Stalk-eyed fly, *Diopsis sp.* population dynamics under varying temperature and Relative Humidity in rice ecosystems

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Abstract

Although the stalk-eyed fly (*Diopsis sp*.) has been observed in Ugandan rice fields, there is limited information on the fly's population and its potential threat to rice production. This study assessed the stalk-eyed fly (*Diopsis longicornis* and *Diopsis apicalis*) population dynamics under varying temperature and relative humidity in rice ecosystems of Uganda. It was conducted in purposively selected small scale rice farming sub-counties in low land rain fed and irrigated rice agro-ecologies (Lake Victoria Crescent, Kasese transition zone and Northern moist farmlands). *Diopsis sp.* populations were monitored by sampling rice fields every 40 days for a period of 17 months. Weather parameters including air temperature and humidity were recorded by use of data loggers throughout the study period. R-statistical tool and MS Excel were used to assess the population dynamics and interactions of the diopsids. *D. longicornis* fly was dominantly abundant in rice fields of Lake Victoria Crescent and Northern Moist zones while *D. apicalis* was dominant in Kasese transition zone. There was significant mean count variations per survey for both species in all the agro-ecological zones with *P*-values of 0.000958 (*D. longicornis*) and 1.12e-12 (*D. apicalis*) in Lake Victoria crescent, 0.000473 (*D. apicalis*) and 0.0173 (*D. longicornis*) in Northern moist farmlands, 0.0188 (*D. apicalis*) and 0.0353 (*D. longicornis*) in Kasese transition zone. Temperature and relative humidity had a direct effect on the population of both species in Northern moist zone and only on *D. apicalis* in Kasese transition zone. The optimum/favorable temperatures for abundance were between 27ºC and 29ºC. Interpretation of the results? Integrated pest management strategies and introduction of improved *Diopsis* pest resistant rice varieties are some of the recommendations for managing the stalk-eyed fly populations in these rice ecosystems.

Key words: Rice ecosystems, *Diopsis longicornis*, *Diopsis apicalis*, Temperature, agro – ecological zones, Relative Humidity

1.0 Introduction

Climatic and weather conditions during cropping seasons are the major factors influencing the intensity and the occurrence of pests. Climatic factors such as temperature, precipitation and relative humidity directly or indirectly influence pest distribution and growth. These factors affect insect rate of development, reproduction, distribution, migration and adaption. Among all the abiotic factors, temperature is the most important one affecting insect distribution and abundance in time and space, since these are cold-blooded animals.

Insect pests, diseases and weeds are the major biotic stresses that inflict enormous losses to rice production in Africa (Nwilene *et al.,* 2013). Amongst the insect pests, the stalk-eyed fly (*Diopsis sp.)* is a significant threat to rice production in tropical regions where warm and humid rice field conditions favors its multiplication. In Uganda's rice fields, the stalk-eyed fly is the most abundant insect pest attacking rice (Weelar *et al.*, 2016).This pest attacks rice plants early in the crop growth stage (usually under 10cm), shortly after emergence in direct-seeded fields or shortly after transplanting. Damage from stalk-eyed fly larvae usually affects the central meristem of the plant, which is bored, resulting in a condition known as dead heart (Togola *et al.,* 2011). Uganda's rice cultivation is mainly paddy rice, grown in different agro-ecological zones which provide favorable temperature, precipitation and humid conditions. The pest occurrence in these zones challenges its control/ management where the majority of farmers are resource constrained in terms of obtaining the expensive pesticides, agricultural extension services and pest resistant varieties. The acclaimed sporadic nature of the diopsids damage implies that they have not benefitted much from research attention (Bocco *et al.,* 2017). There is limited information on the fly population and its potential threat to rice production in Uganda. Currently, it is estimated that some 400,000 farmers mostly on small scale are involved in rice production throughout the country. Small scale farming communities cultivate rice in low land and rain fed rice agro-ecologies in Uganda. Except weeds and diseases, pests are the most serious threats to rice cultivation amongst small scale rice farming communities. This research provides information on changes in the pest populations and effects of temperature and relative humidity on diopsids populations in low land and rain fed rice agro-ecologies in Uganda.

2.0 Study area and Methods

2.1 Location and description of Study sites

The study took place among small scale rice farming sub-counties in low land and rain fed rice agro-ecologies in Uganda. Four rice farming communities in Uganda were purposively selected with the help of respective local area agricultural offices and farming groups. In the Lake Victoria Crescent agro-ecological zone, Muwayo farming area in Bulesa Sub-county, Bugiri District (33º51'32.33"E 0º31'57.42"N Elev. 3548m a.s.l) was selected. In the Northern moist farmlands, Barr farming area in Barr Sub-county, Lira District (33º01'50.56"E 2º11'05.04"N Elev. 3524m a.s.l) and in the west, Mubuku irrigation Resettlement scheme found in Kasese Town Council, Kasese District (30º15'01.25"E 0º21'48.23"N Elev.3389m a.s.l) of the Kasese transition agro-ecological zone were selected. These rice farms were chosen depending on their agro-ecological zones and the type of rice cultivation systems which include irrigated, rainfed lowland, upland, and flood-prone (Seck *et al.,* 2013). The stalk-eyed fly pest populations and weather parameters (temperature and relative humidity) were monitored within these farming communities.

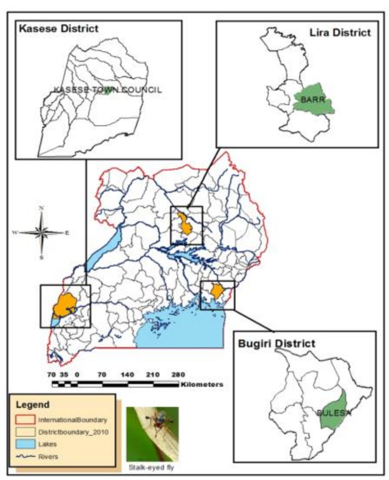


Figure 1: Map of Uganda showing the areas representing the three rice growing agro-ecological zones considered i.e Bugiri district (Lake Victoria Crescent), Lira district (Northern moist farmlands) and Kasese district (Kasese transition zone).

