Journal of Agricultural Science and Technology A 2 (2012) 1003-1010
Earlier title: Journal of Agricultural Science and Technology, ISSN 1939-1250

The Effectiveness of *Coccinellids* as Natural Enemies of *Aphids* in Maize, Beans and Cowpeas Intercrop

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Received: January 17, 2012 / Published: August 20, 2012.

Abstract: A field study was conducted in Busia district of Kenya to elucidate the dynamics of ladybirds in mixed stands of maize, beans and cowpeas to determine their efficacy as sole control measures for *Aphids*. Maize, beans and cowpeas were intercropped using conventional husbandry practices and the general *Coccinellid* quantified as follows: Colonies of four *Coccinellids*, starved for 12 hours to enhance feeding on *Aphids* were assessed. The effects of weather on the abundance of *Coccinellids* were also investigated and involved collection of meteorological data from the Busia District Agricultural Office (BDAO) and from Busia Farmers Training Centre (BFTC) and relating them to the abundance and predation values. The predator population was most abundant in the mixed stands of maize and beans (2.33 predators/30 *Aphids*) as compared to their occurrence in pure stands of cowpeas (0.85 predators/30 *Aphids*). The *genus Cheilomenes* spp. was the most ubiquitous predator with a mean of 4.00 individuals/30 *Aphids* while *Hippodamia variegata* was the least abundant predator species with a mean of 0.92 individuals/30 *Aphids* in all the agro-ecosystems. The larvae of *Hippodamia variegata* were the most bio-efficient, consuming 32.44 *Aphids* while their adults were the least bio-efficient, consuming 4.22 individuals for a period of 12 hours. The *Coccinellids* consumed more *Aphids* at higher aphid densities (24.05 *Aphids*) than at lower aphid densities (9.44 *Aphids*) over the same period of time. Rainfall and relative humidity had significant (F = 3.675; P < 0.05) effects on the abundance of *Coccinellids*. Temperature had significant (F = 3.58; P < 0.05) effect on the abundance of *Coccinellids* though at a lower level. Rainfall (r = -0.162) and relative humidity (r = -0.084) were both inversely correlated with the abundance of *Coccinellids*. On the other hand, temperature was positively correlated (r = 0.159) with the prevalence of *Coccinellids* indicating that warmer and drier conditions favoured their multiplication.

Key words: Efficacy, *Coccinellids*, *Aphids*, natural enemies, ecological factors, crops.

1. Introduction

Ladybirds are the best-known predators with over 450 species in recorded North America alone [1]. They have been often used in biological control of *Aphids* since the first and most successful case of biological control with the introduction of the Australian ladybird beetle *Rodolia cardinalis* in California in 1888 [2]. It was introduced to control scale insects, which had become devastating in the Californian citrus industry [2]. Most ladybird beetles are beneficial as both adults and nymphs feeding primarily on *Aphids* and other small insects [1]. The use of insecticides to control pests is known to cause serious harm to the natural enemies as it has been demonstrated in the control of cowpea aphid [3]. These authors recorded notable decrease in the population of *Aphids* in one year, while very high increase was noted in the following year, an observation they correlated to the decrease in population of the natural enemies namely the coccinellid beetle of the *Anthocoridae*, parasites of the

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family (*Hymenoptera*) and the spiders (*Aranae*). Tuey [4] also correlated a high aphid population to the high population of coccinellid beetles. However, there are a few species that feed on plants as pests. Some ladybirds are more successful as predators than others, the aphidophagous species being less successful than the coccidophagous species.

1.1 Effects of Ecological Factors on the Bioefficacy of Coccinellids.

The length of the life cycle of *Coccinellids* varies depends on temperature, rainfall relative humidity and food supply. Usually the life cycle from egg to adult requires about 3-4 weeks or up to 6 weeks during cooler months. In cooler months, over wintering adults find food, then lay 50-300 eggs in their lifetime among aphid colonies. Eggs hatch in 3-5 days and the larvae feed on *Aphids* or other insects for 2-3 weeks and then pupate. Adults emerge in 7-10 days. There may be five generations per year. In extremely low temperatures such as in autumn, adults hibernate, sometimes in large number, in plant refuse and crevices, beetles are always found under leaves which protect them from cold winter temperatures [5].

The larvae are the most active during the day. They tend to be positively phototaxis and negatively geotaxis, meaning that they move towards light and a way from gravity, which will lead them to the top of the plants where the *Aphids* live [6]. Little information exists on bioefficacy of ladybirds in Kenyan agroecosystems particularly in polycultures that are found ambiguously in a subsistence farming.

