

FACTORS INFLUENCING THE INCIDENCE OF THE BLACK BEAN APHID, *APHIS FABAE* SCOP., ON COMMON BEANS INTERCROPPED WITH MAIZE

OGENGA-LATIGO, M.W.*, C. W. BALIDDAWA^a and J. K. O. AMPOFO^b

International Centre of Insect Physiology and Ecology, P.O. Box 30772, Nairobi, Kenya

^aFAO Horticultural Project, Kawanda Research Station, P. O. Box 7063, Kampala, Uganda

^bSADCC/CIAT Regional Bean Programme, Selian Research Center, P.O. Box 2704, Arusha, Tanzania

(Received 20 February 1993; accepted 14 April 1993)

ABSTRACT

The incidence of the black bean aphid, *Aphis fabae* Scop. (Homoptera: Aphididae), and its colonization of common beans (*Phaseolus vulgaris* L.) grown as sole crop and as intercrops with maize (*Zea mays* L.) of varying growth stages was evaluated in the field and glasshouse. Modification of bean micro-climate and its effects on *A. fabae*, and the species range and abundance of coccinellid predators (Coleoptera: Coccinellidae) of the aphid were also assessed. Results showed that *A. fabae* infestation of beans was greatly reduced when intercropped with older and taller maize plants. Larger maize plants interfered with aphid colonization of beans and only small proportions of beans were infested by the aphid. Shading by older maize plants significantly ($P \leq 0.01$) reduced the level of solar radiation reaching intercropped beans; this reduced the build-up of *A. fabae* populations. Intercropping also reduced the number and diversity of coccinellid predators on beans, contrary to the prediction based on the "enemies hypothesis". Reduced aphid incidence on intercrop beans was attributed to maize interference with aphid host finding behaviour and bean colonization and, to a lesser extent, to reduced build-up of *A. fabae* populations due to shading.

Key Words: *Aphis fabae*, coccinellid predators, intercropping, beans, microclimate.

INTRODUCTION

Polycultures or mixed-cropping are agricultural practices that have received much emphasis in recent agro-ecological studies. These cropping systems influence the abundance, diversity and relative importance of pests and their natural enemies and the yield performance of component crops. Commonly, pest populations are lower in

mixed-crop as compared to monocrop systems. The lower incidences have previously been attributed to: (a) patchy distribution and low concentration of food resources for pests (the "resource concentration hypothesis", 21; 23); (b) adverse modification of crop microclimate (the "microclimate hypothesis", 15; 18); and (c) increased abundance and/or effectiveness of natural enemies (the "enemies hypothesis", 19; 20). However, specific mechanisms responsible for lower pest incidence in intercrop systems have not been critically examined.

*Current address: Department of Crop Science, Makerere University, P.O. Box 7062, Kampala, Uganda.

In many parts of tropical Africa and South America, common beans (*Phaseolus vulgaris* L.) and other legumes are traditionally grown as intercrops with maize (*Zea mays* L.) of varying growth stages (6). The intercrop systems, thus, vary in structural and spatial relationships between component crops, micro-climatic conditions, and their influence on pest incidence and activity of natural enemies. Review of recent studies of pest incidence in legume-maize intercrop systems, however, show that field experiments have been largely based on simultaneous planting of component crops, following agronomic recommendation, rather than on specific designs intended to test the diverse plant-arthropod and predator-prey relationships in these systems. Only a few studies (1; 4) investigated the effects of variation in time of planting of component crops on the incidence of pests. Recently, assessment was also made of the influence of maize row spacing on *A. fabae* incidence on beans (16), and on the magnitude of bean yield losses due to aphid damage and to the effect of intercropping (17).

Altieri *et al.* (1) grew intercrop beans (*P. vulgaris*) on different dates after maize sowing, and found that populations of the leafhopper, *Empoasca krameri*, were reduced by 66% on beans planted 30 days after the maize as compared to a reduction of 26% for simultaneous planting. Factors that defined leafhopper abundance in the intercrops were not determined. Ezueh and Taylor (4) also intercropped cowpea (*Vigna unguiculata* L.) with maize of varied growth stages, and assessed the incidence of three major pests of cowpeas, namely *Maruca testulalis* Geyer, *Cydia ptychora* Meyr and thrips (mainly *Megarulothrips sjostedti* (Trybom)). The cowpeas were, however, sown on seven different dates, 0–12 weeks after maize planting, and the crops sampled only once 28 days after cowpea sowing. Consequently, time related changes in the structural and spatial relationships between component crops, and in pest and natural enemy abundance, remained unaccounted for.