2.2 Methods

2.2.1 Stalk-eyed fly populations monitoring

The *Diopsis species* has been reported across farmers' rice fields in Uganda (Weelar *et al.*, 2016).To determine incidence, abundance and variability of *Diopsis species* insects within the rice fields in a given agro-ecological system, rice fields in each sub-county were sampled every 40 day beginning June 2014 for a period of 17 months. The time interval selected was based on the fact that most insects mature within a period of 3-5 weeks. In each rice field and nearby bush were selected for sampling and 10 sampling points were considered Sampling was carried out using a sweep net (Singh and Sharma, 2014) between 9:00 – 11:00 am in the morning when the morning dew had evaporated. The sweep net had a diameter of 28 cm and length of 45 cm which allowed the net to be swept through dense vegetation, dislodging the insects. The net’s ring was attached to a metal- handle of 90 cm long. Ten (10) sweeps representing a sample were taken with a step forward equivalent to 1 meter while moving diagonally through the rice fields from one corner of the field. Sweeping was done from the plant canopy level including the interspaces between plants as well as close to the plant basal region as far as possible (Magunmder *et al.*, 2013). The net was swung at an angle of 270^{o} (NICRA, 2011) as hard as possible after the last sweep to allow the insects to be deposited at the funnel end of the net. It was closed by gripping the midsection by the palm inverted. Collected insects were placed in plastic bags labeled with tags and later transferred into labeled vials with 70% ethanol alcohol for identifications. *Diopsis species* (*D. longicornis* and *D. apicalis*) insects were identified sorted out and counted by an entomologist. The sampling effort was done consistently.

2.2.2 Weather parameters (temperature and relative humidity) monitoring

To determine the influence of weather parameters on population of Stalk-eyed fly (*Diopsis sp.*), weather parameters affecting behavior, development, survival, reproduction of insects in rice fields including air temperature and humidity (Bale *et al.*, 2002) were recorded each throughout the study period using data loggers(model AZ 8829) positioned at each of the three sites. Temperature and relative humidity data loggers were positioned under a shelter roof to minimize water damages and solar radiation heating. These data loggers recorded temperature every half an hour with an accuracy of ±0.21 K over the 0–50ºC range together with a resolution of 0.02 K at 25ºC (Faye *et al*., 2014).

2.3 Data Analysis

Graphical presentation for the rate of occurrence (incidence), and abundance of the Diopsids in each location for a period of 17 months was done. The variability per survey of the stalk-eyed fly during peak rice sowing seasons in a year was analyzed using bar graphs, boxplots and the Analysis Of Variance (ANOVA) tables performed in R-statistical tool.

Bar and line graphs were plotted to represent the relationship between key climate variables (temperature and relative humidity) and the incidence and abundance of the *Diopsis species* in each agro-ecological zone. The simple and multiple regression analysis using R-statistical tool was done to obtain the R-square values for these relationships.

3.0 Results

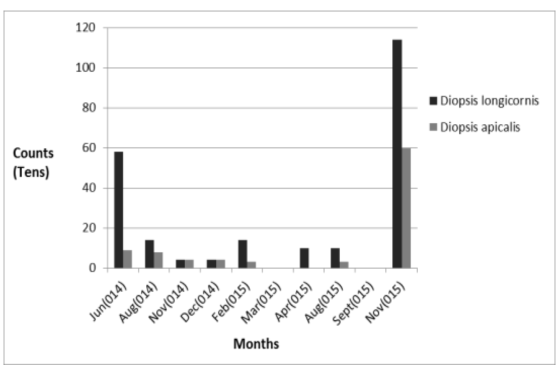
3.1 The incidence, abundance and variability of stalk-eyed fly populations in rice fields for a period of seventeen months

Generally, both species occurred in all the three agro-ecological zones (Lake Victoria Crescent, Northern moist farmlands and Kasese transition zone) surveyed over the study period (17 months). In Bugiri, no incidents were observed in all months except March 2015 and September 2015. Also April 2015 had no *D. apicalis* individual observed. Analysis done on incidence of *Diopsis sp.* in Buwayo rice fields (Bugiri district) from Lake Victoria Crescent zone showed that both *D. longicornis* and *D. apicalis* were observed in all the months the surveys done (figure 2a). The highest counts of *D. longicornis* (over 100 individuals) and *D. apicalis* (about 60 individuals) were observed in the month of November 2015 followed by June 2014 with 56 counts of *D. longicornis* and 8 counts of *D. apicalis* respectively. Equal counts of 5 individuals belonging to each *Diopsis species* were observed in the months of November and December 2014.

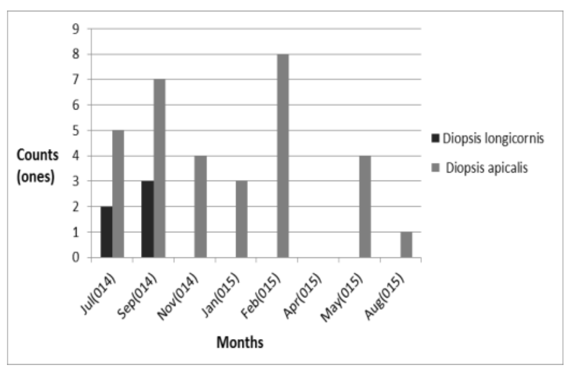
Surveys done in Barr village Rice fields (Lira district) of Northern moist farmlands showed both species occurred in hundreds in all the months surveyed except in February, March and April 2015 where few or no individual species was counted. *D. longicornis* always occurred in more numbers than *D. apicalis* throughout the months surveys were conducted. Almost equal counts of *D. longicornis* and *D. apicalis* were recorded in the month of January 2015. The incidence of these species in the area showed bimodal peaks throughout the months surveyed (figure 2b).

In Mubuku irrigation and resettlement scheme rice fields (Kasese district) of Kasese transition zone, only *D. apicalis* occurred throughout the months surveyed except April 2015 with the highest number of 8 individuals counted in February 2015. *D. longicornis* occurred only in the months of July with 2 individuals and September with 3 individuals counted respectively (figure 2c). Highest incidences of both diopsids were in Bugiri and Lira and the least was in Kasese where only *D. apicalis* was observed.

a)



(b)



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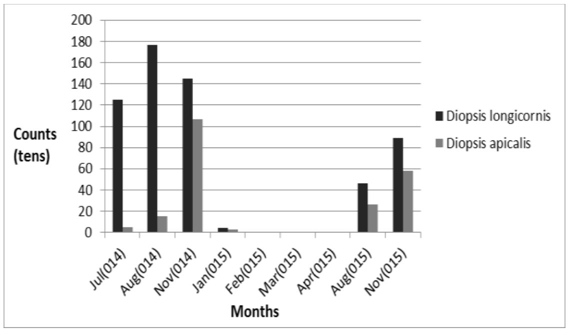


Figure 2: Incidence of *Diopsis species* in; (a): Bugiri district (b): Lira district; and (c): Kasese district rice fields throughout the months surveyed.

