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Abundance, distribution and effects of temperature and humidity on arthropod fauna in different rice ecosystems in Uganda

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Abstract
The study on abundance, distribution and effects of temperature and humidity on arthropod fauna was conducted in smallholder rice farming areas in three agro-ecological zones of Lake Victoria basin, Northern moist farmlands and Western Savannah grasslands in Uganda. Arthropods were collected using a standard sweep net and a total of 17 orders representing 13,272 arthropods were recorded from the three agro-ecological zones during the study. Most arthropod fauna were collected in Bugiri, Lira and Kasese respectively. The most abundant orders throughout the survey included Homoptera, Coleoptera, Hemiptera, Diptera, Hymenoptera and Orthoptera. While the least abundant included Dermaptera, Zoraptera, Phasmatodea, Mantodea, Embioptera and Neuroptera. All orders except Embioptera, Mantodea, Neuroptera and Phasmatodea were collected in all the three agro-ecological zones. The orders Diptera ($p = 0.0282$), Hymenoptera ($p = 0.0051$), Lepidoptera ($p = 0.0149$), Odonata ($p = 0.0356$) showed a significant difference in abundance in the three agro-ecological zones. Temperature and humidity had a significant effect on the arthropod population for example Aranea showed a positive correlation in their abundance with increase in temperature in all the agro-ecologies.

Keywords: Arthropods, rice fields, weather parameters, agro-ecologies, diversity

1. Introduction

A healthy and balanced agro-ecosystem is always in a dynamic state. In a naturally balanced ecosystem, the key components, including arthropods, diseases and weeds are in a shifting balance with other species like natural enemies and crops as components of local food webs [1]. The presence of these key components in a given agro-ecological system varies according to their population and that of their natural enemies at a given time [1]. The variations may often and not always depend on crop phenology, environmental conditions and management practices in a given area. Depending on the prevailing conditions, the populations of such species may reach levels devastating crops, and thus become known as 'pests' [1, 2]. However, the population is often influenced by local management practices, like cropping systems, varieties of crops and use of chemical fertilizers, herbicides and pesticides [2, 3]. Minimizing disruption to the local agro-ecological balance requires sufficient information on existing pest species in the field and their role in a given agro-ecosystem [2, 4].

Introduction of new inputs and practices in traditional farming agro-ecosystems, has led to higher productivity, but with many profound effects including increased vulnerability of agricultural systems, hence reducing their resilience and production sustainability [5]. The changes in species populations can be well monitored in rice agro-ecological systems, where they are used as indicators of environmental change more rapidly than the vertebrates [6]. In a rice agro-ecosystem, the average loss caused by insect-pests was estimated at about 18% in Africa [7]. Over 266 species of insect pests have been recorded on rice crop and of these, 20-33 species are economically important [8]. They include stem borers, plant hoppers, gall midge, leaf folders and other pests while the rest are either beneficial in the form of a wide range of predators and parasitoids [9]. Among abiotic factors, weather parameters play a significant role in rice production system. Weather conditions influence the various growth and development stages of a crop and indirectly, the incidence of pests and diseases [10].

However, in Uganda, very little information is available on the incidence, variability and diversity of arthropods in rice fields. Similarly, little is known on how the weather parameters affect the populations of these arthropods in much of the lowland rain-fed ecosystems which characterize Uganda's rice farming systems [11]. This study was designed to provide baseline information on rice pest fauna in different agro-ecologies so that proper management strategies for their control can be developed. Specifically, the study aimed at: - i) identifying variations of arthropod populations in different agro-ecologies with time, ii) assess the effect of temperature and relative humidity on populations of different arthropod fauna. The study hypothesized that different rice agro-ecologies have similar orders of arthropods in Uganda and that temperature and relative humidity have no effect on arthropod population in rice fields in a period of twelve months from November 2014 to November 2015.

2. Methods and Materials

2.1 Study area

The study took place in smallholder rice farming areas in lowland and rain-fed agro-ecologies in Uganda represented by three agro-ecological zones: Lake Victoria basin, Northern moist farmlands and Western savannah grasslands. The farming communities were purposively selected with the help of respective local area agricultural offices and farming groups which included Bugiri (Muwayo farming area, Bulesa Sub-county, Bugiri District) rice growing agro-ecological area selected in the Lake Victoria Crescent (1174 to 1235 meters above sea level). The Lake Victoria basin experiences two relatively dry periods (December to March and June to July), while peak rainfall (1250 to 1500 mm per annum) periods are in March to May and October to November and a minimum temperature of 12-15 °C [12]. The micro-climates, rainfall patterns and cropping regimes in the Lake Victoria basin and Elgon farmlands are traditionally influenced by Lakes Victoria and Kyoga [13, 14]. West of the Nile, the landscape is an old land surface marked by ridges or laterite-capped hills, long slopes and wide often swampy valleys, while East of the Nile, the landscape is rolling with wide valleys. Rice production is important in parts of Tororo, Busia, Bugiri and parts of Iganga district. Sampling in this area took place in the period of November, 2014 to November 2015.

In the Northern moist farmlands, Barr farming area, Barr Sub-county, Lira District (33°01'50.56"E 2°11'05.04"N 3524FT) was selected [12]. The area is sub-humid and relatively warm with rainfall well distributed from April to October during which, mean monthly rainfall exceeds 110 mm and rice is increasingly becoming important as a commercial crop. The main dry season is December-March. Sampling in this area took place in the period from November 2014 to September 2015.

