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ORIGINAL ARTICLE

Intercropping and diverse field margin vegetation suppress bean aphid (Homoptera: Aphididae) infestation in dolichos (*Lablab purpureus* L.)

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Abstract

Dolichos (*Lablab purpureus* L.) is a drought tolerant legume used as food/feed and improvement of soil fertility. The production of dolichos in Kenya, Nakuru County is however limited by insect pests like bean aphids, pod borers and whiteflies. Field studies were conducted to determine the effect of cropping systems (dolichos monocrop and maize-dolichos intercrop) and field margin vegetation on bean aphids and their natural enemies. The experiment was conducted in Njoro (high field margin vegetation) and Rongai (low field margin vegetation) during May–December 2019 and March–November 2020 cropping seasons. Bean aphid percent incidence, severity of damage and abundance was assessed at seedling, early vegetative, late vegetative and flowering dolichos growth stages. The populations of natural enemies in the plots and field margin vegetation were monitored using pan traps and sweep nets. Species diversity and composition of the field margin vegetation was determined using a quadrat. Results showed that location and cropping system had significant effects on bean aphid infestations. A high bean aphid incidence (38.13%) was observed in Njoro compared to Rongai (31.10%). Dolichos monocrop had significantly higher bean aphid infestation (51.63%) than the maize-dolichos intercrop system (24.62%). A highly diverse Shannon-weaver index was observed in Rongai (1.90) compared to Njoro (1.67). Dolichos monocrop had a more diverse Shannon-weaver index (1.8) than the maize-dolichos intercrop system (1.7). Rongai had the most abundant annual and perennial field margin vegetation species. The field margin species richness and diversity were higher in Rongai (81%) than in Njoro (54%). The findings of this study have demonstrated that a maize-dolichos intercrop in Rongai can reduce bean aphid damage in dolichos.

Keywords: aphids, dolichos, field margin vegetation, natural enemies

Introduction

Dolichos (*Lablab purpureus* L.) is a drought tolerant legume crop with a great potential for sustainable agriculture in dryland ecosystems. It is a major source of proteins, minerals, vitamins and fiber (Soetan and Fafunso 2010) for human food and animal fodder (Njarui and Mureithi 2010). Dolichos can also be incorporated into the soil to improve soil fertility and soil organic carbon (Cheruiyot *et al.* 2003). Despite these benefits, the crop remains underutilized and is cultivated by only a few farmers in Kenya and other parts of the world (Cullis and Kunert 2017). The emerging need to focus on crops with resilience to soil moisture deficit puts dolichos production among the key strategies to mitigate climate change-induced threats to global food security. Efforts to promote the production of dolichos are constrained by insect pests such as pod borers (*Maruca vitrata* Fabricius), whiteflies (*Trialeurodes vaporariorum* Westwood), bollworms (*Helicoverpa amigera*), black bean aphids (*Aphis fabae* Scopoli) and cowpea aphids (*Aphis craccivora* Koch). Among the mentioned pests the bean aphid accounts for 39–90% yield loss (Abate *et al.* 2000; Thejaswi *et al.* 2007; Rekha and Mallapur 2009; Nahashon *et al.* 2016). The direct damage caused by bean aphids is through sucking plant sap, resulting in loss of vigor, leaf curling and distortion of plant parts. The honeydew that is secreted by these insects and deposited on leaves can develop into sooty mold, which blocks light interception for photosynthesis (Guerrieri and Digilio 2008). The indirect damage is through transmission of viruses such as the bean common mosaic virus (BCMV) and bean yellow mosaic virus (Elsharkawy and El-Sawy 2015).

Dolichos is usually cultivated under a monocrop system and often depends on synthetic pesticides for pest control. The use of synthetic pesticides in agroecosystems leads to higher crop yields but is accompanied by negative effects including serious risks to human health through poisoning (Damalas and Eleftherohorinos 2011) and declining biodiversity in fields, cropping systems and the farm environment. This calls for natural pest management options such as intercropping and conservation of biological control agents using field margin vegetation as a safe refuge (Sujayanand *et al.* 2015). Intercropping and field margin vegetation promote diversity and provide a pool of plant species as a source of food for most invertebrates.

Intercropping is practiced in many agricultural systems to increase productivity per unit area compared to monocultures (Glaze-Corcoran *et al.* 2020) and it reduces the negative effects of agriculture on the environment. It reduces the homogeneity of the crop and potentially increases the barriers of pests into the crop as well as limits outbreaks of crop pests by increasing predator biodiversity (Farooq *et al.* 2011). Higher insect pest predation or parasitism rates imply higher pressure on pests which is positive for biological control (Lopes *et al.* 2016). Additionally, intercropping may improve soil conservation, soil nutrient status and crop quality with a possibility of reducing the incidence of weeds, diseases and insect pests. Field margin vegetation on the other hand can be established through sowing seed mixtures of annual and perennial weeds or promoting their natural growth on the crop boundaries. The established or natural field margin vegetation can help reduce pesticide drift and increase the abundance of both crop pollinators and the population of natural enemies.

Natural enemies exhibit selective tendencies towards field margin vegetation and exist in the same ecological niche as both predators and parasitoids. Studies by Dostálek and Münzbergová (2018) showed that crops growing adjacent to field margin vegetation experience low levels of herbivore damage compared to crops on open fields. The interaction of natural enemies and bean aphids is a complex situation that requires the understanding of their ecology and habitat management (Hrček *et al.* 2016). In the present study, the effectiveness of maize-dolichos intercrop and field margin vegetation was determined for the management of bean aphids.