In the present study, attempts were made to isolate the effects of maize growth, and seasonal dynamics of aphid populations, so as to establish the factors responsible for variation in incidence of the bean aphid, *A. fabae*, on common beans intercropped with maize.

MATERIALS AND METHODS

Field, glasshouse and cage experiments were conducted at the Kabete Field Station of the University of Nairobi, located 13 km west of Nairobi, Kenya, at latitude 1° 15' south, longitude 36° 44' east, and a mean altitude of 1940 m asl. The station lies in an agro-climatic zone described as semi-humid. It has two rainy seasons, with the long rains occurring between March and July, during which over 55% of the rains fall, while the short rains fall between October and January (25).

Field experiments were established by planting beans as sole crops and as intercrops with maize of varied growth stages. In 1985, maize (var Kenya Hybrid 512) was planted three times, at two-week intervals, on 7th and 21st March under irrigation, and on 5th April. In the following year, maize was planted four times, at 10-day intervals, on 26th March, 7th, 17th and 27th April. Simultaneously with the last maize planting, common beans (var Mwitmania, GPL.X.92) were planted as sole crop and as intercrops with all the maize. Crop spacings were 100 x 20 cm for maize and 50 x 10 cm for common beans. Plots measured 10 x 10 m, were separated by 2 m wide corridors, and replicated twice. They were kept free of weeds by regular hand weeding, and diammonium phosphate (DAP) fertilizer applied to them at the rate of 200 kg/ha.

Field incidence of *A. fabae* on sole and intercrop beans. The incidence of *A. fabae* on common beans was assessed during 1985, by sampling two bean rows per plot. Each plot was stratified into a four-meter wide inner strip, and two three-meter wide outer strips because of known gradient of aphid infestation in the field. One bean row was then randomly selected from the inner or outer plot strata and marked for permanent sampling. Plants in the marked rows were inspected weekly and the proportion colonized by the aphids determined. Heights of the different maize crops were also measured weekly.

Aphid colonization of beans was assessed in 1986 by recording the cumulative number of alates found on the crop during the first four weeks of growth. Two bean rows, one from the inner or outer plot strata, were marked from each

replicate plot and plants in these rows inspected at four day intervals.

A. fabae landing response and bean colonization. This study was conducted in a glasshouse measuring 3.5 x 2.5 x 2.5 m. *A. fabae* alates used were obtained by rearing the aphid on bean seedlings grown in 15 plastic pots (top diameter 30 cm) placed on one side of the glasshouse and partially screened with polythene sheeting. To ensure a continuous availability of sufficient numbers of alates during the test period, infestation of bean seedlings with *A. fabae* apterae was spread over two weeks.

Test plants were raised in four seedling boxes, each having two compartments measuring 57 x 57 x 7 cm. Using one box at a time, maize was planted three times at 10-day intervals. At the last maize planting, common beans were sown in the fourth box, and as intercrops with all the maize. Seeds were planted in 50 cm long rows, at a spacing of 10 x 5 cm for maize and 10 x 3 cm for beans, and there were six maize and five alternate bean rows in each box compartment. Plants were watered daily, and a solution of 5 g DAP fertilizer added to each box weekly. Based on preliminary trials, the establishment of test plants was synchronized with the availability of *A. fabae* alates.

The plants were moved into the glasshouse ten days after bean emergence, and exposed to dispersing alate aphids from the colonies for two hours. Two bean rows were then randomly selected from each box compartment, and the number of alates found on beans and percentage of beans colonized by the aphid recorded.

To test the landing response of *A. fabae* in the intercrops, leaves of maize plants in the three boxes were coated with diesel oil applied using a small hand sprayer. These plants were then exposed to dispersing aphids as described above, and the number of alates trapped on the leaves counted. For each maize growth stage, the leaf area of five randomly selected plants were measured using an electronic leaf area meter. Analyses were then made of the relationships between maize leaf area and level of *A. fabae* infestation on beans.

Modification of bean microclimate by intercrop maize. Under a wide range of glasshouse and

diurnal field conditions, only variations in temperature and photo-radiation levels significantly influence the development of *A. fabae* and other aphids (3; 11). Day time variation of the two climatic elements were therefore assessed in intercrops planted during the long rains of 1986.

Three thermometers, located at the centre of plots about 10 cm from the ground and protected from direct sunlight, were used to measure ambient temperature levels for each crop combination. Each week, two sets of readings were taken for each thermometer between 1300 and 1400 hr, on bright rain-free days when maximum variation in microclimatic conditions were expected.