The Western savannah grassland agro-ecosystem, Mubuku irrigation resettlement scheme, Kasese Town Council, Kasese District (30°15'01.25"E 0°21'48.23"N 3389FT) was also selected [12]. The zone receives a bimodal type of rainfall with growing seasons in March-June and September-December. Upland rice under irrigation is one of the most important crops in the scheme. The survey in this place was carried out from November 2014 to August 2015 (Fig 1).

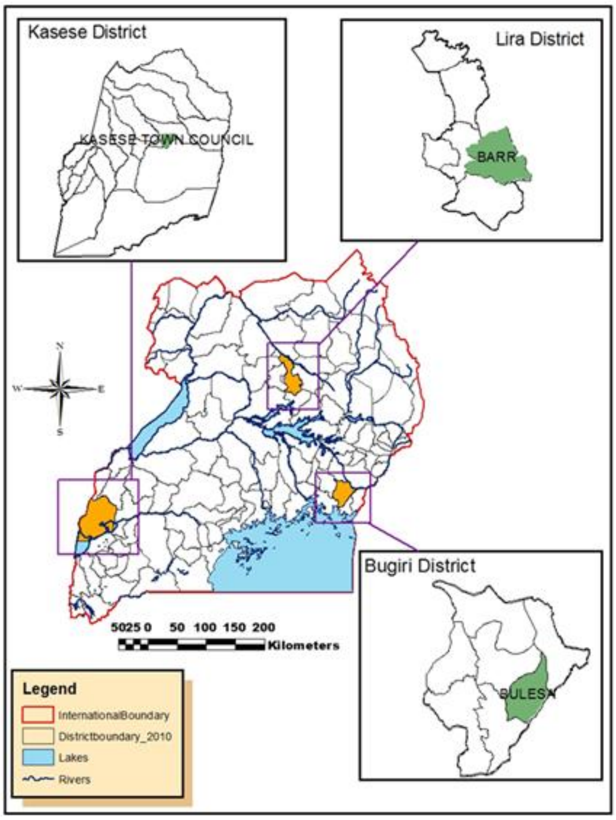

Fig 1: Map of Uganda showing the three districts (Bugiri, Kasese and Lira) that were surveyed for arthropod fauna in the three agro-ecosystems.

2.2 Sampling of terrestrial Arthropod community in rice fields

Sampling of the terrestrial arthropod community was conducted to determine species composition, abundance and distribution in the different rice farming ecosystems in Uganda. Each farming area was divided into four quadrants and from each quadrant; one field was selected at a distance of more than seventy meters between fields depending on the size of the farming area. Sampling was carried out between 7:45-11:45 am using a standard sweep net [15] after a forty day intervals as most rice insect pests mature in a period of 40 days [10]. Sampling was done by walking along a transect diagonally in the field (one sweep / m) taking 10 sweeps per sample. The net was swung at 270º and a total of four samples were collected from each 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 [8, 16]. The net was swung as hard as possible after the last sweep to allow the arthropods to be deposited at the funnel end of the net. Collected arthropods were placed in plastic bags labeled with tags and later transferred into labeled vials with 70% ethanol and transported to Uganda Christian University laboratory for identification [16] and taking counts.

2.3 Identifying, sorting and counting of the collected Arthropod fauna

The arthropod fauna (insects and spiders) collected from the rice fields were identified and classified into the genera taxon using keys and guides. For example Heinrichs and Barrion [9] guide was used as a reference for rice pests, their predators and parasitoids. Their abundance was determined by making counts.

2.4 Determination of environmental parameters affecting composition, abundance and distribution of arthropod community in the different rice farming ecosystems

In rice fields, environmental conditions including temperature, light intensity, and humidity [2] are important in determining the population dynamics of arthropod insect-pests. To determine these parameters, portable weather stations (data loggers model AZ 8829) were installed in the different agro-ecological zones and data was collected every 40 days in each agro-ecology as sampling of arthropod fauna in rice fields took place.

2.5 Data Analysis

Data obtained on the abundance of arthropod fauna from the different rice farming areas was compared using means and standard error values at 95% confidence interval. The mean values in the four different agro-ecologies were statistically analyzed using analysis of variance (ANOVA) tables performed in JMP PRO V12. Correlation analysis was also carried out between the means of the different arthropod orders with the different mean monthly weather variables to establish the effect of the weather parameters on their abundances.

