STUDIES ON GENETIC, CULTURAL AND INSECTICIDAL CONTROLS AGAINST THE BEAN FLY, *OPHIOMYIA PHASEOLI* (TRYON) (DIPTERA: AGROMYZIDAE), IN ETHIOPIA

by

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ABSTRACT

The bean fly (BF), *Ophiomyia phaseoli* (Tryon) (Diptera: Agromyzidae), is the major pest of haricot bean (*Phaseolus vulgaris* L.) in Ethiopia. It mines leaves upon hatching, then moves to the veins and stems. I studied various control measures, including varietal resistance, seeding date, plant density, intercropping, weeding, and seed dressing between 1986 and 1988 at two locations in south-central Ethiopia.

Four of the more than 1500 accessions of bean germplasm tested were highly resistant against BF and are recommended for cropping and breeding programmes. Among plant characters measured stem diameter was positively correlated with the numbers of BF emerging. In contrast to previous reports, thick-stemmed varieties were more tolerant to BF damage than was the thin-stemmed control, 'Mexican 142'.

Seeding dates and plant density can be manipulated so as to reduce fly damage, and hence increase yields. Because seeding dates and plant density interact, the best strategy for farmers to minimize BF damage is to plant from 300,000 to 500,000 seeds/ha. At Awassa, the optimum time for seeding is about 2 weeks after the rains begin. At Melkassa, which has a shorter wet season, seeding should be at the beginning of the rains. Parasitism of BF by the braconid *Opius phaseoli* Fischer reached 93% at Awassa, but the parasitoid was not effective perhaps because it did not arrive in the fields until after BF had

already inflicted damage.

Strip-cropping beans with maize did not affect dry-seed yields of beans, but yields were reduced significantly in weedy fields. Adult BF visiting seedlings, counted 2 weeks after seeding, were from 2- to 3-times more abundant in weed-free than in weedy bean plots, with or without strip-crop. Intercropping or weeding had no effect on parasitism by *Opius phaseoli*.

Of the six seed dressing insecticides tested, the most effective were endosulfan and aldrin. Aldrin should be replaced with endosulfan, which is less persistent in the environment.

The optimal strategy for BF management in subsistence agriculture must be based on a combination of site-specific tactics, including choices between seeding date, plant density and resistant variety.

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Finally, I would like to thank my wife, Az, for spending her honeymoon enumerating bean fly data with me; I would also like to thank my sister, Addes, and my cousin Birtukan Gebre-Wold for their love and support.

DEDICATIONS

To my wife, Az, for giving me Melekot

To my sister, Geremush, for her devotion to me

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ACRONYMS USED IN THE TEXT

AVRDC: Asian Vegetable Research and Development Centre

CAB: Commonwealth Agricultural Bureau

CABIIE: CAB International Institute of Entomology

CIAT: Centro Internacional de Agricultura Tropical

CIBC: Commonwealth Institute of Biological Control

CIE: Commonwealth Institute of Entomology

EGA: Ethiopian Grain Agency

FAO: Food and Agricultural Organization of the UN

IAPSC: Inter-African Phytosanitary Council of the OAU

IAR: Institute of Agricultural Research (Ethiopia)

IRRI: International Rice Research Institute

MOA: Ministry of Agriculture (Ethiopia)

OAU: Organization of African Unity

UNDP: United Nations Development Programme

CHAPTER I

GENERAL INTRODUCTION

Ophiomyia phaseoli (Tryon) (Diptera: Agromyzidae), commonly known as the bean fly, is a small, shining, black, agromyzid fly. This insect has been known by several scientific names, but Spencer (1973) transferred the genus to *Ophiomyia* and it has since been referred to as *O. phaseoli* with the following synonyms:

Oscinis phaseoli Tryon, 1895;

Agromyza phaseoli Coquillett, 1899;

A. fabalis Jack, 1913;

A. destructor Mallock, 1916;

Melanagromyza phaseoli Vanschuytebroek, 1951a; and

M. similis Vanschuytebroek, 1951b.

Detailed information on the bionomics of bean fly is given by Otanes y Quesales (1918), van der Goot (1930), Morgan (1938a), Maher Ali (1957), Lall (1959), Kato (1961), Agarwal and Pandey (1962), Singh and Beri (1971), Greathead (1969), Raros (1975), Burikam (1978), Yasuda (1979, 1980, 1982), Manohar and Balasubramanian (1980a), Kwon *et al*. (1981), AVRDC (1984), and Gupta and Singh (1984a). Adults are about 2 mm long, with a wingspan of approximately 4.5 mm; males are smaller than females (Otanes y Quesales, 1918; van der Goot, 1930; Raros, 1975).

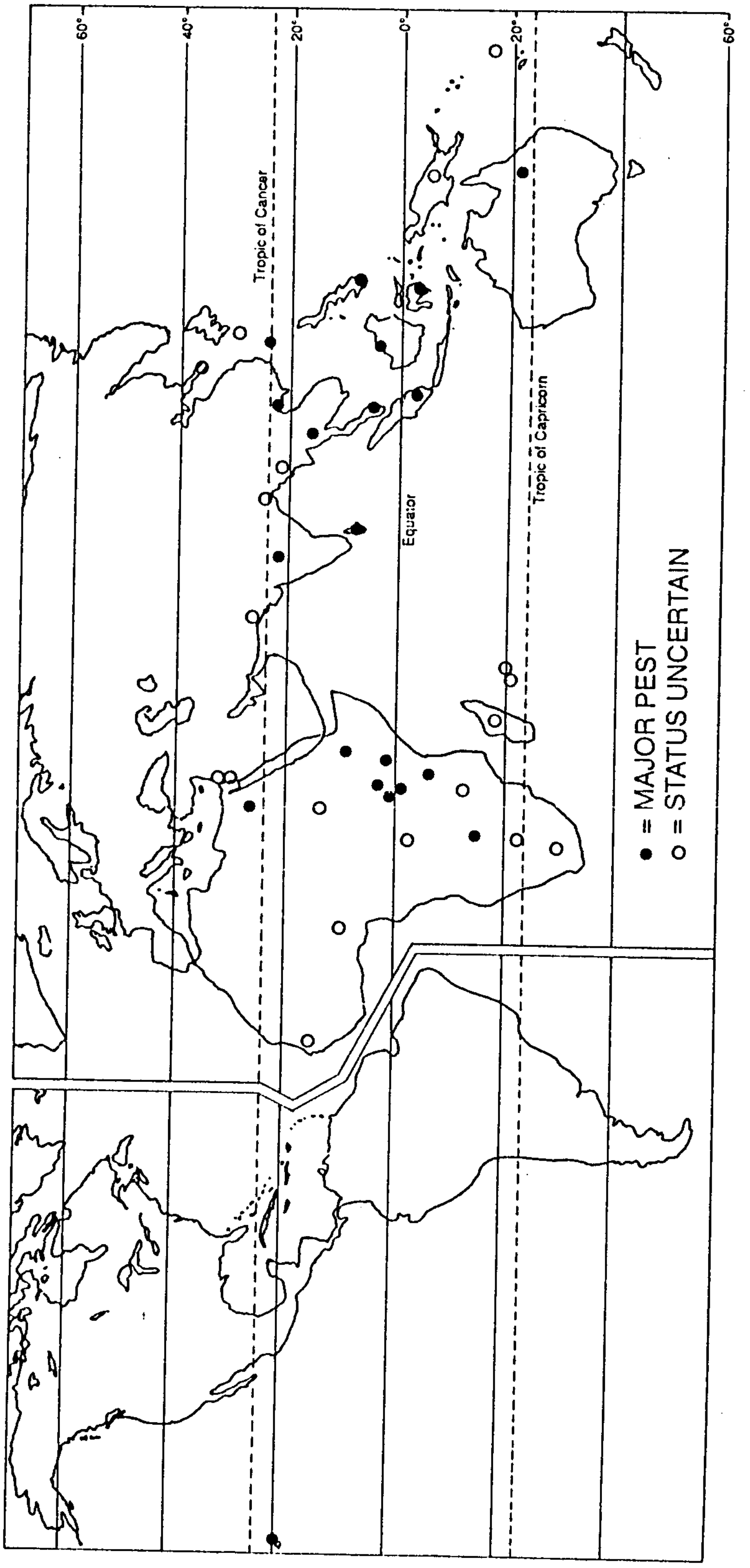
Egg laying on the crop starts as soon as seedlings emerge, but peak damage symptoms become evident about 5 weeks after seeding. The adult female probes the upper surface of the seedling leaf with her ovipositor; she deposits eggs inside the epidermis in about 10% of the punctures thus made (Jack 1913; Davis, 1969). The remaining punctures serve as a source of juice for feeding by the adult fly. Each female lays an average of 100 eggs in her lifetime. The eggs hatch after 2-4 days, and the typical maggot mines the leaf epidermis until it reaches a leaf vein, where it moults into the second instar. The maggot follows the leaf vein downwards and reaches the petiole, where it moults (after about 2 days) into the third instar. The third instar also moves further down the seedling until it reaches the stem just above the ground level, where its feeding produces characteristic swelling and cracks in the stem. Pupation takes place in the stem after 4-5 days of feeding in the third instar. Thus the total larval period is about 10 days. The adult ecloses from the dark brown puparium after about 10 days. The life cycle from oviposition to adult eclosion is completed in 19-30 days depending on the temperature (Otanes y Quesales, 1918; van der Goot, 1930; Lall, 1959; Agarwal & Pandey 1962; Abul-Nasr & Assem, 1968).

Ophiomyia phaseoli is the major pest of haricot bean (bush bean), *Phaseolus vulgaris* L., in Ethiopia. Haricot bean is one of the major pulse crops grown in Ethiopia for domestic consumption and export, accounting for up to 61% of grain legume export (EGA, 1980). An average of well over 56,000 tonnes is produced on more than 78,000 ha of land per annum (MOA, 1982).

This crop is grown in at least 10 of the 14 administrative regions of the country, with Shewa (27.5%), Sidamo (16.5%) and Harerge (13.1%) being the major producers (MOA, 1982). Haricot bean is the major source of protein supplement in the diets of the majority of people in these areas. Although potential yields of well over 3000 kg/ha have been achieved on experimental plots (Ohlander, 1980), the national average stands at about 700 kg/ha (Ohlander, 1980; MOA, 1982) and bean fly is one of the chief causes for this low yield.

Bean fly is believed to have originated in Southeast Asia as shown by native wild host plant records of van der Goot (1930) from Java. To date, it is widely distributed in tropical and subtropical regions of Africa (IAPSC, 1985), Asia, Australia, the Middle East, and Pacific islands including Hawaii (Spencer, 1973; CIE, 1974; Gangrade and Kogan, 1980; Hill, 1983) as shown in Fig. 1.1. *Ophiomyia phaseoli* is perhaps the most important insect pest of standing beans in most of the areas where it occurs (Singh *et al*., 1978). In eastern Africa it is rated as the most serious problem of bean production. In other parts of the world infestation can reach up to 100% (Rose *et al*., 1978), and 90% to 100% seedling mortality can occur under severe infestation (Cheu, 1944; Hassan, 1947; Braithwaite, 1957; Rose *et al*., 1976; Poehlman, 1978; Somaatmadja & Sutarman, 1978). In spite of its economic importance, research on the management of *Ophiomyia phaseoli* on haricot bean has been minimal and data based on controlled experiments are scarce, with the exception

Figure 1.1: World distribution of *Ophiomyia phaseoli* (from literature).


60°
40°
20°
0°
20°
60°
Tropic of Cancer
Equator
Tropic of Capricorn
● = MAJOR PEST
○ = STATUS UNCERTAIN

of insecticide screening trials.

The main objectives of my study were:

(1) to identify genotypes of beans that are resistant to bean fly;

(2) to determine the effects of seeding dates and plant densities on bean fly and its parasitoids;

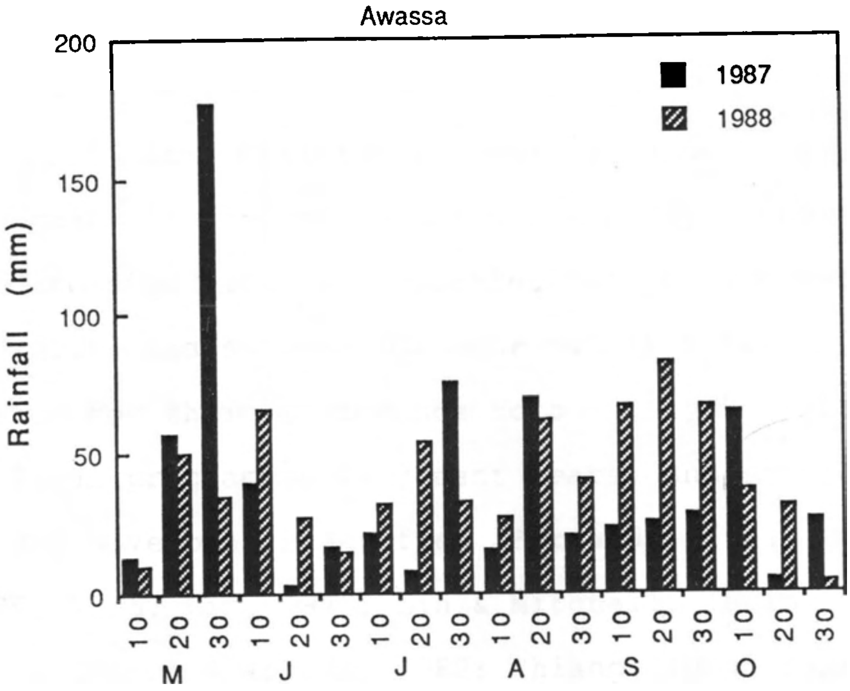
(3) to determine the effects of habitat diversity on the population of the pest and its natural enemies;

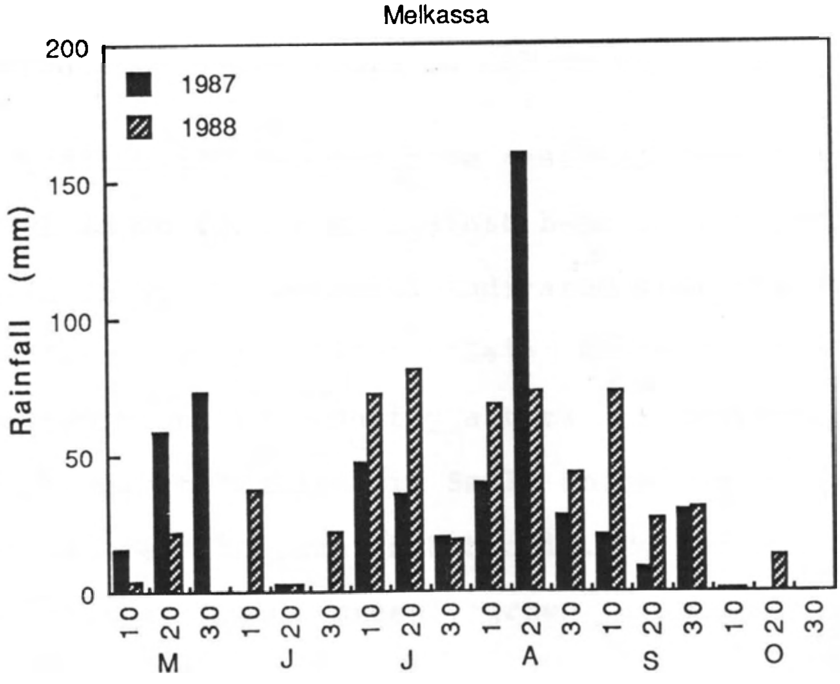
(4) to select effective seed dressing insecticides against bean fly; and

(5) to study the geographic distribution and population dynamics of both the bean fly and its parasitoids in Ethiopia.

