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Effect of intercrops on thrips species composition and population abundance on French beans in Kenya

J. O. Nyasani[1,2,3], R. Meyhöfer[2], S. Subramanian[3]* & H.-M. Poehling[2]

[1]*Kenya Agricultural Research Institute, PO Box 27-60100, Embu, Kenya,* [2]*Leibniz Universität Hannover, Institute of Plant Diseases and Plant Protection, Herrenhäuser Strasse 2, 30419 Hannover, Germany, and* [3]*International Centre of Insect Physiology and Ecology, PO Box 30772-00100, Nairobi, Kenya*

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Abstract

The study aimed at determining thrips species composition and thrips population density on French bean planted as a sole crop and as an intercrop with either sunflower, Irish potato, or baby corn, in various combinations. Field experiments were conducted in two seasons to examine: (1) thrips population development and thrips species composition over time, (2) effect of intercrops on thrips population density and natural enemies, and (3) effect of intercrops on French bean yield. The experiments were conducted at the Kenya Agricultural Research Institute, Embu, Kenya in a randomized complete block design with four replicates. The thrips population on French beans increased with time. It showed a peak at the flowering stage then started declining when the crops were nearing senescence. French beans hosted four thrips species, *Megalurothrips sjostedti* (Trybom), *Frankliniella schultzei* (Trybom), *Frankliniella occidentalis* (Pergande), and *Hydatothrips aldolfifriderici* (Karny) (all Thysanoptera: Thripidae) in order of decreasing abundance. The main thrips species on Irish potato and sunflower was *F. schultzei*. Baby corn hosted only *Frankliniella williamsi* (Hood) and *Thrips pusillus* (Bagnall). A monocrop of French bean hosted more thrips than a French bean intercrop mix. Thrips natural enemies such as *Orius* spp. and *Ceranisus* spp. were recorded in all crop plants but in especially high numbers on French bean and baby corn, respectively. Plots with French bean alone had about 1.4 times higher yields compared to intercropped plots of French bean with sunflower and French bean with baby corn. However, the percentage of pods that could get rejected on the market due to thrips damage was highest on plots with French bean alone (68 and 63%) and lowest on plots with French bean and baby corn (35 and 37%) in the first and second seasons, respectively. This study showed that a complex of thrips is found in the field and its composition varies with crop stage and species. Intercropping French bean with other crops compromises on French bean yield but reduces damage to the French bean pods, thereby enhancing marketable yield.

Introduction

French bean, *Phaseolus vulgaris* L. (Fabaceae), is the most cultivated horticultural crop by both small- and large-scale farmers across Central, Eastern, Western, and Coast provinces of Kenya (Onkoba, 2002). French beans constitute nearly 20% by volume and 60% by value of all fresh horticultural exports from Kenya (HCDA, 2007). Farmers also sell their produce to local supermarkets, greengrocers, restaurants, and fast food kiosks. Pests and diseases are the major constraints to French bean production in Kenya (Nderitu et al., 2007a). The major insect pests affecting French bean production in Kenya are bean stem maggot (*Ophiomyia* spp.), bean flower thrips [*Megalurothrips sjostedti* (Trybom)], western flower thrips [*Frankliniella occidentalis* (Pergande)], common blossom thrips [*Frankliniella schultzei* (Trybom)], bean aphids (*Aphis fabae* Scopoli), red spider mites (*Tetranychus* spp.), the African bollworm [*Helicoverpa armigera* (Hübner)], the legume pod borer [*Maruca vitrata* (Fabricius)], and white

*Correspondence: S. Subramanian, International Centre of Insect Physiology and Ecology, PO Box 30772-00100, Nairobi, Kenya. E-mail: ssubramania@icipe.org

flies [*Bemisia tabaci* (Gennadius)] (Nderitu et al., 2007a). Pests reduce the quality and quantity of pod yield and affect the entire production period. In Kenya, yield losses of more than 40% have been reported due to thrips feeding, resulting in abscission of flower buds, opening of flower peduncles, and flower abortion (Löhr, 1996). Additional losses of 20% at collection points due to rejection of curled pods and pods with blemishes and lesions have been recorded (Kibata & Anyango, 1996; Löhr, 1996).

Four thrips (Thysanoptera: Thripidae) species are common in bean fields in Kenya: *M. sjostedti*, *F. occidentalis*, *F. schultzei*, and *Hydatothrips aldolfifriderici* (Karny) (Nyasani et al., 2010). *Megalurothrips sjostedti* is a common and widespread pest in Africa (Karungi et al., 2000; Alabi et al., 2004; Ngakou et al., 2008). *Megalurothrips sjostedti* and *H. aldolfifriderici* feed mainly on legumes, particularly beans, cowpeas, and soya bean (Nabirye et al., 2003). *Frankliniella occidentalis* is invasive and was reported for the first time in Kenya in 1989 (Kedera & Kuria, 2003). This thrips species is polyphagous, feeding and breeding on more than 240 host species belonging to 62 plant families, mainly from the Solanaceae. *Frankliniella schultzei* is widespread around the world in tropical countries and is an effective vector of tospoviruses (Tommasini & Maini, 1995). There is no information on the role of *F. schultzei* and *H. aldolfifriderici* on French bean production in East Africa as research has always focused on *M. sjostedti* and *F. occidentalis*. Thrips significantly affect the productivity of French bean and their short life cycle enables several overlapping generations of thrips within a production cycle of a given crop (McDonald et al., 1998). Therefore, growers often resort to repeated and indiscriminate use of several groups of insecticides to control thrips. Foliar sprays of chemical insecticides often fail to manage thrips because of their cryptic feeding behaviour and ability to pupate in the soil (Berndt et al., 2004).

