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Determinants of groundnut rosette virus disease occurrence in Uganda

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A B S T R A C T

Groundnut rosette virus disease (GRVD) is the major constraint to groundnut (*Arachis hypogaea*) production in Uganda. It is principally transmitted by the groundnut aphid (*Aphis craccivora* Koch). The disease is known to cause total crop failure in cases where susceptible varieties are used. During any particular season, GRVD displays variations in incidence and severity in different agro-ecologies within the country, but the reasons for the varying disease patterns remain unclear. This study was aimed at establishing the factors influencing the occurrence of GRVD in Uganda. Trials were established for three seasons in four groundnut growing locations situated in different agro-ecologies in Uganda. Four groundnut genotypes were used as treatments in a randomized complete block design with four replications. Disease progress and aphid populations were 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. Soil samples and yield data were also obtained in each season. The study revealed that disease incidence; severity and groundnut yields were significantly affected by season, location and genotype. The same applied to their three way interactions. Levels of disease infection were found to be majorly influenced by rainfall and wind speed. Disease incidence and severity were generally higher in conditions with less rainfall and low wind speeds. The Pearson's two tailed correlation between total rainfall and disease incidence for all trial sites was negative and highly significant ($r = -0.280$, $P \leq 0.01$). The same was true for wind speed and disease incidence ($r = -0.476$, $P \leq 0.01$). However, there was no conclusive trend between temperature and disease incidence with the Pearson's two tailed correlation showing significantly positive and negative trends depending on location.

1. Introduction

The groundnut (*Arachis hypogea* L.), also known as peanut, is the second most highly produced food legume in Uganda after phaseolus beans (UBOS, 2013). The crop has gained popularity, especially in the eastern and northern regions of the country, where it has become part of the peoples' culture (Mahmoud et al., 1991). However, its production is constrained by numerous 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 levels of input use (Mahmoud et al., 1991; Adipala et al., 1998). This situation has led to extremely low yields at farmer level averaging 0.8 tons per hectare of dried pods. This is in contrast to yields as high as 2.5–3.0 tons per hectare reported at research stations within Uganda and other countries with developed agriculture (ICRISAT, 1986; Busolo-Bulafu, 2004). Pests and diseases have been found to cause the greatest economic damage to groundnut production in Uganda. Major pests include: aphids (*Aphis craccivora* Koch), thrips (*Thrips* spp) and termites (*Hodotermes mossambicus*); whereas important diseases include: groundnut rosette virus disease (GRVD), cercospora leaf spots, rusts, and aflatoxin (Okello et al., 2010). Of these diseases, GRVD has been identified as the major constraint to increased groundnut production, causing total crop failure when

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susceptible varieties are used (Okello et al., 2010). Groundnut rosette virus disease is transmitted by the groundnut aphid (*A. craccivora* Koch) and is characterized by unpredictable epidemics that are known to cause 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.

Uganda has three known GRVD hotspots where total crop loss has been observed on unsprayed susceptible varieties. These 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). It has also been observed that different regions in the country have varying levels of GRVD pressure. However, the reasons for the disparity in occurrence remain unclear. 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 cropping systems. A better understanding of the agro-ecological factors affecting GRVD incidence and severity is critical for the successful development of sustainable disease management strategies. This study was conducted in different agro-ecological zones within Uganda with the aim of establishing how selected agro-ecological factors affect GRVD occurrence and severity.

2. Materials and methods

2.1. Study area

Field trials were conducted for three seasons: first rainy season 2011 (2011A), second rainy season 2011 (2011B) and second rainy season 2012 (2012B) at four research stations located in major groundnut producing areas, each representing a different agro-ecological zone within Uganda. These areas fell in the districts of Sironko (01°13′46″N, 34°4′53″ E), Lira (2°14′50″N, 32°54′00″E), Jinja (00°23′00″N, 32°33′00″ E) and Mbarara (00°36′48S, 30°39′30E) districts. Sironko lies within the Highland ranges of Eastern Uganda with average rainfall of 1456 mm/yr. Average temperatures are 22.9 °C and wind speed ranges from 4 to 19 km/h. Lira is found in the North Eastern Savannah Grasslands that is comprised of generally flat isolated hills with average rainfall of 1,465 mm/year. Temperature ranges from 18 to 32.5 °C and wind speed from 7 to 185 km/h. Jinja is located in the Lake Victoria Crescent where there are flat-topped areas and long gentle slopes. Rain fall is bimodal with an average of 1200 mm/year. Temperatures range between 15 and 29 °C and average wind speed is 11 km/h. Mbarara is in the South Western farmlands with average rainfall of about 896 mm/year. Temperature ranges from 13 to 27 °C and average wind speed is 0 km/h (MAAIF, 2010; Climatevo, 2015).