3. Results and Discussion

3.1 Abundance of arthropods in agro-ecosystems

A rich terrestrial arthropod fauna community consisting of 17 orders with a total of 13,272 arthropods was recorded from the three agro-ecological zones during the study. The study highlights abundance and richness of arthropods in rice field ecosystems in Uganda. Similar results showing high arthropod richness in rice ecosystems has been reported by previous researchers like Hoeng et al, [17], Barrion et al, [18], and Thongphak et al, [19]. The terrestrial arthropod fauna comprising of 17 orders recorded in the present study is higher than that documented by Nasiruddin and Roy [20] who reported four economic insect orders, and Rahaman [16]. This may be due to the warm humid tropical climate in Africa [9]. Also the closeness to the equator where the sampling took place provides favorable conditions for these insect pests to thrive [21]. This marks the first study of abundance of arthropod fauna in different rice growing ecosystems in Uganda. Arthropods in orders Diptera, Hymenoptera, Lepidoptera, Odonata, Orthoptera and Zoraptera showed a statistically significant difference in their abundance among the districts while the remaining orders showed no statistically significant difference among the districts during the survey. This may be due to availability of rice food plants throughout the year attributed to different rice growing ecosystems [9, 20]. The study highlights the importance of order Hymenoptera with the largest number of species represented by natural enemies of rice pest arthropods like parasitic wasps and pollinators [9]. Our results are similar to what have been reported by Heinrichs and Barrion [9]. Other arthropods of order Aranae like spiders showed a highly similar composition evident from their species composition, abundance and distribution within the rice agro-ecosystems. This is due to warm and humid climate of tropical Africa, and presence of prey most of which are rice pests. Similar findings were reported by Nasiruddin and Roy [20]. Order Coleoptera was the second most abundant order among all the 17 orders identified. This order is of economic importance because its members have been implicated in vectoring rice yellow mottle virus [22]. A detailed list of the orders recorded and their specific habitat in the different rice ecosystems is provided in Table 1.

Table 1: Habitats from which arthropods of different orders were collected in the survey Districts

District	Habitat	Aranea	Coleoptera	Dermaptera	Diptera	Embioptera	Hemiptera	Homoptera	Hymenoptera	Lepidoptera	Mantodea	Mecoptera	Neuroptera	Odonata	Orthoptera	Phasmatodea	Siphonaptera	Zoraptera	District totals
Bugiri	Benenego	19	1036	4	64	0	512	684	196	4	0	0	0	56	201	0	0	0	
Bugiri	Bush	0	77	8	14	0	29	110	17	14	0	6	0	0	28	0	0	0	
Bugiri	K5	12	219	0	71	0	218	353	104	1	0	2	0	5	110	0	0	0	
Bugiri	Kaiso	0	2	0	50	0	122	218	72	5	0	6	0	8	181	0	0	0	
Bugiri	Ratoons	44	378	2	98	0	16	2	788	37	0	98	0	12	93	0	7	4	
Total		75	1712	14	297	0	897	1367	1177	61	0	112	0	81	613	0	7	4	6417
Lira	Bush	0	9	10	163	0	57	559	11	3	3	2	0	0	0	0	0	0	
Lira	Fallow	62	311	4	292	0	129	51	51	27	0	4	0	45	297	1	8	10	
Lira	Kaiso	0	26	0	310	0	840	475	11	1	0	3	0	0	81	0	0	0	
Lira	Ratoon	40	112	1	45	0	46	15	64	19	0	7	0	9	78	4	9	14	
Lira	Supa	0	10	0	37	0	138	197	0	1	0	0	2	3	15	2	0	0	
Total		102	468	15	847	0	1210	1297	137	51	3	16	2	57	471	7	17	24	4724
Kasese	Fallow	0	2	0	36	0	2	50	4	2	0	0	0	0	0	2	0	0	
Kasese	Nerica	123	401	26	488	2	107	284	154	107	0	51	0	1	115	9	164	1	
Total		123	403	26	524	2	109	334	158	109	0	51	0	1	115	11	164	1	2131

The most abundant orders throughout the survey included Homoptera 2,998 (22.5 9%), Coleoptera 2,583 (19.46%) dominated by beetles, Hemiptera 2,216 (16.69%) and Diptera 1,668 (12.57%) dominated by whiteflies. The whiteflies were mostly collected when the relative humidity was low and particularly in the dry areas of Mubuku farming area in Kasese and Barr, in Lira districts. This may be due to the fact that white flies are dry-season arthropods so their rate of reproduction is boosted mainly in dry areas. Others included; Hymenoptera 1,472 (11.09%) and Orthoptera 1,199 (9.03%). Among the least abundant arthropod orders included Dermaptera 55 (0.02%), Zoraptera 29 (0.022%), Phasmatodea 18 (0.14%), Mantodea 3 (0.02%), Embioptera 2 (0.02%) and Neuroptera 2 (0.02%).

Some orders were collected in some agro-ecologies and not in others and included Embioptera, Mantodea, Neuroptera and Phasmatodea. All the four orders were not collected in Muwayo farming area, Bugiri district. In Mubuku, Kasese district in western Uganda, two orders Mantodea and Neuroptera were not also identified among the collected arthropods. In Barr, Lira district in northern Uganda, only Embioptera arthropod order was not identified among the collected arthropod orders. This spatial variation in abundance may be attributed to dwindling and erratic rainfall patterns, rising air temperature, extreme heat affecting their uniform distribution and biocide application [23] (Table 2). Generally more arthropods were collected in the rice fields in Bugiri 6,417 (48.35%), Lira 4,724 (35.59%) and Kasese 2,131 (16.06%) respectively.