Commercial growers in Kenya rely heavily on pesticides to manage thrips, especially *F. occidentalis* (Nderitu et al., 2007b, 2008). However, *F. occidentalis* has developed resistance to pesticides belonging to the carbamate, organophosphate, organochlorine, and pyrethroid chemical groups (Nderitu et al., 2007a). Small-scale farmers practice intercropping as a cultural control practice against pests and to obtain greater total land productivity, expressed by the land equivalent ratio (Songa et al., 2007). Intercropping tends to result in lower levels of insect pests than the corresponding monocropping due to associational resistance of the agroecosystem to herbivores (Finckh & Karpenstein-Machan, 2002). Intercrops attract or repel pests from the main crop and also encourage build-up of natural enemies. Crop structure, chemical environment, and microclimate are factors that can play a role in pest suppression and are components of associational resistance (Rämert et al., 2002). Effects of intercropping on thrips infestations have been evaluated in several systems, such as strawberry with broad beans (Gonzalez-Zamora et al., 1994), sweet pepper with tomato (Nihoul & Hance, 1994), maize with cowpea (Kyamanywa et al., 1993), French bean with maize (Kasina et al., 2006), and pinto beans with sweet corn (Capinera et al., 1985). In these systems, thrips populations in the intercrop mix were lower than in a sole crop. In the mixed cropping practiced by small-scale Kenyan farmers, the common crop plants grown alongside French bean are baby corn, Irish potato, and sunflower. Baby corn is grown mainly for the export market and Irish potato and sunflower are sold on the local market. However, detailed field experiments looking at the effect of intercrops on thrips species composition and population density on French beans have not been conducted in Kenya and other parts of the world. In this regard, we set out experiments to look at the effect of intercropping French bean with sunflower, Irish potato, and/or baby corn on thrips species, and their natural enemy composition, and population abundance.

Materials and methods

The experiments were conducted at the Kenya Agricultural Research Institute (KARI), Embu station, which is characterized by its fairly flat and structurally good landscape. KARI-Embu is located in the upper midlands 2 (UM2) agroecological zone at an altitude of 1 480 m a.s.l. (00°30′S, 37°27′E). Its soils are classified as humic nitisols. It receives a mean annual rainfall of 1 238 mm. The rainfall is bimodal, with long rains starting from late March to May and short rains starting from October to December. We conducted experiments during two seasons: the long rains season (March–May 2009) and short rains season (October–December 2009). Based on the Kenyan farmers' common French bean cropping systems, we had six treatments: (1) French bean (var. Amy) alone, (2) intercrop of sunflower (Sf) [*Helianthus annuus* L. var. H-8998 (Asteraceae)] and French bean (Fb) (1Sf:5Fb:1Sf:5Fb:1Sf rows), (3) intercrop of baby corn (Bc) [*Zea mays* L. var. ZS 2O6 (Poaceae)], and French bean (1Bc:5Fb:1Bc:5Fb:1Bc rows), (4) intercrop of Irish potato (Ip) [*Solanum tuberosum* L. var. Tigoni (Solanaceae)] and French bean (1Ip:5Fb:1Ip:5Fb:1Ip rows), (5) intercrop of baby corn, French bean, and sunflower (1Bc:5Fb:1Sf:5Fb:1Bc rows), and (6) intercrop of Irish potato, French bean, and sunflower (1Ip:5Fb:1Sf:5Fb:1Ip rows). The same treatments were used in the two seasons.

The treatments were replicated four times in a randomized complete block design. Experimental plots of 5 × 10 m were used. French beans were planted in 10 rows in the experimental plots, spaced at 50 × 10 cm (rows × plants). Spacing for baby corn and Irish potato was 30 cm between plants. There were 2-m buffers left bare all around the experimental plots. Guard rows of French beans were planted around the main experimental field 2.5 m away from the edge to minimize edge effects. Cultural practices as recommended by KARI were adopted (KARI, 2005).

Starting 21 days after planting, field observations were made every 2 weeks for the first two sampling times, and thereafter every week until crop senescence. In each experimental plot, 10 individual plants were randomly sampled and beaten over a white enamel tray to collect thrips and natural enemies. Thrips were further processed in the laboratory and identified using the 'Pest Thrips of the World' Lucid key developed by Moritz et al. (2004). Voucher specimens of slide-mounted thrips from this study are maintained in the thrips specimen collection at *icipe*, Kenya. The phenological stage of French beans was recorded at each observation. At podding stage, French bean pods were harvested from 20 plants in a 1-m^2 quadrat from each experimental plot for assessment of yield and damage. Damage on the pods was rated on a scale of 1–5 adopted from McKenzie et al. (1993), where 1 = no damage (0%), 2 = slight damage (≤25%), 3 = moderate damage (25–50%), 4 = severe damage (50–75%), and 5 = very severe damage (>75%). French bean pods in damage score groups 3–5 were weighed to calculate the percentage of unmarketable pods by weight. The prevailing weather conditions were monitored throughout the experiment from a weather station 200 m away.