2.2. Experimental design

The locations and groundnut genotypes were considered as factors in the study. There were four locations as described above. Four genotypes commonly grown in the country were assessed namely:- Serenut 1R and Acholi white (susceptible to GRVD) and Serenut 6T and Serenut 3R (resistant to GRVD). All genotypes were obtained from the Groundnut Improvement Program at NaSARRI. In each location, the trial was established as a randomized complete block design (RCBD) with 4 replications. Each experimental unit measured 3 m × 3 m, and groundnut seeds were direct seeded at a spacing of 45 cm × 15 cm, with one seed per hill. No fertilizers, pesticides or herbicides were applied in the fields. Hand-weeding was done thrice during each growing season.

2.3. Data collection

Disease status was recorded in terms of incidence and severity. Groundnut rosette virus disease incidence was assessed at 4, 8 and 12 weeks (NaSARRI, unpublished). Incidence was expressed as the percentage of plants infected with GRVD over the total number of plants in the plot. Disease severity was scored at 12 weeks after planting using a scale of 1–9 based on the intensity of disease attack (Okello et al., 2014), where; 1–3 = Low GRVD severity, 4–6 = Moderate severity, 7–9 = High GRVD severity. For 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. Data on the environmental factors of 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. Yield data was obtained for each planting season by weighing the dried pods taken from 5 plants that were randomly selected from each experimental unit. Soil samples were also taken from each trial site and analyzed at the National Agricultural Research Laboratories (NaRL) Kawanda, using Mehlich 3 and Walkley Black procedures (Walkley and Black, 1934; Mehlich, 1984) in order to determine their characteristics.

2.4. Data analysis

Incidence data was used to compute the area the 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 ith observation
t_i = time (days) at the ith observation
n = total number of observations

Data on disease incidence, severity, AUDPC's, yield and aphid occurrence were analyzed using a GenStat computer package (Genstat, 2010) to generate analyses of variance (ANOVA). For the treatments showing significant 'F' statistics, the means were separated using SED (the standard error of the difference between two sample means, SED x 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 et al., 2003).

3. Results

3.1. Incidence and severity of GRVD

Significant differences in GRVD incidence, severity and AUDPC were recorded across season, genotype and site ($P < 0.05$) (Table 1). The two-way interactions of season x site; and site x genotype and the three-way interaction of season x site x genotype significantly ($P < 0.05$) affected GRVD incidence and AUDPC. The only interaction that significantly affected disease severity was the season x site.

Table 1
Summary of F-Statistics for the ANOVA of effect of season, site and genotype on GRVD incidence, severity, AUDPC and yields in four sites over three growing seasons.

Source of variation	F-statistics (Variance ratio)				
	d.f	Incidence (%)	AUDPC	Severity	Yields (kgha-1)
Season	2	316.50*	287.33*	57.14*	22.45*
Site	3	161.84*	119.04*	53.62*	100.80*
Variety	3	12.52*	9.53*	23.29*	15.19*
Season x Site	6	27.91*	24.71*	5.21*	4.94*
Season x variety	6	1.33	1.64	0.60	3.40
Site x variety	6	3.53*	3.44*	1.50	8.85*
Season x Site x Variety	9	4.84*	5.19*	0.57	5.36*

Values with asterisks indicate significance *P = 0.05; d.f = degrees of freedom.

Jinja recorded the highest incidence (37%), severity (5.4) and AUDPC (1096) of GRVD. The lowest incidence (5%) and severity (2.7) were recorded in Lira and Mbarara respectively (Tables 2 and 3, Fig. 1). Overall, the highest GRVD incidence and severity were recorded during the 2011A season (40% and 5.0 respectively) compared to the other two seasons. The lowest GRVD incidence and severity were recorded on Serenut 3R (Table 2 and Fig. 1).

