15). Pesticide application was the least employed, with only 7.6% of farmers interviewed implementing it. Improved varieties such as the Serenut series were being used by 35.2% of the farmers interviewed while 64.8% of farmers planted local varieties such as Etesot, Egoromoit and Kabonge.

Table 8. Management practices currently employed by groundnut farmers in Uganda

Management practices		No. of practicing farmers	Percentage of farmers (%)
Planting improved varieties		37	35.2
Weeding regime	Once	39	37.1
	Twice	62	59.0
	Thrice	4	3.80
Intercropping		68	65.0
Pesticide application		8	7.60
Fertilizer application		9	8.60
Crop rotation		42	40.0
Uproot and burn diseased plants		36	34.3
Fallowing fields		33	31.4
Early planting		84	80.0
Other (e.g. mulching, herbicide use)		5	4.80
Total		105	100

Forty percent (40%) of the farmers practiced crop rotation in their fields while 31.4% reported that they carry out fallowing in their gardens. Among the farmers interviewed, 34.3% reported that they uproot and burn diseased plants, especially during the time of weeding. A larger number (59%) of farmers weeded their gardens twice during the growing season while 37.1% weed only once during the season and 3.8% carried out hand weeding three times during the growing season. Other practices that were rarely practiced by farmers included fertilizer application (8.6%), mulching (2.9%) and herbicide use (1.9%).

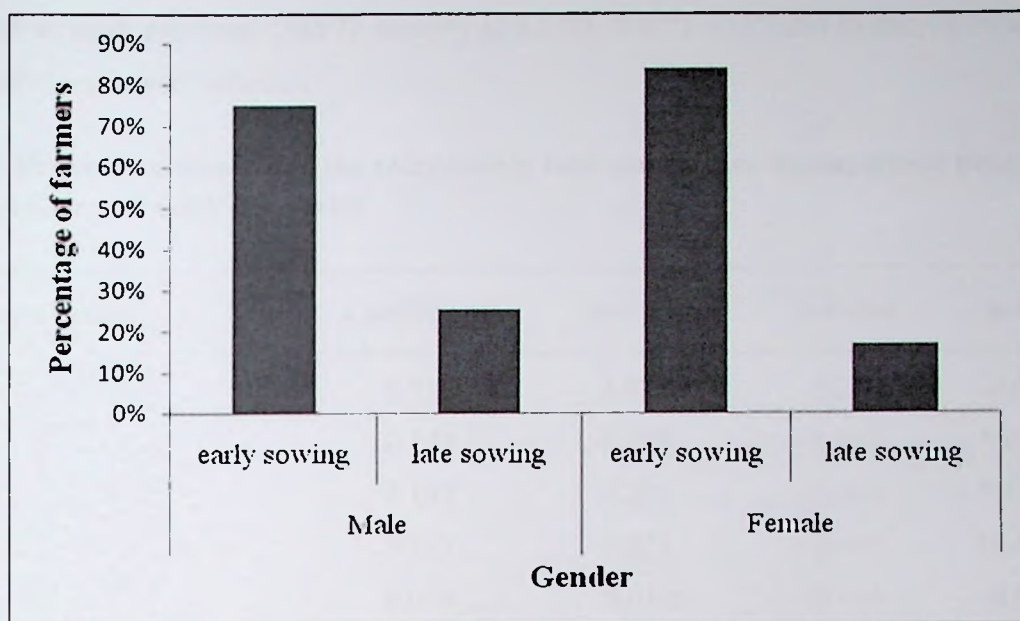


Figure 15. Planting times for female and male farmers obtained during the survey

4.4.4 Relationship between farmers' management practices, gender and GRVD severity

The ANOVA for regression analysis of farmers management practices, their gender and GRVD severity revealed that management practices and gender significantly ($P \leq 0.05$) affected GRVD severity (Appendix 10). The model obtained from linear regression revealed that planting date, variety planted and gender were the only variables that significantly ($P \leq 0.05$) affected GRVD severity in farmer fields (Appendix 11). Variables which were found to have no significant effect on disease severity ($P \leq 0.05$) included: crop rotation, uprooting and burning diseased plants, pesticide application, fertilizer application, mulching, number of times the crop is weeded and fallowing among others (Table 9). A summary of the regression model is expressed in the following equation:

$$\text{GRVD severity} = 3.7 - 0.3 \text{ gender} + 0.3 \text{ planting date} - 0.6 \text{ variety planted}$$

The equation implies that, holding all other factors constant, GRVD severity is lower for female managed gardens compared to male managed gardens. In particular, the GRVD severity in female managed gardens is lower by 34.99% ($[(e^{0.3}) - 1] * 100$) in comparison to male managed fields. A delay in planting (late planting) increases GRVD severity by 34.99% ($[(e^{0.3}) - 1] * 100$)

compared to early planting. GRVD severity is 82.2% $[(e^{0.6}) - 1] \times 100$ higher in local varieties compared to improved varieties.