I describe here a series of experiments that I carried out and results obtained during three season between 1986 and 1988. I chose two agroecologically distinct environments: Awassa (7°05'N 38°29'E; 1700 m above sea level; fluvic utrisol soil type) in southern Ethiopia, and Melkassa (8°24'N 39°21'E; 1550 m a.s.l.; sandy loam) in central Ethiopia (see Fig. A.1). These two locations differ in the distribution and amount of rainfall (Fig. 1.2); the 6-month total rainfall in 1987 (and 1988) at Awassa and Melkassa was 686.5 (735.7) and 540.6 (593.2) mm, respectively.

Figure 1.2: Distribution of rainfall (ten-day totals) at the experimental sites.


Awassa
200
150
100
50
0
Rainfall (mm)
1987
1988
10 20 30 10 20 30 10 20 30 10 20 30 10 20 30 10 20 30
M J J A S O


Melkassa
200
150
100
50
0
Rainfall (mm)
1987
1988
10 20 30 10 20 30 10 20 30 10 20 30 10 20 30 10 20 30
M J J A S O

CHAPTER II

STUDIES ON HOST PLANT RESISTANCE

INTRODUCTION

Host plant resistance (HPR) is regarded as an important component in the management of bean fly. Hundreds of germplasm and breeding materials, particularly of mungbean (*Vigna aureus* (Roxeb.)) and soybean (*Glycine max* (L.) Merrill), have been tested for their resistance to bean fly by international and national programmes in recent years, and sources and mechanisms of HPR have been identified (Fernando, 1944; AVRDC, 1976, 1977, 1979, 1985; Lin, 1979; Lin & Mitchell, 1981b; Chiang & Talekar, 1980; Chiang & Norris, 1982; Chiang, 1984; Talekar *et al.*, 1988). No such concerted efforts have been made with respect to haricot bean, *Phaseolus vulgaris* L., and hence little reliable information is available on HPR to bean fly.

Conflicting reports have resulted from the very limited work on HPR in haricot bean against bean fly. Experiments by Rogers (1974, 1979) in Australia indicated that the bean cultivars 'California Small White', 'Saint Andreas', and 'Tendergreen' were resistant to bean fly attack. By contrast, Negasi (1988) reported that 'California Small White' was among the most susceptible cultivars in Ethiopia. My personal observations confirm that 'Tendergreen', grown for green pods in Ethiopia, is susceptible.

The mechanisms of resistance to bean fly in *P. vulgaris* are largely unknown (Allen & Smithson, 1986). The little data available are those of Rogers (1974, 1979), who reported significant correlations between the numbers of eggs laid per plant and the internode length, leaf hairiness, and stem diameter of the plant; haricot bean cultivars with dense hair, thin stems, and long internodes sustained low egg counts.

Morphological and physiological characters of the plant are known to play important roles in HPR to bean fly in other bean species. For example, Balboa (1972) attributed resistance in mungbean cultivars to the thick pubescence and toughness of the stem. Lin (1979) and Lin & Mitchell (1981a,b) studied correlations between bean fly population and various leaf characters of mungbean and found that presence of antifeedants, thick pubescence, and absence of attractants were negatively correlated with bean fly damage. Chiang & Norris (1982, 1983a) reported that trichome density, leaf area, leaf moisture content, and stem diameter were associated with resistance of soybean to bean fly and related agromyzid species; their studies showed that dense pubescence, small leaves, high leaf moisture, and thin stems were negatively correlated with infestation levels. Chiang & Norris (1983b,c) further showed that phenols and/or tannins, and early differentiation and development of the primary and secondary phloem fibres and associated cortex were also involved in the resistance of soybean to bean fly and *Ophiomyia centrosematis* (de Meijere). From the above reports, it is apparent that the mechanism of resistance in beans to bean fly is antixenosis (non-preference). However, it has also been reported that "although many plants in resistant accessions [of haricot bean] showed beanfly damage, most insects died well before observation, whereas the insects in susceptible entries were alive and feeding on stem tissue during observation. This indicates a possibility of antibiosis in the resistant materials" (CIAT, 1983).

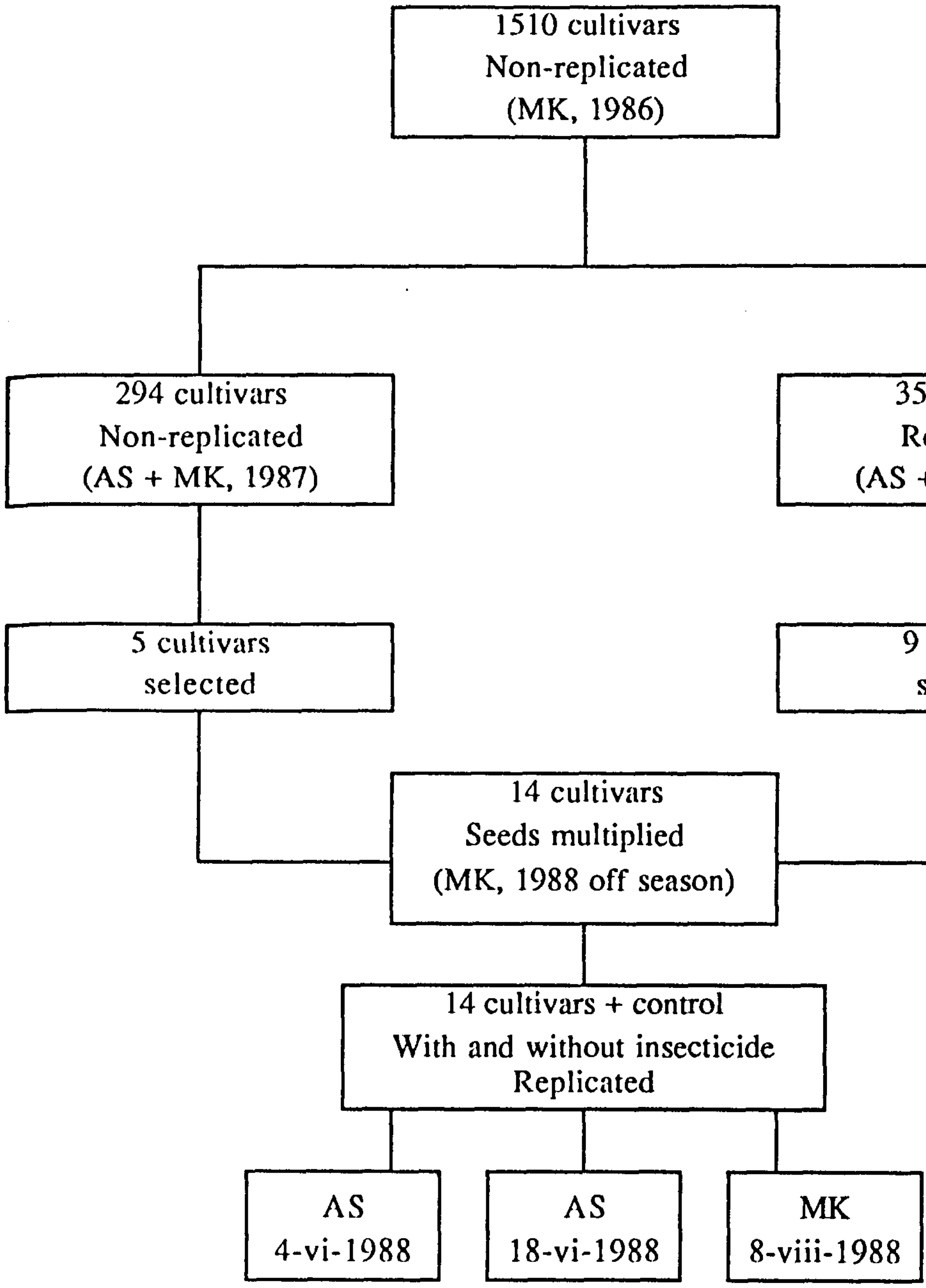
The objective of my research was, firstly, to identify sources of resistance to bean fly in *Phaseolus vulgaris* and, secondly, to look for correlations between phenotypic characters and HPR. Below I describe the various experiments that I conducted and present the results obtained.

MATERIALS AND METHODS

Sources of resistance

Experiments to detect and characterize resistance of haricot bean to bean fly were conducted during three seasons between 1986 and 1988. Figure 2.1 summarizes the various trials conducted over the 3-year period.

Figure 2.1: Schematic summary of field trials conducted for screening of *Phaseolus vulgaris* for resistance to bean fly (AS=Awassa; MK=Melkassa; dates refer to seeding dates).


1510 cultivars
Non-replicated
(MK, 1986)
294 cultivars
Non-replicated
(AS + MK, 1987)
35 cultivars
Replicated
(AS + MK, 1987)
5 cultivars
selected
9 cultivars
selected
14 cultivars
Seeds multiplied
(MK, 1988 off season)
14 cultivars + control
With and without insecticide
Replicated
AS
4-vi-1988
AS
18-vi-1988
MK
8-viii-1988

First season (1986)

A total of 1510 accessions to the CIAT world haricot bean germplasm collection were obtained from CIAT, Cali, Colombia. These, except for three commercial or local cultivars, *viz.* 'Mexican 142', 'Brown Speckled', and 'Red Wolaita', were grown in single-row plots of 3 m length, 80 cm apart, at the Melkassa Research Centre of IAR, Nazareth Research Centre. Single rows of the local cultivars were seeded at regular recurring intervals to assess variation within the experimental field. Seeds were sown 10 cm apart so that there were 30 plants per row. The experimental field was uniform in aspect and soil type, and every attempt was made to keep conditions as uniform as possible during the conduct of the trial. Routine cultural practices of weeding were followed; no fertilizer or pesticides were applied in the trials. Supplementary irrigation was provided as needed.

A sample of five plants was taken from each plot by uprooting one plant from the end of each row, and then at every step along the row, 35 days after seeding; these samples were taken to the laboratory, dissected, and the numbers of bean flies (larvae + puparia) were counted and recorded. Counting was done by a group of 10 individuals, two technicians and eight assistants, who are proficient with bean fly counting. Visual assessments were also made in the field and damage scores were recorded on a 1 to 9 scale, where 1 represented no damage, and 9 extremely severe damage (including stunting, wilting and death of seedling). Evaluation was made by a research officer and two technicians with long time experience in bean fly research, 50 days after seeding. The damage score was added to the bean fly count, and the mean [(bean fly count + damage score)/2] was used as the major criterion for selecting cultivars for subsequent tests. For summarizing the results of this trial, the accessions were grouped into the categories "highly susceptible" (HS), "susceptible" (S), "moderately susceptible" (MS), "moderately resistant" (MR), "resistant" (R), or "highly resistant" (HR) in accordance with the methods used by Chiang & Talekar (1980) for soybean and mungbean. Those accessions whose mean ($\bar{x}$) for the two measured variables mentioned above (bean fly counts and damage score), differed from the grand mean (GM) of all entries by ≥ two standard deviations were rated as HS or HR; those with means greater than one but less than two standard deviations from the GM were rated S or R, and those with means within one standard deviation of the GM were rated MR or MS. Accessions that did not survive to 50 days or those with missing data were not included in the analysis.

Second season (1987)

Two sets of materials were tested in the 1987 growing season at both Awassa and Melkassa; the first set, consisting of 294 top-performing accessions selected from the 1986 trial, was tested in non-replicated, single-row plots; the second set of 35 accessions was evaluated in replicated trials at each site. The 35 accessions in the second set were also present in the first. Three local cultivars were also included in both the non-replicated and replicated trials.

For the non-replicated trials, single-row plots of 5 m length, 60 cm (Awassa) or 80 cm (Melkassa) apart, were used; seeds were spaced at 15 cm. Other cultural practices were similar to those used in 1986.

Percentages of seedling mortality, plant survival, and seed yield were used as criteria for evaluating these accessions. Stand counts were recorded 2 weeks after seeding. Counts of seedlings subsequently killed by bean fly were recorded by observing the field daily after the stand counts until canopy closure; plants killed by bean fly were rogued to avoid double counting. Plant stand and dry-seed yield were recorded for each plot at harvest.

For the replicated trial at Awassa, each plot consisted of three rows of 5 m, with 60 cm between rows, 15 cm between plants; plots were seeded on 23-vi-1987 and grown under natural rain conditions. At Melkassa, each plot consisted of two rows of 5 m, with 80 cm between rows, 15 cm between plants; plots were seeded on 6-viii-1987 and grown with supplementary irrigation as needed. A randomized complete block design (RCBD) with three replications was used at each location.

Stand counts were taken 2 weeks after seeding. Plots were kept weed-free by continuous hand-weeding. No fertilizer or pesticides were applied. Dead plants were counted by checking the plots every day starting 15-20 days after seeding; those plants that were killed by bean fly were rogued to avoid double counting. Visual assessments were also made for the Awassa experiment, and performance scores of 1 (very poor) to 10 (excellent) were given at 35 and 50 days after emergence; averages of the two scores were used in the analyses. These assessments helped in the selection for vigour.

At harvest, the number of pods/plot and of pods damaged by *Heliothis armigera* (Hübner) were counted. The dry beans harvested from each plot were weighed and moisture readings were taken; all yields of beans were adjusted to 10% moisture basis for analysis. Analyses of variance were made on all measured variables with the statistical package MSTAT (Freed *et al.*, 1986).

Third season (1988)

A total of 14 accessions that showed high levels of resistance were selected from the non-replicated and replicated experiments conducted in 1987. Seeds of the selected cultivars were multiplied under irrigation during the 1988 off-season (February to May) at Melkassa. Comparative tests involving these 14 "resistant" selections and the standard susceptible check 'Mexican 142' were conducted in three environments during the 1988 crop season.

The trials were laid out as a two-factor split block design (LeClerg *et al.*, 1962). The factors were two levels of insecticide treatment (0 and 5 g a.i./kg seed dressing with endosulfan) as strips, and cultivars as subplots. The experiment was replicated four times at each location.

Environment 1 was seeded at Awassa, on 4-vi-1988, Environment 2 was also seeded at Awassa on 18-vi-1988, and Environment 3 was seeded at Melkassa on 8-viii-1988. Plot sizes were 4 m x 4.2 m (7 rows) in Environment 1, 3 m x 3 m (5 rows) in Environment 2, and 4 m x 4 m (5 rows) in Environment 3. Thus, inter-row spacings of 60 cm and 80 cm were used at Awassa and Melkassa, respectively. Seeds were spaced at 15 cm in all three environments. Unplanted alleys of 1.5 m between plots, 2.0 m between strips, and 3 m between blocks were allowed to minimize interference among treatments. Plots were kept weed-free by continuous hand-weeding. Stand counts were recorded at about 2 weeks after seeding.

Plants killed by bean fly were recorded and rogued at frequent intervals starting 15-20 days after seeding, until the canopy was closed. Entire plots were harvested to estimate yields; yields were adjusted to 10% moisture with a Dole moisture tester for analysis. All data were analysed by ANOVA.

Correlations between plant characters and resistance

Attempts were made to detect possible mechanisms of resistance in haricot bean cultivars against bean fly during the 1987 and 1988 seasons. Measurements were taken by systematic sampling of four seedlings from each plot of the 35 superior and the three check cultivars grown in 1987 at Melkassa; the samples were taken at the first trifoliolate stage. Four hair density counts were made within a flat metal plate window of 0.5 cm x 0.5 cm on the upper surface of the leaf under a dissecting microscope. Leaf area (cm^2/plant) was determined in the field with a leaf area meter (Li-Cor Instruments, Lincoln, Nebraska) on four plants from each plot. Fresh weights of stem and leaves were taken for the plants sampled, and the samples were then dried in an oven at 100°C for 24 hr, to determine dry matter content.

Stem length, stem thickness, plants with adventitious roots, and number of insects emerging/5 plants were taken for the 15 cultivars (untreated plots) seeded on 18-vi-1988 at Awassa, 37 days after seeding (25-vii-1988). From each plot, five plants were chosen and uprooted by taking odd-numbered rows along one diagonal and even-numbered along the other. Stem length measurements were taken at internodes between the cotyledon and unifoliolate leaf, and the first trifoliolate leaf and the third. Stem thickness, at the base of the second internode, was measured with Vernier calipers. Counts of plants with adventitious roots were also made. The sample plants were then taken to the laboratory to be sealed and kept in pollination bags for 30 days, after which date the adult bean flies and their emerged parasitoids were counted. Plants with adventitious roots (growing from the shoot near ground level) and the insects emerged were also counted for the same experiment at Melkassa; 10 plants were sampled from each plot here.