Throughout the surveys done, a total of 819 *D. longicornis* and 337 *D. apicalis* insect pests were obtained in the three rice growing agro-ecological zones. In both the Lake Victoria crescent zone and Northern moist zone *D. longicornis* had the highest number of individuals with 228 and 586 insects recorded respectively (figure 3). However, few *D. longicornis* insects were recorded in Kasese transitional agro-ecological zone numbering only 5 individuals over the entire study period. *D. apicalis* only dominated in Kasese transitional zone with a record range of 32 insects recorded.

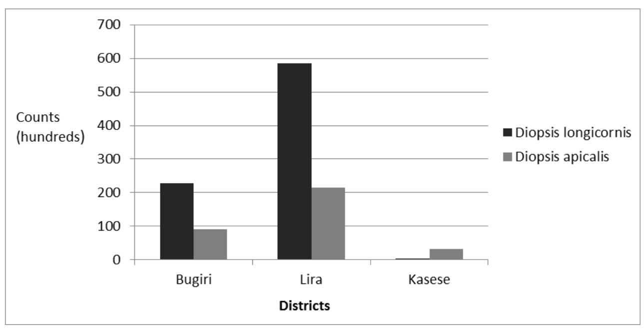


Figure 3: Abundance of *Diopsis species* in the three districts representing the agro-ecological zones.

Both *D. longicornis* and *D. apicalis* species had *P*-values of 0.000958 and 1.12e-12 respectively hence having a very high level of statistical significance in the mean count variations per survey as represented in box plots figure (4a) and 4(b). November 2015 survey had the highest number of Diopsids counted. March 2015, April 2015 and September 2015 had the least number of Diopsids counted in those surveys done Bugiri (Lake Victoria crescent agro-ecological zone) as shown in figures 5 (a).

D. apicalis was statistical significant ($p > 0.000473$) in the mean count variations per survey of individuals from Lira (Northern moist agro-ecological zone) with November 2014 having the highest count and February 2015, March 2015 and April 2015 having the least counts (figure 5 a). However, *D. longicornis* had a p-value of 0.0173 statistical significance in the mean count variation where August 2014 had the highest counts and Feb 2015, March 2015 and April 2015 had the least counts (figure 5b).

Both *D. apicalis* and *D. longicornis* species had p-values of 0.0188 and 0.0353 statistical significance in the mean count variations per survey respectively from Kasese agro-ecological zone with as represented in box plots figures (6 a) and (6b).

(a) **(b)**

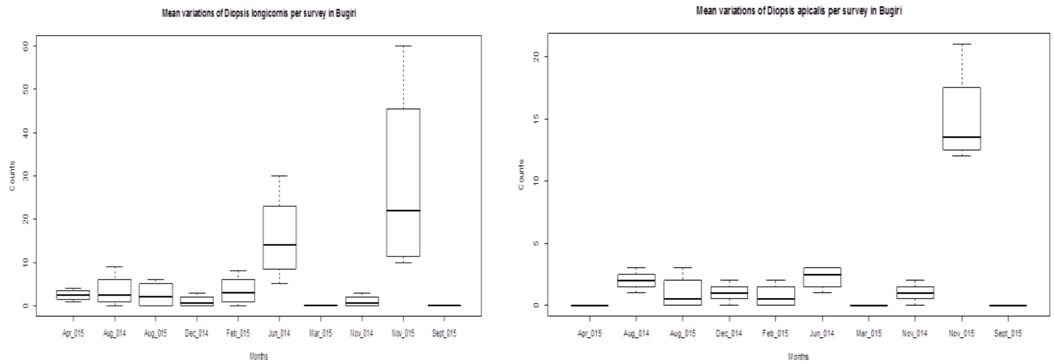


Figure 4: Mean count variations of; (a) *D. longicornis*, and (b) *D. apicalis* per survey in Bugiri district.

(a) **(b)**

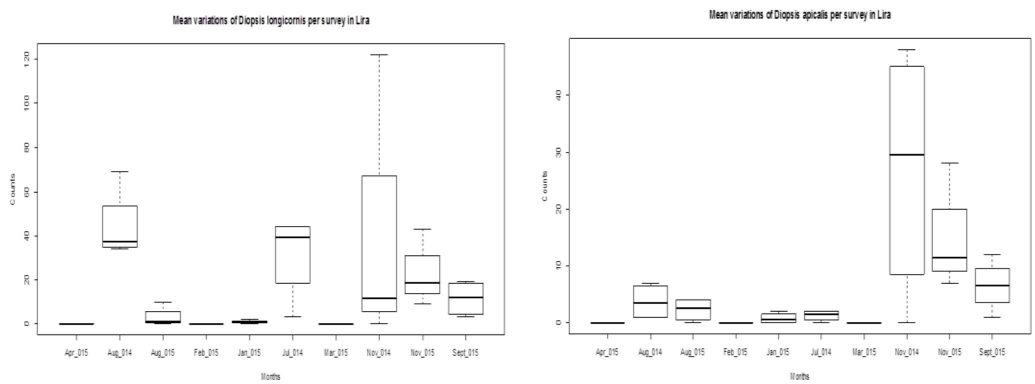


Figure 5: Mean count variations of; (a) *D. longicornis* and, (b) *D. apicalis* per survey in Lira district

(a) **(b)**

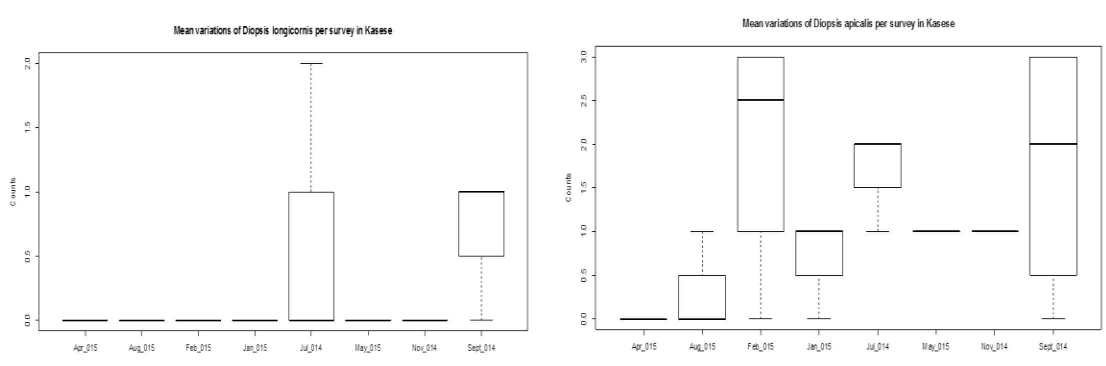


Figure 6: Mean count variations of; (a) *D. longicornis*, and (b) *D. apicalis* per survey in Kasese district.