Table 9. Regression results for the relationship between farmer management practices, gender and GRVD severity

Regression model ^a	Coefficients	Std. Error	t-value	p-value
(Constant)	0.715	3.725	5.210	0.000
Gender	0.108	-0.284	-2.619	*0.010
Planting date	0.142	0.294	2.067	*0.042
Variety planted	0.113	-0.621	-5.491	*0.000
Weeding regime	0.098	0.010	0.104	0.918
Fertilizer application	0.188	0.243	1.293	0.199
Pesticide application	0.200	-0.050	-0.250	0.803
Herbicide application	0.398	-0.372	-0.935	0.352
Crop rotation	0.110	-0.068	-0.614	0.541
Uproot and burn	0.113	0.116	1.025	0.308
Fallowing	0.124	-0.114	-0.919	0.360
Mulching	0.318	-0.346	-1.085	0.281

^aDependent variable: disease severity in field

*Significance at 5% level

4.5 Discussion and conclusions

The aim of this study was to assess the effect of farmers' management practices on the severity of GRVD in Uganda. Farmers were found to be utilizing a range of management practices. However, these practices influenced GRVD severity in different ways and to different degrees. Results revealed that it was planting date (early planting vs. late planting) and variety planted (improved vs. local) which significantly ($P < 0.05$) affected GRVD severity. Farmers who planted their groundnuts during the earlier part of the season had significantly ($P < 0.05$) less GRVD affecting their groundnut crop compared to those who planted late. The same was also true for

farmers who used improved varieties in comparison to those who planted local varieties. Earlier research (Farrell, 1976a) reported that farmers seldom practice early sowing of groundnuts since they prefer sowing their main staple food crops first. The results of this study, however, are divergent from this report. Out of all the farmers interviewed, 80% reported that they had planted their groundnuts at the start of the rainy season and the remaining 20% planted later along the season. It possible that over the years, some farmers may have realized through experience that late sown crops end up more severely affected by GRVD and have therefore chosen early sowing as one of the practices for disease management. Different researchers have reported that GRVD incidence is generally low when groundnuts are planted early in the season compared to the late sown crop (Farrel, 1976; Subrahmanyam and Hildebrand, 1994; Naidu *et al.*, 1999; Adipala *et al.*, 2001). The early sown crops cover the ground before the aphids' main period of flight activity and largely escape infection because aphids prefer younger crops and often alight preferentially on widely spaced plants. The results of this study are in line with these findings; late planting was found to lead to an increase of 34.9% in GRVD severity compared to early planted crops in farmers' fields. Furthermore, experiments conducted on integrated management of groundnuts by researchers at the International Crops Research Institute for the Semi Arid Tropics (ICRISAT) as well revealed that using early sowing and improved genotypes in combination while planting at optimum plant population, exhibited the best performance of groundnuts under high disease situations (Subrahmanyam *et al.*, 2000). The results of this study, which show that use of improved varieties and early sowing are the two major practices that can significantly reduce GRVD severity in farmers' fields are consistent with their reports.

Gender of the farmer, a variable that is not one of the management practices, was also found to affect GRVD severity significantly ($P < 0.05$), with female managed fields having less disease severity compared to male managed ones. This is probably because a greater percentage of women were found to be engaged in early planting compared to the men. Earlier reports have indicated that groundnut in Sub Saharan Africa and Uganda are primarily produced by small holder farmers, the majority of whom are women (Naidu *et al.*, 1999, VECO, 2011). This was confirmed in this study where the majority (81.6%) of groundnut farmers were found operating on acreages less than 0.5 acres and with a greater percentage being women (58%). This is also in

line with reports that females make up approximately 75% of agricultural employment in Uganda (EPRC, 2009).

This study revealed that management practices such as intercropping, planting at close spacing, pesticide application and rouging did not significantly reduce the incidence and severity of GRVD in farmers' fields. Intercropping groundnut with crops such as beans and sorghum has previously been reported to be effective in reducing GRVD incidence (Farrell, 1976; Alegbejo, 1997). It's possible that intercropping was not found to reduce GRVD severity in farmers' fields because farmers were practicing it in a haphazard manner, with no clear spacing which is in contrast to intercropping experiments in which recommended spacings were used. According to the survey results, 65% of the farmers were engaged in intercropping groundnuts with other crops such as maize and cassava. This is supported by reports by Okello *et al.*, (2010), which indicated that the groundnut crop in Uganda is mainly grown as an intercrop with maize and cassava. Intercropping together with varietal mixtures are now recognized by agronomists and other researchers as forms of crop diversity that are important in providing farmers with some degree of resilience and stability that contribute to reliable yields and avoids total crop failure (Smithson and Lenne, 1996). Planting groundnut at close spacings (45x15cm and 30x10cm), has also been reported to lead to reduction of GRVD levels. During the survey, the closest spacings that farmers were found to be using were 40x20cm (5% of the farmers) and 30x15cm (26%), which differs from the recommended. This could explain why no significant reduction in GRVD severity was being realized in their fields.