RESULTS

Sources of resistance

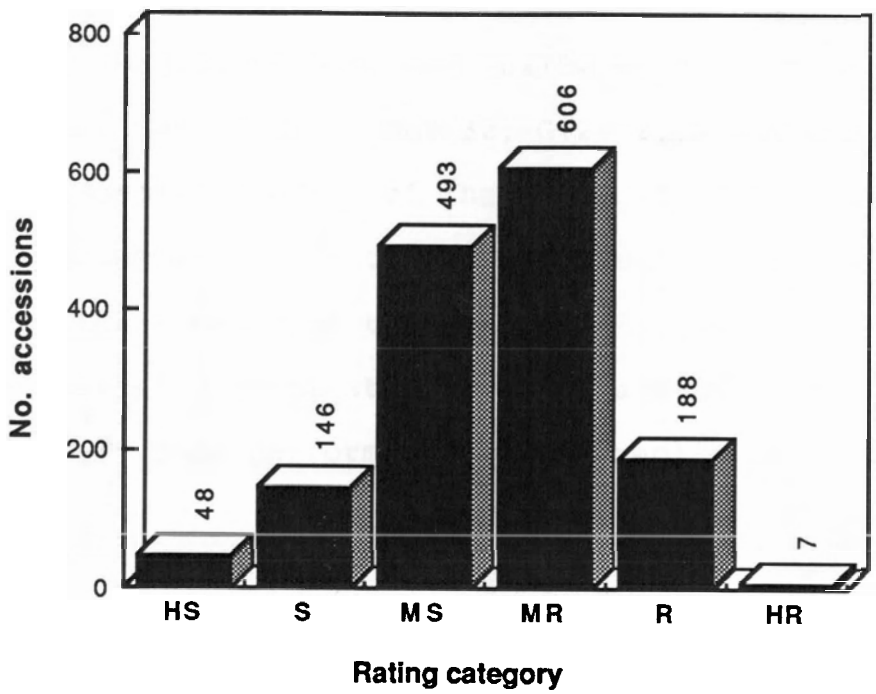
First season (1986)

Twenty two of the 1510 accessions seeded in the 1986 trial at Melkassa were not rated due to poor emergence or missing data whether due to accident or loss of seedlings prior to the damage score rating at 50 days. The number of bean flies per plant averaged 7.14 ± 0.07 (s.e.), and ranged from 1.6 to 26.0 among the 1488 accessions. The mean of damage scores at 50 days was 4.52 ± 0.04, and ranged from 1 to 8. Figure 2.2 shows the frequency distribution for the various categories of resistance for the 1488 haricot bean accessions that yielded data. A total of 294 accessions were selected for further evaluation in 1987. These were all among the top-performing entries in the 1986 trial based on bean fly counts and damage scores, although various agronomic characters were also considered. Of the 294 cultivars, 35 top-performing lines were selected for evaluation in replicated trials in 1987.

Second season (1987)

Seedling mortality caused by bean fly among the 297 entries (294 accessions plus three 'control' cultivars) tested at Awassa averaged 22.8 ± 1.1% (s.e.) and ranged between 0 and 100%. Dry-seed yields averaged 1060.7 ± 61.6 kg/ha, and ranged between 0 and 1570 kg/ha. The most resistant accessions at Awassa (based

Figure 2.2: Frequency distribution of resistance ratings against bean fly for 1488 accessions of *Phaseolus vulgaris*, Melkassa, 1986 (HS=highly susceptible, S=susceptible, MS=moderately susceptible, MR=moderately resistant, R=resistant, HR=highly resistant).



800
600
400
200
0
No. accessions
48
146
493
606
188
7
HS
S
MS
MR
R
HR
Rating category

on seedling mortality, seed yield and plant survival) were G04456, G05773, G13176, G01996, and G05253. The entries G01572, G01571, G00097, G01515, and G00078 were found to be among the most susceptible cultivars.

At Melkassa, seedling mortality averaged 9.8 ± 0.4%. It was 0% in ten of the 297 entries tested and peaked 50% in G00675. Seed yields ranged between 0 and 1275 kg/ha. Entries G05208, G05059, G02472, G02006, and G04194 were the most resistant cultivars, and G00675, G01632, G12532, A 469 and G00715 were most susceptible. None of the top-performing accessions in the non-replicated trial at Melkassa was selected for further evaluation because of the low bean fly selection pressure in the non-replicated trial at this site, and because of their relatively poor performance in the replicated experiments.

Seedling mortality in the replicated trials averaged 18.9 ± 0.9% at Awassa and 14.7 ± 0.9% at Melkassa. Differences in seedling mortality among the cultivars were highly significant at Awassa, and significant at Melkassa (Appendix 2.1). Performance data for the cultivars at Awassa and Melkassa are presented in Tables 2.1 and 2.2, respectively. Seed yield in the 38 cultivars tested at the two locations was significantly influenced not only by bean fly damage but also by plant characters such as the number of pods/plant and leaf area (Appendix 2.2).

Table 2.1: Performance of 38 cultivars of haricot bean against *Ophiomyia phaseoli*, Awassa, 1987*

CIAT Acc.#	Cultivar name	Seedling mortality (%)	Performance score (1-10)	Yield (kg/ha)
G03844	Cascade	6.3a	8.0abc	2284abc
G03696	Coleccion 12-D	6.7ab	8.5a	2636ab
G04958	Varanic 2	8.2abc	7.5a-e	1738d-g
G02005	Gentry 21020	8.5a-d	7.7a-d	2355abc
G01483	PI278672	9.0a-e	7.5a-e	1018e-j
G02472	Guerrero 29-C	10.0a-f	7.7a-d	2370abc
G09409	U.S. Refugee	10.0a-f	6.2a-g	934f-i
EMP 81	EMP 81	10.4a-g	8.2ab	2402abc
G04458	27-R	10.9a-f	5.5a-g	831ghi
G11292	Poroto Tropero	11.5a-i	7.3a-f	2102a-d
G05059	H6 Mulatinho	12.1a-i	7.3a-f	2364abc
G00404	Round Speckled Sugar	12.1a-i	7.2a-f	1191d-i
G00124	PI163557	12.4a-i	7.2a-f	1883a-f
G03645	Jamapa	13.6a-j	7.5a-e	2310abc
G12532	PG 0036	17.9a-k	6.0a-g	536i
Local	Brown Speckled	18.7a-k	6.2a-g	1080e-i
Local	Red Wolaita	18.7a-k	5.0c-g	902g-i

Table 2.1: cont'd.

CIAT Acc. #	Cultivar name	Seedling mortality (%)	Performance score (1-10)	Yield (kg/ha)
G03627	S-182-N	19.4a-k	5.8a-g	1935a-e
G00105	Zarzaleno de Arbor	19.7a-k	5.0c-g	700hi
G00056	Striped Brown	20.7a-k	5.3b-g	714hi
G02548	Col. No. 12	20.7a-k	5.3b-g	534i
G01853	Calima	21.4b-k	6.0a-g	1148e-i
G03807	Brasil 2=Pico de Oro	22.3c-k	5.2c-g	1186d-i
G00734	Otz K'al Tsaik	22.7c-k	4.5efg	903ghi
G13204	Cod-1213	22.7c-k	5.3b-g	287i
G00112	PI155213	23.1c-k	6.8a-g	2834a
G04446	Ex-Puebla 152-Brown Seeded	23.5d-k	5.8a-g	1860b-f
G00402	White Sugar	23.5d-k	6.3a-g	1170d-i
G01820	Negro Iamapa	23.5d-k	5.8a-g	1663c-h
G01996	Gentry 20989	23.9e-k	6.0a-g	2292abc
G00011	Frijol	24.9f-k	4.5efg	840ghi
G01540	Bakon	25.3g-l	5.0c-g	846ghi
G04017	Carioca	25.7h-l	6.3a-g	1949a-e
G12553	PG 0063	26.4i-l	4.3fg	350i

Table 2.1: cont'd.

CIAT Acc.#	Cultivar name	Seedling mortality (%)	Performance score (1-10)	Yield (kg/ha)
G00113	PI155307	28.0jkl	4.8d-g	464i
Local	Mexican 142	28.5jkl	4.0g	541i
G01447	PI251049	30.4kl	6.2a-g	509i
G00158	Yer Fasulyasi	39.2l	3.8g	415i
	Mean	18.9	6.2	1370.4
	SE	0.9	0.2	80.6

*Means , within a column, followed by the the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test).

Table 2.1: Performance of 38 cultivars of haricot bean against *Ophiomyia phaseoli*, Awassa, 1987*

CIAT Acc.#	Cultivar name	Seedling mortality (%)	Performance score (1-10)	Yield (kg/ha)
G03844	Cascade	6.3a	8.0abc	2284abc
G03696	Coleccion 12-D	6.7ab	8.5a	2636ab
G04958	Varanic 2	8.2abc	7.5a-e	1738d-g
G02005	Gentry 21020	8.5a-d	7.7a-d	2355abc
G01483	PI278672	9.0a-e	7.5a-e	1018e-j
G02472	Guerrero 29-C	10.0a-f	7.7a-d	2370abc
G09409	U.S. Refugee	10.0a-f	6.2a-g	934f-i
EMP 81	EMP 81	10.4a-g	8.2ab	2402abc
G04458	27-R	10.9a-f	5.5a-g	831ghi
G11292	Poroto Tropero	11.5a-i	7.3a-f	2102a-d
G05059	H6 Mulatinho	12.1a-i	7.3a-f	2364abc
G00404	Round Speckled Sugar	12.1a-i	7.2a-f	1191d-i
G00124	PI163557	12.4a-i	7.2a-f	1883a-f
G03645	Jamapa	13.6a-j	7.5a-e	2310abc
G12532	PG 0036	17.9a-k	6.0a-g	536i
Local	Brown Speckled	18.7a-k	6.2a-g	1080e-i
Local	Red Wolaita	18.7a-k	5.0c-g	902g-i

Table 2.2: cont'd.

CIAT Acc.#	Cultivar name	Seedling mortality (%)	Yield (kg/ha)
G03627	S-182-N	13.6a-e	896c-i
G01996	Gentry 20989	13.7a-e	1133b-f
G00056	Striped Brown	14.3a-e	436g-j
G01483	PI278672	15.4a-e	653e-j
Local	Mexican 142	15.6a-e	477f-j
G12532	PG 0036	15.7a-e	257ij
G00112	PI155213	15.8a-e	1142b-f
G01540	Bakon	15.8a-e	484f-j
G00402	White Sugar	16.0a-e	576e-j
G03645	Jamapa	16.3a-e	814c-j
Local	Brown Speckled	16.3a-e	565e-j
G04017	Carioca	17.7a-e	1614ab
G00105	Zarzaleno de Arbor	18.1a-e	565e-j
G00158	Yer Fasulyasi	18.5a-e	565e-j
G00011	Frijol	19.0a-e	622e-j
G01447	PI251049	20.2a-e	360hij
G12553	PG 0063	21.2a-e	359hij

Table 2.2: cont'd.

CIAT Acc.#	Cultivar name	Seedling mortality (%)	Yield (kg/ha)
G11292	Poroto Tropero	21.9a-d	1077b-g
G01820	Negro Iamapa	24.1cde	775c-j
G00113	PI155307	29.4de	266ij
G13204	Cod-1213	31.0e	292ij
	Mean	14.7	801.4
	SE	0.9	47.1

*Means, within a column, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test).

Based on overall performance at Awassa and Melkassa, (*i.e.* seedling mortality, seed yield and performance score) EMP 81, G03696, G03844, G02472, G02005, G04958, and G05059 were the most resistant of the 35 cultivars tested, and were selected for subsequent test in 1988. Accessions G03645 and G11292 were also selected based on their performance at Awassa. By contrast, G00158, G12553, the commercial cultivar 'Mexican 142', G01447 and G00113 were highly susceptible at Awassa (Table 2.1), and G013204 and G00113 were highly susceptible at Melkassa (Table 2.2). Although G00112 was a high yielding variety at Awassa, at Melkassa, its performance was average. In addition, its seeds are black, a colour that is not preferred in Ethiopia. The accessions G00734 and G01447 were heavily infected by *Uromyces phaseoli* (causative agent of bean rust) starting at pod set at Awassa.

Third season (1988)

Bean fly damage at Melkassa was slight ($\bar{x}$=2.2 ± 0.3) and differences in seedling mortality among cultivars were non-significant; yield differences within treatments were significant (Table 2.3) due to factors other than bean fly damage however.

Bean fly damage at Awassa was substantial and significant differences in seedling mortality occurred among cultivars without insecticide in both trials (Appendix 2.3).

Table 2.3: Dry-seed yield (kg/ha) of 15 cultivars of *Phaseolus vulgaris* grown with and without endosulfan seed treatment against bean fly, Melkassa, 1988*

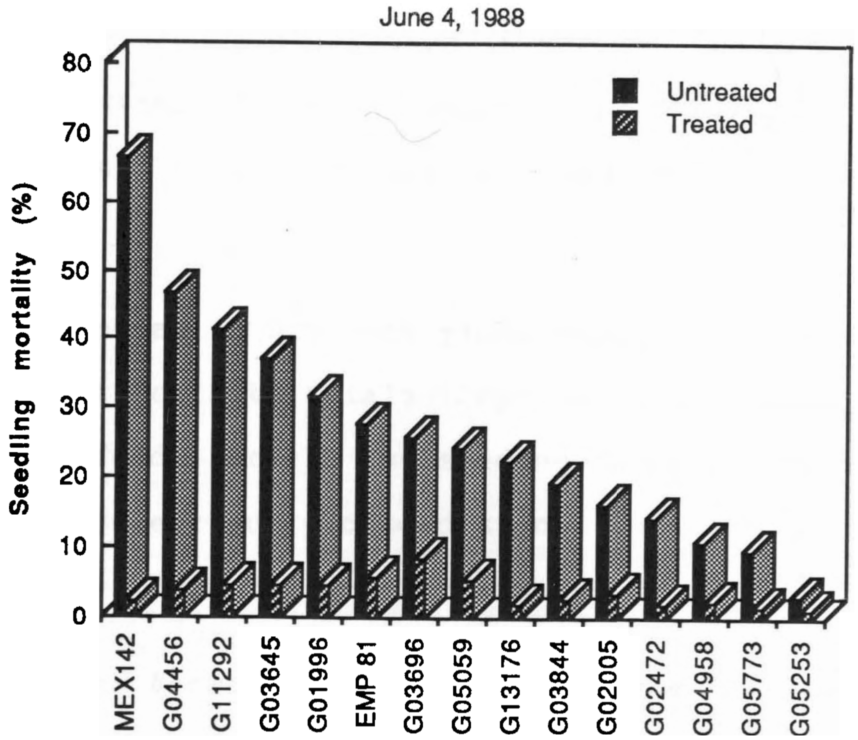
CIAT Acc. #	Cultivar name	Treatment	
		Treated	Untreated
G05253**	60 Dias	956ab	898ab
G02005	Gentry 21020	894ab	930a
G03645	Jamapa	985a	881ab
EMP 81	EMP 81	912ab	882ab
G13176**	Criolla Negra	924ab	864ab
G02472	Guerrero 29-C	856a-d	883ab
G03696	Coleccion 12-d	876abc	794abc
G04456**	Jamapa	884ab	776abc
G01996**	Gentry 20989	729bcd	861ab
G05059	H6 Mulatinho	749a-d	748abc
G05773**	ICA Pijao	754a-d	678bc
G04958	Veranic 2	742bcd	714abc
G03844	Cascade	646cd	774abc
G11292	Poroto Tropero	632d	596c
Local	Mexican 142	390e	355d
	Mean	795.1	775.8
	SE	25.8	23.4

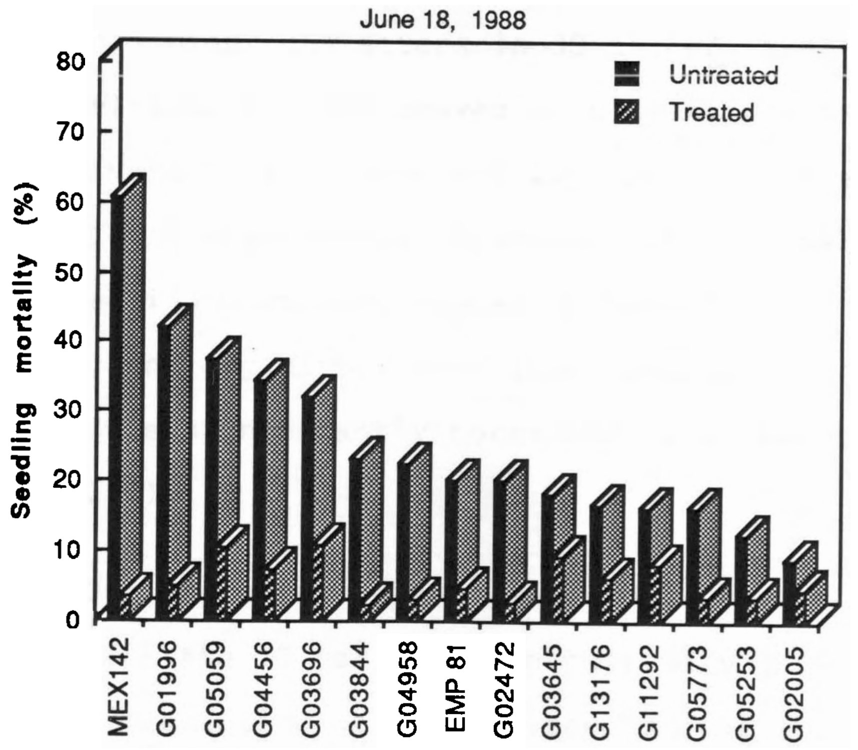
*Means, within a column, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); **selected from non-replicated trials.