Materials and Methods

Experimental site and conditions

This study was conducted on farmers' fields in Njoro and Rongai sub-counties of Nakuru County which is located in the central Rift Valley region of Kenya. Njoro sub-county lies within 0°42' S, 36°10' E in agro-ecological zone III-(6) and an altitude range of 2,225–2,250 meters above mean sea level (AMSL). It receives an annual precipitation of 900–1,000 mm per year, with a daily mean temperature range of 17–22°C. The soils are well-drained dark reddish clay and are classified as mollic Andosols. Rongai sub-county lies within 0°10' S, 35°51' E in agro-ecological zone III-(5) and an altitude range of 1,912–1,925 AMSL. The sub-county receives an annual precipitation of 850–900 mm per year and has a daily mean temperature range of 18–25°C. The soils are well-drained sandy clay loams classified as vitric Andosols (Jaetzold *et al.* 2012).

Experimental design and treatment application

The field experiments were conducted during May–December 2019 and March–November 2020 crop growing seasons. A total of 16 farms, eight farms in each location, were selected for the research. Each experiment was conducted in a randomized complete block design (RCBD) with eight replications per location. Dolichos monocrop and maize-dolichos intercrop were established on plots measuring 10 m × 10 m with field margin vegetation. A compound fertilizer, grade 23-23-0 (NPK), was used during planting which supplied 13.8 kg $N \cdot ha^{-1}$ and 13.8 kg $P_2O_5 \cdot ha^{-1}$ as basal application. Maize variety H516 was obtained from the Kenya Seed Company and dolichos variety DL1002 was obtained from the KALRO Katumani Seed Unit. Dolichos monocrop was planted at a spacing of 60 cm × 30 cm, two seeds per hill, giving a plant population of 111,111 plants $\cdot ha^{-1}$. In the maize-dolichos intercrop, maize was planted at a spacing of 75 cm × 30 cm, one seed per hill, giving a plant population of 44,444 plants · ha^{-1} while dolichos was planted between maize rows at an intra-row spacing of 30 cm, two seeds per hill, giving a bean plant population of 88,888 plants · ha^{-1}. Topdressing of maize was done at the 7-leaf stage using calcium ammonium nitrate (CAN) fertilizer at the rate of 60 kg N · ha^{-1}. The fields were not sprayed with any pesticides during the whole experimental period.

Data collection

Bean aphid percent incidence, severity and abundance

The percent incidence of aphid (*PIA*) was determined by visually examining and counting the number of plants infested with black bean aphid (*Aphis fabae*) and cowpea aphid (*A. craccivora*) at seedling, early vegetative, late vegetative and flowering growth stages and then the damage was expressed as a percentage of the total number of plants observed. The *PIA* was calculated according to the following formula:

$$PIA\,(\%) = \frac{\text{Number of infested plants}}{\text{Total number of plants observed}} \times 100.$$

The aphid abundance score (*AAS*) was determined by visually observing and scoring the level of bean aphid infestation on 10 randomly selected plants from the 10 middle rows in a zigzag pattern at seedling, early vegetative, late vegetative and flowering growth stages of dolichos. The aphid abundance score was scored using a 6-point scale according to a modified version of Mkenda *et al.* (2015) where: 1 = no aphid infestation, 2 = a few scattered aphids (1–100), 3 = a few isolated colonies (101–300), 4 = several isolated colonies (301–600), 5 = large isolated colonies (601–1000) and 6 = large continuous colonies (>1001). The aphid severity score (*ASS*) was determined by visually observing and scoring the level of aphid damage on 10 randomly selected plants as in *AAS*. It was scored using a 5-point scale according to Mkenda *et al.* (2015) where: 1 = no infestation or damage, 2 = light damage and infestation (< 25%) of plant parts, 3 = average damage and infestation (26–50%) of plant parts, 4 = high infestation and damage (51–75%) of plant parts showing yellowing of lower leaves and 5 = severe infestation damage (>75%) of plants with yellow and severely curled leaves or a dead plant. The severity and abundance were later converted into percentage and real bean aphid count for analysis.

The diversity and abundance of natural enemies

Pan trapping

Pan trapping was done according to Saunders and Luck (2013) using yellow plastic pans measuring 20 cm diameter and 5 cm high to capture the natural enemies at the ground level. The pans were filled with a premixed liquid solution containing 250 ml of water, 5 g of salt to preserve the natural enemies and 5 ml of odorless liquid detergent to break the surface tension of the water. The pan traps were placed at the ground level, one at the center of the experimental plot and another along the field margin vegetation in both monocrop and intercrop systems. The traps were left in the field for 48 h. After this period, the trapped insects were retrieved by sieving and washing with clean water. The insects were picked from the sieve using a camel hair brush size 00 and placed in 50 ml plastic falcon tubes filled with 25 ml of 70% ethanol for preservation before being taken to the laboratory. The insects were placed under a dissecting microscope (Leica ZOOM 2000 Inc. Buffalo. NY U.S.A 14240-0123) at 200× magnification for counting and identification up to the family level using Simon and Schuster's identification key (Arnett and Jacques 1981). This data collection procedure was repeated at seedling, early vegetative, late vegetative and reproductive growth stages of dolichos.

Sweep netting

Sweep net sampling was used to capture the natural enemies in the field margins according to Spafford and Lortie (2013). It involved sweep netting along the field margin vegetation surrounding the dolichos monocrop and maize-dolichos intercrop at seedling, vegetative and reproductive dolichos growth stages. While moving forward about 5 m the sweeps were done along the field margin vegetation by making 10 sweeps parallel to the field margin and within 0.5 m of the margin. The sweep net bag was closed immediately after sweeping. This was followed by carefully opening the sweep net and manually sucking the collected insects into an aspirator and transferring them to a jar containing 2 ml of formalin where they were left for 2 h to die. The preparation and identification of the insects were the same as for pan trapping.