The objectives of these studies were therefore to evaluate this deficit using intercropped maize beans and cowpeas in Busia district of Kenya. The study assessed the comparative bio-efficacy of predation of different species of *Coccinellids*, evaluated the functional responses of different species of *Coccinellids* and determined the effects of ecological factors on the seasonality and dynamics of *Coccinellids* under natural conditions.

2. Materials and Methods

Study site: these studies were conducted at Nasewa Secondary School (NSS) situated at 20°00′ N of the Equator and 34°10′ E of the Greenwich Meridian and at altitude of 1,231 m. NSS is in Busia District of Western Province of Kenya and is located 7 km South of Nambale town along Nambale-Matayos road only a few kilometres from Kenya Uganda Boarder. The rainfall is bimodal occurring in two seasons: March to May and August to November with two distinct peaks in May and September. The range of annual rainfall is 1,000-1,500 mm. Temperatures are high due to the low altitude and proximity to Lake Victoria with the average daily temperature being 26.0 °C.

The plots were planted at the beginning of the rains with commercial cultivar of hybrid seed maize WS 502 from Western Seed Company Ltd. and cowpea, Ken-Kunde variety N-26 and beans, K-22 were obtained from Kenya Agricultural Research Institute (KARl). Planting was done using recommended husbandry practices of spacing, fertilizer rate and clean weeding .

3. Evaluation of Functional Responses of Different Species and Developmental Stages of *Coccinellids*.

The identities of adults and larvae of *Cocconellids* under test were colonies of ladybirds established from specimen collected from field and brought to the laboratory. Adult ladybirds of four species: *Cheilomenes* spp., *Henosepilachna* spp., *Exochomus* spp., *H. variegata* and larvae of *H. variegata* were all starved for 12 hours to standardize their physiological status. They were usually held in the laboratory vials of three replicates. 30 *Aphids A. fabae* held on branches of beans were dipped in water in the beakers and given to each specy. Covering the part of plant infested by 30 *Aphids* with a polythene paper, the handling time, was monitored and evaluated [7]. The rate of predation by each specy was determined through evaluation of predation of each of the four species for 12 hours. Analysis of variance (ANOVA) was used to compare predation rates of different species of ladybirds relative to time. Also, each predator specie was kept separately and exposed to three regimes of prey densities, namely: 30, 40 and 50 *Aphids*. There were three replications of each prey density regime. The experimental set-up was held in the laboratory at 26.0 °C for 24 hours. ANOVA was used to compare predation rates of predators in different regimes of prey densities.

4. Results

4.1 The Effect of Different Ecological Factors on the Population of Coccinellids

The population of *Coccinellids* was at the peak in March with a mean of 2.49 individuals and declined to 1.25 individuals in May which was their lowest population status (Table 1).

Rainfall was the highest in May and declined to the lowest level status in July (Fig. 1). Rainfall had a very significant ($P > 0.05$) effect on the occurrence of *Coccinellids* in various agro-ecosystems (Table 2). The population of *Coccinellids* was the highest in March and lowest in May. High rainfall coincided with low levels of *Coccinellids*; thus rainfall was inversely correlated (r = -0.162**) with the abundance of *Coccinellids* (Table 3) indicating that high rainfall suppressed *Coccinellids* activities.

The effect of temperature on the occurrence of *Coccinellids* was significant ($F = 3.582$**, $P < 0.05$) effect (Table 4). This showed that temperature positively correlated with the abundance of *Coccinellids* with Pearson correlation coefficient of 0.159** (Table 5).

The relative humidity had a very high significant ($P < 0.05$) effect on the population of *Coccinellids* (Table 6). The population of ladybirds reached peak levels in March and declined to lower levels in May. Relative humidity inversely correlated (r = -0.84) with the occurrence of *Coccinellids* (Table 7). Relative humidity