Data analysis

To avoid pseudo-replication, the observed insect counts recorded per plant were converted into additive components and the mean population density per plant was calculated. The thrips count data were analysed using repeated measures analysis of variance (ANOVA) using SAS statistical software (SAS Institute, 2008). Long and short rains data were analysed separately. Yield data were subjected to one-way ANOVA in a randomized complete block design using SAS. Specific comparisons among treatments were made with Tukey's honestly significant difference test at $\alpha = 0.05$. Correlation between the prevailing weather conditions (average daily temperature, rainfall, and sunshine hours) and thrips population per sample date was calculated using Proc CORR (SAS Institute, 2008).

Results

Thrips population development and affinity to different crop plants

The weather pattern during the two seasons was variable. The mean daily temperatures during the long rains (March–May 2009) and short rains (October–December 2009) season were 21.1 and 19.7 °C, respectively. Mean rainfall and daily sunshine during the long and short rains were 3.7 and 2.0 mm and 8.5 and 6.6 h, respectively. Thrips populations per sample date regardless of treatment were strongly correlated with average temperature ($r = 0.604$, d.f. = 10, $P = 0.037$). A Pearson correlation analysis failed to explain the effect of rain ($r = 0.367$, d.f. = 10, $P = 0.24$) and sunshine hours ($r = 0.274$, d.f. = 10, $P = 0.39$) on thrips population. The overall thrips population in the long rains season was about 3× higher than that recorded in the short rains ($F_{1,3} = 91.40$, $P = 0.002$) (Figure 1). Nevertheless, thrips population development over time was similar in both seasons. Colonization of crops started at 14 days after plant emergence, the population peaks were at the flowering stage and they

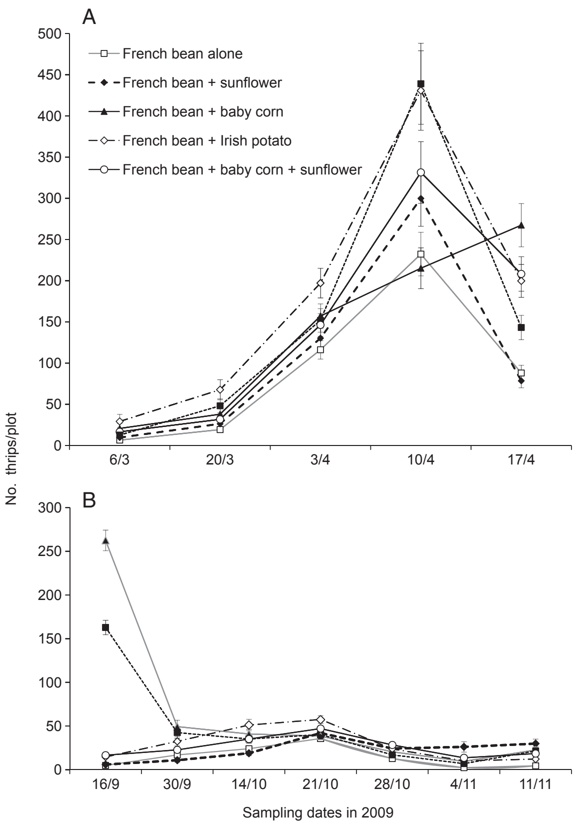

Figure 1 Mean (± SE) number of thrips captured in each treatment at the various sampling dates during the (A) long and (B) short rains seasons at KARI-Embu, Kenya in 2009.

declined during crop senescence. The increase in thrips abundance from 1 week before flowering, to flowering stage, was two- to three-fold in all treatments (Figure 1).

Although population development was similar in all treatments and seasons, several thrips species were recorded on the crop plants. The main thrips species on French beans in the two seasons in order of decreasing population abundance were *M. sjostedti*, *F. schultzei*, *F. occidentalis*, and *H. aldolfifriderici*. In sunflower and Irish potato, the thrips species observed in order of decreasing population abundance were *F. schultzei* (>70%), followed by *F. occidentalis* (>15%), and *M. sjostedti* and *H. aldolfifriderici*, which were recorded in low numbers. The thrips species observed on baby corn were different from those that colonized other crops; *Frankliniella williamsi* (Hood) (>80%) was dominant on baby corn during the short rains and *Thrips pusillus* (Bagnall) (>80%) in the long rains season. The pattern of thrips population development on the French bean guard rows in the N/S and E/W directions was the same ($F_{1,3} = 1.27$, $P = 0.34$). There was evidence of equal immigration of thrips in the N/S and E/W directions within the experimental plots ($F_{1,3} = 0.77$, $P = 0.44$).

Population development of thrips species on French beans and intercrops

Because the economic importance of insect herbivores depends greatly on the life stage and tissue of the plant they attack, and on their method of feeding, we focused on the week before flowering (budding) and the flowering stage of French beans, which are the most susceptible stages of the crop to damage (Edwards & Singh, 2006). All crop plants used in the experiment flowered at the same time.