Field margin vegetation composition

The field margin vegetation composition was determined by randomly throwing a 1 m^2 quadrat two times along the field margin vegetation when most of the field margin plant species were at flowering stage for ease of identification of each species. The field margin plants were identified to species level using pictorial aids (e-library) and authentic identification was done by a plant taxonomist at the Department of Biological Science, Egerton University. All the individual field margin plants that were in the quadrat were counted and the ratio of one species to the total count of the field margin plants (Mahajan and Fatima 2017) was calculated as follows:

$$\text{Relative abundance of species (\%)} = \frac{\text{Number of specific species in the quadrat}}{\text{Total number of all species in the quadrat}} \times 100.$$

The same formula was used to calculate the percent family composition of the field margin vegetation.

Data analysis

All data on insect counts were first subjected to Shapiro-Wilk's test to check if the distribution of the values were statistically different from the normal distribution. Bean aphid percent incidence, severity and abundance were analyzed using PROC TTEST in SAS to compare the monocrop and intercrop systems in the two locations. Data on natural enemy population counts from the pan traps and the sweep nets were transformed using square root transformation. The counts were subjected to analysis of variance (ANOVA) using the general linear model procedure in SAS (SAS Institute version 9.4, 2002). Means were separated using Tukey's Honest Significant Difference (HSD) test at $p \leq 0.05$.

The diversity of the insect families was evaluated using the Shannon-Weaver index of diversity (H) and the Pielou evenness index (E) (Pielou 1966). This was done to determine the diversity levels of the insects. Data on the field margin vegetation was analyzed by ranking each field margin vegetation species out of the entire margin vegetation population. Field margin species richness and diversity were evaluated in each location using the Simpsons' species diversity index (D) (De Bello *et al.* 2006).

$$H = -\sum p_i (\ln p_i),$$

where: H – the Shannon's diversity index, p_i – the proportion of individuals found in the i^{th} species and *ln* – the natural log of individuals found in the i^{th} species.

$$E = \frac{H}{\ln S},$$

where: E – the Pielou's Index of Evenness, H – the calculated Shannon Index, *ln* – the species diversity under maximum and equitability conditions and S – the number of species in the community.

$$D = 1 - \frac{\sum n(n-1)}{N(N-1)},$$

where: n – the number of individuals displaying one species and N – the total number of all individuals.

Results

Effect of cropping systems, location and crop growth stages on bean aphids

Results showed that the cropping system and crop growth stage significantly influenced bean aphid percent incidence, severity and abundance (Tables 1 and 2). Dolichos monocrop showed a significantly higher bean aphid incidence, severity and abundance than maize-dolichos intercrop. The Njoro location under dolichos monocrop system recorded a higher bean aphid percent incidence, severity and abundance (51.63%, 37.59 and 61.94, respectively) than in the maize-dolichos intercrop (24.62%, 26.75 and 2.04, respectively) (Table 1). The same trend was observed for Rongai under dolichos monocrop and maize-dolichos intercrop (Table 1). At seedling stage, the bean aphid percent incidence was significantly lower for both dolichos monocrop and maize-dolichos intercrop than for the rest of the growth stages. There were no significant differences between bean aphid percent incidence in early vegetative (48.38%) and late vegetative stages (59%) of dolichos in dolichos monocrop (Table 2). The aphid incidences were the same at early vegetative (29.66%), late vegetative (26.99%) and flowering (27.14) stages of dolichis in the maize-dolichos intercrop system (Table 2). The reproductive stage under monocrop showed the highest severity of damage (45.43) by bean aphids and was not different from late vegetative (38.93) (Table 2). This was followed by early vegetative stage (31.13) which was not significantly different from seedling stage (24.75). In the maize-dolichos intercrop system, the bean aphid severity did not differ across the different growth stages. The bean aphids were least abundant in the monocrop at

Table 1. The effect of cropping systems (2019 and 2020) on bean aphid percent incidence, severity and abundance in Njoro and Rongai locations

Cropping system	% Incidence		% Severity of damage		Abundance [numbers/plant]	
	Njoro	Rongai	Njoro	Rongai	Njoro	Rongai
Monocrop	51.63***	39.82***	37.59***	32.53***	61.94***	19.33**
Intercrop	24.62***	22.38***	26.75***	25.75***	2.04	1.45

**, ***significant at $p \leq 0.01$ and $p \leq 0.001$, respectively

Table 2. Bean aphid percent incidence, severity and abundance (2019 and 2020) as influenced by crop growth stages in monocrop and intercrop systems

Dolichos growth stage	% Incidence		% Severity of damage		Abundance [numbers/plant])	
	monocrop	intercrop	monocrop	intercrop	monocrop	intercrop
Seedling	12.30 ± 2.88 c	10.91 ± 2.59 b	24.75 ± 1.14 b	25 ± 1.34 a	0.82 ± 0.69 c	2.19 ± 1.53 b
Early vegetative	48.38 ± 4.98 b	29.66 ± 3.99 a	31.13 ± 1.72 b	27.31 ± 1.12 a	30.72 ± 17.63 b	2.75 ± 1.37 ab
Late vegetative	59.00 ± 4.96 ab	26.29 ± 2.94 a	38.93 ± 2.37 a	26.37 ± 1.03 a	66.07 ± 20.57 a	1.38 ± 0.75 a
Reproductive	63.22 ± 5.45 a	27.14 ± 3.24 a	45.43 ± 3.37 a	26.31 ± 0.88 a	64.93 ± 21.91 ab	0.65 ± 0.34 ab

Means in a column followed by the same letters are not significantly different according to Tukey's HSD test at $p \leq 0.05$

Table 3. Effect of location on bean aphid incidence, severity and abundance

Cropping system	% Incidence	% Severity of damage	Abundance [numbers/plant]
Njoro	38.13***	32.17***	31.99***
Rongai	31.10***	29.14***	10.59*

*, ***significant at $p \leq 0.05$ and $p \leq 0.001$, respectively

seedling stage (0.82) but as the crop advanced in stage, especially at late vegetative, the abundance increased (Table 2). Njoro showed a significantly high bean aphid incidence, severity and abundance (Table 3).