3.2. Aphid populations

There was no significant difference ($P > 0.05$) in aphid numbers per plant among all the genotypes during the two seasons sampled for the districts of Mbarara and Sironko. The aphid population dynamics show that in Sironko in 2011A, aphids were mainly apparent at 8 weeks after planting whereas in 2011B, though the populations were not as high, they were apparent by 4 weeks after planting (Fig. 2). In Mbarara, aphids were in the fields by 4 weeks after planting, which was the peak for 2011A whereas the peak was at 8 weeks after planting in 2011B (Fig. 2). The genotype Acholi white sustained the highest aphid populations (Fig. 2).

3.3. Groundnut yields

Groundnut yields significantly varied among genotypes, seasons and sites ($P < 0.05$). Similarly, there were significant interactions between season x site, site x genotype x season and site x genotype on groundnut yields ($P < 0.05$) (Table 1). In general, the highest yield was obtained during 2011B, followed by 2011A and 2012B respectively (Table 4). Serenut 1R attained the highest yields whereas Acholi white produced the lowest yields. Mean yields were highest in Lira followed by Mbarara, Jinja and Sironko respectively (Table 4).

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

General trends of rainfall versus GRVD incidence for all locations and seasons showed that high amounts of total rainfall corresponded to less GRVD incidence and vice versa for all the four varieties (Fig. 3). Pearson's two tailed correlation between total rainfall and GRVD incidence overall, was negative and highly significant ($r = -0.280$, $P \leq 0.01$; $N = 144$).

There was a highly significant positive relationship between GRVD incidence and average temperatures at the Mbarara site ($r = 0.444$, $P \leq 0.01$; $N = 36$) but a significant negative correlation was recorded at Lira ($r = -0.470$, $P \leq 0.01$; $N = 36$). Conversely, there was no significant relationship between incidence and average temperatures at the two other sites. In general, there was no obvious trend between temperature and GRVD incidence in all sites.

Average wind speeds recorded were highest in 2011B (59.5 km/h) and lowest in 2011A (31.4 km/h) for Jinja and Lira respectively

Table 2
Influence of season, site and genotype on GRVD incidence (%).

Season	Site	Incidence (%)					s.e.d
		Genotype					
		Acholi white	Serenut 1R	Serenut 3R	Serenut 6T	Mean	
2011[a]	Jinja	66.30	55.00	66.09	72.61	65.00	
	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**	*8.4*
	s.e.d					*423*	
2011[b]	Jinja	53.48	39.57	16.09	28.91	34.51	
	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**	*3.5*
	s.e.d					*175*	
2012[c]	Jinja	18.00	14.50	6.00	10.00	12.12	
	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**	*1.8*
	s.e.d					*0.9*	

[a] First rainy season (March–June, 2011).
[b] Second rainy season (September–December, 2011).
[c] Second rainy season (September–December, 2012).

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

Season	Site	AUDPC					*s.e.d*
		Genotype					
		Acholi white	Serenut 1R	Serenut 3R	Serenut 6T	Mean	
2011[a]	Jinja	2398	1138	2044	2422	2000	
	Lira	567	487	147	221	**355**	
	Mbarara	620	1050	826	707	**801**	
	Sironko	1841	2079	886	1855	**1665**	
	Mean	**1356**	**1188**	**976**	**1301**	**1205**	*295.2*
	s.e.d					*1476*	
2011[b]	Jinja	1071	1092	329	605	**774**	
	Lira	175	245	56	91	**142**	
	Mbarara	56	140	0	35	**58**	
	Sironko	273	326	112	238	**237**	
	Mean	**394**	**451**	**124**	**242**	**303**	*90*
	s.e.d					*45*	
2012[c]	Jinja	721	721	203	409	514	
	Lira	49	74	60	7	**47**	
	Mbarara	7	18	14	39	**19**	
	Sironko	217	158	119	112	**151**	
	Mean	**248**	**242**	**99**	**142**	**183**	*84.6*
	s.e.d					*42.3*	

[a] First rainy season (March–June, 2011).
[b] Second rainy season (September–December, 2011).
[c] Second rainy season (September–December, 2012).