Seedling mortality in all the "resistant" selections was significantly lower than that in the standard check 'Mexican 142' (Fig. 2.3). No significant differences in seedling mortality were found within insecticide-treated plots. For example, in the experiment seeded on June 4, percent seedling mortality was low ranging between 1.2% in G05253 and 8.6% in G03696 (grand $\bar{x}$=3.7 ± 0.3%). In contrast, mortality figures ranged betweem 2.9% in G05253 and 66.3% in the standard check ('Mexican 142') ($\bar{x}$=26.4 ± 2.3%) in untreated plots. Similar results were obtained for the June 18 seeding; differences among treated plots ranged between 2.3% (G03844) and 10.7 (G03696), with a grand mean of 5.7 ± 0.5% (Fig. 2.3); they were non-significant. In untreated plots, the lowest mortality was 8.7% (G02005) and the highest was 60.6% ('Mexican 142') ($\bar{x}$=25.4 ± 2.3%). These substantial differences in seedling mortality between treated and untreated plots, particularly in the susceptible check, indicate that the seed treatment was effective against bean fly.

Differences in yield loss (proportion of yield difference between treated and untreated plots within a cultivar) caused by bean fly among cultivars were highly significant for both trials at Awassa (Appendix 2.4). Percent yield losses for the two seeding dates ranged between 85.1% and 59.1% for the June 4 and June 18, 1988, seedings, respectively, in the standard check cultivar, to 4.0% and 8.8%, and 4.3% and 11.2% for G05773 and G05253, respectively, indicating that these cultivars are

Figure 2.3: Percent seedling mortality caused by bean fly in 15 cultivars of *Phaseolus vugaris* grown with and without endosulfan seed treatment, Awassa, 1988 (separate trials seeded on June 4 and June 18).


June 4, 1988
Untreated
Treated
Seedling mortality (%)
0
10
20
30
40
50
60
70
80
MEX142
G04456
G11292
G03645
G01996
EMP 81
G03696
G05059
G13176
G03844
G02005
G02472
G04958
G05773
G05253


June 18, 1988
Untreated
Treated
Seedling mortality (%)
0
10
20
30
40
50
60
70
80
MEX142
G01996
G05059
G04456
G03696
G03844
G04958
EMP 81
G02472
G03645
G13176
G11292
G05773
G05253
G02005

resistant. As was the case in percent seedling mortality, yield losses of some cultivars showed interaction with seeding dates. Percent dry-seed yield losses in the two seeding dates for G11292, G04456, G03844 and G03645, for example, were 34.8 and 0, 63.7 and 24.3, 0 and 27, and 38.5 and 14.7, respectively (Fig. 2.4).

Differences in dry-seed yield among cultivars were highly significant for both trials (Appendix 2.5). Table 2.4 shows dry-seed yields for the two seeding dates at Awassa. All the resistant selections produced significantly higher yields than the check without the seed treatment.

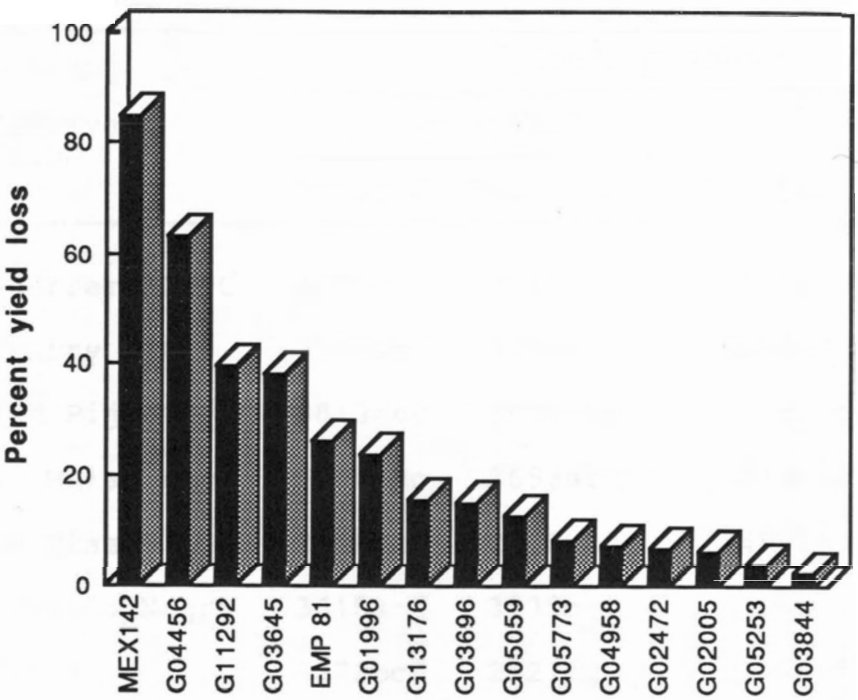
Correlations between plant characters and resistance

Analysis of variance on measurements of morphological and physiological plant characters in 38 haricot bean cultivars grown at Melkassa in 1987 showed no significant differences among cultivars in leaf area and dry matter; differences in pubescence were significant (Appendix 2.6). Correlation analyses between seedling mortality caused by bean fly and leaf area, pubescence, and dry matter were also done but none of these characters was significantly correlated with seedling mortality (Appendix 2.7).

Table 2.5 represents measurements of the various plant characters for the 15 haricot bean cultivars grown without insecticide protection at Awassa (seeded June 18, 1988). Significant differences ($P<0.05$) were found among the cultivars

Figure 2.4: Percent dry-seed yield loss caused by bean fly in 15 cultivars of *Phaseolus vulgaris*, Awassa, 1988 (yield in treated plots represented 100%; June 4 and 18 were seeding dates).

June 4, 1988



June 18, 1988

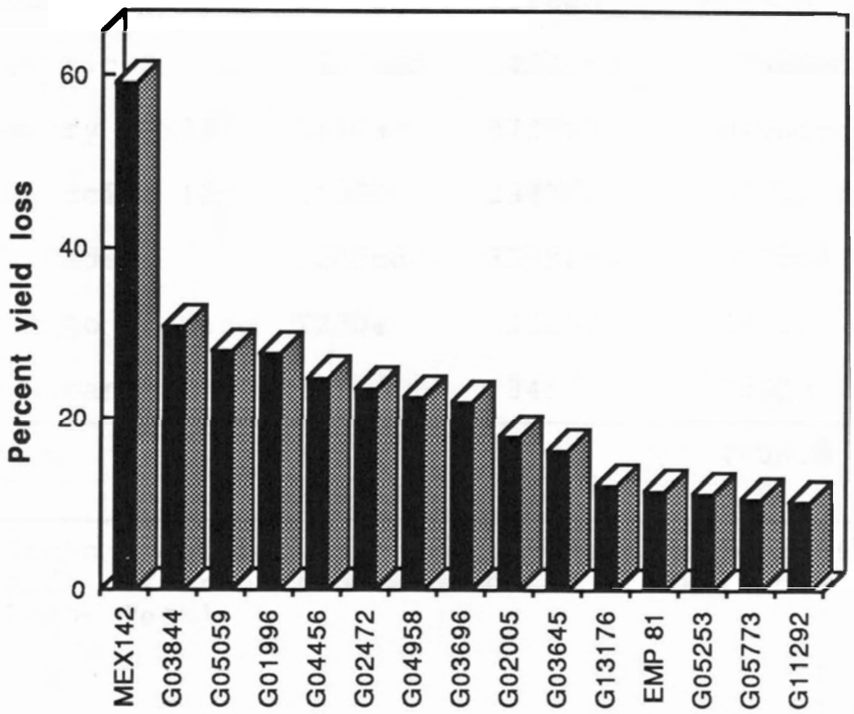


Table 2.4: Dry-seed yield (kg/ha) of 15 cultivars of *Phaseolus vulgaris* grown with and without endosulfan seed treatment against bean fly, Awassa, 1988*

CIAT Acc. #	Cultivar name	Seeding date			
		4-vi-1988		18-vi-1988	
		Treated	Untreated	Treated	Untreated
G02472	Guerrero 29-C	4216a	3919a	5110a	3902abc
G02005	Gentry 21020	3980ab	3724ab	5096a	4186a
G05773	ICA Pijao	3813abc	3661abc	4518a-e	4121ab
G05059	H6 Mulatinho	3850abc	3693abc	4719abc	3434b-f
G05253	60 Dias	3900abc	3733ab	3499fg	3106def
G13176	Criolla Negra	3615a-d	3039c-f	4325b-e	3776a-d
EMP 81	EMP 81	3272bcd	2521fg	3946def	3493a-f
G04456	Jamapa	3798a-d	1379i	4942ab	3742a-e
G03645	Jamapa	3341bcd	2056gh	4552a-d	3881abc
G04958	Veranic 2	3505bcd	3438a-d	3950def	3298c-f
G01996	Gentry 20989	3619a-d	2738ef	4155c-f	3040ef
G03696	Coleccion 12-d	3100d	2937def	3915def	3061def
G03844	Cascade	3202cd	3213b-e	3815ef	2783fg
G11292	Poroto Tropero	2230e	1453hi	2190h	2261g
Local	Mexican 142	2396d	346j	2886g	1168h
	Mean	3455.7	2790.1	4108.0	3283.5
	SE	94.9	143.5	123.6	140.6

*Means, within a column, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test).

Table 2.5: Plant character measurements for 15 cultivars of *Phaseolus vulgaris*, Awassa, 1988*

CIAT Acc. #	Cultivar name	Stem thickness (mm)	Stem length (mm)	advent. root formation (% of plants)
G05253	60 Dias	5.4bc	72.5abc	23.1 (20.0)**
G05773	ICA Pijao	6.5a	70.5bcd	26.0 (25.0)
G02005	Gentry 21020	5.4bc	68.5cd	32.9 (30.0)
G02472	Guerrero 29-C	5.8ab	68.2cde	25.6 (30.0)
G13176	Criolla Negra	5.2bcd	67.7cde	16.4 (15.0)
G04958	Veranic 2	5.5bc	59.5f	35.8 (35.0)
G03844	Cascade	4.4de	64.5def	38.7 (40.0)
EMP 81	EMP 81	5.6bc	78.0a	42.1 (45.0)
G05059	H6 Mulatinho	5.7bc	76.2ab	29.1 (30.0)
G03645	Jamapa	5.1bcd	67.5cde	38.8 (40.0)
G01996	Gentry 20989	4.8cd	77.5a	38.7 (40.0)
G04456	Jamapa	5.6bc	71.5a-d	23.1 (20.0)
G03696	Coleccion 12-d	5.3bc	66.0c-f	23.1 (20.0)
G11292	Poroto Tropero	5.3bc	66.5cde	57.7 (65.0)
Local	Mexican 142	3.9e	61.2ef	32.3 (35.0)
	Mean	5.3	69.1	32.7
	SE	0.1	0.9	3.1

*Means, within a column, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); **values are arcsine transformations and (original).

in stem thickness and stem length; differences in percentages of plants with adventitious roots were non-significant. Only stem diameter was significantly correlated ($r=-0.557$; $df=13$; $P<0.05$) with seedling mortality caused by bean fly damage. That is, the character stem thickness of some haricot bean cultivars was negatively correlated with seedling mortality and positively correlated with dry-seed yield.

Significant differences ($P<0.05$) were found among cultivars in the number of bean flies emerging/5 plants (Appendix 2.8). Seedling stem-thickness and bean fly emergence/5 plants (in the trial seeded on June 18 at Awassa) were positively correlated (Fig. 2.5). However, resistant cultivars did not necessarily support fewer insects than did susceptible cultivars. For example, the number of insects per five plants for the resistant cultivars G05253 and G05773 at Awassa (June 18) was 14 and 26, respectively whereas it was only 7.2 for the susceptible cultivar 'Mexican 142' (Table 2.6). Moreover, the highest number of bean flies per five plants (17.6) was recorded for the resistant cultivar G05253 at Melkassa (Table 2.6) as opposed to 10.1 for 'Mexican 142'.

DISCUSSION

In this chapter, I have presented results of a series of related experiments carried out during three seasons between 1986 and 1988 to determine sources and correlations between

Figure 2.5: Relationship between stem thickness and bean fly emergence/5 plants in 15 cultivars of *Phaseolus vulgaris*, Awassa, 1988 ($r=0.740$; $df=13$; $P<0.01$; arrow bars are $\bar{x} \pm$ se).