The diversity and abundance of natural enemies

Pan trapping

The arthropods collected in the pan traps were grouped into predators, parasitoids and other groups of insects. The natural enemies collected from pan traps were from six orders (Hymenoptera, Diptera, Coleoptera and Opiliones) while other insects were from Orthoptera, Hymenoptera, Diptera and Hemiptera orders. A total of 15 insect families (Braconidae, Ichneumonidae, Chalcidoidea, Tachinidae, Syrphidae, Coccinellidae, Carabidae, Pholcidae, Pentatomidae, Formicidae, Apidae, Acrididae, Muscidae, Gryllidae and Aphididae) were identified from the orders. Pentatomidae and Acrididae were significantly higher in Njoro than in Rongai ($F = 4.63$, $df = 1$, $p = 0.03$). The Braconidae ($F = 8.02$, $df = 1$, $p = 0.004$), Ichneumonidae ($F = 7.21$, $df = 1$, $p = 0.0075$) and Gryllidae ($F = 16.83$, $df = 1$, $p < 0.0001$) were significantly higher in Rongai than in Njoro (Table 4). The families of Aphididae ($F = 9.30$, $df = 1$, $p = 0.0024$) and Muscidae ($F = 20.24$, $df = 1$, $p < 0.0001$) were more abundant in dolichos monocrop than in maize-dolichos intercrop (Table 4). The Braconidae ($F = 17.51$, $df = 1$, $p < 0.0001$), Ichneumonidae ($F = 28.59$, $df = 1$, $p < 0.0001$), Carabidae ($F = 0.42$, $df = 1$, $p = 0.01$), Pholcidae ($F = 21.24$, $df = 1$, $p < 0.0001$), Apidae ($F = 5.02$, $df = 1$, $p = 0.02$) and Pentatomidae ($F = 11.68$, $df = 1$, $p = 0.0007$) were significantly more abundant in crop margin vegetation than in the crop center (Table 4). The growth stages of dolichos influenced the population of natural enemies of bean aphids. The population of most natural enemies at seedling stage of dolichos was low while their population increased at early and late vegetative stages (Table 5). Rongai had an insect diversity index of 1.72 and 2.07 during May–December 2019 and March–November 2020 cropping seasons (Table 6). However, the similarities in abundance at both locations varied. The measure of similarities was determined by family evenness (*E*) which was high (0.76) in Rongai during March-November 2020 (Table 6). High evenness meant that the species were more evenly distributed and high diversity meant a rich and diverse insect family. The family diversity in the monocrop system (1988) was more than in the intercrop system (1694) during March–November 2020 growing season (Table 7). The highest diverse index was in the dolichos-maize intercrop (2.02) during March–November 2020 growing season and 0.75 for evenness in the same period (Table 7).

Sweep netting

The natural enemy families found at the field margins were Braconidae, Ichneumonidae, Chalcidoidae, Tachinidae, Syrphidae, Chrysopidae, Formicidae, Acrididae, Coccinellidae, Carabidae, Aphididae, Apidae, Pholcidae, Muscidae and Pentatomidae from eight orders. The Braconoidae ($F = 6.48$, $df = 1$, $p = 0.011$), Coccinellidae ($F = 9.53$, $df = 1$, $p = 0.0023$) Acrididae ($F = 4.35$, $df = 1$, $p = 0.03$), Aphididae ($F = 6.4$, $df = 1$, $p = 0.01$) and the Muscidae ($F = 16.83$, $df = 1$, $p < 0.0001$) natural enemies were significantly higher in Njoro than in Rongai (Table 8). The Chrysopidae

Table 4. Natural enemies and other insects captured in pan traps as affected by location, cropping system and trapping position

Natural enemy category	Order	Family/ sub-family	Location		HSD	Cropping system		HSD	Pan-trapping position		HSD
			Njoro	Rongai	$p \leq 0.05$	mono-crop	inter-crop	$p \leq 0.05$	crop center	crop margin	$p \leq 0.05$
Parasitoids	Hymenoptera	Braconidae	2.10 b	3.05 a	0.48	2.74 a	2.41 a	0.48	2.05 b	3.09 a	0.48
		Ichneumonidae	0.66 b	1.06 a	0.24	0.80 a	0.92 a	0.24	0.55 b	1.17 a	0.24
		Chalcidoidea	0.18 a	0.20 a	0.10	0.17 a	0.21 a	0.10	0.15 a	0.23 a	0.10
	Diptera	Tachinidae	1.51 a	1.04 a	0.56	1.46 a	1.09 a	0.56	1.39 a	1.16 a	0.56
Predators	Diptera	Syrphidae	0.32 a	0.30 a	0.21	0.34 a	0.27 a	0.21	0.23 a	0.39 a	0.21
	Coleoptera	Coccinellidae	0.01 a	0.03 a	0.03	0.03 a	0.01 a	0.03	0.01 a	0.03 a	0.03
		Carabidae	3.25 a	3.01 a	0.74	3.30 a	2.95 a	0.74	2.74 b	3.51 a	0.74
	Opiliones	Pholcidae	1.04 a	1.11 a	0.36	1.16 a	0.97 a	0.36	0.72 b	1.42 a	0.36
	Hemiptera	Pentatomidae	0.11 a	0.05 b	0.05	0.07 a	0.08 a	0.05	0.03 b	0.12 a	0.05
Other insects	Hymenoptera	Formicidae	3.00 a	3.49 a	1.28	2.96 a	3.53 a	1.28	3.47 a	3.01 a	1.28
		Apidae	0.52 a	0.53 a	0.15	0.59 a	0.45 a	0.15	0.43 b	0.60 a	0.15
	Orthoptera	Acrididae	1.11 a	0.50 b	0.27	0.78 a	0.83 a	0.27	0.77 a	0.83 a	0.27
		Gryllidae	0.13 b	0.32 a	0.10	0.24 a	0.21 a	0.10	0.23 a	0.22 a	0.10
	Hemiptera	Aphididae	0.44 a	0.24 a	0.20	0.48 a	0.19 b	0.20	0.34 a	0.33 a	0.20
	Diptera	Muscidae	11.21 a	10.00 a	1.57	12.46 a	8.75 b	1.57	9.93 a	11.28 a	1.57