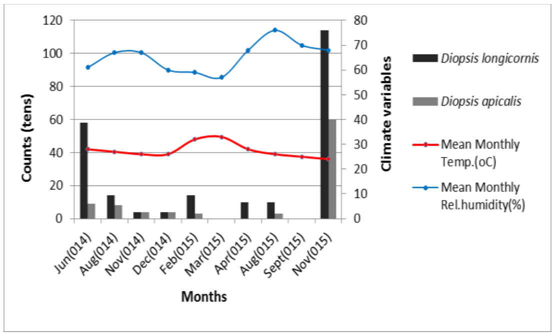
3.2 Influence of temperature and humidity on *Diopsis* species growth and development and their variation in a year

Temperatures in Bugiri district (Lake Victoria crescent) decreased slightly during June 2014 up to December 2014 but increased drastically from January until March 2015 which showed the highest temperature recorded (35^{o}C). The temperatures started dropping gradually during April 2015 until December 2015 which had the lowest recorded temperature of 23^{o}C (figure 7a). The relative humidity in this district increased during June 2014 upto November 2014 where it reduced towards December 2014. Relative humidity further reduced until March 2015 where it recorded the lowest of 55%. However, there was a drastic increase in relative humidity during April 2015 to August 2015 where it recorded the highest peak in (78%) and started dropping towards November 2015).There was no clear relationship (> 0.05) between the temperature and relative humidity with the incidence and abundance of *Diopsis sp.* in Bugiri district. However, the favorable/optimum temperature and relative humidity for the abundance of these flies were 25^{o}C and 68% respectively (figure 7a). These weather parameters had no statistical significant relationship with both species.

In Lira district, there was a gradual rise in temperature during August 2014 until March 2015 having the highest of 26^{o}C. After March 2015, temperatures started dropping until November 2015 having lowest temperature of 24^{o}C (figure 7b). However, the relative humidity recorded in this area followed drastic falls and risings throughout the period with the lowest percentage of 36% recorded in January 2015 and the highest (75%) recorded during April 2015. Both *D. longicornis* and *D. apicalis* occurred in abundance during months with high relative humidity and few during months with low relative humidity in Northern moist farmlands agro-ecological zone (figure 7b). During months with high temperatures, both *Diopsis species* were very few in numbers and months with low temperature had large numbers (hundreds) of the species. The optimum/favorable temperature for the abundance of *D. longicornis* and *D. apicalis* was 27^{o}C. Likewise, the favorable relative humidity for the abundance of *D. longicornis* and *D. apicalis* was 75% and 70% respectively. The weather parameters had no statistical significant relationship with *D. apicalis* (p-value > 0.05). However, temperature had a very low level of statistical significance (p-value=0.0453) with *D. longicornis* and *relative humidity* had no statistical significance (p-value>0.05) in the incidence and abundance of this species.

Temperatures recorded from Kasese district of Kasese transition zone showed a gradual rise during November 2014 until February 2015 which had the highest (29^{o}C) heat recorded. April 2015 had the lowest temperature (25^{o}C) recorded (figure 7c). Meanwhile, the relative humidity records showed drastic increase and decreases throughout the period where January 2015 had the lowest percentage (41%) and April 2015 with the highest percentage (65%) recorded. Since *D. longicornis* occurred only twice (July and September) in the area, there was no clear graphical relationship between this species and these weather variables in Kasese transition agro-ecological zone. While for *D. apicalis* which occurred almost every month surveyed showed significant relationships of p= 0.137 (temperature) and 0.225 (relative humidity) with these weather variables (figure 7c). This species (*D. apicalis*) did not occur at the highest relative humidity and lowest temperatures of 65% and 26^{o}C respectively. However, this species occurred in abundance within temperatures and relative humidity of 29^{o}C and 48 % respectively. *D. apicalis* showed no significant relationship (temperature p-value=0.137 and relative humidity p-value=0.225) in occurrence and abundance with the weather parameters.

(a)



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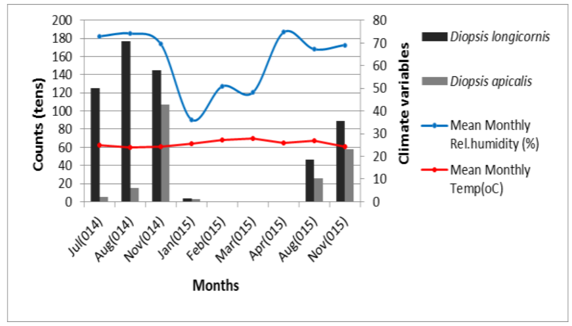

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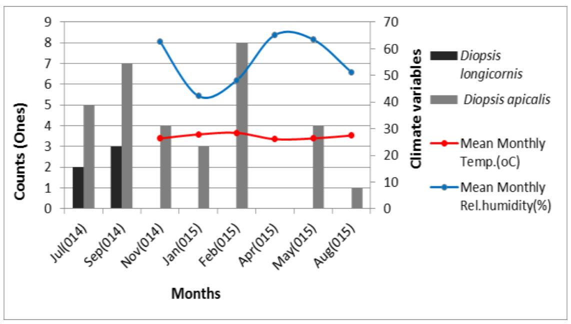

Figures 7: Climate variables against incidence and abundance of *Diopsis species* in; (a) Bugiri district (Lake Victoria crescent, (b) Lira district (North moist zone); and (c) Kasese district (Kasese transition zone).

4.0 Discussion

4.1 The incidence, abundance and variability per survey of stalk-eyed fly populations in rice fields for a period twelve months.

In all the agro-ecological zones surveyed, the *Diopsis sp.* mean counts of the population varied per survey. Insect populations are very dynamic where the number of individuals in a population may change from day to day, season to season, or year to year due to their interactions with the environment (Pedigo and Rice, 2006; and Young, 2012). Generally, *D. apicalis* and *D. longicornis* occurred in large numbers in all the three agro-ecological zones with both rainfed low land and irrigated rice ecosystems surveyed. The stalk-eyed fly is most abundant in lowland (irrigated and rainfed) rice ecosystems (Nwilene *et al.*, 2013 and Koudamiloro *et al.*, 2015).