The use of pesticides for management of GRVD, though recommended, is associated with several challenges. One is the fact that the relationships between viruses and their vectors are complex and a decrease in vector populations doesn't necessarily achieve a corresponding decrease in virus spread (Thresh, 2003). Improper use of pesticides has also been reported to alter the delicate balance between aphids and their natural enemies, possibly resulting into the development of insecticide resistant biotypes (Naidu *et al.*, 1999). More still, financial constraints also limit the use of pesticides by small holder farmers. Thresh (2003), reported that it is inappropriate to promote the use of pesticides on subsistence crops whose value is seldom sufficient to cover the cost of treatment. In this study, only 7.6% of the farmers mentioned that

they had applied pesticides at some point during crop growth. Financial limitations among the groundnut farmers, most of whom cultivate on less than an acre of land, could have contributed to the low usage of this method of GRVD management. In this study, results revealed that pesticide usage was not significantly reducing GRVD in the fields of farmers practicing this control technique. This could also be attributed to financial constraints since it has been reported that even farmers who opt for chemical control at times find it difficult to treat their crops throughout their entire vulnerable growth periods (Thresh, 2003). This could lead to unscheduled pesticide applications which may not be effective in GRVD control in the long run.

Roguing (uprooting of diseased plants) was being practiced by about 34% of the farmers. However, this approach has been reported to be most effective against viruses that do not spread quickly or far in any considerable amount (Putter, 1980), which is not the case for GRVD. Roguing has also been reported to be unpopular with some farmers who may not be prepared to allocate the time and effort required to inspect crops and identify and remove diseased plants or others who are reluctant to remove any diseased plants that may contribute some little yield (Thresh, 2003). This, to some extent, explains why this practice may not have significantly contributed to reduction in GRVD severity.

This study was aimed at evaluating the influence of farmers' management practices on the severity of GRVD. From the study, we were able to get updated information on the various GRVD management practices that farmers are currently employing in their fields. However, early planting and the use of improved varieties were the main practices which seemed to be contributing to reduction in GRVD severity in their fields.

CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECCOMENDATIONS

5.1 General Discussion

This study was initiated with the aim of establishing the influence of ambient ecological factors such as rainfall, temperature, wind speed and soil factors, and general farmers' practices on the occurrence and severity of GRVD in different agro-ecologies of Uganda.

The incidence and severity of GRVD were found to be correlated to the weather factors that were studied. Trends of disease incidence showed that high amounts of total rainfall generally corresponded to less incidence (and vice-versa) for all the varieties planted across all seasons. Previous researchers in their studies have linked rainfall with lower aphid populations (Wightman *et al.*, 1990; Hassan *et al.*, 2009). This is as a result of rainfall washing away the aphids, consequently leading to lower GRVD incidence in the groundnut crop due to decreased numbers of the vector. Higher wind speed also corresponded to lower GRVD incidence within the groundnut crop. Hasan *et al.*, (2009) reported that high wind speeds have a negative influence on population buildup of aphids, which could consequently lead to reduction in GRVD incidence. However, this situation can be altered when aphids originating from other areas are carried on winds from one area and deposited into another (Betts, 1975; Thresh, 1983) instead leading to population build up of the aphids. This could explain why GRVD incidence increased in Jinja during 2011B with an increase in wind speed. Temperature differences recorded during the study were minimal and no distinct trend with GRVD incidence was observed. Although in most cases, an increase in temperature led to a corresponding increase in GRVD incidence, this wasn't the case in Jinja and Lira in 2011A. Different researchers have linked higher temperatures with an increase in aphid numbers (Bakhetia and Sindhu, 1983; Hasan *et al.*, 2009). Since Jinja and Lira districts recorded the highest rainfall amounts during 2011A, it's possible that at these trial sites, the effects of the high rainfall amounts in reducing aphid numbers could have exceeded the effects of the minimal increase in temperature.