Family/sub-family means in a row followed by the same letters for location, cropping system and pan trap position were not significantly different according to Tukey's HSD test at $p \leq 0.05$

Table 5. Natural enemies and other insects captured in pan traps at different growth stages of dolichos

Natural enemy category	Order	Family/ sub-family	Dolichos growth stages				HSD
			seedling	early vegetative	late vegetative	reproductive	$p \leq 0.05$
Parasitoids	Hymenoptera	Braconidae	2.32 a	2.99 a	2.23 a	2.76 a	0.89
		Ichneumonidae	0.71 a	0.83 a	0.73 a	1.16 a	0.44
		Chalcidoidea	0.26 a	0.13 ab	0.07 b	0.29 a	0.19
	Diptera	Tachinidae	0.85 ab	1.86 a	1.76 a	0.62 b	1.05
Predators		Syrphidae	0.22 b	0.69 a	0.25 b	0.07 b	0.40
	Coleoptera	Coccinellidae	0.04 a	0.01 a	0.01 a	0.03 a	0.06
		Carabidae	2.90 a	4.03 a	2.71 a	2.87 a	1.38
	Opiliones	Pholcidae	0.77 a	1.08 a	1.00 a	1.42 a	0.67
	Hemiptera	Pentatomidae	0.03 b	0.06 b	0.04 b	0.18 a	0.09
Other insects	Hymenoptera	Formicidae	2.27 a	2.93 a	3.96 a	3.82 a	2.37
		Apidae	0.42 b	0.78 a	0.57 ab	0.29 b	0.29
	Orthoptera	Acrididae	0.36 b	0.67 b	0.58 b	1.59 a	0.51
		Gryllidae	0.29 a	0.27 a	0.17 a	0.17 a	0.18
	Hemiptera	Aphididae	0.40 ab	0.62 a	0.28 ab	0.04 b	0.38
	Diptera	Muscidae	11.11 b	15.82 a	6.71 c	8.78 bc	2.91

Family/sub-family means in a row followed by the same letters are not significantly different according to Tukey's HSD test at $p \leq 0.05$

was more abundant in Rongai than in Njoro ($F = 7.75$, $df = 1$, $p = 0.05$) (Table 8). The dolichos monocrop had more Syrphidae than the maize-dolichos intercrop system ($F = 4.23$, $df = 1$, $p = 0.03$) (Table 8). At seedling stage, the population of most of the natural enemies was low but as the crop advanced to the vegetative stage the natural enemies increased for all-natural enemy families except for Chalcidoidae (Table 9). Rongai was highly diverse in both May–December 2019 (2.22) and March–November 2020 (2.18) cropping seasons (Table 10). The

Table 6. Insect diversity in Njoro and Rongai during 2019 and 2020 cropping seasons

Parameters	Location			
	Njoro		Rongai	
	season 1	season 2	season 1	season 2
Total insect families (**S*)	14	15	14	15
Abundance	3,425	4,194	3,182	3,208
Shannon–Weaver index (*H*)	1.38	1.96	1.72	2.07
Evenness index (E)	0.52	0.72	0.70	0.76

*S = family richness; season 1 = May–December 2019 and season 2 = March–November 2020 cropping season

Table 7. Insect diversity as influenced by dolichos-maize cropping systems

Parameters	Cropping system			
	dolichos monocrop		dolichos-maize intercrop	
	season 1	season 2	season 1	season 2
Total insect families (**S*)	14	15	14	15
Abundance	1,552	1,988	1,221	1,694
Shannon–Weaver index (*H*)	1.63	1.99	1.76	2.02
Evenness index (*E*)	0.62	0.74	0.67	0.75

**S* = family richness; season 1 = May–December 2019 and season 2 = March–November 2020 cropping season

Table 8. Numbers of natural enemies captured by sweep net as influenced by location and cropping system