The level of solar radiation (photosynthetically active radiation, PAR) reaching bean plants was monitored using a LI-COR solar monitor consisting of a one meter line quantum sensor (LI-191SB), with a spectral response of $\pm 7\%$, and a microprocessor controlled light meter/integrator (LI-1776 Solar Monitor). For each intercrop, five pairs of alternate readings of instantaneous measurements of solar radiation (micro Einstein/sec/cm²) were taken just above bean plants and above maize crops or open space. Differences between radiation levels recorded above bean crops and those above the maize canopies or open space were expressed as percentage reduction in solar radiation reaching intercrop beans.

Effect of shading on *A. fabae* populations. Because of the large reduction of solar radiation reaching intercrop beans recorded in the field, the effect of varying the intensity of sunlight on the development of *A. fabae* populations on beans was investigated under cage conditions. Cages used measured 150 x 60 x 90 cm. The top of the control cage was covered with thin transparent polythene that allowed maximum incoming solar radiation, while treatment cages were screened with the polythene plus varied layers of green nylon mosquito netting. In the latter cages, relative light levels were approximately 65%, 15% and 5% of that in the control cage, reflecting variation in light penetration of maize canopies observed in the field. The sides of cages were screened with green mosquito netting that allowed free circulation of air and minimized temperature variation within the cages.

Test plants were raised by planting five bean

seeds in each of 40 plastic pots (top diameter 15 cm), and later thinning to three plants per pot. Two weeks after germination, each seedling was infested with four apterous *A. fabae* adults after which ten pots were placed in each cage.

During transfer, aphids are often injured and they may also fail to settle and effectively reproduce on the plants, thus leading to substantial reduction in population development. To reduce these variations, only four plants per cage bearing the largest aphid colonies were counted *in situ*, and the plants returned to the cages and used in subsequent assessment carried out at three-day intervals over three weeks.

Relative photosynthetic activity of the bean plants was measured in the last week of sampling using an infra-red leaf chamber gas analyzer (Model DL-1: The Analytical Development Co. Ltd., England). Rates of *A. fabae* population increase were calculated following the procedure described by Tamaki, McGuire and Turner (24), and the relationships between number of aphids on beans and level of shading, and between rate of aphid population increase and bean photosynthetic activity determined.

Abundance and diversity of coccinellid predators on beans. Evaluation of predator abundance and diversity was carried out in the same plots and bean rows, when assessing *A. fabae* incidence on beans. Plants in the two marked bean rows in each plot were searched weekly, and the species and number of coccinellid adults and larvae found recorded. Counts of the predators were taken between 1100 and 1500 hr, mainly on bright rain-free days, to minimize the influence of diurnal rhythms and the prevalent weather conditions on the activity of coccinellids (7).

RESULTS

Incidence of *A. fabae* on sole and intercropped beans. Intercropping reduced the incidence of *A. fabae* on common beans, particularly beans intercropped with more mature maize (Fig. 1). At peak incidence, four weeks after bean emergence, beans intercropped with maize planted two and four weeks earlier had significantly ($P \leq 0.01$) lower levels of aphid infestation compared to the

sole crop. There was also a significant negative relationship between percentage bean plants infested by aphids and height of intercrop maize ($Y = 53.65 - 0.494X + 0.0011X^2$).

The inhibitory influence of larger maize plants on colonization of beans by *A. fabae* was also reflected by data collected during 1986. The cumulative number of alates found on beans over a four-weeks period declined from an average of 405/row on sole crop beans to 42/row on beans intercropped with the oldest maize (Fig. 2).

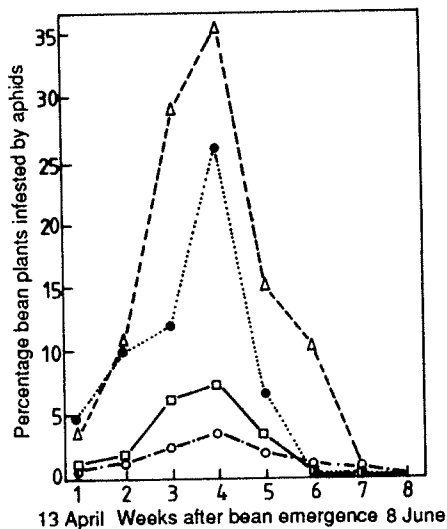


Fig. 1. Incidence of *Aphis fabae* on common beans grown as sole crop (Δ) and as intercrops with maize planted at the same time (●), and two (□) and four weeks earlier (○), Kabete, Kenya, 1985.