Incidence and severity levels of GRVD were found to vary within the different agro-ecologies in every season. Generally for all the three growing seasons, the highest levels of GRVD incidence were recorded in Jinja, confirming past reports that identified this location as one of the hotspots of the disease (Okello *et al.*, 2010). This was further confirmed by the fact that the highest levels of GRVD severity during the survey were recorded in the Lake Victoria Crescent agro-ecological Zone (LVCZ), in which Jinja is located. Approximately 50% of the most severely affected fields were found to be located in this zone. Results of the survey revealed that improved varieties for instance Serenut 1, 2, 3 and 4, were majorly being grown in the northern and eastern areas of Uganda, with farmers in the LVCZ utilizing less of these varieties. Farmers within this zone mainly grew local varieties for instance Red Beauty, which are more susceptible to GRVD. The situation in Northern Uganda (with the highest percentage of farmers growing improved varieties), could be as a result of NGOs who operated in post war Northern Uganda frequently supplying seed aid (improved varieties) to re-settled communities from the two decade long “Kony” insurgency. The high levels of GRVD in Jinja could therefore be partially attributed to the low utilization of improved varieties within the region compared to the Northern and Eastern regions of Uganda. The generally lower levels of wind speed in Jinja could also be another reason for this trend since Lira district, which had much faster wind speed had lower GRVD levels. Furthermore, soil analysis results from the trial sites revealed that Jinja had the highest levels of soil nitrogen and sites with lower soil nitrogen for instance Mbarara, had the lowest GRVD levels. It’s therefore possible that the higher GRVD levels in Jinja could have resulted from more soil nitrogen which some researchers in the past have linked to higher aphid populations within a given crop (possibly due to enhanced vegetative growth), hence more GRVD spread (Mattson, 1980; Duffield *et al.*, 2008).

Farmers’ practices as well play a key role in determining the levels of GRVD in groundnut fields. Results showed that farmers were employing a range of practices in their groundnut fields, including early sowing, intercropping, use of improved groundnut genotypes, crop rotation and uprooting and burning diseased plants among others. However, from the analysis, it was planting date (early planting vs. late planting) and variety planted (improved vs. local) that significantly affected GRVD severity. Farmers who planted their fields during the earlier part of the season and those who used improved varieties experienced significantly less GRVD in their fields

compared to those who did the opposite. In view of the current global climatic changes and unpredictable weather patterns and considering the fact that neither researchers nor farmers can control the weather, it would be wise to put more efforts in promoting the working strategies such as the use of improved varieties and early sowing (planting at the onset of the rains) in GRVD control (Adipala *et al.*, 2002).

5.2 Conclusions

The study revealed that levels of GRVD infection were indeed related to the agro-ecological factors studied; rainfall, temperature, wind speed and soil. Higher rainfall amounts led to lower levels of GRVD within the groundnut crop. Higher wind speeds also generally corresponded to lower GRVD levels within the groundnut fields. However, the relationship between GRVD and temperature was not clearly defined, with higher temperatures corresponding to higher GRVD incidence in some locations and the reverse occurring in others.

This study confirmed that indeed GRVD levels vary in the different agro-ecological zones of Uganda in any given season. This was observed in the results from the trial sites, which were located in different agro-ecologies, having different levels of the disease during all the three growing seasons. Disease levels were consistently highest in the Lake Victoria Crescent agro-ecological zone, followed by the Highland ranges, then the South Western Farmlands and finally the North Eastern Savannah grasslands. Trial sites in Jinja and Sironko, which had the highest GRVD levels, also produced the lowest groundnut yields. The trial site in the Lake Victoria Crescent agro-ecology (Jinja, Nakabango) was confirmed to be a hotspot for GRVD. Factors that could have contributed to this include the low wind speeds and higher levels of disease inoculum built up as a result of farmers using mostly local varieties compared to other major groundnut producing regions within the country. Most of these farmers still use these varieties because they usually save them as home saved seed and they have preferred attributes (seed size and red colour) in spite of their performance. The higher levels of nitrogen could also have further contributed to enhanced GRVD levels.

While it's true that the above factors contributed to disease levels, the different practices implemented by the farmers within the different agro-ecological zones were also found to influence GRVD in the field. Farmers were found to be implementing a number of practices in their groundnut fields. However, only two major practices significantly reduced GRVD severity in their fields. These included; the use of improved varieties and early planting.

It can be concluded, therefore, that ecological factors particularly rainfall and farmers' practices and their consequential interactions, are ultimately the main influencing factors of GRVD severity in groundnut fields. The study hypotheses which state that; (1) Incidence and severity of GRVD are influenced by differences in weather and soil characteristics and (2) severity levels of GRVD vary with farmers' management practices, therefore hold true. This information contributes to our understanding of why the disease is characterized by sporadic epidemics that cause serious crop losses and at times total crop failure in farmers' fields. It also gives a clearer understanding as to which practices farmers are currently employing in groundnut production in Uganda, to which extent they are being utilized and which particular ones are contributing significantly to the reduction of GRVD severity.

5.3 Recommendations

In light of the findings of this study, it is recommended that more detailed work should be carried out on other ecological factors that were not considered here. For instance, the naturally occurring alternative hosts of the disease that possibly serve as sources of inoculum for GRVD during subsequent planting seasons in the different agro-ecologies. The diversity of alternative hosts in the different agro-ecologies could be a contributing factor in the differences in GRVD infection levels. This knowledge would give insight into the off season survival of the virus and how it spreads into the groundnut crop during each growing season.