Natural enemy category	Order	Family/ sub-family	Location		HSD	Cropping system		HSD
			Njoro	Rongai	$p < 0.05$	monocrop	intercrop	$p \le 0.05$
Parasitoids	Hymenoptera	Braconidae	0.91 a	0.60 b	0.24	0.70 a	0.81 a	0.24
		Ichneumonidae	0.15 a	0.08 a	0.12	0.12 a	0.11 a	0.12
		Chalcidoidea	0.33 a	0.26 a	0.22	0.37 a	0.22 a	0.22
	Diptera	Tachinidae	0.84 a	0.50 a	0.38	0.67 a	0.66 a	0.38
Predators		Syrphidae	0.05 a	0.06 a	0.06	0.09 a	0.02 b	0.06
	Neuroptera	Chrysopidae	0.01 b	0.07 a	0.04	0.03 a	0.04 a	0.04
	Coleoptera	Coccinellidae	0.30 a	0.08 b	0.14	0.26 a	0.12 a	0.14
		Carabidae	0.67 a	0.73 a	0.26	0.67 a	0.73 a	0.26
	Opiliones	Pholcidae	0.35 a	0.26 a	0.17	0.31a	0.31 a	0.17
	Hemiptera	Pentatomidae	0.71 a	0.68 a	0.35	0.80 a	0.59 a	0.35
Other insects	Hymenoptera	Formicidae	0.20 a	0.16 a	0.14	0.17 a	0.18 a	0.14
		Apidae	0.15 a	0.17 a	0.11	0.15 a	0.17 a	0.11
	Orthoptera	Acrididae	0.44 a	0.21 b	0.21	0.27 a	0.39 a	0.21
	Hemiptera	Aphididae	0.32 a	0.08 b	0.17	0.13 a	0.27 a	0.17
	Diptera	Muscidae	3.28 a	2.03 b	0.62	2.92 a	2.39 a	0.62

Family/sub-family means in a row followed by the same letters for location and cropping system are not significantly different according to Tukey's HSD test at $p \le 0.05$

family evenness (*E*) was high (0.80) in Rongai during May–December 2019 (Table 10). The dolichos monocrop system was highly diverse during May–December 2019 and the insect families remained even throughout all the cropping systems and seasons (Table 11).

Field margin vegetation

A total of 50 species of field margin vegetation were identified. The species were categorized into 19 families and further clustered into 27 perennial and 23 annual plants. There was variation in species numbers across

Table 9. Numbers of natural enemies captured by sweep net as influenced by dolichos growth stages

Natural enemy category	Order	Family/sub-family	Dolichos growth stages				HSD $p \leq 0.05$
			seedling	early vegetative	late vegetative	reproductive	
Parasitoids	Hymenoptera	Braconidae	0.96 a	0.71 ab	0.89 ab	0.45 b	0.44
		Ichneumonidae	0.29 a	0.01 b	0.06 b	0.10 ab	0.22
		Chalcidoidea	0.20 b	0.03 b	0.18 b	0.78 a	0.41
	Diptera	Tachinidae	0.25 b	0.39 b	1.12 a	0.92 ab	0.72
Predators		Syrphidae	0.06 a	0.01 a	0.03 a	0.12 a	0.12
	Neuroptera	Chrysopidae	0.04 a	0.04 a	0.04 a	0.03 a	0.09
	Coleoptera	Coccinellidae	0.31 a	0.17 a	0.17 a	0.12 a	0.26
		Carabidae	0.89 a	0.98 a	0.59 ab	0.35 b	0.48
	Opiliones	Pholcidae	0.15 b	0.32 ab	0.25 ab	0.51 a	0.31
Other insects	Hemiptera	Pentatomidae	0.42 a	0.51 a	0.81a	1.04a	0.65
	Hymenoptera	Formicidae	0.26 a	0.21 a	0.17a	0.07 a	0.27
		Apidae	0.18 a	0.25 a	0.12a	0.10 a	0.22
	Orthoptera	Acrididae	0.15 b	0.42 ab	0.18 ab	0.56 a	0.39
	Hemiptera	Aphididae	0.40 a	0.14 a	0.17 a	0.09 a	0.33
	Diptera	Muscidae	2.90 a	2.70 a	2.67 a	2.34 a	1.16

Family/sub-family means in a row followed by the same letters are not significantly different according to Tukey's HSD test at $p \leq 0.05$

Table 10. Insect diversity in Njoro and Rongai during 2019 and 2020 cropping seasons

Parameters	Location			
	Njoro		Rongai	
	season 1	season 2	season 1	season 2
Total number of families (**S*)	16	16	16	16
Abundance	644	514	451	375
Shannon–Weaver index (*H*)	2.19	2.04	2.22	2.18
Evenness index (*E*)	0.79	0.73	0.80	0.79

**S* = family richness; season 1 = May–December 2019 and season 2 = March–November 2020 cropping season

Table 11. Insect diversity as affected by cropping systems

Parameters	Cropping system			
	monocrop		intercrop	
	season 1	season 2	season 1	season 2
Total number of families (**S*)	15	15	15	15
Abundance	276	249	220	205
Shannon–Weaver index (*H*)	2.13	2.09	1.92	2.04
Evenness index (*E*)	0.78	0.77	0.71	0.76

**S* = family richness; season 1 = May–December 2019 and season 2 = March–November 2020 cropping seasons

the two seasons that influenced the total field margin vegetation. The March–November 2020 cropping season had a higher field margin vegetation than the May–December 2019 cropping season (Fig. 1). Results from the field margin species richness and diversity indicated that there was a 81% chance of individuals selected from Rongai being of different species compared to 54% for Njoro (data not shown). Rongai had a higher field margin population that was composed of perennial vegetation (Fig. 2). The dominant field margin vegetation was in the family Onagraceae (stemless primose) with an abundance of 56% in Njoro while for Rongai was Scrophulariaceae (pimpernel) with 35% of abundance (Fig. 3).