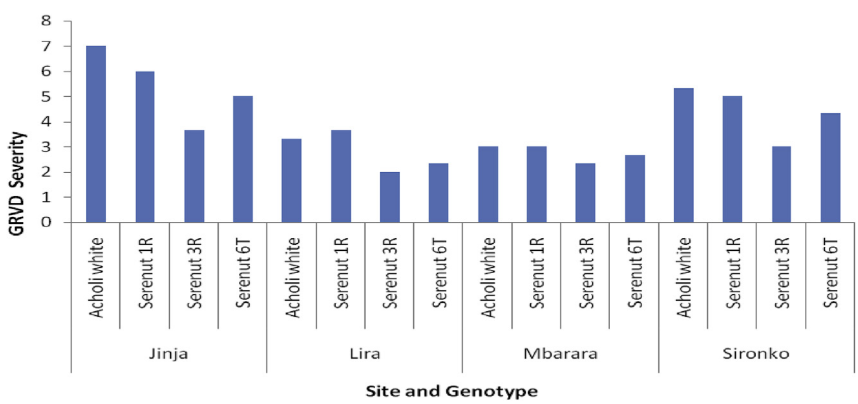

Fig. 1. Mean GRVD severity for four groundnut genotypes at trial sites. Severity score 1 = very low GRVD and 9 = most severe GRVD symptoms.

(Fig. 4). In fact, a highly significant negative correlation ($r = -0.476$, $P \leq 0.01$; $N = 48$) was observed between the wind speed and GRVD incidence for locations sampled.

3.5. *Soil characteristics of the four trial sites*

Analysis of soil samples collected from the field trial sites revealed that soils in Jinja and Sironko were mainly clay whereas those from Lira and Mbarara were sandy-clay-loam-type. The former generally had higher pH, more organic matter, soil nitrogen, calcium, magnesium, potassium, clay and silt compared to the latter. In general, soils from all the trial sites had very low levels of phosphorus, which were much lower than the critical level. Mbarara and Lira were the only sites that had nitrogen below the critical level of 0.2%. In addition to this, Mbarara was the only site that had percentage organic matter content below the critical level of 3%.

4. Discussion

The purpose of this study was to establish the influence of ecological factors on the occurrence of GRVD in different agro-ecologies of Uganda. The incidence and severity of GRVD were found to be influenced by some of the weather factors that were prevalent in the locations studied. The general trend showed that high amounts of total rainfall negatively influenced GRVD incidence and vice-versa. 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 thereby exposing them to predation or they may be killed directly by soil particles splashed onto their colonies. Hassan et al. (2009), in their study on aphid populations on a mustard crop, noted that even slight rainfall amounts quickly lowered aphid populations from fields that were monitored at different times of the day. This implies that more stringent GRVD management should be applied in seasons and areas that are characterized by shorter rains. The same is true for wind speed and aphid numbers. Wind speeds recorded during the course of the study were generally higher in 2011B compared to 2011A. Elsewhere, other researchers have reported that high wind speeds have a negative influence on population buildup of aphids (Hassan et al., 2009), causing them to be blown away, subsequently lowering their populations. Accordingly, this may explain the results of this study, which showed that there was a significantly negative relationship