Occurrence with a statistical difference in mean counts per survey of diopsids throughout the twelve months in Lake Victoria Crescent agro-ecological zone (Bugiri district) was attributed to the presence of rice as its host and other alternative hosts. Rice (*Oryza sativa*) seedlings, rice crops cultivated in wet season, rice ratoons left after harvests, wild rice (*Oryza longistaminata*) belonging to the rice family during dry seasons are all hosts to the *Diopsis sp.* (Nwilene *et al.*, 2013). Presence of *Diospsis sp*. in large populations during November and June was due to the intensive rice cropping seasons of these months. Studies carried out elsewhere have shown that availability of host plant greatly influences stem borer's population dynamics (Price *et al.*, 2011). In the wet season, stem borer incidence is intense during October-November resulting in white ear head damage at the flowering stage in rice. Occurrence of the insect pest populations in the non-rice cropping season (for dry month of February 2015) was due to availability of other substitute hosts such as wild rice and ratoons. In the dry season, the pest incidence occurs from February to April infesting the crop at vegetative stages. In the absence of cultivated rice crop, a host plant such as *O. longistaminata* (wild rice) can serve as a substitute host, especially where it is in abundance (Ba *et al.,* 2008). Absence of the insect pest in Bugiri during the months of March 2015, April 2015 and September 2015 was due to limited availability of host plants since activities such as land preparation activities by farmers were ongoing. These activities involve clearing all vegetation including rations. Diopsis sp. is not known to attack other crop plants other than cultivated rice (Heinrichs, 2002).

Surveys done in Northern moist agro-ecological zone Rice fields (Lira district) with a statistical significant difference in mean counts showed both species occurred in hundreds in all the months surveyed except in February, March and April (2015) where few or no individual species was counted. Absence of *Diopsis sp.* in February, March and April was attributed to a long dry season without host crop (rice) cultivated where it looked for alternative host wild rice plants in the nearby bushes. The rice plant is an ideal host for a large number of insect pests including *Diopsis sp*. (Heinrichs, 2002). *D. longicornis* always occurred in large numbers more than *D. apicalis* throughout the months a survey was done. The dominance in abundance of *D. longicornis* in rice fields of both Lake Victoria Crescent and Northern Moist agro-ecological zones could be explained by geographic range temperatures. These zones experience range temperatures between 24°C and 28°C. Geographical ranges of insects are not directly limited by vegetation, but instead are restricted by temperature (Gaston, 2003). Furthermore, this dominance was due to the rainfed lowland rice ecosystem which has stream water flowing through the rice fields throughout the year. Many insect species of *D. longicornis* are found in areas with water throughout the year and occur in swarms in shady areas near streams and canals and on weeds along levees in fallow lowlands during the dry season (Heinrichs and Barrion, 2004).

The high occurrence and abundance of *D. apicalis* population in Kasese transition agro-ecological zone (Kasese district) could be due to high temperatures experienced by the zone where the rice fields are located favoring their occurrences. A high population of *D. apicalis* in February 2015 was due to presence of a host insect (*D.longicornis*) in which eggs are laid during reproduction. *D. apicalis* oviposits exclusively on stems infested with *D. longicornis* (Bocco *et al.,* 2017). Also availability of host cultivated rice and infestation from neighboring bushes increased D.apicalis populations. Insect pests abandon rice fields left without cultivated crops for nearby bushes and later return during intensive cropping seasons (Chasen *et al.,* 2014). *D. longicornis* occurred only in the months of July with 2 individuals and September with 3 individuals counted respectively. Low *D.longicornis* populations were due to high mortalities resulted from parasitoid attacks from *D.apicalis* (Heinrichs and Barrion, 2004; Feijen, 2012). July and September are months in dry season where these pests infest the crop both at vegetative and heading stages (Heinrichs, 2004; Alam, 2016).

Abundance of stalk-eyed fly, *Diopsis sp.* in large numbers in both Lake Victoria crescent and Northern moist zones where there is rainfed lowland rice system more than in Kasese transitional agro-ecological zone was due to the monoculture rice cultivation over a wider stretch of land and limited chemical use. Insect pest populations are compromised by irrigated rice production systems through cultivation practices such as, intensive use of chemical inputs (fertilizers and pesticides) and asynchronous planting (Heinrichs and Barrion, 2004).

4.2 Variation of temperature and relative humidity in Diopsis species growth and development

Temperature and relative humidity had a direct effect on the population of both *D. longicornis* and *D. apicalis* in Northern moist zone and only on *D. apicalis* in Kasese transition zone. Climatic and weather conditions during cropping seasons are the major factors influencing the intensity and the occurrence of pests (Kocmankova *et al.*, 2008) but temperature and humidity stand out as the most important ones constraining abundance and distribution of insects (savopoulou - soultani *et al.*, 2012; and Khaliq *et al.*, 2014). A large population of Diopsids during months with high relative humidity was due to adult emergencies where higher humidity was important for egg hatching activity and development. Previous studies done on insect pests showed that the percentage of adult stage emergence increased with the increase of relative humidity (Akter, 2013). Months with high temperatures had a low population of both *Diopsis sp.* and months with low temperature had large population. Temperature causes the direct effects like survival, growth and development, voltinism and dispersal of insect pests (Karuppaiah and Sujayanad, 2012). Insects do not bear the challenge against high and low thresh hold temperatures. High thermal thresh hold influence the insects trend stage, growth or some internal metabolic activities (Khaliq *et al.*, 2014). The favorable optimal relative humidity for the abundance of *D. longicornis* and *D. apicalis* was between 48% -75%. Likewise, the favorable optimal temperature for the occurrence of *D. longicornis* and *D. apicalis* was between 25ºC - 29ºC for all the agro-ecological zones. Most insect activity and reproduction occurs at temperatures between 15ºC - 35ºC but each species usually has an optimum temperature (Reznik *et al.*, 2009).

However, there was no clear effect of temperature and relative humidity on the population dynamics of *D.longicornis* in the Lake Victoria crescent and Kasese transition zones. Besides temperature and relative humidity, biotic (biological) factors such as natural enemies including predatory insects (Tahir and Butt, 2008), parasitoids (Bonet, 2009) and nematodes (Denno *et al.*, 2008) which also affect the populations of *Diopsis sp.* On addition to biotic factors, the *Diopsis sp*. population can also be suppressed chemical (insecticide) application (Sarwar *et al.*, 2005; Ssemwogerere *et al.*, 2013) and rice farming practices (Kumar, 2012).

5.0 Conclusion and Recommendations

Stalk-eyed flies were abundant in Lake Victoria crescent and Northern moist zones where there is rainfed lowland rice system more than in Kasese transitional zone which has low land irrigated rice ecosystem. Large fly populations were mainly during the months of November and June when there is intensive rice cropping. However, *D. apicalis* was dominant in Kasese transition agro-ecological zone only. Temperature and relative humidity had a direct effect on the population of both species in Northern moist zone and only on *D. apicalis* in Kasese transition. Optimum/favorable temperature for their abundance was between 27ºC to 29ºC.