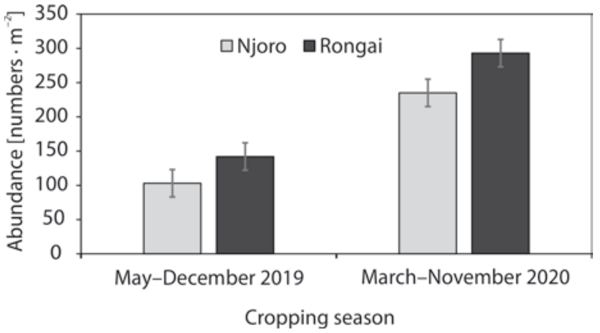

Fig. 1. Field margin vegetation abundance in Njoro and Rongai locations

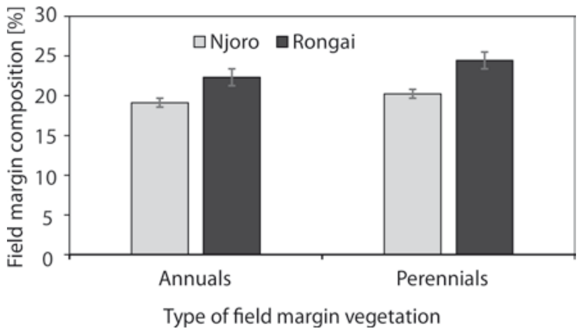

Fig. 2. Percent composition of annual and perennial field margin vegetation in Njoro and Rongai locations

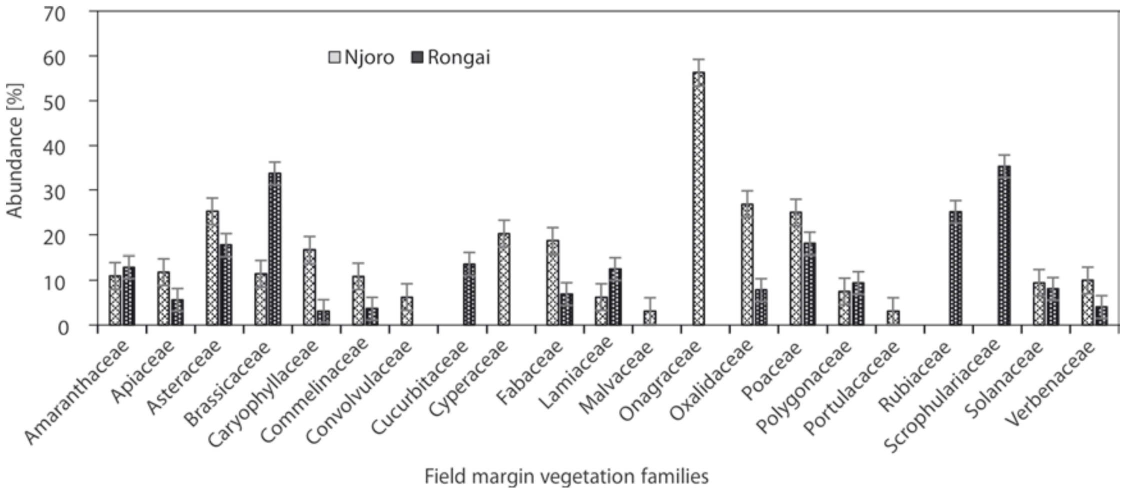

Fig. 3. The abundance of field margin vegetation families in Njoro and Rongai locations

Discussion

The results of this study showed a significant reduction of bean aphids in the dolichos-maize intercrop compared to the dolichos monocrop. The reduced bean aphid incidence, severity and abundance in the intercrop system could be attributed to the intercrop species interference with the ability of pests to locate host plants. The presence of maize in the intercrop is known to deter the bean aphid from locating the host probably through interfering with semiochemicals produced by insects and which are used by natural enemies to locate their prey (Mbata *et al.* 2004). The insect cues are processed in the olfactory system for locating the host (Webster and Cardé 2017). Similar results have been reported in a maize-bean intercrop with a significant reduction in stalk borer density compared to the maize monocrop (Songa *et al.* 2007). Intercropping is practiced for more agronomic advantages which include weed suppression, nutrient sharing and insect pest management (He *et al.* 2019).

Besides the possible interference of maize on aphid infestation in the dolichos-maize intercrop, the results showed a high abundance of predators and parasitoids in the dolichos monocrop. The monocrop had a high number of natural enemies in both locations. The resource concentration hypothesis suggests that higher herbivore numbers in a monocrop system are due to their ability to locate the host, resulting in higher feeding rates and an ability to achieve higher reproduction rates than herbivores with narrow host ranges (Grez and Gonzalez 1995). Natural enemies use olfactory, visual and sometimes acoustic cues from their prey to assess food information and hence multiply their population (Li *et al.* 2014). This is contrary to the natural enemy hypothesis (Root 1973) which states that the effect of natural enemies is enhanced in a mixed cropping system that provides a variety of microhabitats. Tiroesele *et al.* (2019) reported that intercropping sorghum with other legumes significantly increased insect diversity and reduced the pressure of herbivore populations on crops.

In regard to location, the bean aphid percent incidence, severity and abundance varied across the two locations. Njoro had high bean aphid infestation compared to Rongai. As explained earlier, Njoro has a relatively cool and wet environment while Rongai has a relatively warm and dry environment. The different environmental conditions support different plant species distribution which directly influences insect diversity. Rongai had more diverse and richer vegetation species than Njoro. For this reason, more diverse and evenly distributed natural enemies were observed in Rongai. A rich and diverse range of species supports the survival of natural enemies by providing various forage resources. The presence of natural enemies keeps the bean aphid population in balance and reduces their damage on the host crop (Perdikis *et al.* 2011). These results are in agreement with Amaral *et al.* (2013) who reported that the adult and larvae of coccinellids were commonly observed feeding on aphids in the margins and in the plots of chili pepper fields, while the adult coccinellids were frequently found on plant flowers near the crops and extrafloral nectaries. During the growing season, the range of temperature was 15–25°C in Njoro and 18–27°C in Rongai. Although temperature plays an important role in growth, development and reproduction of aphids, it had no direct effect on the bean aphid incidence, severity and abundance in Njoro. From this perspective, the results differ from Forrest (2016) who found that high temperatures between 21and 27°C had a direct effect on the bean aphid life cycle by exacerbating the potential number of generations per season since they are exothermic and tend to be active under warm conditions.