In Bugiri district, of 6,417 (48.35%) arthropods collected in rice fields, the most abundant orders included Coleoptera, 1,712 (26.68%) which were mostly collected in July 2015, 1,271 (74.51%), 373 (21.79%) and 39 (2.28%) in February 2015 and December 2014 respectively. This was followed by order Homoptera 1,367 (21.30%) where most of them; 726 (53.11%) were collected in August 2015, 312 (22. 82%) in November 2014 and 182 (13.31%) in December 2014. 1177 (18.34%) were of order Hymenoptera where 773 (65.68%) were collected in February 2015, 213 (18.10%) in November, 97 (8.24%) in December 2014 and 79 (6.71%) in July 2015. A total of 897 (13.98%) arthropods of order Hemiptera were also identified where 386 (43.03%) were collected in December 2014, 290 (32.33%) in November 2014 and 205 (22.85%) were collected in July 2015. A total of 613 (9.55%) Orthopterans were collected mostly in July and November 2015. A total of 297 (4.63%) were of order Diptera and their numbers were almost equally distributed throughout the survey period. While some orders were collected in small numbers and included; Zoraptera 4 (0.06%), Siphonaptera 7 (0.11%), Dermaptera 14 (0.22%) in Bugiri district in the Lake Victoria crescent in Eastern Uganda. Four orders were not found in Bugiri District which included Phasmatodea, Neuroptera, Mantodea, and Embryoptera (Table 1).

Statistical analyses using ANOVA showed that arthropods in orders Aranea, Diptera, Hemiptera, Homoptera, Hymenoptera, Mecoptera, Odonata, Orthoptera and Siphonaptera showed a statistically significant difference in abundance when their means were compared in the different surveys Table 2.

Table 2: Analysis of variance results for the Orders showing statistically significant difference in abundance in the different surveys in Bugiri

Order	Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Aranea	Survey	7	311.79545	44.5422	3.6302	0.0078*
	Error	25	306.75	12.27		
	C. Total	32	618.54545			
Diptera	Survey	7	1375.2	196.457	4.2457	0.0033*
	Error	25	1156.8	46.272		
	C. Total	32	2532			
Hemiptera	Survey	7	41173.409	5881.92	10.5809	<.0001*
	Error	25	13897.5	555.9		
	C. Total	32	55070.909			
Homoptera	Survey	7	81937.011	11705.3	32.5326	<.0001*
	Error	25	8995.05	359.8		
	C. Total	32	90932.061			
Hymenoptera	Survey	7	120701.53	17243.1	30.2599	<.0001*
	Error	25	14245.8	569.8		
	C. Total	32	134947.33			
Mecoptera	Survey	7	1987.5788	283.94	10.7831	<.0001*
	Error	25	658.3	26.332		
	C. Total	32	2645.8788			
Odonata	Survey	7	309.98182	44.2831	3.436	0.0103*
	Error	25	322.2	12.888		
	C. Total	32	632.18182			
Orthoptera	Survey	7	3698.7606	528.394	7.4075	<.0001*
	Error	25	1783.3	71.332		
	C. Total	32	5482.0606			
Siphonaptera	Survey	7	5.7651515	0.823593	5.4906	0.0007*
	Error	25	3.75	0.15		
	C. Total	32	9.5151515			

Where

DF = degrees of freedom

* = means the p value is statistically significant

Only orders showing statistical significance in abundance are represented in the table

In Lira district, Barr farming area, a total of 4,724 (35.59%) arthropods were collected from the rice fields. The most abundant arthropod orders collected included Homoptera 1297 (27.46%) which were mostly collected in August 2015 and September 2015. Hemiptera collected were 1,210 (25.61%) of which 85.54% were collected in August 2015, 9.75% in November 2014. Diptera 847 (17.93%) were mainly collected in the seventh survey while Orthopterans 471 (9.97%) were mainly collected in the first survey (61.99%), and the seventh survey (20.38%) Table 3.

Statistical analyses showed that arthropods in orders Coleoptera, Hemiptera, Homoptera, Lepidoptera, Odonata and Orthoptera showed a statistically significant difference in abundance when their means were compared in the different the surveys.

Table 3: Analysis of variance results for the Orders showing statistically significant difference in abundance in the different surveys in Lira

Order	Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Coleoptera	Survey	6	15356.198	2559.37	6.9952	0.0003*
	Error	22	8049.25	365.88		
	C. Total	28	23405.448			
Hemiptera	Survey	6	167653.54	27942.3	8.8391	<.0001*
	Error	22	69546.25	3161.2		
	C. Total	28	237199.79			
Homoptera	Survey	6	111077.34	18512.9	9.57	<.0001*
	Error	22	42558.45	1934.5		
	C. Total	28	153635.79			
Lepidoptera	Survey	6	75.31034	12.5517	3.1379	0.0224*
	Error	22	88	4		
	C. Total	28	163.31034			
Odonata	Survey	6	254.26552	42.3776	6.5333	0.0005*
	Error	22	142.7	6.4864		
	C. Total	28	396.96552			
Orthoptera	Survey	6	16385.76	2730.96	15.4072	<.0001*
	Error	22	3899.55	177.25		
	C. Total	28	20285.31			

Where
DF = degrees of freedom
* = means the p value is statistically significant
Only orders showing statistical significance in abundance are represented in the table

In Kasese district from the Western savannah grassland agro-ecological zone, a total of 2,131 (16.06%) arthropods were collected in the rice fields. The most abundant order collected was Diptera 524 (24.59%) where 159 (30.34%) were collected in the first survey, 107 (20.42%) in the second survey, 143 (27.29%) in the third survey, 58 (11.07%) in the fourth, 39 (7.44%) and 18 (3.44%) in the fifth and sixth surveys respectively. The second most abundant order was Coleoptera 403 (18.91%) where 371 (92.06%) was collected in the sixth survey and a few in the first, second and third surveys.