While promoting GRVD management packages, special attention should be given to the use of improved varieties and early sowing (planting at the onset of the rains) since these were the two practices that were found to be more effective in controlling GRVD in farmers' fields. Government agencies such as the National Agricultural Advisory Services (NAADS) and non governmental organizations, which provide inputs to farmers and conduct trainings for farmer

groups should emphasize the use of an integrated approach mainly based on the two or more cropping practices rather than a single practice such that farmers can exploit their synergistic interactions, thereby increasing the potential for GRVD management. Researchers on the other hand should continue to focus on developing improved varieties that have high levels of resistance to GRVD since the ones present do succumb when infection levels are high.

It is as well proposed that the Lake Victoria Crescent agro-ecology be targeted by researchers for dissemination of sustainable groundnut management packages since this area was identified as one of the regions with the highest levels of GRVD severity while at the same time the farmers mainly used local varieties of groundnut that were susceptible to disease possibly because they have had less access to more resistant varieties.

Finally, it is recommended that the use of sprinkler irrigation while following an appropriate watering schedule is considered as one of the ways of supplementing water while designing irrigation technologies for situations where water supplementation is required. This method could possibly aid in reducing aphid numbers given that the effect of the sprinklers is similar to that of rain which reduces aphid numbers consequently leading to lower levels of GRVD in groundnut fields. The crop requirement should be observed while doing this such that the groundnuts are not exposed to fungal diseases as a result of excessive moisture. This however, would raise the costs of production and may therefore be best suited for large scale commercial farmers.

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APPENDICES

Appendix 1. Analysis of variance for the effect of season, location and variety on GRVD incidence (%) in Lira, Jinja, Mbarara and Sironko districts for growing seasons 2011A, 2011B and 2012B

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	2	9564.19	4782.09	316.50	<.001
Site	3	7335.75	2445.25	161.84	<.001
Variety	3	567.51	189.17	12.52	<.001
Season.Site	6	2530.44	421.74	27.91	<.001
Season.Variety	6	120.20	20.03	1.33	0.249
Site.Variety	9	480.56	53.40	3.53	<.001
Season.Site.Variety	18	1317.01	73.17	4.84	<.001
Residual	141	2130.41	15.1		
Total	191	24077.53			
CV(%)	42.1				

Appendix 2. Analysis of variance for the analysis of the effect of season, location and variety on severity in Lira, Jinja, Mbarara and Sironko districts for growing seasons 2011A, 2011B and 2012B

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	2	169.542	84.771	57.14	<.001
Site	3	238.641	79.547	53.62	<.001
Variety	3	103.641	34.547	23.29	<.001
Season.Site	6	46.375	7.729	5.21	<.001
Season.Variety	6	5.375	0.896	0.60	0.727
Site.Variety	9	19.964	2.218	1.50	0.155
Season.Site.Variety	18	15.208	0.845	0.57	0.916
Residual	141	209.193	1.484		
Total	191	809.495			
CV%	32.4				

Appendix 3. Analysis of variance for the effect of season, location and variety on AUDPC in Lira, Jinja, Mbarara and Sironko districts for 2011A, 2011B and 2012B growing seasons

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	2	39986507.	19993254.	287.33	<.001
Site	3	24849701.	8283234.	119.04	<.001
Variety	3	1989837.	663279.	9.53	<.001
Season.Site	6	10317807.	1719635.	24.71	<.001
Season.Variety	6	686310.	114385.	1.64	0.139
Site.Variety	9	2155784.	239532.	3.44	<.001
Season.Site.Variety	18	6496600.	360922.	5.19	<.001
Residual	141	9811290.	69584.		
Total	191	96578408.			
CV%	46.8				