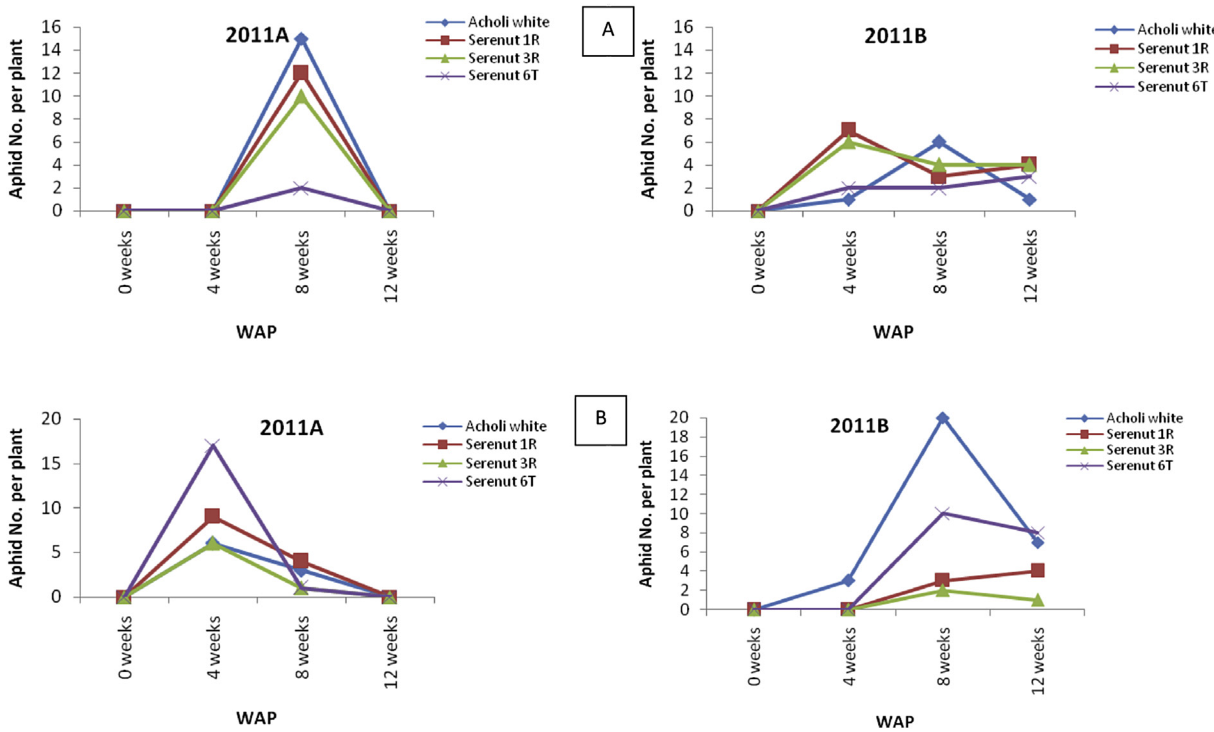

Fig. 2. Aphid dynamics on groundnut on the different genotypes in Sironko (A) and Mbarara (B) districts.

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

Season	Site	Groundnut yields (kg/ha)					*s.e.d*
		Genotype					
		Acholi white	Serenut 1R	Serenut 3R	Serenut 6T	Mean	
2011[a]	Jinja	561	3069	903	1194	1432	
	Lira	2250	2750	2696	3042	**2684**	
	Mbarara	1425	1089	903	1769	**1296**	
	Sironko	195	111	264	2139	**677**	
	Mean	**1108**	**1755**	**1191**	**2036**	**1522**	*489.5*
	s.e.d					*2448*	
2011[b]	Jinja	1272	3130	1444	1336	1796	
	Lira	1408	2588	2521	2258	**2194**	
	Mbarara	2067	1467	1483	3330	**2087**	
	Sironko	458	250	1292	333	**584**	
	Mean	**1301**	**1859**	**1685**	**1815**	**1665**	*288.4*
	s.e.d					*1442*	
2012[c]	Jinja	835	1107	1459	694	1024	
	Lira	1542	2944	1735	2024	**2061**	
	Mbarara	760	1888	646	877	**1043**	
	Sironko	154	239	210	145	**187**	
	Mean	**823**	**1545**	**1012**	**935**	**1079**	*289.4*
	s.e.d					*144.7*	

[a] First rainy season (March–June, 2011).
[b] Second rainy season (September–December, 2011).
[c] Second rainy season (September–December, 2012).

between wind speed and GRVD incidence. Areas with lower wind speeds should therefore be targeted by researchers for dissemination of GRVD management options. Furthermore, an increase in temperature has been reported to facilitate an increase in aphid numbers (Bakhetia and Sindhu, 1983; Hassan 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 though this was not the case for Lira. While there was a huge difference between rainfall amounts received in Lira and Mbarara districts during the course of the study, temperature differences were minimal, indicating that rainfall could have been of higher influence than temperature in this study.

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 and the lowest scores in Lira district. This confirms past reports that identified Jinja (Nakabango) as one of the hotspots for GRVD in Uganda (Okello et al., 2010). However,

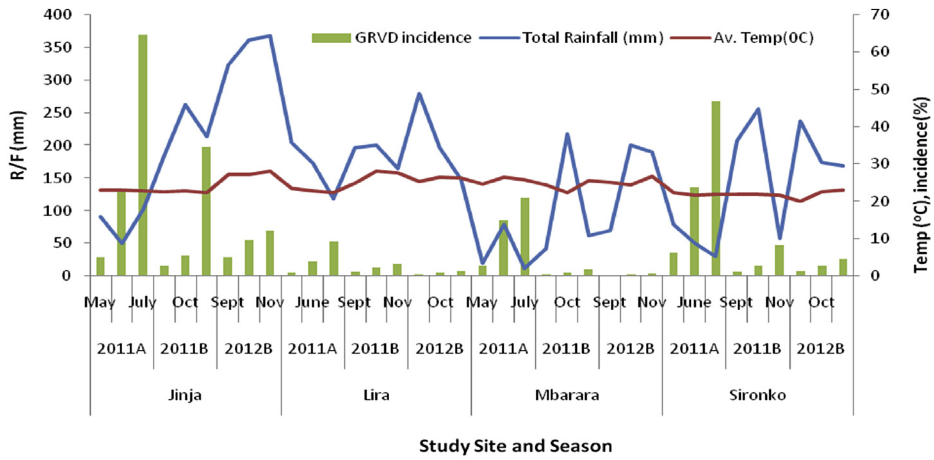

Fig. 3. Trends of GRVD incidence versus total rainfall and average temperature.