***A. fabae* landing response and bean colonization in the glasshouse.** Field results of aphid dispersal and bean colonization were supported by glasshouse tests. The number of *A. fabae* alates trapped on oil-sprayed maize leaves were significantly ($P \leq 0.01$) positively correlated with maize leaf area ($Y = 0.95 + 0.0143X - 0.00004X^2$; $R^2 = 0.994$); more aphids landed on the larger maize plants. This landing resulted in substantial reduction in the number of colonizers reaching intercrop beans, as was evidenced by the highly significant ($P \leq 0.01$) negative correlation between the number of *A. fabae* trapped on maize leaves and the number colonizing intercrop beans ($Y = 2.181 - 0.188X + 0.005X^2$; $R^2 = 0.990$), and

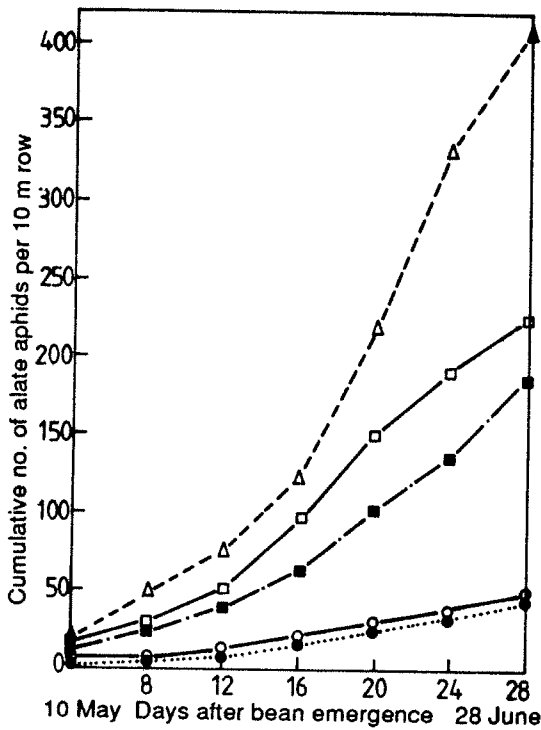


Fig. 2. Cumulative number of alate aphids found on beans grown as sole crop (Δ) and as intercrops with maize planted at the same time (\square) and 10 (\blacksquare), 20 (\circ) and 30 (\bullet) days earlier, Kabete, Kenya, 1986.

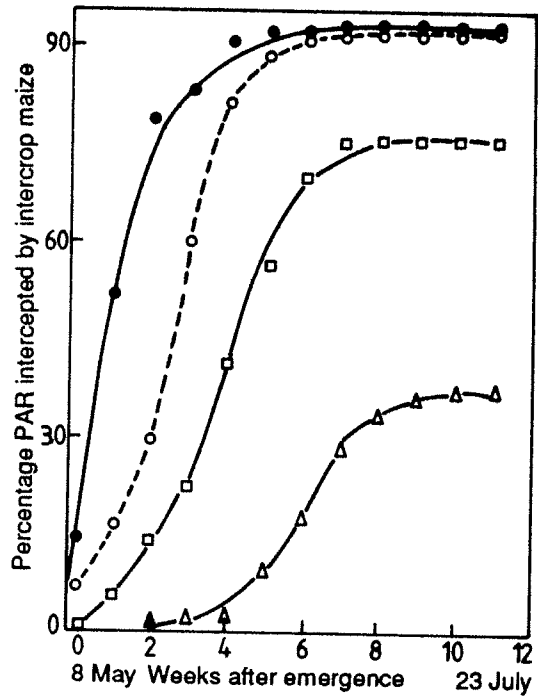


Fig. 3. Relative reduction in the level of solar radiation (PAR) reaching bean plants intercropped with maize planted at the same time (Δ), and 10 (\square), 20 (\circ), and 30 (\bullet) days earlier, Kabete, Kenya, 1986.

TABLE 1. Mean afternoon ambient temperature ($^{\circ}\text{C}$) around beans intercropped with maize planted at the same time with (0), and 10, 20, 30 days (d) earlier, Kabete, Kenya, 1986

Time of sampling (WABE)	Crop combination				
	Sole crop beans	Beans/ 0d maize	Beans/ 10d maize	Beans/ 20d maize	Beans/ 30d maize
1	23.9b	23.9b	23.8b	22.2b	22.1a
2	25.3c	25.3c	24.7b	24.0ab	23.5a
3	23.1b	23.8b	20.4a	20.0a	20.5a
4	23.2c	22.8bc	21.6bc	20.3ab	19.3a
5	25.2b	24.6b	23.7a	22.4a	22.8a
6	25.0b	25.4b	22.5a	21.3a	21.4a
7	18.6b	18.1b	17.8b	16.6a	16.7a
8	21.7c	21.4c	19.9b	17.8a	17.7a

WABE: Weeks after bean emergence.

a,b,c: Means in each row followed by the same letters are not significantly different at $P \leq 0.05$ (Duncan's Multiple Range Test).

between the number of alates trapped and percentage of beans infested by the aphid ($Y = 72.742 - 3.831X = 0.093X^2$; $R^2 = 0.996$).