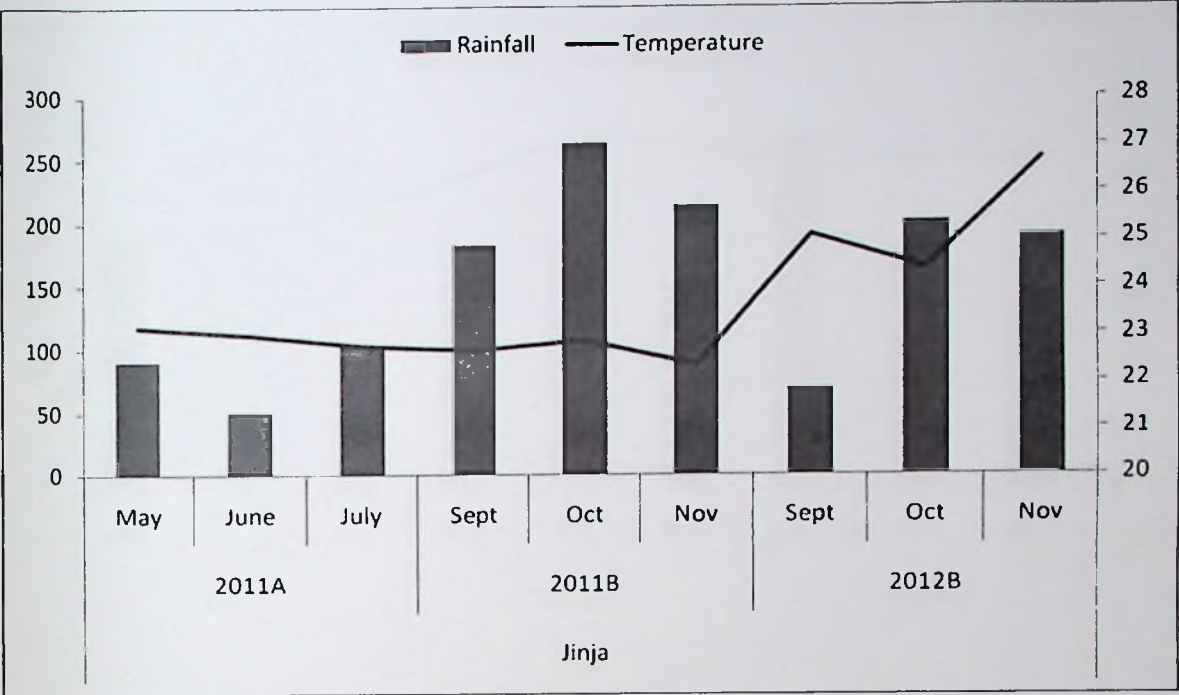
Appendix 4. Analysis of variance for the effect of season, location and variety on groundnut yields in Lira, Jinja, Mbarara and Sironko districts for growing seasons 2011A, 2011B and 2012B

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Season	2	11969701.	5984851.	22.45	<.001
Site	3	80622434.	26874145.	100.80	<.001
Variety	3	12148667.	4049556.	15.19	<.001
Season.Site	6	7909234.	1318206.	4.94	<.001
Season.Variety	6	5446850.	907808.	3.40	0.004
Site.Variety	9	21241139.	2360127.	8.85	<.001
Season.Site.Variety	18	25717297.	1428739.	5.36	<.001
Residual	141	37592894.	266616.		
Total	191	203300585.			
CV(%)	36.3				

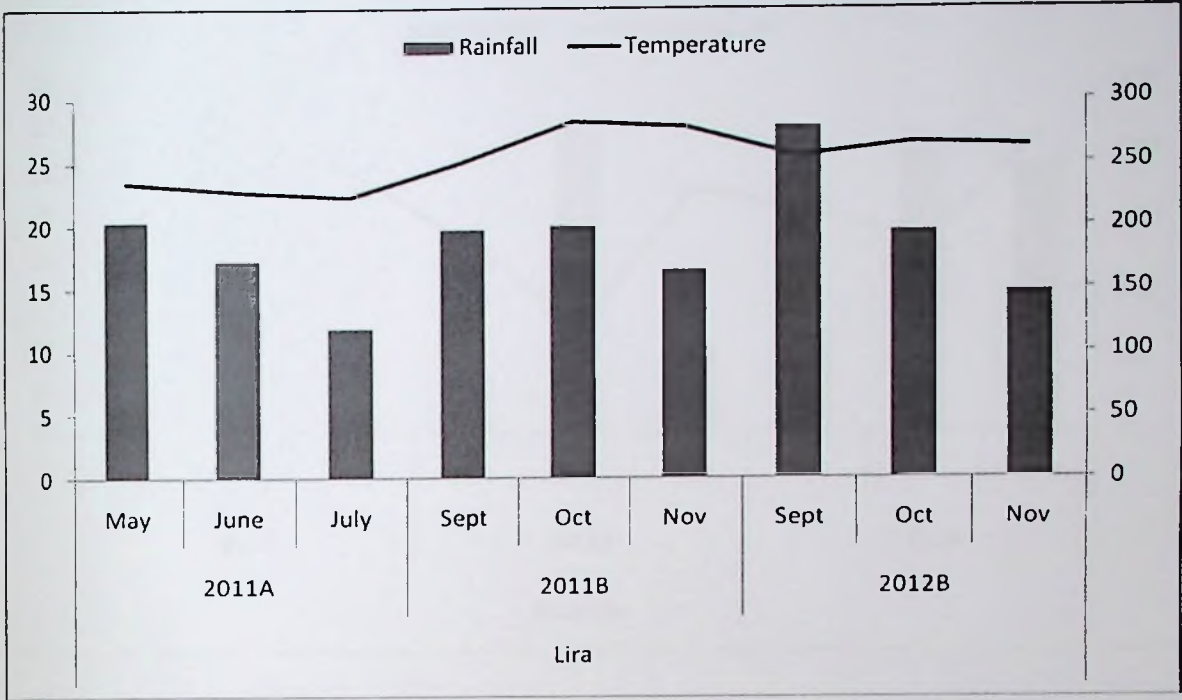
Appendix 5. Analysis of variance for the effect of season, location and variety on aphid numbers in Mbarara and Sironko districts for growing seasons 2011A and 2011B