Integrated pest management strategies such as use of non-hazardous pesticides early sowing, fertilizer adjustment and burning rice stubble should be emphasized in Lake Victoria crescent and Northern moist zones to control the high levels of *Diopsis species* populations. Also introduction of improved *Diopsis* resistant rice varieties to reduce on the losses inflicted by the diopsids in-order to improve food security in Uganda.

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6. References

Abrol, D. (2013). Integrated Pest Management. 1st ed. Burlington: Elsevier Science.

Africa Rice Center (WARDA). 2007. Africa Rice Trends: Overview of recent developments in the Sub-Saharan Africa rice sector. Africa Ruce Center Brief. Cotonou, Benin: Africa Rice Center (WARDA). 10p.

Africa Rice Center (WARDA)/FAO/SAA. 2008. NERICA®: the New Rice for Africa – a Compendium. EA Somado, RG Guei and SO Keya (eds.). Cotonou, Benin: Africa Rice Center (WARDA); Rome, Italy: FAO; Tokyo, Japan:Sasakawa Africa Association. 210 pp.

Agrawal, A., Ackerly, D., Adler, F., Arnold, A., Cáceres, C., & Doak, D., *et al*. (2007). Filling key gaps in population and community ecology. Frontiers In Ecology And The Environment, 5(3), 145-152. http://dx.doi.org/10.1890/1540-9295(2007)5[145:fkgipa]2.0.co;2

Akter T., Effects of temperature and relative Humidity on The Angoumois Grain Moth, Sitotroga cerealella (Olivier) on Stored Rice Grain in Laboratory Condition, Intl J Agri Crop Sci. Vol., 6 (11), 648-653.

Alam, M., Haque, M., Islam, M., Hossain, E., Hasan, S., Hasan, S., & Hossain, M. (2016). Comparative Study of Integrated Pest Management and Farmers Practices on Sustainable Environment in the Rice Ecosystem. International Journal Of Zoology, 2016, 1-12. http://dx.doi.org/10.1155/2016/7286040

Alibu S., Otim M.H., Okello S. E. A., Lamo J., Ekobu M., Asea G., 2016. Farmer's Knowledge and Perceptions on Rice Insect Pests and Their Management in Uganda. Academic Editor: Les Copeland. © 2016 by the authors; licensee MDPI, Basel, Switzerland.

Ane N.U and Hussain M. (2015), Diversity of insect pests in major rice growing areas of the world Journal of Entomology and Zoology Studies, 4(1): 36-41

Awika *et al.*,(2011). Advances in Cereal Science: Implications to Food Processing and Health Promotion ACS Symposium Series; American Chemical Society: Washington, DCBale, J. ., van Lenteren, J. ., & Bigler, F. (2008). Biological control and sustainable food production. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1492), 761–776. http://doi.org/10.1098/rstb.2007.2182

Awio T., Karungi J., Bua B., and Lamo J., 2016, Relating water management regimes and rice genotypes with occurrence of insect pests and diseases of rice in Uganda, Journal of Global Agriculture and Ecology, 4(1): pp 12-20

Bambaradeniya, C. N. B.; Amerasinghe, F. P. 2003. Biodiversity associated with the rice field agroecosystem in Asian countries: A brief review. Working Paper 63. Colombo, Sri Lanka: International Water Management Institute.

Baker, R., Narechania, A., Johns, P. and Wilkinson, G. (2012). Gene duplication, tissue-specific gene expression and sexual conflict in stalk-eyed flies (Diopsidae). Philosophical Transactions of the Royal Society B: Biological Sciences, 367(1600), pp.2357-2375.

Begon, M., Mortimer, M., & Thompson, D. (2009). Population Ecology. Chichester: John Wiley & Sons.

Bhullar, N. and Gruissem, W. (2013). Nutritional enhancement of rice for human health: The contribution of biotechnology. Biotechnology Advances, 31(1), pp.50-57.

Bocco, R., Gandonou C. B., Dannon, A. E., Zanklan, A. S., 2017. Diopsids (*D. thoracica* and *D. apicalis*) damaging rice production in Africa: A review. Int. J. Curr. Res. Biosci. Plant Biol. 4(6), 33-41. doi: https://doi.org/10.20546/ijcrbp.2017.406.004

Bommarco, R., Kleijn, D. and Potts, S. (2013). Ecological intensification: harnessing ecosystem services for food security. Trends in Ecology & Evolution, 28(4), pp.230-238.

Bonet A (2009). Parasitoid wasps, natural enemies of insects. Tropical Biology and Conservation Management, Vol. VII, parasitoid wasps, Natural enemies of insects.

Chasen E.M., Dietrich C., Backus E.A., and Cullen E.M., 2014, Potato Leafhopper (Hemiptera: Cicadellidae) Ecology and Integrated Pest Management Focused on Alfalfa, J Integr Pest Manag (2014) 5 (1): A1-A8

Chidawanyika F. Mudavanhu P. and Nyamukondiwa C., (2012). "Biologically Based Methods for Pest Management in Agriculture under Changing Climates: Challenges and Future Directions" 3 Insects 1171-1189.

Denno, R.F., D. S. Gruner, and I. Kaplan. 2008. Potential for Entomopathogenic Nematodes in Biological Control: A Meta-Analytical Synthesis and Insights from Trophic Cascade Theory. Journal of Nematology 40(2): 61-72.

Dixon, A. (2005). Insect predator-prey dynamics. Cambridge: Cambridge University Press.

FAO. 2015, Country fact sheet on food and agriculture policy trends. Food and Agriculture Policy Decision Analysis (FAPDA) team. I4915E/1/09.15

Fao.org. (2017). FAO Cereal Supply and Demand Brief | FAO | Food and Agriculture Organization of the United Nations. [online] Available at: http://www.fao.org/worldfoodsituation/csdb/en/ [Accessed 21 Apr. 2017].Feijen, H. and Feijen, C. (2012). A New Species of Diopsis. (Diptera: Diopsidae) from South Africa and Swaziland, and Brief Review of African Species with a Large Apical Wing Spot. African Invertebrates, 53(1), pp.125-142.

Gaston K.J., 2003, The structure and Dynamics of Geographical ranges, Oxford University Press Inc. New York.

Gianessi, 2014. Importance of Pesticides for Growing Rice in South and South East Asia, Crop life International, International Pesticide Benefits Case Study No. 108.

GRiSP (Global Rice Science Partnership). 2013. Rice almanac, 4th edition. Los Baños (Philippines): International Rice Research Institute. 283 p.