The arthropods in Orders Homoptera 334 (15.67%) and Siphonaptera 164 (7.70%) were also abundant. Homopterans were mainly collected in the first, second and third surveys while those of Siphonaptera were mainly collected in the seventh survey. The remaining orders were collected in relatively smaller numbers Table 4. Two orders Mantodea and Neuroptera were not identified in the arthropods collected in Kasese district Mubuku farming area. The orders Aranea, Coleoptera, Dermaptera, Hemiptera, Homoptera, Mecoptera and Orthoptera showed a statistically significant difference in abundance in the different surveys during the study. These findings are similar to what was reported by Nasiruddin and Roy [20].

Table 4: Analysis of variance results for the Orders showing statistically significant difference in abundance in the different surveys in Kasese.

Order	Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Aranea	Survey	5	465.375	93.075	4.8526	0.0055*
	Error	18	345.25	19.1806		
	C. Total	23	810.625			
Coleoptera	Survey	5	27726.208	5545.24	3.9137	0.0141*
	Error	18	25503.75	1416.88		
	C. Total	23	53229.958			
Dermaptera	Survey	5	128.33333	25.6667	4.0705	0.0120*
	Error	18	113.5	6.3056		
	C. Total	23	241.83333			
Hemiptera	Survey	5	1106.2083	221.242	6.64	0.0011*
	Error	18	599.75	33.319		
	C. Total	23	1705.9583			
Homoptera	Survey	5	4716.8333	943.367	6.6932	0.0011*
	Error	18	2537	140.944		
	C. Total	23	7253.8333			
Mecoptera	Survey	5	283.375	56.675	3.7063	0.0176*
	Error	18	275.25	15.2917		
	C. Total	23	558.625			
Orthoptera	Survey	5	869.7083	173.942	5.3406	0.0035*
	Error	18	586.25	32.569		
	C. Total	23	1455.9583			

Where
DF = degrees of freedom
* = means the p value is statistically significant
Only orders showing statistical significance in abundance are represented in the table

The different orders were also compared in the different Districts surveyed. The results showed that only six orders; Diptera, Hymenoptera, Lepidoptera, Odonata, Orthoptera and Zoraptea showed a statistically significant difference in abundance Table 5.

Table 5: Analysis of variance results for the Orders showing statistically significant difference in abundance in the different Districts.

Order	Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Diptera	District	2	6500.466	3250.23	3.7254	0.0282*
	Error	83	72414.092	872.46		
	C. Total	85	78914.558			
Hymenoptera	District	2	18471.88	9235.94	5.6247	0.0051*
	Error	83	136288.96	1642.04		
	C. Total	85	154760.84			
Lepidoptera	District	2	129.5703	64.7851	4.4238	0.0149*
	Error	83	1215.5111	14.6447		
	C. Total	85	1345.0814			
Odonata	District	2	86.2315	43.1158	3.474	0.0356*
	Error	83	1030.1057	12.4109		
	C. Total	85	1116.3372			
Orthoptera	District	2	2871.38	1435.69	4.3772	0.0156*
	Error	83	27223.329	327.99		
	C. Total	85	30094.709			
Zoraptera	District	2	10.609514	5.30476	5.6009	0.0052*
	Error	83	78.611416	0.94713		
	C. Total	85	89.22093			

Where
DF = degrees of freedom
* = means the p value is statistically significant
Only orders showing statistical significance in abundance are represented in the table

3.2 Effect of temperature and humidity on the abundance of major arthropod populations in different rice agro-ecological systems in Uganda

Weather parameters including temperature, relative humidity were recorded daily over the period of study in the three agro-ecologies. The effects of these parameters on abundance of the different arthropods were evaluated in the different agro-ecosystems. Arthropods are cold blooded and their body temperature changes approximately with the temperature of the surrounding environment [1].

3.2.1 Effect of temperature on arthropod populations

In Bugiri, a mean monthly temperature of 25.83 ± 6.8 ºC with a range of 34.94 ºC was recorded. The arthropod numbers in orders Mecoptera, Hymenoptera, Siphonaptera, Zoraptera, Lepidoptera, Aranea and Diptera increased with increase in mean monthly temperature. However, as temperature increased, arthropods in orders Orthoptera, Homoptera, Hemiptera, Odonata, Dermaptera and Coleoptera decreased. Arthropods in order Orthoptera in particular showed a relatively strong negative correlation (Fig 2; Appendix 1). This may be because temperature exerted an effect on the critical developmental stages of the arthropods in these orders affecting their growth and hence their abundance [2, 3]