Source of variation	d.f.	s.s.	m.s.	v.r.	F	pr.
Season	1	5.12	5.12	0.24	0.627	
Site	1	12.22	12.22	0.57	0.454	
Variety	3	28.30	9.43	0.44	0.725	
Season.Site	1	4.53	4.53	0.21	0.647	
Season.Variety	3	19.23	6.41	0.30	0.825	
Site.Variety	3	152.55	50.85	2.38	0.082	
Season.Site.Variety	3	51.59	17.20	0.80	0.498	
Residual	45	961.84	21.37			
Total	63	1290.41				

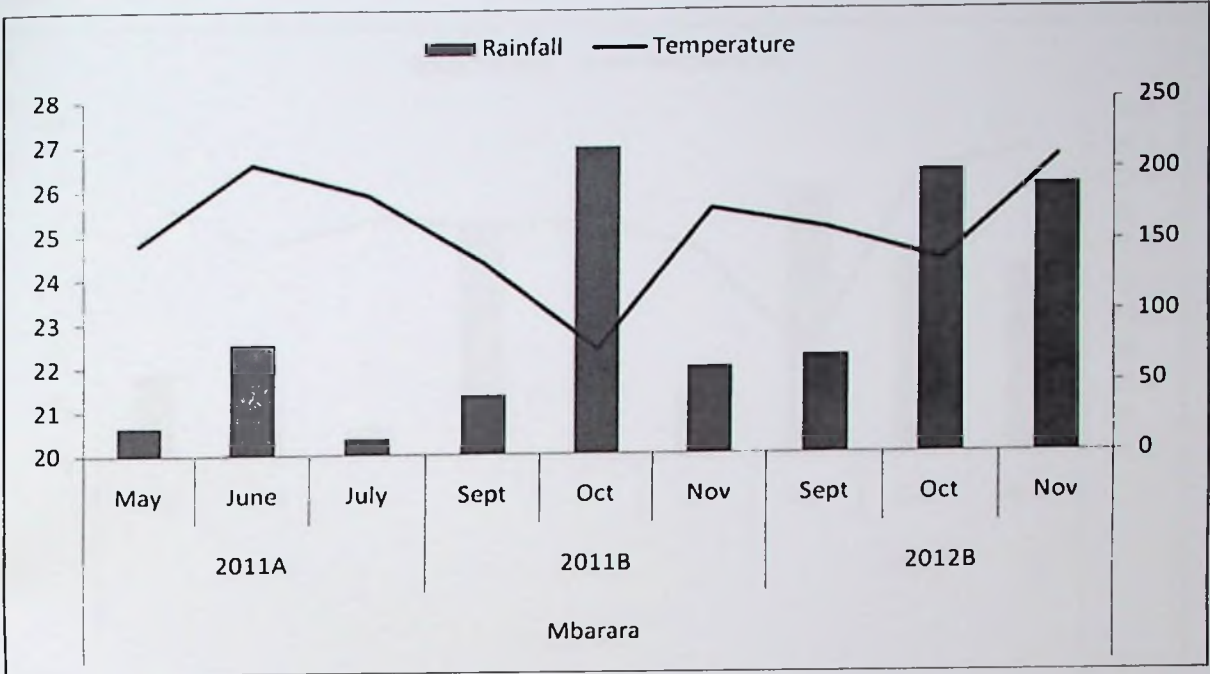
Appendix 6. Rainfall and temperature for growing seasons 2011A, 2011B and 2012B at Jinja District