Heinrichs, E. (2004). Rice-feeding insects and selected natural enemies in West Africa. Los Baños: International Rice Research Institute; Abidjan: West Africa Rice Development Association.

Heinrichs, E. A. and A. T. Barrion (2004). Rice feeding insects and selected natural enemies in West Africa. Biology, ecology, identification. G.P. Hettel (ed) International Rice Research Institute PP. 40–47

Hurrell, J., & Deser, C. (2010). North Atlantic climate variability: The role of the North Atlantic Oscillation. Journal Of Marine Systems, 79(3-4), 231-244. http://dx.doi.org/10.1016/j.jmarsys.2009.11.002

IPCC. 2007. Climate Change 2007: The Physical Science Basis. S. Solomon, D.Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller editors. Cambridge University Press, Cambridge, UK.

J.A.J. Metz and O. Diekmann (2014), The Dynamics of Physiologically Structured Populations , Bulletin Of Mathematical Biology, 49(4), 511-515. http://dx.doi.org/10.1016/s0092-8240(87)80012-5

Jaworski T, Hilszczański J. The effect of temperature and humidity changes on insects development their impact on forest ecosystems in the expected climate change. Leś Pr Bad. 2013;74(4): 345–355. doi: 10.2478/frp-2013-003

Khan S.A., Kumar S., Hussain M., Kalra N. (2009) Climate Change, Climate Variability and Indian Agriculture: Impacts Vulnerability and Adaptation Strategies. In: Singh S.N. (eds) Climate Change and Crops. Environmental Science and Engineering. Springer, Berlin, Heidelberg.

Khush, G. (2013). Strategies for increasing the yield potential of cereals: case of rice as an example. Plant Breeding, p.n/a-n/a.

Koudamiloro A., Nwilene F. E., Togola A., and Akogbeto M. 2015, Insect Vectors of Rice Yellow Mottle Virus, Journal of Insects, Volume 2015, pages12 http://dx.doi.org/10.1155/2015/721751

Kumar P., (2012). Feeding the future: crop protection today, Acta Chim. Pharm. Indica: 2(4), 2012.

Lachaud, J., Cerdan, P. and Pérez-Lachaud, G. (2012). Poneromorph Ants Associated with Parasitoid Wasps of the GenusKapalaCameron (Hymenoptera: Eucharitidae) in French Guiana. Psyche: A Journal of Entomology, 2012, pp.1-6.

Lamb, H. (2011). Climate. London: Routledge.

Landman, W. (2010). Climate change 2007: the physical science basis. South African Geographical Journal, 92(1), 86-87. http://dx.doi.org/10.1080/03736245.2010.480842

Litsinger J.A., Canapi B.L., and Bandong J. P., (2011). Rice Insect Pest Losses: Cultural Practices Mitigate Irrigated Rice Insect Pest Losses in the Philippines, Philippine Journal of Science,Vol. 140 No. 2, December 2011

Liu, M., Lin, S., Dannenmann, M., Tao, Y., Saiz, G., Zuo, Q., Sippel, S., Wei, J., Cao, J., Cai, X. and Butterbach-Bahl, K. (2013). Do water-saving ground cover rice production systems increase grain yields at regional scales?. Field Crops Research, 150, pp.19-28.

Lobell, D., & Gourdji, S. (2012). The Influence of Climate Change on Global Crop Productivity. PLANT PHYSIOLOGY, 160(4), 1686-1697. http://dx.doi.org/10.1104/pp.112.208298

M.A. Hixon, S.W. Pacala, and S.A. Sandin, Population regulation: historical context and contemporary challenges of open vs. closed systems, Journal of Ecology, Volume 83, Issue 6, pages 1490–1508, June 2002.

Maclean, J., Hardy, B. and Hettel, G. (2013). Rice almanac. 1st ed.Los Baños: IRRI.

Magurran, A. and McGill, B. (2011). Biological diversity. 1st ed. Oxford: Oxford University Press.

Makosa D., 2015, Constraints and opportunities to upgrading Ugandas rice markets: A value chain approach. Journal of Development and Agricultural Economics; 7(12): 386- 399.

Marcus Allen (2007) What Makes a Fly Enter Diapause?, Fly, 1:6, 307-310, DOI: 10.4161/fly.5532

Martins, J.C., Picanço, M.C., Bacci, L. (2016). Life table determination of thermal requirements of the tomato borer Tuta absoluta, Journal of pest science, Volume 89, Issue 4, pp 897–908.

McLoughlin, P., Morris, D., Fortin, D., Vander Wal, E. and Contasti, A. (2010). Considering ecological dynamics in resource selection functions. Journal of Animal Ecology, 79(1), pp.4-12.

Miyashita, T., Chishiki, Y. and Takagi, S. (2012). Landscape heterogeneity at multiple spatial scales enhances spider species richness in an agricultural landscape. Population Ecology, 54(4), pp.573-581.

Mohamed Ahmed, 2014. Analysis of price incentives for rice in Uganda for the time period 2005–2013 Technical notes series, MAFAP, FAO, Rome.

Mohanty S, Wassmann R, Nelson A, Moya P, and Jagadish S.V.K., 2013. Rice and climate change: significance for food security and vulnerability. IRRI Discussion Paper Series No. 49. Los Baños (Philippines): International Rice Research Institute. 14 p.

NICRA team of rice pest surveillance, 2011. Manual for Rice Pest Surveillance. Jointly published by National Centre for Integrated Pest Management, New Delhi, Central Research Institute for Dryland Agriculture and Directorate of Rice Research, Hyderabad 40 pp.

Norman J.C., and Kebe B. 2006. African smallholder farmers: Rice production and sustainable livelihoods. International Rice Commission Newsletter 55:33

NRDS (National Rice Development Strategy), 2009.Ministry of agriculture, animal industry and fisheries, Government of the Republic of Uganda.

Nwilene, F.E., Nwanze, K.F. and Okhidievbie, O. (2006) African Rice Gall Midge: Biology, ecology and control– Field Guide and Technical Manual. Africa Rice Center, Cotonou, Benin.

Nwilene FE, Nacro S, Tamo M, Menozzi P, Heinrichs EA, Hamadoun A.2013, Managing Insect pests of Rice in Africa. In: Wopereis MCS, Johnson DE, Ahmadi N, Tollens E, Jalloh A, editors. Realizing Africa's Rice Promise. Wallingford (UK): CABI; p. 229

O'Connell, A., Nichols, J., & Karanth, K. 2010, Camera Traps in Animal Ecology.

Olofsson, P., Foody, G., Stehman, S. and Woodcock, C. (2013). Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. Remote Sensing of Environment, 129, pp.122-131.