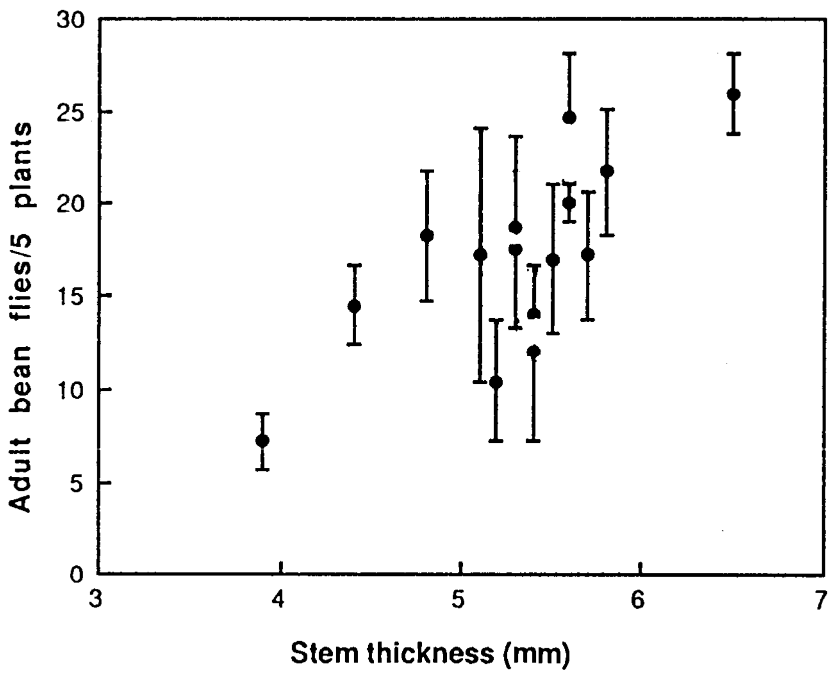

Adult bean flies/5 plants
Stem thickness (mm)
30
25
20
15
10
5
0
3
4
5
6
7

Table 2.6: Mean numbers of adult bean flies emerging/5 plants in 15 cultivars of *Phaseolus vulgaris* at two locations, 1988*

CIAT Acc. #	Cultivar name	Location	
		Awassa	Melkassa
G05253	60 Dias	14.0b-e	17.6a
G05773	ICA Pijao	26.0a	7.1d
G02005	Gentry 21020	12.0cde	6.7d
G02472	Guerrero 29-C	21.7ab	10.0bcd
G13176	Criolla Negra	10.5de	11.1a-d
G04958	Veranic 2	17.0a-d	9.7bcd
G03844	Cascade	14.5b-e	10.0bcd
EMP 81	EMP 81	20.0abc	11.5bcd
G05059	H6 Mulatinho	17.2a-d	10.0bcd
G03645	Jamapa	17.2a-d	10.5bcd
G01996	Gentry 20989	18.2a-d	9.1cd
G04456	Jamapa	24.7a	16.6ab
G03696	Coleccion 12-d	17.5a-d	15.0abc
G11292	Poroto Tropero	18.7a-d	14.7abc
Local	Mexican 142	7.2e	10.1bcd
	Mean	17.1	11.3
	SE	1.0	0.6

*Means, within a column, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test).

plant characters and resistance in *Phaseolus vulgaris* cultivars to bean fly. In the first season (1986) I used the number of bean flies per plant and a damage score as the criteria for selecting resistant cultivars. In the second season (1987), I use dseedling mortality, percentage survival of plants, and dry-seed yield in the non-replicated trials. Evaluation in the replicated experiments was based on ANOVA of seedling mortality due to bean fly, a performance score, and dry-seed yield. My criteria for evaluation in the third season, where I compared 14 resistant cultivars with a standard commercial cultivar, were seedling mortality and yield loss due to bean fly. To determine correlations between plant characters and resistance, I measured several morphological and physiological plant characters and ran correlation analyses between these and seedling mortality, dry-seed yield, and bean fly numbers.

In the light of results of experiments described in this chapter, seedling mortality is perhaps the best parameter as a basis for selecting resistant cultivars once the material has been reduced to a manageable size. However, at the initial stage of screening where hundreds of materials are involved, use of this parameter may be impractical because of the requirement for frequent inspection of the plots and roguing of dead plants. Under such circumstances the use of a subjective damage score rating made at an appropriate time would still permit selection of resistant materials, although substantial experience regarding assessment of bean fly damage would be required. Bean fly counts or percent infestation should not be used as major criteria in screening for resistance to bean fly. For one thing, they do not necessarily measure bean fly resistance, and for another, as we are going to see in the next chapter, higher numbers of bean flies do not always cause high seedling mortality or low seed yield; if there is adequate moisture in the soil, and if good crop husbandry is followed, seedling mortality is low and bean yields are high even when bean fly numbers are high.

Taking percentages of surviving plants as secondary data helps to account for seedling mortality that occurs after canopy closure; bean plants usually lodge towards maturity because of girdled or weakened stems caused by bean fly.

A valuable confirmation of the effect of bean fly resistance is demonstration of yield loss due to bean fly, which can be obtained by paired comparison of yields in insecticide protected and unprotected plots. This is possible in situations where bean fly is the only insect pest causing significant yield losses.

Seedling mortality and percent dry-seed yield loss due to bean fly (difference between treated and untreated plots) are better measures of resistance than is a comparison of yield differences *per se*. This is because yield differences among different cultivars could be caused not only by bean fly, but also by other factors, including yield components and other plant characters (Appendix 2.9). For example, stepwise multiple regression analyses (SAS, 1985) showed that yield in the 15 cultivars seeded on June 4, 1988, at Awassa, was estimated by the equation:

$$\hat{Y} = 3410.073 - 74.528X_1 + 25.716X_2 \quad (R^2=0.930, P=0.0001),$$

and the experiment seeded on June 18, 1988, by:

$$\hat{Y} = 2326.421 - 56.425X_1 + 52.903X_2 \quad (R^2=0.678, P=0.0011),$$

where X_1= % seedling mortality and X_2= pods/plant.

Some cultivars, including G11292, G03844, G03645, and G05059 performed differently at the two seeding dates at Awassa (Fig. 2.3); that is, it is possible that there are interactions between cultivars and seeding dates. By contrast, the accessions G05253, G05773, G02005 and G02742 followed consistent trends on both sowing dates. Otanes y Quesales (1918) reported a similar situation in the Philippines; for example, in his experiments, 100% of the bean cultivar 'Canadian Wonder' seeded in late March was killed by bean fly whereas mortality was only 56% if the same cultivar was seeded in early May. These results suggest that it is desirable to conduct resistance screening trials replicated both over space and time.

The observed negative correlation between stem diameter and seedling mortality is in agreement with reports by Krishna Moorthy & Srinivasan (1989) who observed a negative relationship between plant vigour and seedling mortality caused by bean fly, but at variance with the findings of Chiang (1984), Chiang &

Norris (1982, 1983a), and Talekar *et al*. (1988) who all worked on soybean or mungbean. Chiang & Talekar (1980) and Talekar *et al*. (1988) reported highly significant positive correlations between the numbers of insects per plant and the percentages of plants severely damaged by bean fly and related agromyzid species in soybean and mungbean; this was not so in my experiments with haricot bean.

Although there was a highly significant positive correlation between seedling stem thickness and bean fly emergence, no significant correlations existed between the numbers of adult bean flies emerging per plant and yield, or between percent infestation and yield. These variables were used by several researchers (Raros, 1975; Rogers, 1974,1979; Sandhu *et al*., 1977; Singh & Mishra, 1977; Chiang & Talekar, 1980; Reddy *et al*., 1983; Talekar *et al*., 1988) as criteria for selecting bean or pea cultivars for resistance to bean fly. My experiments suggest that these may not always be reliable measures of resistance. Chiang (1984), Chiang & Norris (1982, 1983a), and Talekar *et al*. (1988), also found positive correlations between stem diameter and bean fly numbers and concluded that such cultivars were susceptible. In the case of haricot bean these cultivars were resistant. What happened here is that thick-stemmed cultivars were more vigourous, were not so easily killed by bean fly and therefore gave greater yields in spite of the fact that they supported high pest populations. These responses satisfy Painter's (1951) definition of tolerance; that is, plants that show little damage in spite of supporting a pest population adequate to severely damage susceptible hosts. These results suggest that breeding programmes for bean fly resistance must look for plant vigour, at least until other mechanisms of resistance are found.

In summary, the cultivars G05253, G05773, G02005, and G02472 were consistent in their performance against bean fly and therefore can be considered reliable sources of resistance. All of these accessions have black seed coats and for this reason, are not in high demand, especially for export. Thus, these accessions are now being crossed with commercial cultivars such as 'Mexican 142' that have desirable seed coat colour, seed shape and size.

CHAPTER III

STUDIES ON SEEDING DATE AND PLANT DENSITY

INTRODUCTION

The importance of time of seeding as a control method for bean fly was first recognized by Otanes y Quesales (1918) in the Philippines. Van der Goot (1930) reported that delayed seeding in Java resulted in increased plant mortality caused by bean fly. Hassan (1947) also reported that, in Egypt, bean fly can cause a total seedling loss in late-seeded crops. Moutia (1945) suggested that seeding should not take place when bean fly is common. Otanes y Quesales (1918) and Raros (1975) observed marked differences in bean fly damage among haricot bean cultivars seeded in different seasons. Observations by Negasi & Abate (1986) indicated that, in northern Ethiopia, early seeded beans escaped bean fly damage and gave higher yields. Kwon *et al*. (1981) reported that bean fly attack increased with delayed seeding.

By contrast, Kooner *et al*. (1977) observed that the incidence of bean fly in India was higher in early-seeded than in late-seeded peas (*Pisum sativum* L.).

Planting beans during dry spells is known to cause high plant mortality (Caldwell, 1939; Swaine, 1969; Lin *et al*., 1977; Manohar & Balasubramnian, 1980b), but such losses have been attributed to the low vigour of the plants rather than to the direct effect of bean fly.

Little information is available regarding the influence of plant density on the incidence of bean fly. Abate *et al*. (1986) and Negasi & Abate (1986) reported that the fly's damage in densely-seeded bean plots was significantly lighter than that in thinly seeded plots. It should be pointed out here, however, that most of the reports quoted above are based on casual observations rather than on data obtained from controlled experiments. If proven effective, the adjustment of seeding dates and plant density could provide sound, low cost management methods, especially in subsistence agriculture. It was with this objective in mind that I carried out the following experiments.

MATERIALS AND METHODS

Seeding date and plant density experiments were conducted in the two, more or less contrasting, environments of Awassa in southern Ethiopia, and Melkassa in central Ethiopia (see Fig. A.1) during the 1987 and 1988 main crop growing seasons. A randomized complete block design (RCBD) was laid out in split plots. Four seeding dates were used for main plots and five plant densities as subplots, with 100,000 (P1), 200,000 (P2), 300,000 (P3), 400,000 (P4) and 500,000 (P5) plants/ha. The experiment was replicated three times at both locations in both years, thus there were 60 subplots (4 x 5 x 3) at each location in each year. Each subplot was 7 m x 10 m (70 m^2); unseeded alleys of 2, 2.5, and 3 m were left between subplots, mainplots, and replications, respectively, in order to minimize interference among treatments. The total area of each experimental field was 111 m by 47.5 m (7272.5 m^2). Seeds of the moderately susceptible bean variety 'Negro Mecentral' were manually sown in rows spaced 40 cm apart (25 rows per subplot). The desired plant populations were achieved by spacing the seeds in the rows at approximately 25, 12.5, 8.3, 6.3, and 5.0 cm for subplots P1, P2, P3, P4 and P5, respectively. Ten-day intervals were allowed between seedings. In 1987, the first seeding at Awassa was June 12 but July 6 at Melkassa. In 1988, seeding at Awassa started on June 7 and at Melkassa on July 4. The starting dates were chosen in accordance with the amount of rainfall rather than with calendar dates. No fertilizer or pesticide treatments were used; plots were kept weed-free by frequent hand-weeding.

Stand counts were taken about 2 weeks after seeding. Records of bean seedlings that had been killed by bean fly were made by checking fields regularly, at least once every second day, starting about 15 days after seeding. To avoid double counting dead seedlings were rogued and then taken to the laboratory for rearing adult bean fly and its parasitoids (see methods described in the preceding chapter). Ten of the dead plants rogued were dissected, and the immature bean flies (puparia + larvae) were counted (1987). In addition, I sampled 25 live plants/plot by randomly uprooting one plant from odd-numbered rows along one diagonal and one plant from even-numbered rows along the other diagonal (35 days after seeding) in 1988. Infested plants (seedlings with bean fly damage symptoms, *i.e.*, seedlings with mines, swellings, cracks, or bean fly immatures in the stem) were counted, and the percentage of infestation was determined from these samples. The live plants were then taken to the laboratory, and adult insects were reared from them according to the procedures described for dead plants. Bean fly counts from dead plants were pooled over all samples collected at different times.

Yields of dry seed were taken from 20 rows (56 m^2) at harvest and adjusted to 10% moisture.

RESULTS

To evaluate the effects of seeding date and plant density on bean fly I used several criteria, including abundance of bean fly, as measured by the number of bean fly emergence/10 plants; seedling mortality rates caused by this pest; infestation levels; and yield of dry seed. I also studied the influence of seeding dates and plant densities on levels of parasitism.

Abundance of bean fly

Seeding date (SDt), plant density (PDt) and season had significant effects on the number of bean flies that emerged from dead plants at both locations (Appendix 3.1). Interactions were significant among SDt x PDt treatments at Awassa and among season x SDt x PDt treatments at Melkassa.

Table 3.1 summarizes the bean fly emergence data for Awassa. Bean fly numbers varied with seeding date and plant density; they ranged between 8.2 in P5 sown at S4 in 1987 and 55.6 in P1 sown at S3 in 1988. Mean numbers of bean fly varied among seeding dates, but they declined with increasing plant density. The overall mean bean fly numbers/10 dead plants in 1988 (32.7 ± 1.5) were significantly greater than those in 1987 (19.8 ± 1.1).

At Melkassa, the mean numbers of bean flies emerging/10 dead plants ranged between 0 and 9.6 (Table 3.2). In general, bean fly numbers at Melkassa tended to increase with late seeding and declined with increasing plant density. The overall mean number of bean flies/10 dead plants in 1988 (3.3 ± 0.4) was significantly greater than that in 1987 (1.5 ± 0.2).

Both at Awassa and Melkassa, there was a significant negative curvilinear relationship between plant density and adult bean fly emergence/10 dead plants (Fig. 3.1). At Awassa, pest populations and hence seedling mortality tended to decline with later seeding dates (Fig. 3.2) whereas the situation was reversed at Melkassa (Fig. 3.3). (Note that the order of S1 to S4 is reversed in Figures 3.2 and 3.3).

Although the overall population trends were similar, estimates based on the emergence of adult bean flies were, on average, lower ($\bar{x}$=19.8 ± 2.1) than the estimates obtained by the

Table 3.1: Adult bean fly emergence/10 plants in *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), Awassa*

Yr	SDt	PDt					
		P1	P2	P3	P4	P5	Mean
1	S1	30.5f-i	28.6f-j	28.3f-j	25.5f-j	20.9i-m	26.8
1	S2	26.4f-j	19.5j-m	14.8k-n	12.7mn	13.1lmn	17.3
1	S3	31.6e-h	27.1f-j	21.0i-m	20.4i-m	20.1j-m	24.0
1	S4	12.8mn	12.4mn	12.5mn	8.7n	8.2n	10.9
2	S1	43.0bc	42.1bcd	32.4e-h	34.6c-f	22.4h-m	34.9
2	S2	48.2ab	33.0d-g	28.7f-j	26.5f-j	24.2g-k	32.1
2	S3	55.6a	40.3b-e	19.2j-m	27.7f-j	23.8g-k	33.3
2	S4	43.4bc	35.3c-f	25.7f-j	22.9g-l	24.1g-k	30.3
Mean		36.4	29.8	22.8	22.4	19.6	

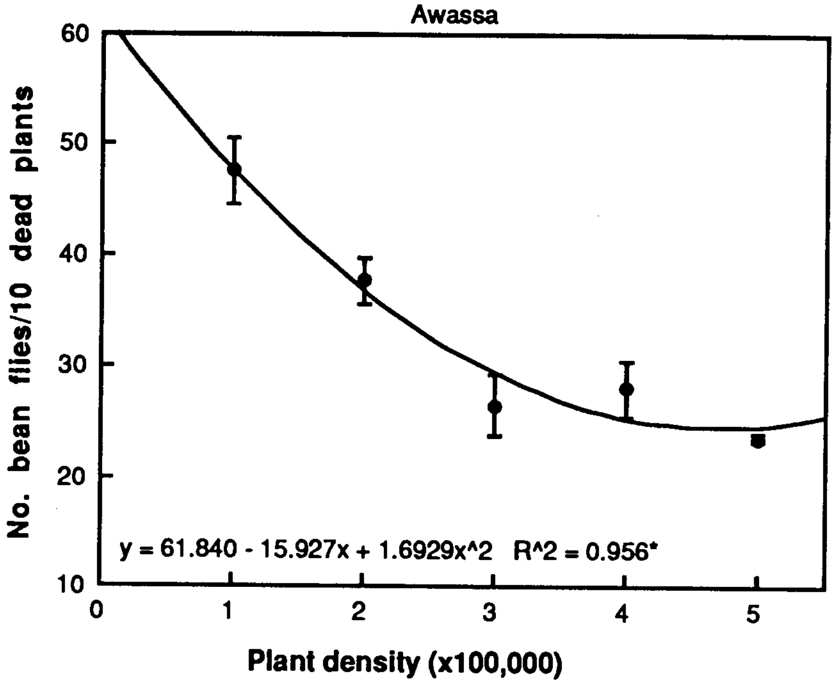
*All means followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); years 1 and 2 refer to 1987 and 1988, respectively.