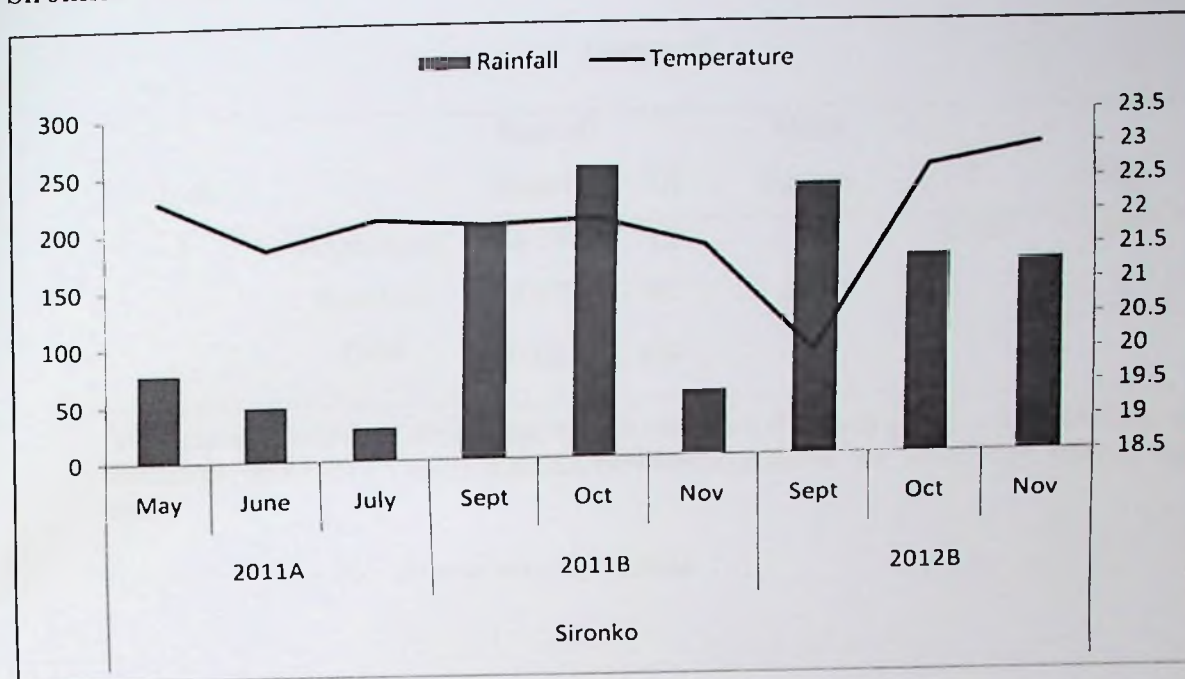
Appendix 7. Rainfall and temperature for growing seasons 2011A, 2011B and 2012B at Lira District



Appendix 8. Rainfall and temperature for growing seasons 2011A, 2011B and 2012B at Mbarara District.



Appendix 9. Rainfall and temperature for growing seasons 2011A, 2011B and 2012B at Sironko District.



Appendix 10. Analysis of variance for regression analysis of management practices and GRVD severity

ANOVA^b

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	14.580	12	1.215	4.387	.000 ^a
	Residual	25.477	92	.277		
	Total	40.057	104			

^aPredictors: (Constant), mulching, uproot and burn diseased plants, crop rotation, gender, fertilizers, pesticides, variety planted, herbicides, number of weedings, fallow, planting date

^bDependent Variable: disease severity in field

Appendix 11. Summary of regression model for relationship between farmers' management practices and GRVD severity

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.603 ^a	.364	.281	.526

^a Predictors: (Constant), mulching, uproot and burn diseased plants, crop rotation, gender, fertilizers, pesticides, variety planted, herbicides, number of weedings, fallowing, planting date

Appendix 12. Questionnaire used for farmer interviews during survey on farmers' management practices in 2012

Date of interview:

Name of respondent:

Gender:.....

District:.....

Sub-county:.....

Parish:.....

1. When did you plant the groundnuts, early (at the start of the season/rains) or late (from 5 weeks after the start of the planting season/rains)?

.....

2. What is the acreage/size of land planted with groundnuts?

.....

3. What cropping system did you use: (intercropping/mono-cropping)?

.....

If intercropping, please specify the intercrop (s):

i)..... ii).....

iii).....iv).....

4. At what spacing did you plant the groundnuts?

.....

5. How much seed did you use(or seed rate per acre):

.....

6. Which variety(s) of seed did you plant? Local or improved varieties?

.....

Specify variety name(s) i).....ii).....

iii).....iv).....

Did you plant them separately or in mixtures?

.....

7. How many times did you weed during the season?

.....

8. Where did you obtain from the seed?.....

 9. Which methods of ploughing did you employ on your farm?
 Hoeing/tractor/oxen.....
 10. What is the current stage of growth of the groundnuts?.....
 11. At what stage was the disease most severe:.....
 12. Which inputs did you apply in the groundnut field? Organic fertilizers/ inorganic fertilizers/pesticides/herbicides etc. (specify input and quantities below)

Input	Name	Application rate
Organic fertilizers		
Inorganic fertilizers		
Pesticides		
Herbicides		

13. Is there any other special practice that you carried out in the field? (tick): mulching/
 fallowing/ terracing/zero tillage/shallow ploughing/ deep ploughing/Other
 (specify).....

 14. What quantity of groundnuts do you hope to harvest? (kg dry
 unshelled).....
 15. Score of GRVD severity in the field (done by researcher)(1-9 scale):
 1:1-3 2. 3-6 3:6-9