Onunkun, O. (2014). Field Efficacy of Insecticides on Population Dynamics of Grain Sucking Bugs of Upland Rice, Oryza Sativa. IOSR Journal Of Agriculture And Veterinary Science, 7(2), 52-55. http://dx.doi.org/10.9790/2380-07235255

Pedigo LP, Rice ME (2006). Entomology and Pest Management. 5th Edition. Prentice Hall

Popp, J., Peto, K. & Nagy, J. (2013), Pesticide productivity and food security. A review. Agron. Sustain. Dev. 33, 243–255).

Price, P. (2011). Insect Ecology. 1st eds Cambridge: Cambridge University Press.

Reznik S.Y., Voinovich N.D. and Vaghina N. P., 2009, Effect of temperature on the reproduction and development of Trichogramma buesi (Hymenoptera: Trichogrammatidae), Eur. J. Entomol. 106: 535–544, 2009

R.J. Putman and S. D.,Wratten, 2012. Principles of Ecology, Croom Helm limited,

Roos, A., & Persson, L. (2013). Population and community ecology of ontogenetic development. Princeton: Princeton University Press.

Rötter, Reimund P.; Sehomi, Fanou L.; Höhn, Jukka G.; Niemi, Jarkko K.; Van den Berg, Marrit (2016) : On the use of agricultural system models for exploring technological innovations across scales in Africa: A critical review, ZEF- iscussion Papers on Development Policy, No. 223

Saito K., Nelson A., Zwart S. J., Niang A. Sow A., Yoshida H. and Wopereis M.C.S, 2013.Towards a Better Understanding of Biophysical Determinants of Yield Gaps and the Potential for Expansion of the Rice Area in Africa, CAB International

Sarwar M, Ali A, Ahmad N, Tofique M (2005). Expediency of Different Botanical Products Intended for Managing the Population of Rice Stem Borers. Proce. 25th Pakistan Conger. of Zoology, March 1-3, Sindh Agric. Uni., Tandojam, 25: 15-23.

Sarwar, M., 2012. Management of rice stem borers (Lepidoptera: Pyralidae) through host plant resistance in early, medium and late plantings of rice (Oryza sativa L.). Journal of Cereals and Oilseeds, 3(1), pp.10-14.

Saumya Awasthi and JP Lal, 2015. Application of molecular markers to improve drought tolerance and yield enhancement in upland rice, Annals of Plant Sciences,4 (04), 1051-1056

Savopoulou-Soultani M., Papadopoulos N.T., Milonas P., and Moyal P., 2012, Abiotic Factors and Insect Abundance, Journal of Entomology, Volume 2012 (2012), Article ID 167420, 2 pages.

Seck, P.A., Diagne, A., Mohanty, S. and Wopereis, M.C.S. (2012) Crops that feed the world 7: rice. Food Security 4, 7–24.

Seck, P.A., Touré, A.A., Coulibaly, J.Y., Diagne, A. and Wopereis, M.C., 2013. Africa's rice economy before and after the 2008 rice crisis. Realizing Africa's Rice Promise, Oxfordshire and Boston: CAB International, pp.24-34.

Selvaraj S., Ganeshamoorthi P., Pandiaraj T. (2013). Potential impacts of recent climate change on biological control agents in agro-ecosystem: A review. Int J Biodivers Conserv. 5(12): 845-852.

Sharma, V. and Wardhan, H. (2017). Marketed and Marketable Surplus of Major Food Grains in India. 1st ed. New Delhi: Springer India.

Ssemwogerere C., Nyaburu M. K., Ochwo-Ssemakula, Kovach J., Kyamanywa S., and Karungi J., (2013), Species composition and occurrence of thrips on tomato and pepper as influenced by farmers' management practices in Uganda, journal of plant protection research, vol. 53

Sushil Pandey, Derek Byerlee, David Dawe, Achim Dobermann, Samarendu Mohanty, Scott Rozelle, and Bill Hardy, editors. 2010. Rice in the global economy: strategic research and policy issues for food security. Los Baños (Philippines): International Rice Research Institute. 477p.

Tahir HM, Butt A (2008). Activities of spiders in rice fields of central Punjab, Pakistan. Acta. Zool. Sinica. 54: 701-711.

Takada, M., Kobayashi, T., Yoshioka, A., Takagi, S. and Washitani, I. (2013). Facilitation of ground-dwelling wolf spider predation on mirid bugs by horizontal webs built byTetragnathaspiders in organic paddy fields. Journal of Arachnology, 41(1), pp.31-35.

Tanakorn Sritarapipat, Preesan Rakwatin, Teerasit Kasetkasem, 2014. Automatic Rice Crop Height Measurement Using a Field Server and Digital Image Processing. Basel, Jan; 14(1): 900–926. Published online 2014 Jan 7. doi: 10.3390/s140100900.

Togola, A., F.E. Nwilene, A. Agbaka, F. Degila, A. Tolulope and D. Chougourou, 2011. Screening upland varieties of NERICA and its parents for resistance to stalk-eyed fly, Diopsis sp. (Diptera, Diopsidae) in Benin. J. Applied Sci., 11: 145-150

Turchin, P. (2003). Complex population dynamics. Princeton, N.J: Princeton University Press.

Wall, R. and Shearer, D. (2008). Veterinary Ectoparasites. 1st ed.New York, NY: John Wiley & Sons.

Warren, I., Fowler, K. and Smith, H. (2010). Germline transformation of the stalk-eyed fly, Teleopsis dalmanni. BMC Molecular Biology, 11(1), p.86.

Veres, A., Petit, S., Conord, C. and Lavigne, C. (2013). Does landscape composition affect pest abundance and their control by natural enemies? A review. Agriculture, Ecosystems & Environment, 166, pp.110-117.

Weelar G. C, Awio B. Ochwo-Ssemakula M. Lamo J. Otim M. H., 2016. Evaluation of rice genotypes for resistance to the stalk-eyed fly (*D. longicornis*) in rice in Uganda. International Journal of Agronomy and Agricultural Research (IJAAR) ISSN: 2223-7054 (Print) 2225-3610 Vol. 9, No. 2, p. 9-21, 2016

Wopereis, M., Johnson, D., Ahmadi, N., Tollens, E. and Jalloh, A. (2013). Realizing Africa's rice promise. 1st ed.

World Meteological Organisation (WMO), 2013, Higher temperatures affect intensive rain showers.Zada.

H., A. U. R. Saljoqi., A. Farid., F. Ullah and I. A. Khan. 2014. Influence of weather parameters on population dynamics of apple codling moth cydia pomonella (Lepidoptera; Tortricidae) at Matta Swat valley. Sarhad J. Agric. 30(3): 351-356