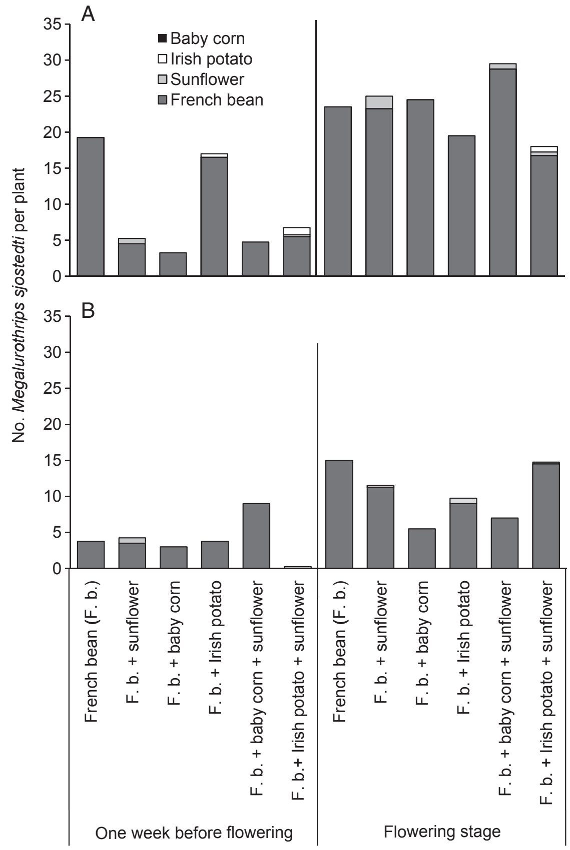

Figure 2 Mean number of *Megalurothrips sjostedti* captured per French bean, sunflower, Irish potato, and baby corn plant in the various treatments at 1 week before flowering and at flowering stage in the (A) long and (B) short rains seasons at KARI-Embu, Kenya in 2009.

Megalurothrips sjostedti. In the long rains season, there were significantly more *M. sjostedti* on a monocrop of French bean at 1 week before flowering compared with the population on French bean in the intercrop mix ($F_{5,15} = 26.37$, $P<0.001$) (Figure 2). However, this difference was no longer significant at flowering 1 week later ($F_{5,15} = 1.14$, $P = 0.38$) (Figure 2). In the short rains season there were no significant differences in the number of *M. sjostedti* hosted by French beans in the different treatments at 1 week before flowering and at flowering stage ($F_{5,15} = 1.95$ and 2.27, $P = 0.14$ and 0.060, respectively) (Figure 2). Although there were no significant differences among treatments, there was a general increase in *M. sjostedti* population from 1 week before flowering, to flowering stage, in both seasons. We observed a different trend in the *M. sjostedti* population on the intercrops that were grown together with French bean. In both the short and long rains seasons, the population of *M. sjostedti* was highest on French beans and lowest on Irish potato and sunflower ($F_{3,9} = 58.57$ and 53.41, respectively, both $P<0.001$) (Figure 2). *Megalurothrips sjostedti* was not recorded on baby corn in the two seasons (Figure 2).

Frankliniella schultzei. There were no significant differences in the numbers of *F. schultzei* hosted by a monocrop of French bean compared with other treatments at 1 week before flowering and flowering stage in the long rains season ($F_{5,15} = 1.66$ and 0.48, $P = 0.20$ and 0.78, respectively) and in the short rain season ($F_{5,15} = 2.61$ and 1.27, $P = 0.068$ and 0.33, respectively) (Figure 3). In both seasons, a characteristic trend in *F. schultzei* population in the various treatments was observed. The population of *F. schultzei* on French beans decreased with the increase in number of associate crops (Figure 3). The population of *F. schultzei* on sunflower was low at 1 week before flowering and at flowering stage in the long rains season

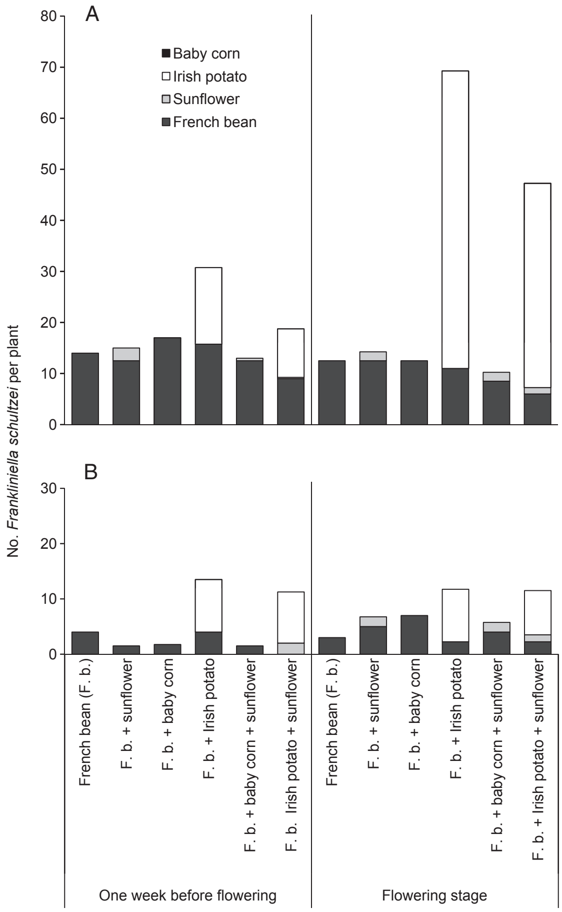

Figure 3 Mean number of *Frankliniella schultzei* captured per French bean, sunflower, Irish potato, and baby corn plant in the various treatments at 1 week before flowering and at flowering stage in the (A) long and (B) short rains seasons at KARI-Embu, Kenya in 2009.