Dolichos growth stage also influenced aphid incidence, severity and abundance. At seedling stage, the aphid population was low but progressively increased with an advance in growth stage of plants up to late vegetative growth stage. The low population of the bean aphids at seedling stage can be attributed to the fact that aphids were yet to locate the host plants. As the dolichos crop advanced in growth, it produced new leaves which are preferred by bean aphids. The newly developing tissues provide sap in the vascular bundles that are sucked by the aphids (Dixon 2012). The results in the current study are in agreement with Dixon and Agarwala (1999) who reported that the period during which the aphid colony remains suitable for a coccinellid coincides with the period that the larvae of a coccinellid complete its developmental stage before moving to the pupal stage. Aphids are parthenogenetic and can give birth to 60–80 young ones during their 20–30 day reproductive period (Vellichirammal *et al.* 2017). As their population grows, they cause more damage to the crop, up to a point where the members of the colony cannot be supported by the host plant due to overpopulation and the aphids develop wings with which they migrate to newly developed leaves.

Field margins are a habitat for the natural enemies of bean aphids by providing food in the form of nectar, pollen, and alternative prey/host, as well as shelter. Rongai had a higher population of perennial and annual weeds than Njoro, making it an area with high diversity of field margin vegetation. The observed vegetation abundance is influenced by agricultural practices carried out in that location. Farmers in Rongai have large parcels of land which are located in the upper midland transition agro-ecological zone, where agricultural enterprises are mainly livestock and there is less crop cultivation. Livestock grazing causes little disturbance of the soil and encourages the build-up of weed seed banks which explains the greater diversity of field margin vegetation. Njoro is located at a lower highland semi-humid agro-ecological zone where farmers practice intensive agriculture with frequent soil disturbance, which can lead to depletion and or destruction of weed seed banks (Bajwa *et al.* 2015). Perennial crops have a greater ability to enhance the diversity and abundance of natural enemies of insects and thereby reduce pest infestations (Asbjornsen *et al.* 2014). They store the nectar sugar for longer times at low concentrations which is available for beneficial insects during times of low supply. According to Farkas *et al.* (2012) plants with different life cycles and reproductive strategies, like annuals and perennials, may react differently to the availability of resources. In contrast to insect pests, diversified systems and dolichos crops adjacent to diverse field margin vegetation recorded more natural enemies than the dolichos that was adjacent to less field margin vegetation. Natural enemies may utilize a broad range of other food sources, including plant-provided food such as pollen, extra floral nectar, and honeydew (Wäckers *et al.* 2007).

The populations of natural enemies were higher in field margin vegetation than in the dolichos crop at the reproductive stage. This trend implies that field margin vegetation acts as a habitat for enhancing the natural enemy population during low bean aphid infestation. These results agree with Balzan and Moonen (2014) who reported that the sucking bugs of Pentatomidae and Miridae appeared to be influenced by the management of herbaceous field margin vegetation. At the seedling stage the population of the natural enemies in dolichos was lower than at other growth stages due to low bean aphid infestation during the early growth stages (Mkenda *et al.* 2015).

In the present study, the highest number of natural enemies was obtained from pan traps. The traps were targeted to collect the natural enemies inside the crop region that feed on the bean aphids and fall on the ground during ecological disturbances like rain and wind. This is in agreement with previous studies, in which pan traps collected more species of insects in the crop and around the edges of cultivated crops (González *et al.* 2020). The sweep net was targeted to capture the natural enemies that were flying from the field margin vegetation to the dolichos crop. The insects were classified as predators, parasitoids, symbiotic insects and other insects. The symbiotic insects were from the Formicidae family (ants) and other insects were from other families like Muscidae. The Diptera (Muscidae) were captured in high numbers in both pan traps and sweep nets. They do not prey upon bean aphids, but act as scavengers (Leksono *et al*. 2018). The second dominant family was Carabidaes. They are ground-dwelling insects that are associated with predators of bean aphids falling off the plant after disturbance. Formicidae (ants) commonly protect aphids from predators and parasitoids. It is a symbiotic relationship since, in turn, the bean aphids provide energetic food for them in the form of secreted waste called honeydew (Novgorodova and Gavrilyuk 2012). The bean aphids are attacked by some families of Hymenoptera like Braconidae. They are primary parasitoids that cause permanent paralysis upon oviposition which prevents any further development of the aphid (Quicke 2015).

Conclusions

The findings of this study showed that intercropping maize and dolichos reduced incidence, severity of damage and the abundance of bean aphids in dolichos. Hence, it played a role in reducing aphid damage compared to the monocrop system. Concerning the two experimental locations, Rongai had a more diverse number of field margin vegetation and subsequently a higher number of natural enemies. Similarly, Rongai had a smaller population of bean aphids. This implies that an area with more diverse and larger populations of field margin vegetation could be a potential habitat for natural enemies of bean aphids. Understanding the interaction of diverse cropping systems with non--crop vegetation is essential for understanding the need for conservation of natural vegetation which is a haven for natural pest regulators. Therefore, Rongai can host a large population of natural enemies due to the fact that it can provide habitats and food for natural enemies.

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