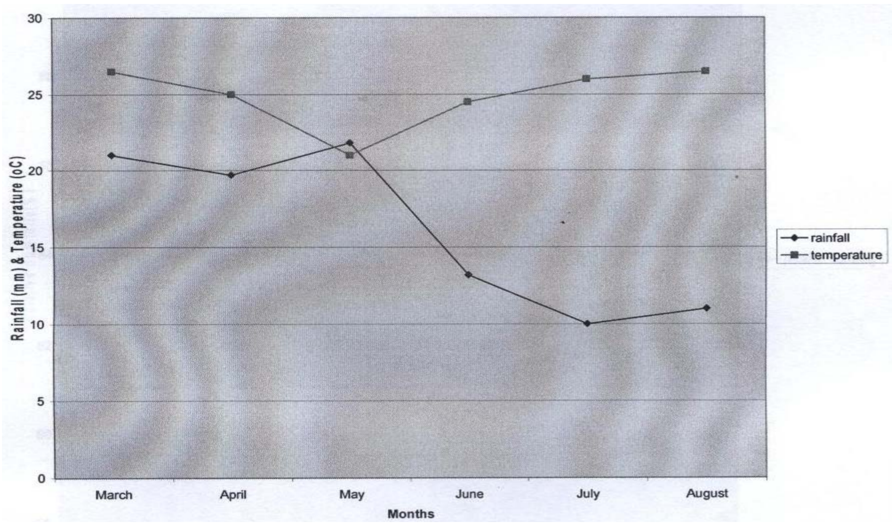

Fig. 1 Average monthly rainfall and temperature in Busia, 2006.

Table 1 Monthly occurrence of *Coccinellids*.

Month	N	Sum	Mean
March	72	179	2.49
April	72	122	1.69
May	72	90	1.25
June	72	177	2.46
July	72	150	2.08
Total	360	718	1.99

Table 2 Univariate analysis of variance of the effect of rainfall on the prevalence of *Coccinellids*.

Source	Type III sum of squares	df	Mean square	*F*	Sig.
Corrected model	79.850	4			
Simplity parameters	1,432.011	1	19.962		
Rainfall	79.850	4	1,432.011	3.675	0.006
Error	1,928.139	355	19.962	263.655	0.000
Total	3,440.000	360	5.431	3.675	0.006
Corrected total	2,007.989	359			

R Squared = 0.040 (adjusted R Squared = 0.029).

Univariate analysis of variance.

Table 3 The correlation of rainfall with the occurrence of *Coccinellids*.

	Rainfall	Number of *Coccinellids*
Rainfall pearson correlation		-0.162**
Sig. (2-tailed)	1.000	0.002
N	360	360
Number of pearson correlation *coccinelids* Sig. (2tailed)	-0.162**	1.000
N.	0.002	
	360	360

** Correlation is significant at the *P* = 0.05 level (2 tailed).

Table 4 Effects of temperature on the abundance of *Coccinellids*.

Source	Type III sum of squares	df	Mean square	*F*	Sig.
Corrected model	58.843a	3	19.614	3.582	0.014
Simplity parameter	1,282.509	1	1,282.509	234.243	0.000
Temperature	58.843	3	19.614	3.582	0.014
Error	1,949.146	356	5.475		
Total	3,440.000	360			
Corrected total	2,007.989	359			

a. R. Squared = 0.029 (Adjusted R. Squared = 0.021). Univariate analysis of variance of data.

Table 5 Correlation of temperature with the occurrence of *Coccinelids*.

	Number of *Coccinelids*	Temperature
	1.000	0.159**
Number pearson correlation of Sig. (2 tailed) Coccinelids		0.002
N	360	360
Temperature person correlation	0.159**	
Sig. (2 tailed)	0.002	1.000
N	360	360

** Correlation is significant at the *P* = 0.05 level (2 tailed).

Table 6 Effects relative humidity on the abundance of *Coccinelids*.

Source	Type III sum of squares	df	Mean square	F	Sig.
Corrected model	79.850a	4	19.962	3.675	0.006
Interpret	1,432.011	1	1,432.011	263.655	0.000
Relative	79.850	4	19.962	3.675	0.006
Humidity	192.139	355	5.431		
Error	3,440.000	360			
Total	2,007.989	359			
Corrected total					

R Squared = 0.040 (Adjusted R Squared = 0.029).

Table 7 Correlation of relative humidity with the population of *Coccinellids*.

	Coccinellids number	Relative humidity
Coccinellids pearson correlation number Sig. (2 tailed)	1.000	-0.084
		0.113
N	360	360
Relative humidity Pearson Correlation	-0.084	1.000
Sig. (2 tailed)	0.113	
N	360	360

was the highest in May and declined to low levels in July (Fig. 2).

4.1.1 Assessment of Bio-efficacy of Different Species of *Coccinellids*

Univariate analysis of bio-efficacy of different species of *Coccinellids* preying on *Aphids* showed that all the species had a significant predation level ($P < 0.05$) with the larvae of *H. variegata* being the most bio-efficient consuming on average, 32.4 *Aphids* over the experimental period. On the other hand, adults of *H. variegata* were rated the least bio-efficient among all consuming on average, 12.11 *Aphids* during the same period. The consumption of *Aphids* by coccinellid adults was, in descending order as follows: *Cheilomenes* spp. (23.1 *Aphids*), *Henosepichna* spp. (17.33 *Aphids*) and *Exochomus* spp. (15.6 *Aphids*) (Table 8).