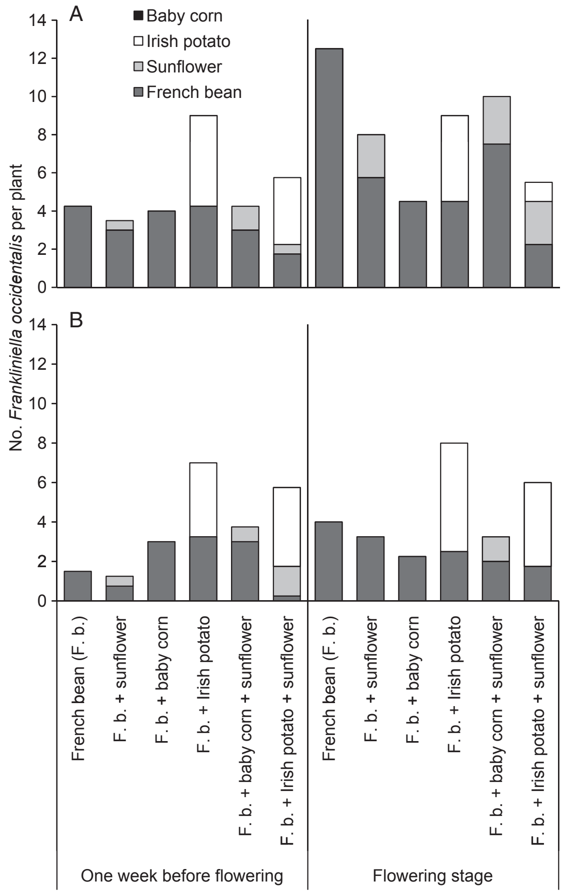

Figure 4 Mean number of *Frankliniella occidentalis* per French bean, sunflower, Irish potato, and baby corn plant in the various treatments at 1 week before flowering and at flowering stage in the (A) long and (B) short rains seasons at KARI-Embu, Kenya in 2009.

(Figure 3). The trend of *F. schultzei* on intercrops was different from the trend on French bean plants. The population of *F. schultzei* on Irish potato at flowering stage was highest compared with French bean and sunflower in the long and short rains seasons ($F_{1,3}$ = 31.68 and 11.88, P = 0.011 and 0.041, respectively) (Figure 3). *Frankliniella schultzei* was not recorded on baby corn (Figure 3).

Frankliniella occidentalis. There were three- and two-fold increases in the population of *F. occidentalis* on a monocrop of French bean from 1 week before flowering, to flowering stage in the long and short rains, respectively (Figure 4). There were no significant differences in the number of *F. occidentalis* recorded on a monocrop of French bean compared with other treatments at 1 week before flowering and at flowering stage in the long rains season ($F_{5,15}$ = 0.48 and 1.21, P = 0.79 and 0.35, respectively) (Figure 4). A similar trend was recorded in the short rains season (Figure 4). There were no significant differences in the number of *F. occidentalis* hosted by French beans and Irish potato at 1 week before flowering and at flowering stage in the two seasons (Figure 4). Sunflower hosted the lowest number of *F. occidentalis* compared with French bean and Irish potato at 1 week before flowering and at flowering stage in the two seasons (Figure 4). We did not record *F. occidentalis* on baby corn (Figure 4).

Hydatothrips aldolfifriderici. The population of *H. aldolfifriderici* on French bean doubled from 1 week before flowering to the flowering stage in the long rains season (Figure 5). However, there were no significant differences in the number of *H. aldolfifriderici* hosted by French beans

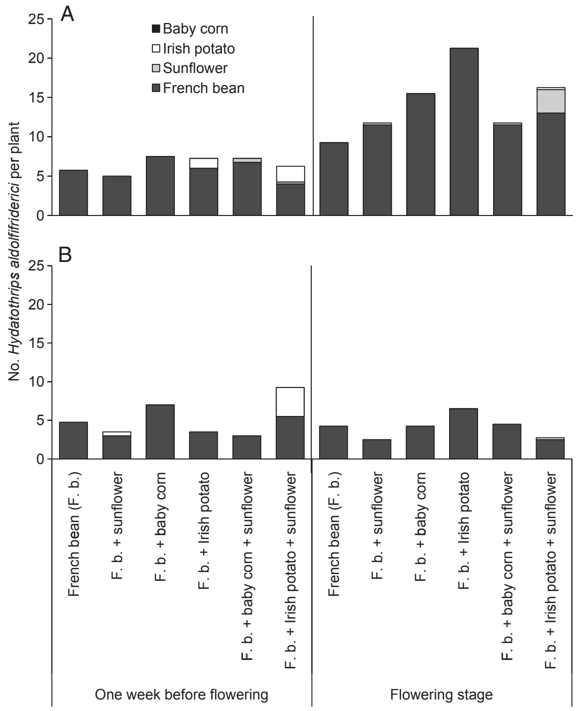

Figure 5 Mean number of *Hydatothrips aldolfifriderici* captured per French bean, sunflower, Irish potato, and baby corn plant in the various treatments at 1 week before flowering and at flowering stage in the (A) long and (B) short rains seasons at KARI-Embu, Kenya in 2009.