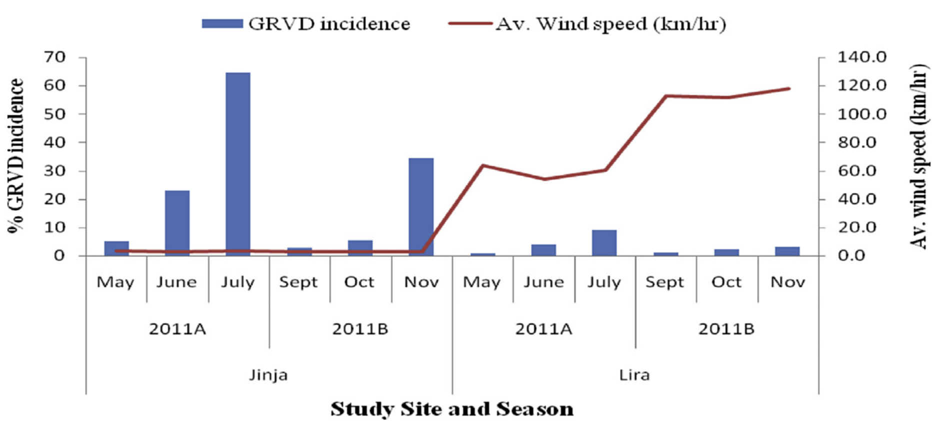

Fig. 4. Trends of GRVD incidence versus average wind speed in Jinja and Lira.

our 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 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. Previous research has shown that the main groundnut varieties grown in Jinja are local varieties such as “Red beauty”, which are highly susceptible to GRVD (Mugisa et al., 2015). 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 subsequent seasons.

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 (Slansky and Rodriguez, 1987; Duffield et al., 1997). 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. However, there was no significant difference in the number of aphids obtained in Mbarara and Sironko.

The higher groundnut yields in Lira and Mbarara could be attributed to less GRVD incidence and severity in addition to having favorable soils for groundnut production. 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 (FAO, 2009). Top soils that are loose allow the pegs, on which the fruits are formed, to enter the soil easily, thus promoting growth. The reverse was true for Jinja and Sironko districts. These two districts 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), these sites were also found to have clay soils which don't promote groundnut growth.

Genotype significantly influenced GRVD incidence and severity, with the varieties Acholi white and Serenut 1R sustaining the highest GRVD incidence and severity, followed by Serenut 6T and Serenut 3R proved to be the most resistant variety and had the lowest levels of GRVD. Even though Serenut 1R was more affected by GRVD compared to Serenut 3R, it yielded higher, suggesting that the variety could have some degree of tolerance to GRVD. When planted using recommended practices, Serenut 1R has been reported to yield between 2500 and 3700 kg/ha compared to Serenut 3R which yields between 2500 and 2900 kg/ha (Okello, 2010). Despite the reported resistance levels of Serenut 3R however, the variety succumbed considerably to the disease when GRVD incidence was particularly very high (2011A). This was also reported in a recent study by Bua and Opio (2014), who recommended that improved groundnut genotypes grown under conditions of high disease pressure, should be sprayed continuously against the vector.

5. Conclusion

This study has shown that rainfall, temperature and wind speed indeed influence GRVD infection levels in the various agro-ecologies in Uganda. Rainfall and wind speed particularly played a greater role in disease infection with increase in both factors having a negative influence on disease levels. This implies that more stringent GRVD management is required in seasons and areas that are characterized by shorter and/or less rains and lower wind speeds. The trial site in the Lake Victoria Crescent agro-ecology (Jinja) was confirmed to be a hotspot for GRVD. This particular location should therefore be targeted by researchers for dissemination of sustainable groundnut management packages since it's a major groundnut producing area in Uganda. Disease incidence and severity levels were found to vary in different agro-ecological zones in each season due to differences in weather factors. This could partially account for the sporadic nature of GRVD.

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