4.1.2 Functional Responses of *Coccinellids* to Varying Population Densities of *Aphids*

Coccinellids exhibited a positive functional response with a population density of 50 recording the highest number of *Aphids* preyed upon by the *Coccinellids* (Table 9). The functional response was the lowest at lower aphid population densities. The effect of population density to functional response of *Coccinellids* was significant ($P < 0.05$). Their differences in functional responces were based on variation in size, voracity satiation time, and handling time (time spent by predators in attacking, killing, subduing and digesting the prey) [8].

5. Discussions

The peak population of the predators and that of *Aphids* were synchronized which portrayed beneficial adaptation of the predators to their prey. However, other studies have shown that indigenous predatory agents suffered from hyperparatisitism and predation by their local enemies [9]. Nevertheless, no parasitized *Coccinellids* were recorded during these studies. Parasitic agents if any, apparently hardly colonized the indigenous predators. Hence, parasites of *Coccinellids* and *Aphids* appeared to be rare in Busia District. On the other hand, Matson [10] reported heavy parasitism of *Taxoptera citricidus* in Baringo district, implying that indigenous parasitoids attacked aphid species on crops such as citrus.

Cheilomenes spp. was the most abundant predator in all the agro-ecosystems in these studies while the least abundant predator was *variegata.* Others were sparse in population and included: *Exochomus* spp., and *Henosepichna* spp.. *variegata* larva was the most efficient predator of *A. fabae* in these studies as the nymphal stage was the most destructive stage of the insect's life cycle. The species were largely polyphagous and fed also on *A. caccivora.* The predatory larvae dominated during the rainy season and therefore synchronised with low aphid population levels. Other predatory *Coccinellids* recorded in these studies were: adults of the *Cheilomenes* spp., *Exochomus* spp., *H. variegata and Henosepilachna* spp..

Univariate analysis of variance showed that the association between weather factors (rainfall, temperature and relative humidity) and the *Coccinellids* was not as strong as expected. Several major factors contributed to this discrepancy. Weather factors apparently influenced aphid infestation in a holistic approach that was not easily discernable with univariate analysis of variance. This was clearly evident during the short sporadic rain periods of March

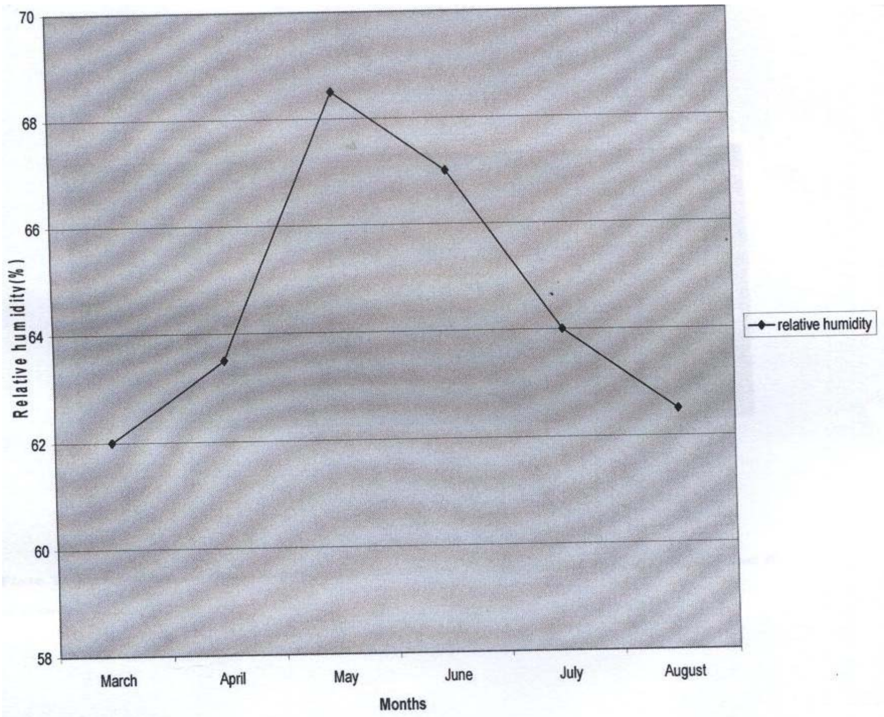

Fig. 2 Average monthly relative humidity in Busia, 2006.