in all treatments at both 1 week before flowering and at flowering stage in the long rains season ($F_{5,15}$ = 0.99 and 0.82, P = 0.45 and 0.55, respectively) (Figure 5). In the short rains season there were no significant differences in the number of *H. aldolfifriderici* hosted on French bean as a monocrop and when intercropped with either sunflower, baby corn, or Irish potato at 1 week before flowering and at flowering stage ($F_{5,15}$ = 0.67 and 2.83, P = 0.65 and 0.054, respectively) (Figure 5). The population of *H. aldolfifriderici* on French bean was higher than on sunflower and Irish potato at both 1 week before flowering and at flowering stage in the two seasons (Figure 5). *Hydatothrips aldolfifriderici* was not recorded on baby corn (Figure 5).

Effect of intercrops on the population density of natural enemies on French beans

Two natural enemies of thrips were collected from the field studies: *Orius* spec. (Hemiptera: Anthocoridae) and *Ceranisus* spec. (Hymenoptera: Eulophidae). A monocrop of French beans harboured the lowest number of *Orius* spec. (on average 2.3 individuals per plant) compared to that recorded on French beans in the other treatments in both the long and short rains season ($F_{5,15}$ = 2.93 and 3.83, P = 0.048 and 0.019, respectively). The number of *Orius* spec. recorded on French bean and baby corn in the French bean-baby corn intercrop mix was not different in both the long and short rains season (Table 1). Conversely, the number of *Orius* spec. hosted by sunflower when it was intercropped with French bean alone was about 3× higher than that recorded on French bean in both the long and short rains season (Table 1). Irish potato hosted the fewest *Orius* spec. (on average 0.1 individuals per plant) compared to French beans (5.3 individuals per plant) in the French bean-Irish potato intercrop mix in the long rains season (Table 1). In the long rains season, the number of *Orius* spec. hosted by French bean and Irish potato in the French bean-Irish potato intercrop mix did not differ (Table 1).

The number of *Ceranisus* spec. hosted by a monocrop of French bean was about twice that recorded on French bean in the other treatments in the two seasons ($F_{5,15}$ = 4.27 and 5.07, P = 0.012 and 0.006, respectively) (Table 2). The number of *Ceranisus* spec. recorded on French bean and sunflower in the French-sunflower intercrop mix did not differ in the two seasons (Table 2). Nevertheless, we observed that the population of *Ceranisus* spec. on sunflower decreased with the increase in the number of intercrops in the long and short rains seasons (Table 2). French bean harboured about 41× more *Ceranisus* spec. than baby corn in the French bean-baby corn intercrop mix in the long rains season (Table 2). Conversely, there were no differences in the number of *Ceranisus* spec. hosted by French bean and baby corn in the French bean-baby corn intercrop mix during the short rains season (Table 2). French bean hosted about 4× more *Ceranisus* spec. than Irish potato in the French bean-Irish potato intercrop mix during the long rains season (Table 2). However, in the short rains season there were no differences in the number of *Ceranisus* spec. hosted by French bean and in the French bean-Irish potato intercrop mix.

Effect of intercrops on French bean yield

Intercropping French bean with other crops had a significant impact on French bean pod yield. A monocrop of French bean yielded about 1.4 times more than French bean intercropped with either baby corn or sunflower in the two seasons ($F_{5,15}$ = 5.33 and 4.73, P = 0.005 and 0.008, respectively) (Table 3). The proportion of French bean pods that would get rejected in the market due to thrips damage based on the damage scores on a scale of 1–5 varied with the treatments (Table 3). Thrips damage in a sole crop of French bean was highest (63–68% yield loss) compared to when French bean was intercropped with other crops (Table 3). The least damage to the French bean

Table 1 Mean (± SE) density of *Orius* spec. on French bean, sunflower, baby corn, and Irish potato in the various treatments in the long and short rains season at KARI-Embu in 2009

	No. *Orius* spec. per plant			
Treatment	French bean	Sunflower	Baby corn	Irish potato
Long rains season				
French bean	2.3 ± 0.81c			
French bean + sunflower	4.7 ± 1.23b	15.4 ± 3.37a		
French bean + baby corn	6.6 ± 1.52ab		5.3 ± 2.21	
French bean + Irish potato	5.3 ± 1.32b			0.1 ± 0.13
French bean + baby corn + sunflower	8.5 ± 1.81a	4.5 ± 1.35b	3.6 ± 1.13	
French bean + Irish potato + sunflower	3.1 ± 0.97bc	7.3 ± 1.86b		0.2 ± 0.28
F	2.93	5.91	0.81	0.54
d.f.	5,15	2,6	1,3	1,3
P	0.048	0.038	0.44 ns	0.52 ns
Short rains season				
French bean	3.2 ± 0.95b			
French bean + sunflower	4.3 ± 1.13b	13.9 ± 1.86a		
French bean + baby corn	6.7 ± 1.46ab		7.4 ± 1.36	
French bean + Irish potato	5.4 ± 1.30b			5.3 ± 1.16
French bean + baby corn + sunflower	10.7 ± 1.98a	5.8 ± 1.2b	4.4 ± 1.05	
French bean + Irish potato + sunflower	3.7 ± 1.03b	10.2 ± 1.59a		2.2 ± 0.74
F	3.83	6.43	3.07	4.83
d.f.	5,15	2,6	1,3	1,3
P	0.019	0.032	0.18 ns	0.12 ns

Means within a column followed by the same letter are not significantly different (Tukey's HSD test: P>0.05); ns, not significant (ANOVA: P>0.05).

pods (35–37% yield loss) was recorded when French bean was intercropped with baby corn.