Modification of bean microclimate by intercrop maize. Intercrop maize, particularly older plants, lowered ambient temperatures around bean plants (Table 1). In the fifth week of bean growth, for example, maximum temperatures recorded around sole crop beans and beans in the simultaneous intercrop averaged 25.2°C and 24.6°C, respectively. These were significantly ($P < 0.01$) higher than the 22.8°C and 22.4°C recorded in the two intercrops with the oldest maize plants, respectively.

The greatest variation in bean microclimatic conditions was, however, related to the level of solar radiation reaching beans in the intercrops (Fig. 3). Larger proportions of incident light were intercepted by older maize plants, and the pattern of light interception was closely related to the growth characteristics of the maize. In the 30-day maize intercrop, there was a quadratic change in the pattern of light interception ($Y = 30.461 + 18.899X - 1.276X^2$) with maize growth, and it peaked at the time of maize tasselling. In the younger maize intercrops, less light was intercepted and the pattern of shading was essentially sigmoidal ($\log Y = 0.266 + 0.436X - 0.027X^2$ for 10-day maize, and $\log Y = 0.239 + 0.298X - 0.011X^2$ in the simultaneous intercrop), reflecting the lower rates of growth of these late planted maize.

Effect of shading on *A. fabae* populations. The build-up of *A. fabae* populations on caged beans (Fig. 4) showed that low light levels in the intercrops had adverse effects on aphid development. At 5% incident light, aphid multiplication was virtually inhibited and its population peaked within six days. In contrast, rapid build-up of *A. fabae* populations occurred at 65% and 100% radiation levels and, three weeks after infestation, there were 565 and 771 aphids per plant, respectively (Fig. 4).

There was a highly significant ($P \leq 0.01$) positive correlation between the mean number of aphids per plant and the level of light reaching bean plants ($Y = 25.75 + 11.97X - 0.0406X^2$; $R^2 = 0.98$). A significant positive correlation was also

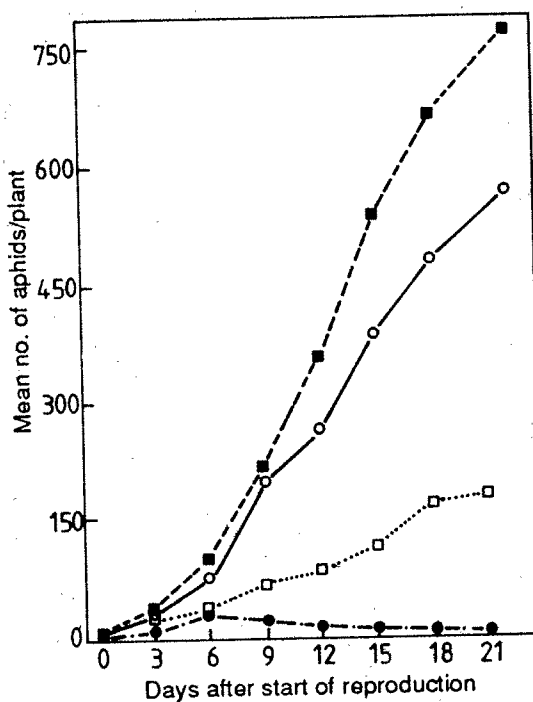


Fig. 4. Build-up of *Aphis fabae* populations on bean plants kept in cages at 100% (□), 65% (○), 15% (■), and 5% (●) relative light levels.

obtained between the rates of aphid population increase and bean photosynthesis ($Y = 0.889 + 0.119X - 0.0086X^2$, $R^2 = 0.96$). Evidently, lower light levels in older maize intercrops reduced bean photosynthetic activity and the build-up of *A. fabae* populations on beans.