Table 3.2: Adult bean fly emergence/10 plants in *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), Melkassa*

Yr	SDt	PDt					
		P1	P2	P3	P4	P5	Mean
1	S1	1.5e-m	1.5e-l	1.2f-n	0.8h-n	1.3f-n	1.2
1	S2	1.7e-k	1.2g-n	0.6i-n	0.4j-n	0.2k-n	0.8
1	S3	1.3f-n	0.8h-n	0.6i-n	0.2k-n	0.3k-n	0.7
1	S4	5.2bc	3.6cde	3.5c-f	2.0e-j	1.7f-k	3.2
2	S1	0.0n	0.1mn	0.1lmn	0.0n	0.0n	0.0
2	S2	9.4a	4.6bcd	3.2c-g	2.3d-i	2.3d-i	4.4
2	S3	9.6a	4.8bcd	2.3d-i	2.1d-i	1.8e-k	4.1
2	S4	5.1bc	5.1bc	7.6ab	2.3d-i	2.6c-h	4.5
Mean		4.2	2.7	2.4	1.3	1.3	

*All means followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); years 1 and 2 refer to 1987 and 1988, respectively.

Figure 3.1: Relationship between plant density and bean fly emergence at two locations, 1988 (*=P<0.05; **=P<0.01; arrow bars are $\bar{x} \pm$ se).


Awassa
No. bean flies/10 dead plants
60
50
40
30
20
10
0
1
2
3
4
5
y = 61.840 - 15.927x + 1.6929x^2 R^2 = 0.956*
Plant density (x100,000)

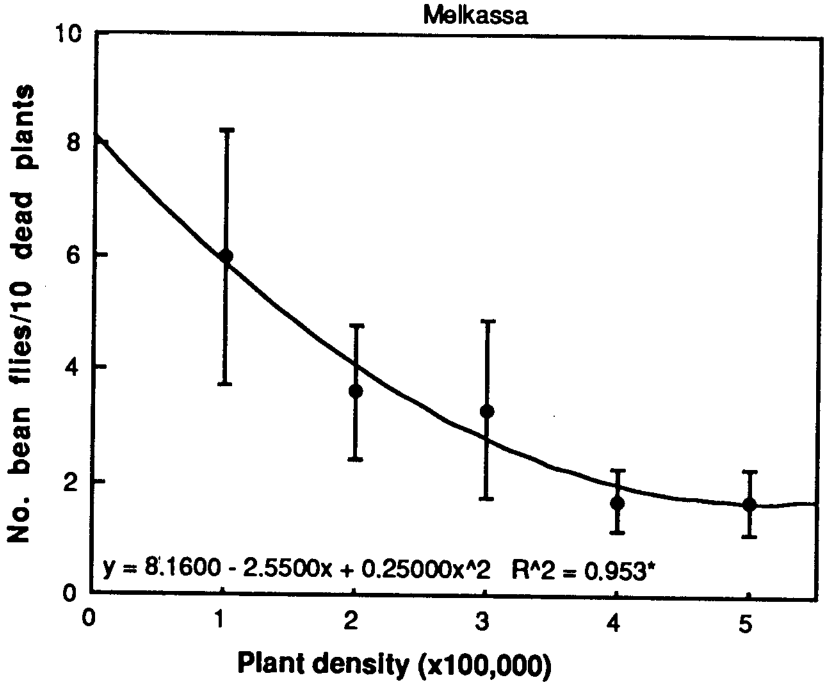

Melkassa
No. bean flies/10 dead plants
10
8
6
4
2
0
1
2
3
4
5
y = 8.1600 - 2.5500x + 0.25000x^2 R^2 = 0.953*
Plant density (x100,000)

Figure 3.2: Mean numbers of adult bean flies emerging/10 living plants seeded at different dates and densities, Awassa, 1988 (the vertical axis represents bean flies/10 plants).

Awassa

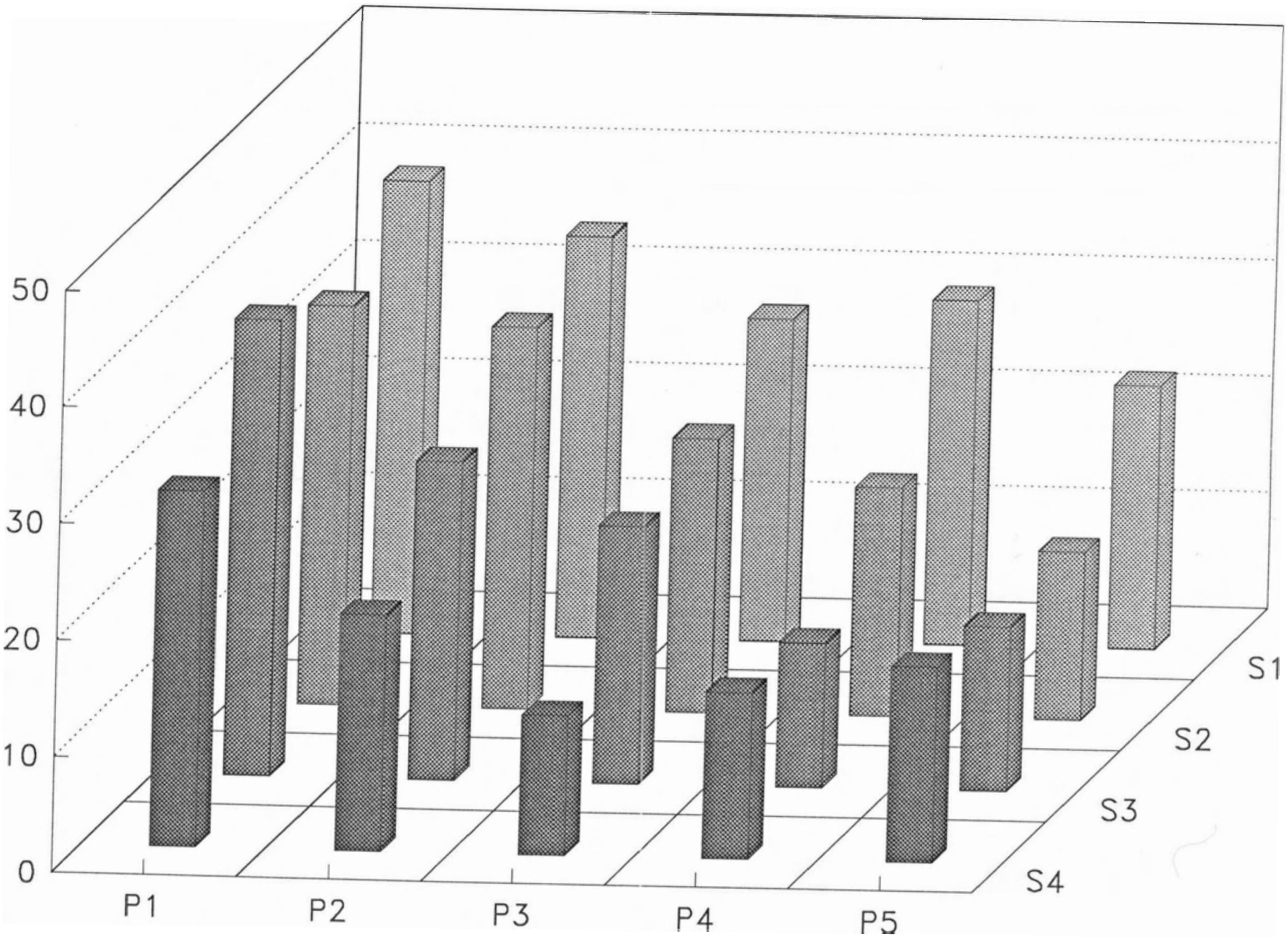
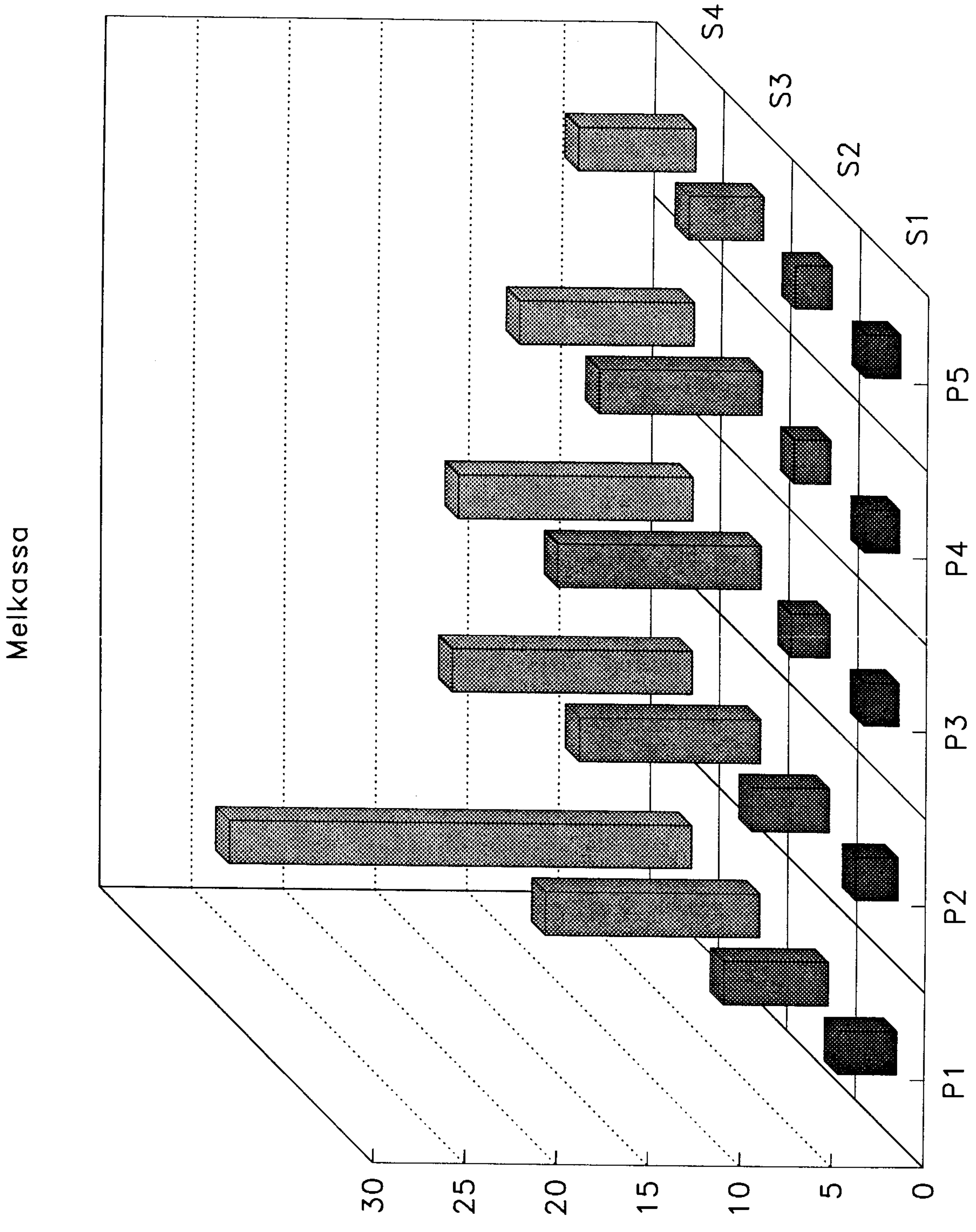


Figure 3.3: Mean numbers of adult bean flies emerging/10 living plants seeded at different dates and densities, Melkassa, 1988 (the vertical axis represents bean flies/10 plants).


Melkassa
30
25
20
15
10
5
0
P1
P2
P3
P4
P5
S1
S2
S3
S4

dissection of the plant method (total of larvae and puparia, $\bar{x}=27.5 \pm 1.6$). Estimates at Awassa (1987) differed significantly (t-test, $t=3.03$; $df=118$).

Seedling mortality rates

Differences in percentages of seedling mortality for seasons (Y) and plant density (PDt), for Y x SDt, and Y x SDt x PDt interactions were significant at Awassa (Appendix 3.2). At Melkassa, differences for Y, SDt, PDt, and for Y x SDt x PDt interactions were also significant.

Seedling mortality data for haricot bean seeded at different dates and densities at Awassa are presented in Table 3.3. Percentages of seedling mortality ranged between 0.5% in P5 sown at S3 in 1988 and 42.6% in P1 sown at S3 in 1987. In general, although seedling mortality in relation to seeding dates varied between seasons, it declined with increasing plant density (Table 3.3) at Awassa.

At Melkassa, seedling mortality ranged between 0.6% in P5 sown at S4 in 1988, and 34.9% in P1 sown at S3 in 1987 (Table 3.4). In general, seedling mortality tended to increase with late seeding at Melkassa. By contrast, it declined with increasing plant density in both seasons.

As was the case in bean fly abundance presented above, there were significant negative curvilinear relationships between plant density and seedling mortality (Fig. 3.4).

Table 3.3: Percentages of seedling mortality caused by bean fly in *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), Awassa*

Yr	SDt	PDt					
		P1	P2	P3	P4	P5	Mean
1	S1	39.3a	28.7bc	14.7efg	15.2efg	12.3f-j	22.0
1	S2	12.9f-g	10.4g-k	4.7l-p	5.4k-p	2.9p-s	7.3
1	S3	42.6a	21.3cde	10.3g-k	15.1efg	7.9h-m	19.4
1	S4	18.8def	17.4efg	9.8g-l	5.8k-p	5.0i-p	11.4
2	S1	14.0e-i	7.7i-m	4.8l-p	2.9p-s	3.1o-r	6.5
2	S2	36.1ab	26.3bcd	14.2e-i	11.8f-j	10.6g-k	19.8
2	S3	8.0j-o	3.2n-r	1.0r-s	1.1qrs	0.5s	2.8
2	S4	14.5e-h	7.7i-m	4.2m-q	3.9m-r	2.1p-s	6.5
Mean		23.3	15.3	8.0	7.7	5.6	

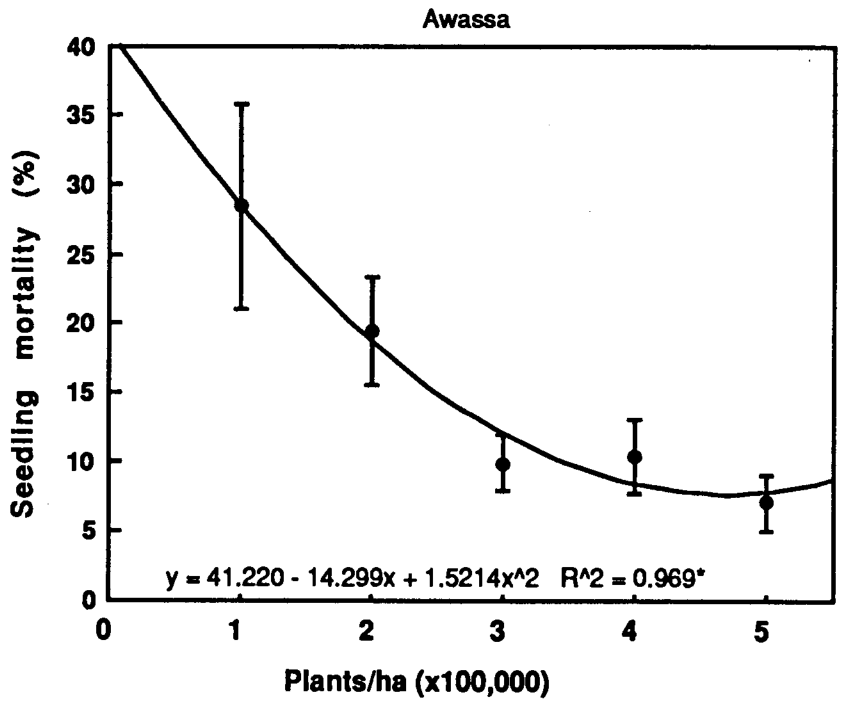
*All means followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); years 1 and 2 refer to 1987 and 1988, respectively.