Table 8 Bio-efficacy of different species of *Coccinellids* on *A. fabae*.

Specie	Stage	N	Mean	Std. deviation	Sum	Variance
Cheilom	Adult	9	23.1111	10.0180	208.00	100.361
Exochom	Adult	9	15.5556	5.7033	14,000	32.528
H. varie	Adult	9	12.1111	5.8190	109.00	33.861
H. varie	Larva	9	32.4444	11.033	292.00	121.778
Heosep	Adult	9	17.3333	6.3443	156.00	40.250
Total		54	17.4630	11.3864	943.00	129.650

Key: Cheilom = *Cheilomenes* spp.;
Exochom = *Exochomus* spp.;
H. varie = *Hippodamia* spp. Henosep;
Heosep = *Henosepichna* spp..

Table 9 Functional responses of *Coccinellids* to varying population densities of *Aphids*.

Aphids Number	N	Mean	Std. Deviation	Sum	Variance
30.00	18	9.4444	5.9530	170.00	35.438
40.00	18	18.8889	9.1837	340.00	84.340
50.00	18	24.0556	12.9682	433.00	168.173
Total	54	17.4630	11.3864	943.00	129.650

and July when populations of *Coccinellids* were the most abundant. The effects of ecological factors were either direct by dislodging or drowning of *Aphids* as found by Mailu [9], or indirect via influencing host plant quality [11]. Matson and Haack [12] implicated weather and especially drought stress as having the greatest effects on the magnitude of aphid infestation. Indeed, it was observed during these studies that crops under drought stress during the dry season harboured higher aphid infestations than the same crops grown in the rainy season. Thus relatively drier months (March and July) experienced higher aphid incidences than rainy months (April and May). Similar observations have been reported by Ciesla, Mustafa and Allard [13-15].

It was demonstrated in these studies that the different agroecosystems studied had an insignificant impact on the abundance of *Coccinellids*. The mixtures of maize and beans supported high population levels of *Coccinellids* apparently because the bean aphid *A. fabae* upon which the beetles fed was quite abundant during the pre-flowering stage of beans. On the other hand, the tasselling stage of maize coincided with higher levels of the predators because they fed on pollen grains. However, the pure stand cowpea supported the lowest population of *Coccinellids* due to the mutualistic association of *A. fabae* on cowpeas with the black ants ("Attendant ants") such that *A. fabae* provided black ants with secretions for nourishment while the ants protected the *Aphids* from predation by *Coccinellids*.

The predators showed a positive functional response as in the highest regime of prey density, capture efficiency increased and handling time (time spent chasing, killing and consuming prey) decreased [16]. The current studies showed that different crops were attacked by a complex of insects species, some of which formed the prey for the ladybirds. Of the pests known to attack crops such as cowpea in Africa and specifically in east Africa, most of them were phytophagous and attacked a variety of other legumes and other plants in the tropics [17]. Although a total of 22 species in six insect orders were recorded, this was proportionally fewer than expected. This was probably because of variations in the density of crop pests which synchronized with areas, seasons and weather as well as other conditions such as mixed and pure standing farming. Data were collected and analyzed for only a single season. It therefore would have been possible to collect more insect pest species than collected if sampling had been extended over several seasons and in different parts of Busia District. Current results showed that most of the insect pest species recorded were well known pests of legumes in the tropics, though their occurrence seemed to be of varied magnitudes. The studies showed that the leaf feeders formed the largest group of pests.

6. Conclusions and Recommendations

From the current studies, the following conclusions and recommendations were made:

The fact that *H. variegata* larva was the most bio-efficient agent against *Aphids* in these studies had tremendous significance. This pointed to the fact that the predator could be put to use in the control of *Aphids*. There is then need to study this predator with a view to understand its exact ecology and biology. Its predatory potential based on such factors as its discovery rate, speed of movement, range of perception, capture efficiency and handling time ought to be determined. Equally important, was *Cheilomenes* spp. which was relatively bio-efficient as predators of *Aphids*. It should in future be studied as a potential agent for *Aphid* control.

Although biological control may be successful on its own, and no other control measures are required, it is quite often necessary and almost always desirable to integrate biological control with other measures, including at times the careful use of pesticides in integrated pest management. This approach should be investigated and implemented for the benefits of farmers.

Future studies should be focused on the identification of a wide range of predators which cover all major species in the pest complex of the crops and agroecosystems studied. This would seem to be important in view of the immense benefits attributed to predators as bio-control agents.

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