Discussion

Our results show that thrips populations vary with season and are strongly correlated with the mean temperature of the season. This was supported by the high thrips catches recorded during the long rains because of the high temperatures (21.1 °C) that were favourable for thrips reproduction and dispersal. Our results are in agreement with those of Stacey & Fellowes (2002) and Pearsall & Myers (2001) who showed that temperature affects the development rate of thrips, and consequently their population dynamics. Rainfall and sunshine hours could not explain the variation in thrips population between seasons. Earlier research has shown that rainfall affects thrips populations both negatively and positively (Morsello et al., 2010). It can suppress populations by killing larvae, and thrips populations so affected often recover slowly (Morsello & Kennedy, 2009). Rainfall also suppresses thrips dispersal by suppressing flight (Lewis, 1997). However, by maintaining adequate soil moisture, rainfall can positively influence thrips populations by fostering plant growth and enhancing pupal survival (Morsello & Kennedy, 2009). Our results can be best explained by the findings of Morsello & Kennedy (2009) who found that the degree to which population growth is affected by precipitation depends on the timing, amount, and duration of the precipitation.

Our results clearly show that the main thrips species on French bean in Kenya in order of decreasing abundance are *M. sjostedti*, *F. schultzei*, *H. aldolfifriderici*, and *F. occidentalis*. Previous studies have placed much emphasis on *F. occidentalis* (Kasina et al., 2006; Nderitu et al., 2007a, 2008) and little emphasis on *F. schultzei* and *H. aldolfifriderici*. *Frankliniella schultzei* closely resembles *F. occidentalis* and because of a lack of good identification keys in Kenya in the past, it often has been mistaken for *F. occidentalis*. Furthermore, *F. occidentalis* has developed resistance to the commonly used pesticides and the other thrips species that are susceptible to the commonly used pesticides have been thought to be of minor importance. Our results also showed that a monocrop of French bean favoured the highest population of *M. sjostedti* compared to when French bean was intercropped with baby corn, Irish potato, or sunflower. *Megalurothrips sjostedti* also dominated in the field in the two seasons: the thrips species is native to Africa and is widespread indeed (Nabirye et al.,

Table 2 Mean (± SE) density of *Ceranisus* spec. on French bean, sunflower, baby corn, and Irish potato in the various treatments in the long and short rains season at KARI-Embu in 2009

	No. *Ceranisus* spec. per plant			
Treatment	French bean	Sunflower	Baby corn	Irish potato
Long rains season				
French bean	8.5 ± 0.81a			
French bean + sunflower	3.9 ± 0.95b	2.5 ± 0.80		
French bean + baby corn	4.1 ± 0.97b		0.1 ± 0.16	
French bean + Irish potato	2.3 ± 0.72b			0.6 ± 0.47
French bean + baby corn + sunflower	4.9 ± 1.06b	1.5 ± 0.60	0.5 ± 0.41	
French bean + Irish potato + sunflower	3.7 ± 0.91b	0.2 ± 0.23		0.1 ± 0.15
F	4.27	3.10	1.24	1.76
d.f.	5,15	2,6	1,3	1,3
P	0.012	0.12 ns	0.35 ns	0.28 ns
Short rains season				
French bean	10.8 ± 1.61a			
French bean + sunflower	4.4 ± 1.00b	3.7 ± 0.99		
French bean + baby corn	4.5 ± 1.01b		6.5 ± 1.38	
French bean + Irish potato	4.2 ± 0.98b			3.2 ± 0.90
French bean + baby corn + sunflower	5.7 ± 1.14b	1.6 ± 0.63	4.0 ± 1.02	
French bean + Irish potato + sunflower	4.3 ± 0.99b	0.8 ± 0.45		1.6 ± 0.62
F	5.07	4.08	2.72	2.19
d.f.	5,15	2,6	1,3	1,3
P	0.006	0.076 ns	0.20 ns	0.24 ns

Means within a column followed by the same letter are not significantly different (Tukey's HSD test: P>0.05); ns, not significant (ANOVA: P>0.05).

Table 3 Effect of thrips density on mean (± SE) French bean pod yield, yield loss, and percentage yield loss as influenced by the different treatments at KARI-Embu, Kenya in 2009