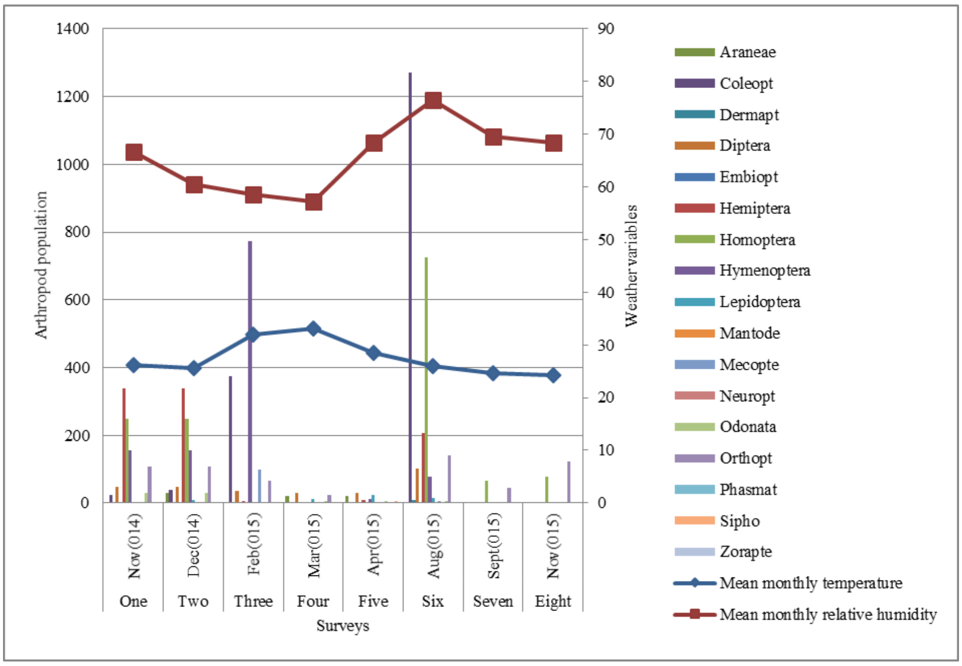

Fig 2: Effect of temperature and humidity on arthropod population in Bugiri District

In Lira District, a mean temperature of 25.65 ± 3.75 ºC with a range of 22.6 ºC was recorded. The population of arthropods in Hymenoptera, Mantodea, Hemiptera, Dermaptera, Neuroptera, Siphonaptera, Lepidoptera, Phasmatodea and Aranea orders increased as the mean monthly temperature also increased. Those of Coleptera, Diptera, Orthoptera Zoraptera and Odonata where affected negatively were their numbers decreased as the mean monthly temperature increased (Fig 3; Appendix 1).

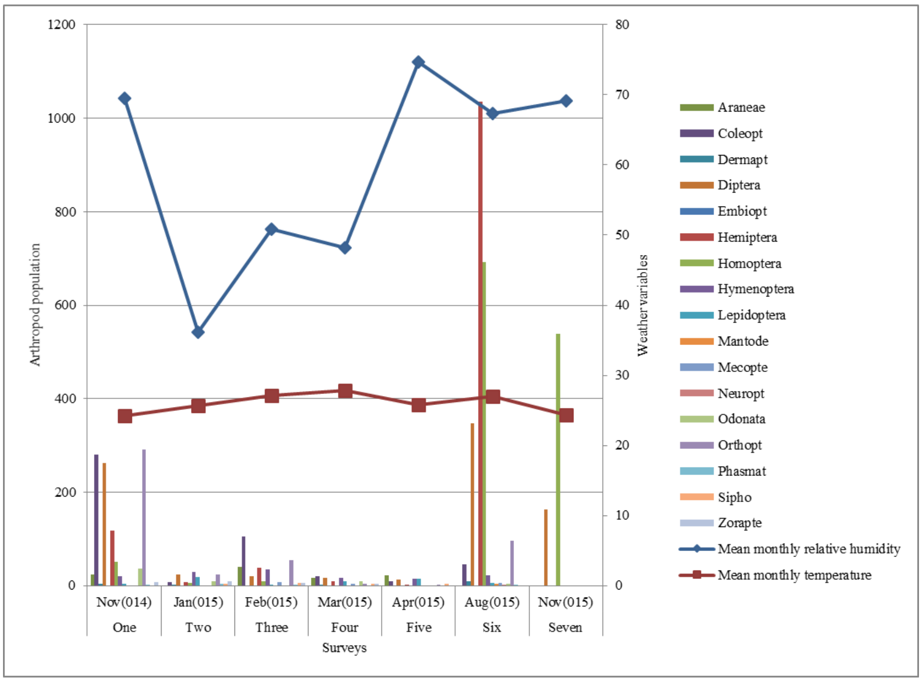

Fig 3: Effect of temperature and humidity variability on arthropod populations in Lira District

In kasese District, the mean temperature was 26.44 ± 3.43 °C and a range of 18.2 °C. The highest mean temperature was 28.5 °C and the lowest mean temperature 26.1 °C recorded in the months of February 2015 and April 2014 respectively. Increase in temperature led to increase in the number of arthropods in ten orders which included Mecoptera, Homoptera, Aranea, Diptera, Coleoptera, Embioptera, Hemiptera, Dermaptera, Phasmatodea and Siphonaptera while in five orders, increase in temperature resulted in decrease in the numbers of arthropods collected. These included; Lepidoptera, Odonata, Hymenoptera, Zoraptera and Orthoptera respectively (Figure 4; Appendix 1). Temperature influences the behavior, distribution, development, survival and reproduction of arthropods [9]. Temperature can exert different effects on the developmental stage of an insect [3]. Higher temperatures likely stimulate the reproduction of adults and lead to faster population growth and may lead to an additional generation in some insect pests [24, 25].