Abundance and diversity of coccinellid predators on beans. Coccinellid predators were most abundant on sole crop beans and, throughout the study period, fewer predators were found on beans intercropped with the more mature maize (Fig. 5). On sole crop beans, and to a lesser extent on beans planted simultaneously with intercrop maize, the number of coccinellids built up rapidly and reached a peak five weeks after bean emergence. In contrast, the build-up of predators on beans intercropped with the older maize plants was low, and their populations declined after the sixth week of bean growth. The low number of coccinellid predators on intercrop beans was probably due to low *A. fabae* incidence

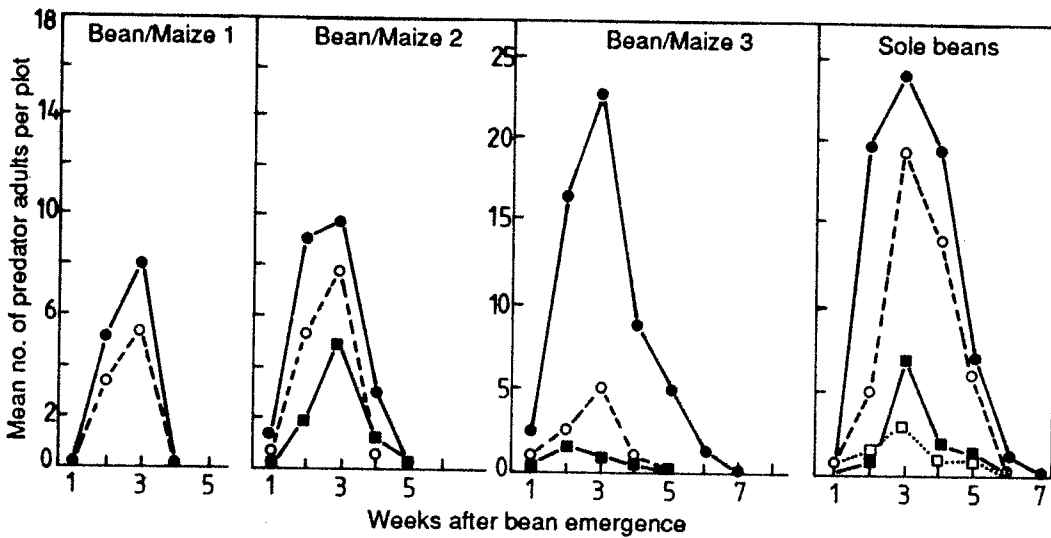


Fig. 5. Relative abundance and persistence of adults *Cheilomenes lunata* (●); *C. vicina* (■); *Hippodamia variegata* (○) and *Platynaspis capicola* (□) on common beans grown as sole crop and as intercrops with maize planted at the same time (maize 3), and two (maize 2) and four (maize 1) weeks earlier, Kabete, Kenya, 1985.

TABLE 2. Occurrence of coccinellid predators on common beans grown as sole crop and as intercrops with maize planted at the same time (0), and two and four weeks (wk) earlier, Kabete, Kenya, 1985

Coccinellid species	Crop combination			
	Sole bean	Bean/0wk maize	Bean/2wk maize	Bean/4wk maize
<i>Cheilomenes aurora</i> Gerst	*	*	—	—
<i>C. lunata</i> Fab.	*	*	*	*
<i>C. sulphurea</i> Oliv.	*	*	—	—
<i>C. vicina</i> Muls.	*	*	*	—
<i>Hippodamia variegata</i> Goez.	*	*	*	*
<i>Platynaspis capicola</i> Crot.	*	—	—	—
<i>Scymnus trepidulus</i> Weise	*	*	*	*

*: species present; —: species not observed.

on beans. At peak populations, there was a highly significant ($P \leq 0.01$; $R^2 = 0.99$) correlation between the mean number of predators on beans and percentage bean plants infested by aphids ($Y = 1.29 + 0.31X + 0.0024X^2$).

The greatest diversity of predator species was recorded on sole crop beans, and species number declined with increased age of intercrop maize (Table 2). The species *Platynaspis capicola* Crotch was not found in any of the intercrops, while *Cheilomenes aurora* Gerst. and *C. sulphurea* were found only on sole crop beans and on beans planted simultaneously with intercrop maize

(Table 2). The persistence of the different coccinellid species was also reduced on beans intercropped with the older maize crops.

DISCUSSION

This study clearly demonstrated that maize growth was important in reducing *A. fabae* infestation of intercrop beans. Larger plants adversely influenced the host finding and colonization behaviour of aphids, and the activity of aphid natural enemies. They also altered the microclimatic conditions to which the aphids were exposed.

Greater canopy cover provided by older and larger maize plants probably constituted a direct visual barrier to bean colonization by *A. fabae* (12). More likely, however, the maize plants disrupted the physical process of host location. Aphids that land on a potential host plant sample it for suitability, and the rejection of a non-host is usually followed by take-off from the plant (26). It was considered that as a consequence of this take-off, fewer *A. fabae* alates penetrated the larger maize canopies to reach and colonize intercrop beans. This is supported by results of the glasshouse test, which showed that where many *A. fabae* alates landed on the larger maize plants, the number of colonizing aphids and the extent of bean infestation was greatly reduced. In a related study (16), densely planted maize significantly inhibited aphid infestation of intercrop beans.