Treatment	Thrips density at flowering	Pod yield (kg ha^{-1})	Yield loss due to thrips damage [kg ha^{-1} (%)]
Long rains season			
French bean alone	137.0 ± 21.5a	4500 ± 241a	3060.0 (68)
French bean + Irish potato + sunflower	51.0 ± 8.4b	4250 ± 227ab	1912.5 (45)
French bean + Irish potato	58.7 ± 9.6ab	4000 ± 214ab	1600.0 (40)
French bean + baby corn + sunflower	100.2 ± 15.9ab	3750 ± 201ab	1312.5 (35)
French bean + baby corn	111.2 ± 17.6ab	3250 ± 174b	1137.5 (35)
French bean + sunflower	116.2 ± 18.3ab	3250 ± 174b	1202.5 (37)
$F_{5,15}$	3.57	5.33	
P	0.025	0.005	
Short rains season			
French bean alone	26.5 ± 6.5a	5250 ± 374a	3307.5 (63)
French bean + Irish potato + sunflower	14.0 ± 3.7ab	4500 ± 321ab	2160.0 (48)
French bean + Irish potato	15.0 ± 3.9ab	3750 ± 268ab	1612.5 (43)
French bean + baby corn + sunflower	9.5 ± 2.6b	4000 ± 286ab	1560.0 (39)
French bean + baby corn	10.7 ± 2.9b	3250 ± 232b	1202.5 (37)
French bean + sunflower	8.5 ± 2.4b	3500 ± 250b	1365.0 (39)
$F_{5,15}$	3.92	4.73	
P	0.018	0.008	

Means within a column followed by the same letter are not significantly different (Tukey's HSD test: P>0.05).

2003; Alabi et al., 2004; Ngakou et al., 2008). In addition, natural enemies such as *Orius albidipennis* Reuter play an important role in regulating *M. sjostedti* population (Gitonga et al., 2002). In our studies, *Orius* spec. were recorded in high numbers in intercrops compared to a sole crop of French bean and their predation activity could have contributed to the low populations of *M. sjostedti*. Kyamanywa & Ampofo (1988) also reported that the population density and activity of *M. sjostedti* were significantly lower in a mixed crop than in the single crop of cowpea. They reported that less light was intercepted by the cowpea canopy in the cowpea/maize mixed crop than in the sole crop of cowpea. The reduced light intensity in the cowpea/maize mixture contributed to the relative scarcity of *M. sjostedti* in the mixture. We observed a similar case in our field experiments.

A monocrop of French bean harboured larger populations of *F. occidentalis* than when French bean was intercropped with baby corn, sunflower, and/or Irish potato. This was due to the attraction of *F. occidentalis* to sunflower and Irish potato in the intercrop mix. The population of *F. schultzei* or *H. aldolfifriderici* on French bean did not depend on the intercrops grown together with French bean.

French bean supported the highest population of *Orius* spec. when intercropped with baby corn and sunflower, whereas a monocrop of French bean supported the lowest population of *Orius* spec. Low numbers of *Orius* spec. on French bean in Kenya have been reported by Gitonga (1999) and Kasina et al. (2006). We did not investigate the biological reason for the high number of *Orius* spec. on French bean in the intercrops, but earlier research has shown that polycropping creates a microclimate that favours natural enemies (Rämert et al., 2002; Munyuli et al., 2007). From our field observations, we noticed that *Orius* spp. preferred to feed on French bean and sunflower flowers, and maize silk and tassels. A monocrop of French bean supported the highest population of *Ceranisus* spec. as compared to when it was grown together with intercrops. This may imply that the microclimate created by the intercrops does not favour *Ceranisus* spec. Tamò et al. (1993) found out that *Ceranisus* spec. was present in high numbers on cowpea because of the larger populations of *M. sjostedti*. In our experiments *M. sjostedti* was also present in high numbers on a sole crop of French bean compared to French bean/intercrop mix.

Sunflower and Irish potato hosted mainly *F. schultzei* (>74 and >80%, respectively) and *F. occidentalis* (>15 and >16%, respectively). *Megalurothrips sjostedti* and *H. aldolfifriderici* were of minor importance on both sunflower and Irish potato. This implies that *F. schultzei* prefers sunflower (Asteraceae) and Irish potato (Solanaceae) to French bean (Fabaceae) and baby corn (Poaceae), whereas *M. sjostedti* and *H. aldolfifriderici* do not. Schellhorn et al. (2010) showed that *F. occidentalis* and *F. schultzei* prefer feeding and reproducing on solanaceous plants. Our results showed that *Orius* spec. prefers sunflower to Irish potato, which is in agreement with Chyzik & Ucko (2002).

In both the long and short rains seasons, baby corn did not harbour thrips that are of economic importance to French bean. Our results are in agreement with those of Kyamanywa et al. (1993) and Kasina et al. (2006). The only thrips species that were recorded on baby corn were corn thrips, *F. williamsi*, and palm thrips, *T. pusillus*. This is the first record of *F. williamsi* from East Africa, which has been shown to transmit maize chlorotic mottle virus (Jiang et al., 1992). *Thrips pusillus* has been reported from Kenya (Mound, 2010). The biological reason why *M. sjostedti*, *F. schultzei*, *F. occidentalis*, and *H. aldolfifriderici* seem to reject baby corn needs to be studied further to understand the role of baby corn in thrips management. An intercrop of French bean with Irish potato and sunflower gave good French bean pod yield comparable to a monocrop of French bean. However, the thrips population densities on the monocrop of French bean were quite high, the percentage of the produce that could get rejected in the market due to thrips damage was also quite high, reducing the marketable yield. Irish potato and sunflower were also reproductive hosts of *F. schultzei* and *F. occidentalis* that are of economic importance to French beans. The best thrips management strategy may be to have sunflower and Irish potato flower before French bean, to attract the *Frankliniella* species to the sunflower and Irish potato flowers. The farmer can then spray the sunflower and Irish potato plants to kill the thrips. This strategy would need to be tested in field studies.

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