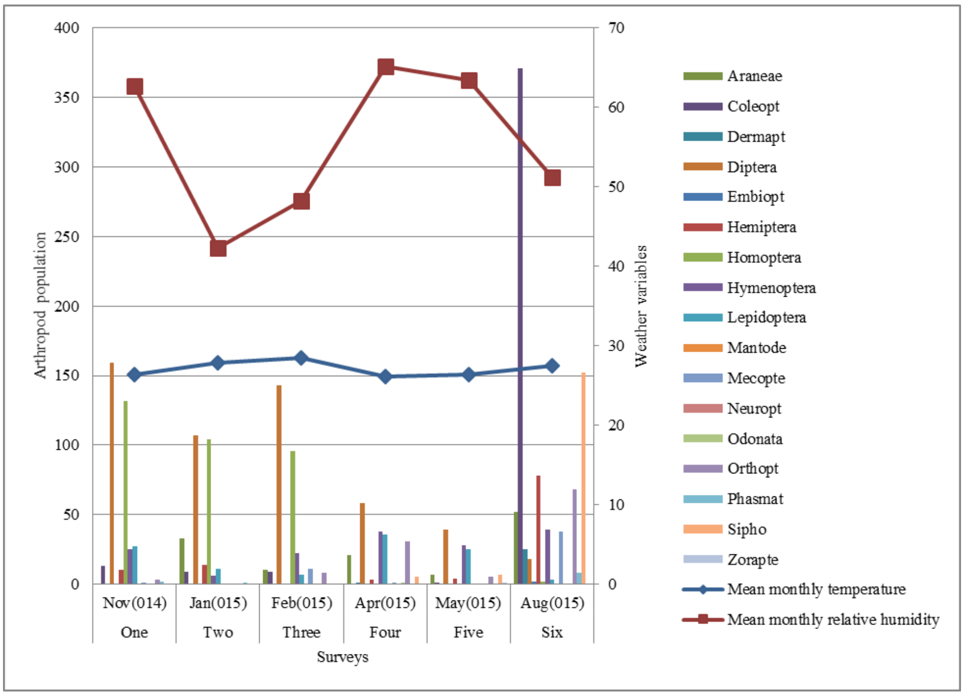

Fig 4: Effect of temperature and humidity variability on arthropod populations in Kasese District

Temperature is an important environmental factor, which exerts a profound influence on the development of arthropod populations including insects. It affects their metabolic rate which depends on their body temperature which in turn depends on the ambient temperature because they are ectothermic. The metabolic rate of an arthropod increases linearly with ambient temperature and hence results in faster development at higher temperature [26]. This may be the reason why increase in temperature showed a positive correlation with increase in the number of different arthropod orders.

3.2.2 Effect of humidity on arthropod populations

Humidity is a very important factor affecting arthropod populations in a given ecosystem because most of arthropods like insects are cold blooded and therefore, sensitive to desiccation. Humidity protects them because they have a large body surface relative to their body volume. Similarly, their eggs require high humidity for efficient hatching [9].

In Bugiri, the highest mean monthly relative humidity was 76.4% recorded in September 2014 and the lowest was 57.4% recorded in March 2015. Increase in the mean monthly relative humidity showed a positive correlation with increase in the number of arthropod populations in seven orders of Homoptera, Dermaptera, Coleoptera, Orthoptera, Diptera, Lepidoptera and Hemiptera. These results are similar to what has been reported by Manikandan et al, [27], for order Hemiptera. The orders which showed a negative correlation with increase in mean monthly relative humidity included Aranea, Hymenoptera, Mecoptera, Odonata, Siphonaptera and Zoraptera (Fig 2; Appendix 1).

In Lira district Barr farming area, the highest mean relative humidity recorded in this area was 74.7% in the month of April in 2015 and the lowest was 36.14% recorded in the month of January 2015. The population of arthropods in nine orders increased as the mean monthly relative humidity increased. These orders included Diptera, Homoptera, Hemiptera, Coleoptera, Mantondea, Neuroptera, Orthoptera, Odonata and Aranea. Order Diptera showed a strong positive correlation with mean monthly relative humidity which may be due to increased rates of development and increased numbers of generations with less time between generations [3]. Those which showed a negative correlation with increase in mean monthly relative humidity were five orders including Hymenoptera, Lepidoptera, Phasmatodea, Zoraptera, and Mecoptera (Fig 3; Appendix 1).

In Kasese district, the highest mean relative humidity was 65.2% recorded in the month of April in 2015 and the lowest was 42.3% recorded in the month of January 2015. In this area, orders which showed a negative correlation with increase in humidity included Aranea, Coleoptera, Dermaptera, Diptera, Embioptera, Hemiptera, Homoptera, Mecoptera, Phasmatodea and Siphonaptera. The population of other orders like Hymenoptera, Lepidoptera, Odonata, Orthoptera and Zoraptera showed a positive correlation with increase in the mean relative humidity. Humidity has been implicated as one of the favorable factors for outbreak of arthropods particularly the rice pest insects [9]. An increase in the relative humidity in the leaf canopy leads to an increase in the number of arthropods collected (Fig 4; Appendix1).