The data also showed that as intercrop maize plants grew, changes in bean microclimate occurred, as both light and ambient temperature levels were significantly reduced. However, temperature variation in the different intercrops probably had no significant effects on *A. fabae* incidence on beans. This is because the ranges obtained were small, with the highest variation being less than 4°C, even during the afternoon period when maximum variability would be expected. When temperature levels are integrated over a 24-hour period, this variation is even smaller and cannot contribute to the large differences in aphid incidence on the bean crops.

Shading was probably the most important microclimatic variation resulting from the growth of intercrop maize. Evidence from cage studies showed that large reduction in solar radiation levels reaching beans in the intercrops reduced bean photosynthetic activity and deprived *A. fabae* of plant assimilates required for growth, development, and reproduction (1). This nutritional deprivation seems of particular importance amongst homopterans, since morphs of many species are apterous or sedentary and essentially parasitic on host plants. Shading probably also affected the host finding behavior of the aphids, either because of their strong positive phototactic reaction (12) or a strong negative reaction to the darker bean habitats. In previous studies, shading was shown to reduce the

nutritional quality of plants, and to adversely affect pest feeding and dispersal (13; 21). It seems, therefore, that where substantial maize growth is achieved before the build-up of *A. fabae* infestation on beans, effective control of the aphid may occur not only by the direct effects of maize on the aphid but also through adverse modification of bean microclimate.

Results also indicated that the species range and populations of coccinellid predators preying on *A. fabae* on beans declined with maize growth and increased structural complexity of the bean-maize intercrops. This was contrary to general predictions based on the "enemies hypothesis" (19; 23), and to reports of natural enemy abundance in diverse agroecosystems (10; 20). It was apparent that natural enemies played a limited role, if any, in reducing aphid incidence on intercrop beans. The availability of *A. fabae* prey seemed the critical factor influencing the dynamics of coccinellid populations on beans. Predators were least abundant and diverse on beans intercropped with the oldest maize plants, which also had the lowest levels of aphid infestation. In diverse crop situations, predators accumulate only in patches of high prey density, as low prey levels reduce tenure time and reproductive responses (2; 8; 14). This characteristic perhaps explains the greater abundance and diversity of coccinellids on sole crop beans on which large populations of aphids obtained.

Another factor that may have influenced predator abundance and diversity on intercrop beans was habitat preference, as evident by the absence of *P. capicola* from all intercrop beans. Such habitat discrimination is an important characteristic of many predator species, and influences their responses to crop and prey situations (5; 9). It is also likely that intercrop maize interfered with the movement and foraging behaviour of the predators, as shown by Risch *et al.* (22) for the coccinellid *Coelomegilla maculata* (DeGeer).

It is concluded that intercropping beans with rapidly growing maize may constitute an important factor in reducing the incidence of pests on beans. Enhanced *A. fabae* control by natural enemies seems of little importance. The key factors for aphids, and probably other related pests, are: reduced resource concentration, interference with

host finding behaviour and, in advanced stages of maize growth, the modification of bean microclimate. However, as shown by a related assessment of bean yields (17), the reduction in pest incidence through intercropping may not necessarily be of agricultural significance. Yield gains resulting from reduced pest attack under these circumstances are often too small compared to losses resulting from crop competition. Before recommending a given intercropping practice for pest control, therefore, these relationships must be adequately studied.

ACKNOWLEDGEMENTS

This work was conducted at the Field Station of the University of Nairobi, Kabete, when the first author was an ARPPIS Scholar at the International Centre of Insect Physiology and Ecology (ICIPE). The support of the two institutions is greatly acknowledged. The research was financed by a scholarship grant by the Ford Foundation.