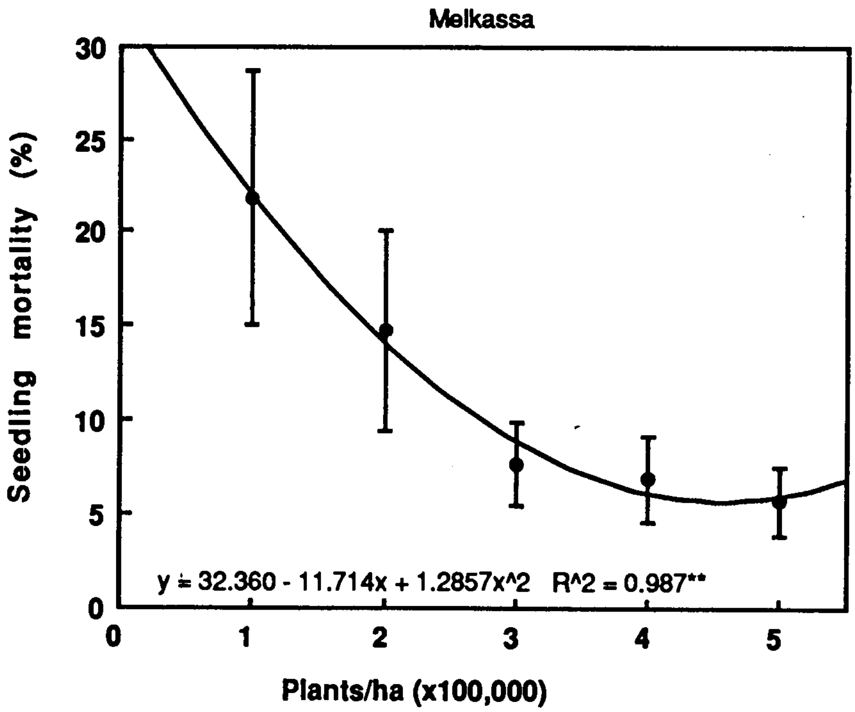
Table 3.4: Percentages of seedling mortality caused by bean fly in *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), Melkassa*

Yr	SDt	PDt					
		P1	P2	P3	P4	P5	Mean
1	S1	15.3c	6.5d-k	5.9e-k	4.2g-k	4.3f-k	7.2
1	S2	5.8e-k	4.4f-k	2.5ijk	2.1ijk	1.5jk	3.3
1	S3	34.9a	25.4b	10.5c-f	11.5cde	9.8c-g	18.4
1	S4	31.3a	22.5b	12.0cd	9.7c-h	7.1d-j	16.5
2	S1	12.0cd	7.1d-j	9.8c-h	5.3f-k	3.2ijk	7.5
2	S2	5.9e-k	5.0f-k	3.6h-k	2.5ijk	2.5ijk	3.9
2	S3	8.3d-i	4.1g-k	2.4ijk	2.2ijk	1.7ijk	3.7
2	S4	3.8g-k	2.9ijk	1.5jk	2.0ijk	0.6k	2.2
Mean		14.7	9.7	6.0	4.9	3.9	

*All means followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); years 1 and 2 refer to 1987 and 1988, respectively.

Figure 3.4: Relationship between plant density and seedling mortality caused by bean fly in *Phaseolus vulgaris* at two locations, 1987 (*=P<0.05; **=P<0.01; arrow bars are $\bar{x}$ ± se).


Awassa
40
35
30
25
20
15
10
5
0
0
1
2
3
4
5
Seedling mortality (%)
Plants/ha (x100,000)
y = 41.220 - 14.299x + 1.5214x^2 R^2 = 0.969*


Melkassa
30
25
20
15
10
5
0
0
1
2
3
4
5
Seedling mortality (%)
Plants/ha (x100,000)
y = 32.360 - 11.714x + 1.2857x^2 R^2 = 0.987**

The overall mean seedling mortality in 1987 was significantly greater than it was in 1988 at both locations. For example, the overall means in 1987 (and 1988) at Awassa and Melkassa were 19.0 ± 1.6% (8.9 ± 1.3%) and 11.4 ± 1.3% (4.4 ± 0.5%), respectively.

Seedling mortality was significantly correlated with the numbers of adult bean flies that emerged/10 plants at Awassa ($r=0.867$; $df=18$; $P<0.01$) and Melkassa ($r=0.523$; $df=18$; $P<0.05$).

Percent infestation

Percent infestation (proportion of bean seedlings with bean fly damage symptoms) was recorded in 1988. Only SDt treatments were significant at Awassa whereas both SDt and PDt treatments were significant at Melkassa. In general, percent infestation decreased with delays in seeding dates at Awassa whereas the reverse was true for Melkassa (Table 3.5). Plots with higher plant density suffered significantly less bean fly damage than the low-density plots.

Correlations between infestation levels and bean fly emergence were highly significant both at Awassa ($r=0.690$; $df=18$; $P<0.01$) and Melkassa ($r=0.824$; $df=18$; $P<0.01$). By contrast, infestation and seedling mortality were not correlated either at Awassa ($r=0.371$; $df=18$; $P=1.000$) or Melkassa ($r=-0.215$; $df=18$; $P=1.000$). There were highly significant negative correlations between infestation levels and seed yield at Melkassa ($r=-0.745$; $df=18$; $P<0.01$) but not at Awassa

Table 3.5: Percent bean fly infestation (35 days after seeding) in *Phaseolus vulgaris* seeded at different dates and densities, 1988*,**

Treatments	Location	
	Awassa	Melkassa
Seeding date		
S1	98.9a	48.5c
S2	88.3b	45.1c
S3	73.9c	74.4b
S4	76.5c	95.2a
Plant density		
P1	90.7a	75.7a
P2	87.0a	67.3ab
P3	82.3a	72.0a
P4	82.7a	56.3b
P5	79.3a	57.7b
Mean	84.4	65.8
SE	2.0	3.2

*Means, within a column, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); **data were transformed to their arcsine values before analysis.

(r=0.341; df=18; P=0.141).

Dry-seed yield

Yield differences for Y, SDt, PDt and for Y x SDt interactions were significant at Awassa (Appendix 3.3); at Melkassa, significant differences were found for Y, SDt, PDt, and for Y x SDt and SDt x PDt interactions.

Table 3.6 summarizes the dry-seed yield data for Awassa. Seed yields ranged between 1474 kg/ha in P1 sown at S4 in 1987 and 4049 kg/ha in P4 sown at S1 in 1988. Mean yields varied among seasons whereas they increased with increasing plant density up to P3; they levelled off at P4 and declined at P5. Figure 3.5 shows the relationships between plant density and seed yield.

The overall yield in 1988 (3149 ± 71.4 kg/ha) was significantly higher than in 1987 (2596 ± 64.6 kg/ha) at Awassa.

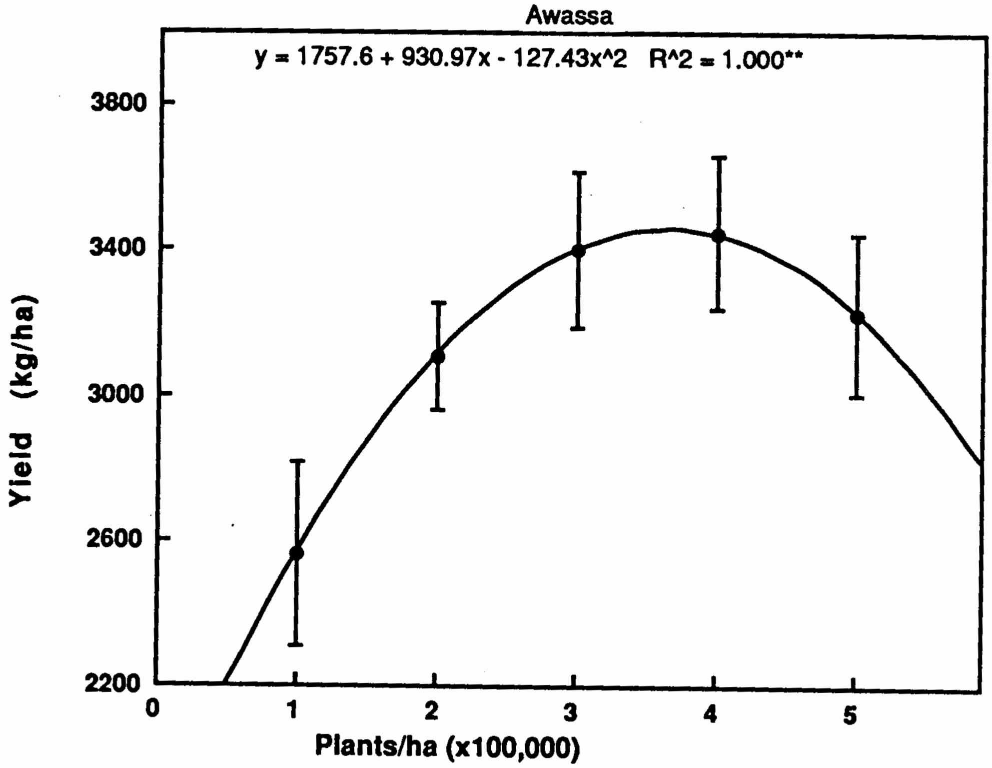
The 2-year dry-seed yield data for Melkassa are summarized in Table 3.7. Yield values ranged between 227 kg/ha in P5 sown at S4 in 1987 and 3543 kg/ha in P5 sown at S1 in 1988. In general, at Melkassa, dry-seed yields declined with late seeding and increased with increasing plant density. The declines in seed yield at high plant densities were associated with declines in the number of pods/plant (Fig. 3.6) and seeds/pod (Fig. 3.7) rather than with bean fly damage.

Table 3.6: Dry-seed yield (kg/ha) in *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), Awassa*

Yr	SDt	PDt					
		P1	P2	P3	P4	P5	Mean
1	S1	1841kl	2324ijk	2804d-i	2549g-j	2698e-j	2438
1	S2	2311ijk	2874d-i	2793d-i	2870d-i	2841d-i	2738
1	S3	2172jk	2935c-h	3192c-f	3149c-g	2980c-h	2885
1	S4	1474l	2116jk	2650f-j	2785d-i	2585f-j	2322
2	S1	2821d-i	3506abc	4020a	4094a	3886ab	3657
2	S2	2477hij	3039c-h	3199c-f	3391bcd	3031c-h	3028
2	S3	3052c-h	3086c-h	3346bcd	3296cde	3045c-h	3165
2	S4	1902kl	2795d-i	3039c-h	3060c-h	2932c-h	2746
Mean		2253	2834	3130	3143	3000	

*All means followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); years 1 and 2 refer to 1987 and 1988, respectively.

Figure 3.5: Relationship between plant density and dry-seed yield in *Phaseolus vulgaris* at two locations, 1988 (**=P<0.01; arrow bars are $\bar{x}$ ± se).


Awassa
y = 1757.6 + 930.97x - 127.43x^2   R^2 = 1.000**
Yield (kg/ha)
3800
3400
3000
2600
2200
0
1
2
3
4
5
Plants/ha (x100,000)

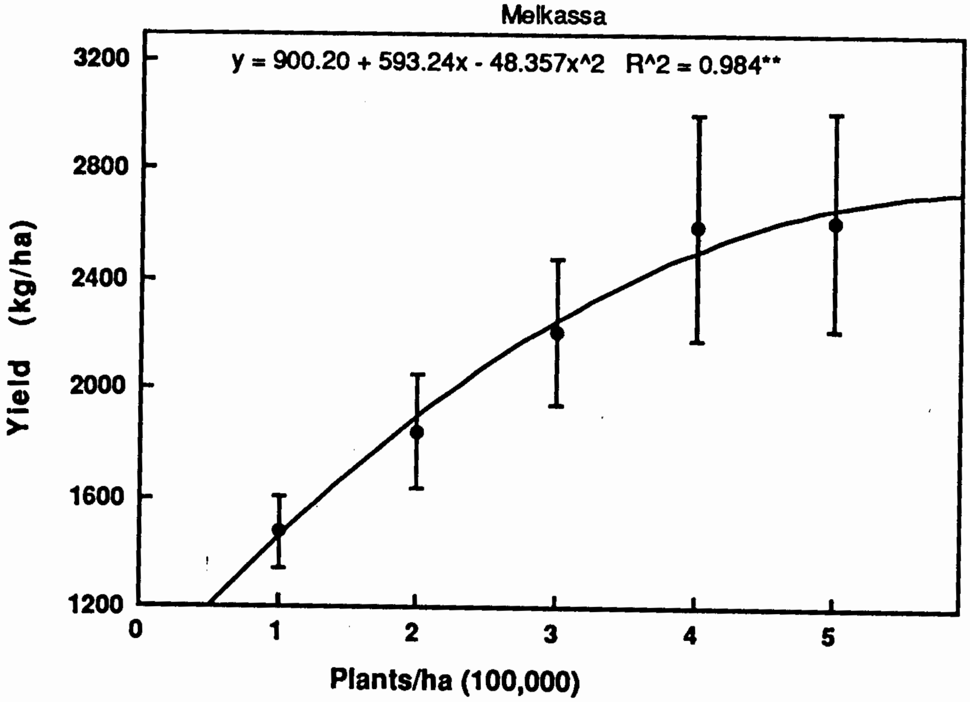
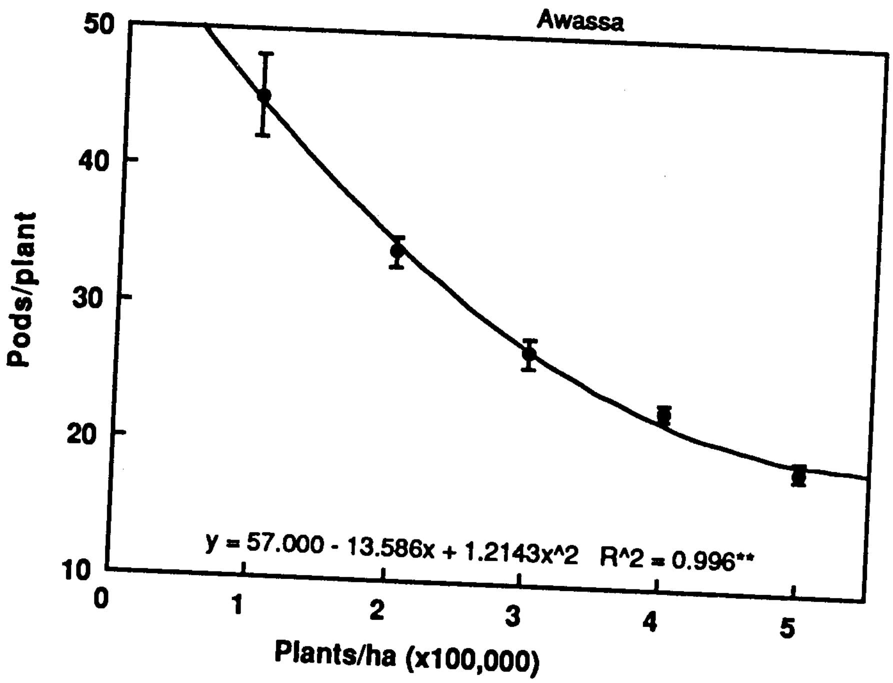

Melkassa
y = 900.20 + 593.24x - 48.357x^2   R^2 = 0.984**
Yield (kg/ha)
3200
2800
2400
2000
1600
1200
0
1
2
3
4
5
Plants/ha (100,000)

Table 3.7: Percentages of seedling mortality caused by bean fly in *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), Melkassa*