Increase in humidity also has a negative effect on arthropod population as it increases fungal pathogens of arthropods when humidity increases which results into decrease their population [28]. This would have been one of the reasons why some arthropod population decreased as relative humidity increased coupled with spraying of the vegetative stage of the rice between March and August particularly in Kasese.

Appendix 1: Correlation coefficients between the different arthropod orders and the weather parameters temperature and relative humidity

District	Variable	Order	Correlation coefficient
Bugiri	Mean monthly relative humidity	Coleoptera	0.53
Bugiri		Dermaptera	0.62
Bugiri		Diptera	0.29
Bugiri		Hemiptera	0.11
Bugiri		Homoptera	0.64
Bugiri		Lepidoptera	0.17
Bugiri		Orthoptera	0.4
Bugiri		Aranea	-0.48
Bugiri		Hymenoptera	-0.45
Bugiri		Mecoptera	-0.43
Bugiri		Odonata	-0.13
Bugiri		Siphonaptera	-0.04
Bugiri		Zoraptera	-0.01
Bugiri	Mean monthly temperature	Mecoptera	0.52
Bugiri		Hymenoptera	0.46
Bugiri		Siphonaptera	0.37
Bugiri		Zoraptera	0.34
Bugiri		Aranea	0.27
Bugiri		Lepidoptera	0.27
Bugiri		Diptera	0.07
Bugiri		Orthoptera	-0.57
Bugiri		Homoptera	-0.4
Bugiri		Odonata	-0.25
Bugiri		Dermaptera	-0.12
Bugiri		Coleoptera	-0.03
Lira	Mean monthly relative humidity	Diptera	0.53
Lira		Homoptera	0.43
Lira		Orthoptera	0.3
Lira		Hemiptera	0.27
Lira		Coleoptera	0.24
Lira		Mantodea	0.24
Lira		Neuroptera	0.24
Lira		Odonata	0.07
Lira		Aranea	0.04
Lira		Zoraptera	-0.68
Lira		Hymenoptera	-0.57
Lira		Phasmatodea	-0.53
Lira		Lepidoptera	-0.38

Lira		Mecoptera	-0.25
Lira	Mean monthly temperature	Siphonaptera	0.55
Lira		Hymenoptera	0.43
Lira		Neuroptera	0.34
Lira		Mantodea	0.34
Lira		Hemiptera	0.3
Lira		Dermaptera	0.22
Lira		Aranea	0.19
Lira		Lepidoptera	0.15
Lira		Phasmatodea	0.05
Kasese	Mean monthly temperature	Homoptera	0.38
Kasese		Mecoptera	0.37
Kasese		Aranea	0.33
Kasese		Diptera	0.28
Kasese		Coleoptera	0.2
Kasese		Embioptera	0.18
Kasese		Hemiptera	0.18
Kasese		Dermaptera	0.17
Kasese		Phasmatodea	0.15
Kasese		Siphonaptera	0.15
Kasese		Lepidoptera	-0.89
Kasese		Odonata	-0.52
Kasese		Hymenoptera	-0.49
Kasese		Zoraptera	-0.37
Kasese		Orthoptera	-0.02
Kasese	Mean monthly relative humidity	Lepidoptera	0.89
Kasese		Hymenoptera	0.63
Kasese		Odonata	0.49
Kasese		Zoraptera	0.41
Kasese		Orthoptera	0.01
Kasese		Aranea	-0.52
Kasese		Homoptera	-0.39
Kasese		Mecoptera	-0.32
Kasese		Hemiptera	-0.27
Kasese		Coleoptera	-0.24
Kasese		Phasmatodea	-0.22
Kasese		Embioptera	-0.22
Kasese		Dermaptera	-0.2
Kasese		Diptera	-0.19
Kasese		Siphonaptera	-0.19

4. Conclusion

In conclusion, the abundance, distribution and effects of temperature and relative humidity on arthropod fauna was conducted in smallholder rice farming areas in three agro-ecological zones in Uganda. The most abundant orders were Homoptera 2,998 (22.5 9%), Coleoptera 2,583 (19.46%), Hemiptera 2,216 (16.69%), Diptera 1,668 (12.57%), Hymenoptera 1,472 (11.09%) and Orthoptera 1,199 (9.03%). Among the least abundant arthropod orders included Dermaptera 55 (0.02%), Zoraptera 29 (0.022%), Phasmatodea 18 (0.14%), Mantodea 3 (0.02%), Embioptera 2 (0.02%) and Neuroptera 2 (0.02%).

Some orders were collected in some agro-ecologies and not in others and included Embioptera, Mantodea, Neuroptera and Phasmatodea. All the four orders were not collected in Muwayo farming area, Bugiri district. The different arthropod fauna showed a difference in their abundance and distribution in the three agro-ecologies in Uganda.

Temperature and humidity significantly affect arthropod population for example arthropods in order Aranea showed a positive correlation in their abundance with increase in temperature in all the agro-ecologies studied.

The findings highlight the existence of stable relationships among arthropod populations under minimal biocide application. It provides background information for proper crop management strategies like exploration of integrated pest management strategies which is possible through understanding the abundance, distribution and fluctuation of different arthropods under different weather variables.

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