REFERENCES

- Altieri, M.A., C.A. Francis, A. Van Schoonhoven and D.J. Doll, 1978. A review of insect prevalence in maize (*Zea mays*) and bean (*Phaseolus vulgaris* L.) polyculture systems. *Field Crops Research* 1: 33-49.
- Bryant, K.M. and S.D. Wratten, 1984. The response of polyphagous predators to prey spatial heterogeneity: aggregation by carabid and staphylinid beetles to their cereal aphid prey. *Ecological Entomology* 9: 251-259.
- Davidson, J. 1925. Biological studies of *Aphis rumicis* Linn. Factors affecting the infestation of *Vicia faba* with *Aphis rumicis*. *Annals of Applied Biology* 12: 472-507.
- Ezueh, M.I. and T.A. Taylor, 1984. Effects of time of intercropping with maize on cowpea susceptibility to three major pests. *Tropical Agriculture Trinidad* 61: 82-86.
- Ewert, M.A. and H.C. Chiang, 1966. Dispersal of three species of coccinellids in corn fields. *Canadian Entomologist* 98: 999-1003.
- Francis, C.A., M. Prager and G. Tejada, 1982. Effects of relative planting dates in bean (*Phaseolus vulgaris* L.) and maize (*Zea mays* L.) intercropping. *Field Crops Research* 5: 45-54.
- Frazer, B.D. and D.A. Raworth, 1985. Sampling for adult coccinellids and their numerical response to strawberry aphids (Coleoptera: Coccinellidae; Homoptera: Aphididae). *Canadian Entomologist* 117: 153-161.
- Hassell, M.P. and T.R.E. Southwood, 1978. Foraging strategies in insects. *Annual Review of Ecology and Systematics* 9: 75-98.
- Honek, A. 1985. Habitat preferences of aphidophagous coccinellids (Coleoptera). *Entomophaga* 30: 253-264.
- Horn, D.J. 1981. Effect of weedy background on colonization of collards by green peach aphid (*Myzus persicae*), and its major predators. *Environmental Entomology* 10: 285-289.
- Kennedy, J.S. and H.L.G. Stroyan, 1959. Biology of aphids. *Annual Review of Entomology* 4: 139-160.
- Kennedy, J.S., C.O. Booth, and Kershaw, W.J.S. 1961. Host finding by aphids in the field. III. Visual attraction. *Annals of Applied Biology* 49: 1-21.
- Kyamanywa, S. and J.K.O. Ampofo, 1988. Effect of cowpea/maize mixed cropping on the incident light at the cowpea canopy and flower thrips (Thysanoptera; Thripidae) population density. *Crop Protection* 7: 186-189.
- Letourneau, D.K. 1990. Mechanisms of predator accumulation in a mixed crop system. *Ecological Entomology* 15: 63-69.
- Mumford, J.D. and C.W. Baliddawa, 1983. Factors governing insect occurrence in various cropping systems. *Insect Science and its Application* 4: 49-64.
- Ogenga-Latigo, M.W., J.K.O. Ampofo and C.W. Baliddawa, 1992. Influence of maize row spacing on infestation and damage of intercropped beans by the bean aphid (*Aphis fabae* Scop.) I. Incidence of aphids. *Field Crops Research* 30: 111-121.
- Ogenga-Latigo, M.W., C.W. Baliddawa and J.K.O. Ampofo, 1992. Influence of maize row spacing on infestation and damage of intercropped beans by the bean aphid (*Aphis fabae* Scop.). II. Reduction in bean yields.

- Field Crops Research* 30: 123–130.
18. Perrin, R.M. 1980. The role of environmental diversity in crop protection. *Protection Ecology* 2: 77–114.
 19. Pimentel, D. 1961. Species diversity and insect population outbreaks. *Annals of the Entomological Society of America* 54: 76–86.
 20. Risch, S.J. 1979. A comparison of sweep sampling of the insect fauna from corn and sweet potato monocultures and dicultures in Costa Rica. *Oecologia* 42: 195–211.
 21. Risch, S.J. 1981. Insect herbivore abundance in tropical monocultures and polycultures: an experimental test of two hypotheses. *Ecology* 62: 1325–1340.
 22. Risch, S.J., R. Wrubel and D.A. Andow, 1982. Foraging by a predacious beetle, *Coelomegilla maculata* (Coleoptera: Coccinellidae) in a polyculture: effects of plant density and diversity. *Environmental Entomology* 11: 949–950.
 23. Root, R.B. 1973. Organization of plant-arthropod associations in simple and diverse habitats: The fauna of collards (*Brassica oleracea*). *Ecological Monographs* 43: 95–124.
 24. Tamaki, G., J.U. McGuire and J.E. Turner, 1974. Predator power and efficiency: A model to evaluate their impact. *Environmental Entomology* 3: 625–630.
 25. Taylor, C.M. and E.F. Lawes, 1971. Rainfall intensity frequency duration data for stations in East Africa. *East African Meteorological Department Technical Memorandum No. 17*.
 26. Van Emden, H.F. 1973. Aphid host plant relationships. In: *Perspectives in Aphid Biology*, pp.54–64. The Entomological Society of New Zealand *Bulletin No. 2*.