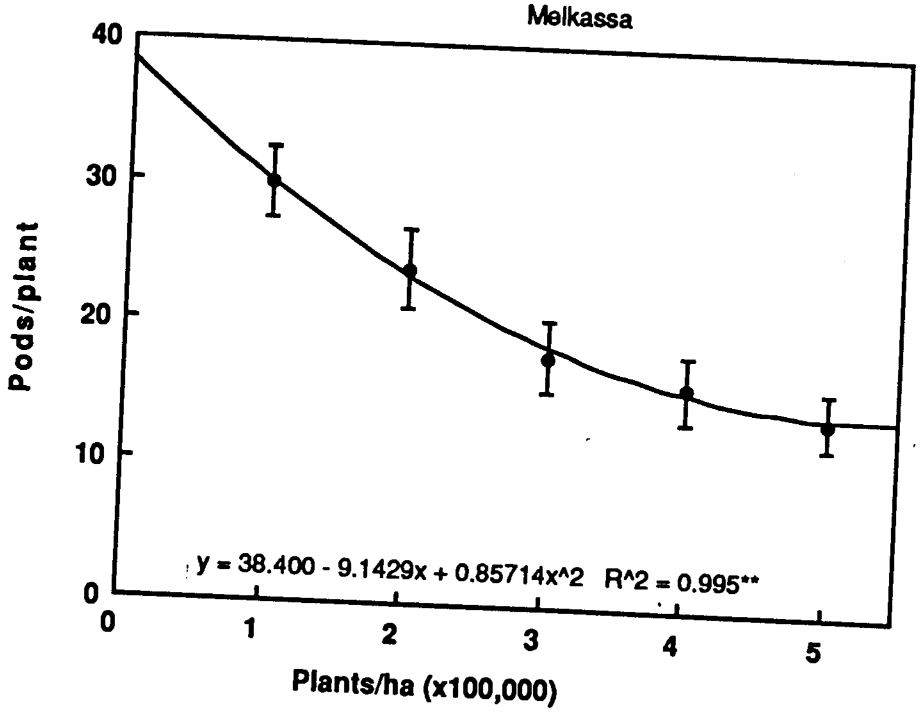
Yr	SDt	PDt					
		P1	P2	P3	P4	P5	Mean
1	S1	498n-r	858k-q	957j-o	1078i-n	943j-p	867
1	S2	512n-r	451o-r	586m-r	435o-r	885j-q	574
1	S3	325pqr	365o-r	569m-r	640l-r	509n-r	482
1	S4	379o-r	269q-r	355o-r	387o-r	227r	323
2	S1	1431g-k	1987efg	2605cd	3394ab	3543a	2592
2	S2	1571f-i	2046def	2389cde	2951bc	2864bc	2364
2	S3	1766fgh	2105def	2431cde	2562cde	2384cde	2249
2	S4	1136i-m	1230h-l	1426g-k	1464g-j	1673f-i	1386
Mean		952	1164	1415	1614	1628	

*All means followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); years 1 and 2 refer to 1987 and 1988, respectively.

Figure 3.6: Relationship between plant density and the numbers of pods/plant in *Phaseolus vulgaris* at two locations, 1988 (arrow bars are $\bar{x} \pm$ se).

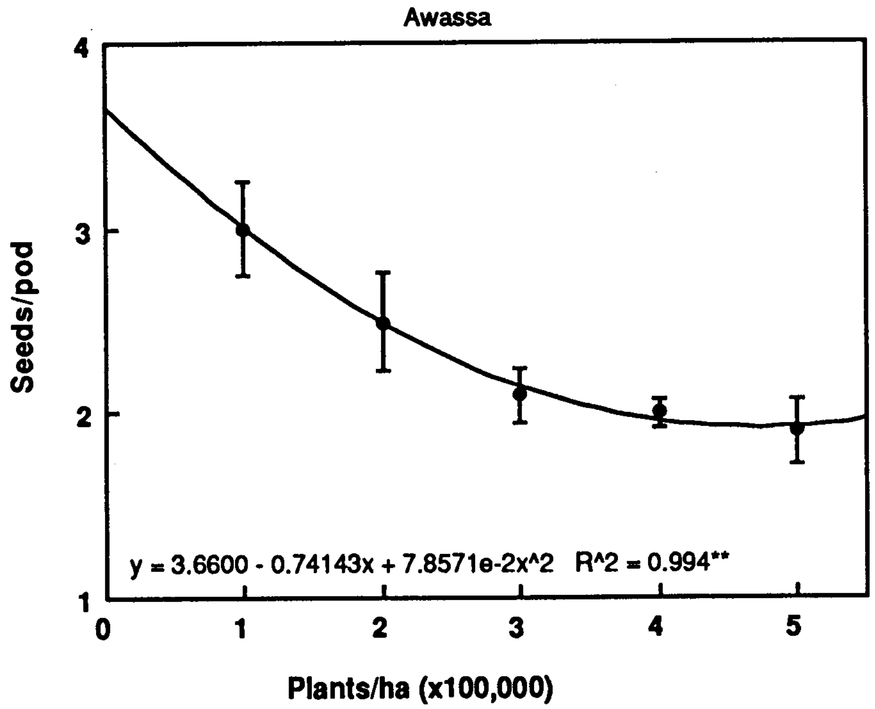


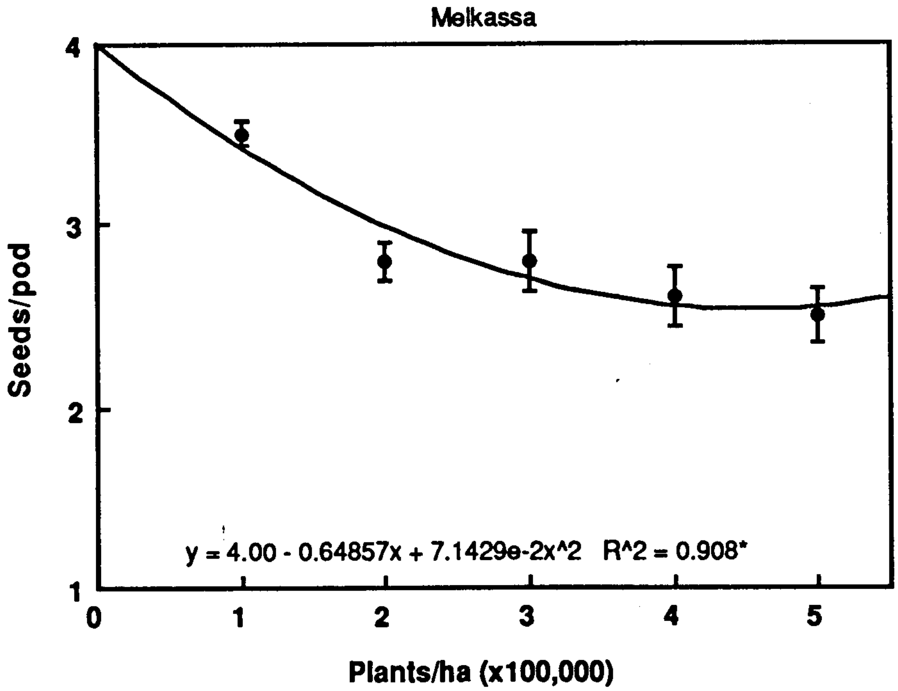
Awassa
Pods/plant
50
40
30
20
10
0
1
2
3
4
5
y = 57.000 - 13.586x + 1.2143x^2 R^2 = 0.996**
Plants/ha (x100,000)



Melkassa
Pods/plant
40
30
20
10
0
0
1
2
3
4
5
y = 38.400 - 9.1429x + 0.85714x^2 R^2 = 0.995**
Plants/ha (x100,000)

Figure 3.7: Relationship between plant density and the numbers of seeds/pod in *Phaseolus vulgaris* at two locations, 1988 (**=P<0.01; arrow bars are $\bar{x}$ ± se).


Awassa
Seeds/pod
4
3
2
1
0
1
2
3
4
5
y = 3.6600 - 0.74143x + 7.8571e-2x^2 R^2 = 0.994**
Plants/ha (x100,000)


Melkassa
Seeds/pod
4
3
2
1
0
1
2
3
4
5
y = 4.00 - 0.64857x + 7.1429e-2x^2 R^2 = 0.908*
Plants/ha (x100,000)

As was the case for the yield data for Awassa mentioned above, the overall mean yield in 1988 (2148 ± 102.4 kg/ha) was significantly greater than in 1987 (561 ± 39.3 kg/ha). The high yields in 1988 resulted from increased number of pods/plant and seeds/pod (Melkassa, Appendices 3.4 & 3.5) and of 1000-seed weight (Awassa and Melkassa, Appendix 3.6).

Parasitism

The levels of bean fly parasitism in this experiment were recorded for two groups of parasitioids, *viz.* the braconid *Opius phaseoli* Fischer and the pteromalids *Sphegigaster* spp. and other Chalcidoidea.

Opius phaseoli

The percentages of bean fly parasitism by *Opius phaseoli* varied with season, seeding dates and plant densities at Awassa and with season and seeding dates at Melkassa (Appendix 3.7).

Table 3.8 summarizes data for percent parasitization by *Opius phaseoli* of bean fly in haricot bean seeded at different dates and densities during 2 years at Awassa. The levels of parasitism ranged between 58.6% in P4 sown at S4 in 1987 and 93.3% in P3 sown at S1 in 1988. Parasitization at Awassa appeared to decline with late seeding; plant density did not show consistent trends.

At Melkassa, seeding dates had a significant effect on percent parasitization; mean percent parasitization in S1, S2,

Table 3.8: Percent parasitization by *Opius phaseoli* of bean fly in haricot bean seeded at different dates (SDt) and densities (PDt), Awassa*

Yr	SDt	PDt					
		P1	P2	P3	P4	P5	Mean
1	S1	81.7efg	85.3cde	84.0c-f	86.0cde	85.3cde	84.5
1	S2	73.9h-k	76.2ghi	68.3i-l	65.3j-m	64.5lm	69.7
1	S3	75.8ghi	71.1h-l	69.5h-l	69.0h-l	67.6i-m	70.6
1	S4	66.0j-m	64.2lm	64.9klm	58.6m	73.9hij	65.5
2	S1	93.0a	92.3ab	93.3a	92.3ab	92.0ab	92.6
2	S2	88.9a-d	89.0abc	87.2b-e	86.5cde	86.3cde	87.6
2	S3	76.3gghi	76.0ghi	73.3h-k	71.8h-l	81.7d-g	75.8
2	S4	83.2c-g	77.5fgh	68.4i-l	69.9h-l	74.2hij	74.6
Mean		79.8	79.0	76.1	75.0	78.2	

*All means followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); years 1 and 2 refer to 1987 and 1988, respectively.

S3, and S4 in 1987 (and 1988), respectively, was 25.8cd (6.7e), 22.5d (44.5b), 40.1bc (57.5ab), and 41.2bc (69.2ab). Plant density did not have a significant effect on parasitization by *Opius phaseoli* of bean fly at Melkassa.

During the 1988 season, estimated levels of parasitization were based on insect counts from dead and living plants at both locations. The two methods of sampling did not differ when estimates were compared by t-test either at Awassa (t=1.75; df=118) or at Melkassa (t=0.21; df=118).

In general, parasitization decreased with delayed seeding at Awassa but increased at Melkassa. In effect, seeding dates had more influence on parasitization by *Opius phaseoli* than did plant densities at both locations (Appendix 3.8).

Sphegigaster and other Chalcidoidea

Three species of Chalcidoidea were found on bean fly in haricot bean. *Sphegigaster brunneicornis* (Ferrière) and *S. stepicola* Boucek were the two most common species among the Chalcidoidea. Of the two, the former was more common at Awassa and the latter at Melkassa. An undetermined species of *Eupelmus* was another chalcidoid that was occasionally encountered at Awassa.

Plant density did not have a significant effect on parasitization; by contrast, seasons and seeding dates had significant influence at both locations (Appendix 3.9). Although it appeared that parasitism by Chalcidoidea was favoured by late seeding, the trends were not consistent.

Parasitization levels by Chalcidoidea were generally low, averaging only about 5% of the total percentages of bean fly on haricot bean (Appendix 3.9). In contrast, chalcids accounted for most of bean fly parasitism on the wild host plant (see Table A.2).

DISCUSSION

In this chapter, I reported the effects of seeding dates and plant densities on bean fly abundance, on its damage to the crop, on crop yield and on parasitism levels by *Opius phaseoli* and some Chalcidoidea.

Seeding dates and plant densities had significant effects on bean fly numbers, on its damage to the crop, and on bean yields. Although the last seeding gave the lowest yield at both locations, judged on the basis of bean fly numbers, the low yields obtained in S4 were not simply the result of bean fly damage, but probably reflect also the influence of low moisture. Any plots that are seeded late may not get optimum rainfall during their growth period, and this is especially true for Melkassa where the period of rainfall is very short (July and August).

Dry-seed yields in 1988 were significantly greater than those in 1987 at either location. These increases in yields were associated with decreases in bean fly damage. It is interesting to note here that, although the overall bean fly numbers were significantly greater in 1988 than in 1987 at both locations, seedling mortality was greater in 1987 than in 1988. These results indicate the importance of moisture, or the lack of it, in bean fly management. When there is adequate moisture in the soil, plants are more vigourous. Even if they are attacked by bean fly they can form adventitious roots and thus may have a better chance of surviving to produce seeds.

The observed variability in bean fly numbers, crop damage, and bean yields suggests that recommendations on seeding date should not be based on calendar dates; other factors in the local environment, such as the expected availability of moisture during the entire growth period must be taken into consideration.

Significant curvilinear relations were found between the plant density and the percent seedling mortality, the number of bean flies/plant, and the dry-seed yield at both locations. That is, the percent seedling mortality and the numbers of bean flies/plant declined with increasing plant density but, dry-seed yields increased with density to a maximum and then declined. The low yields at high plant densities may have resulted from competition among plants for space, nutrients and other essentials that resulted in fewer pods/plant and seeds/pod rather than from bean fly damage. It is also possible that, at high densities, the percentage of plants that survived and contributed to seed yield was reduced (Leakey, 1972).

Ohlander (1980) recommended early seeding of beans at the rate of 250,000 seeds/ha in Ethiopia; Karel & Mghogho (1985) reported the highest seed yields of 1230 kg/ha at 200,000 seeds/ha under Tanzanian conditions. Leakey (1972) and Edje *et al*. (1975) reported that bean yields are influenced by soil fertility and seed rates. These reports and the above results suggest that the response of haricot bean yield to differences in plant populations is perhaps area-specific.

I used the SORT subprogramme menu of MSTAT (Freed *et al*., 1985) to determine the "best" SDt x PDt treatment combinations for my results; seed yield, seedling mortality, and bean flies/10 plants were the first, second, and third primary sorting keys. Thus, at Awassa, P3, P4, and P5 (in descending order) seeded at S1 were the three best treatment combinations, whereas P5 and P4 seeded at S1 or P5 seeded at S2 were the best treatments at Melkassa. These results suggest that 300,000 to 400,000 seeds/ha should be sown about 2 weeks after the rains have started at Awassa; and 300,000 to 500,000 seeds/ha should be sown as soon as the rains have started at Melkassa.

The decision to choose seeding rates may be dictated by the cost of seeds and the extra benefits that may accrue from increased seed rates; the rates of increase in crop yield decline beyond P3. However, it should be noted that weeds were suppressed at higher bean plant densities provided only that the plots were weeded during the initial stages of crop establishment.

In the same experiment, I also tested the effects of seeding dates and plant densities on bean fly parasitism by the wasp, *Opius phaseoli*. Seeding dates had significant effects on parasitization, but differences among plant densities did not follow consistent trends. It appears, however, that seeding dates influenced parasitization by influencing the pest population rather than directly affecting the parasite population. For example, significant correlations were found between bean fly numbers and percent parasitization both at Awassa ($r=0.508$; $df=18$; $P<0.05$) and Melkassa ($r=0.649$; $df=18$; $P<0.01$). These findings agree with Greathead's (1969) conclusion that *Opius phaseoli* is density-dependent. Although parasitism by *Opius phaseoli* was generally high, reaching 93% at Awassa and about 69% at Melkassa, it did not give adequate control of bean fly on a standing crop. This may be because bean fly damage is inflicted on the crop long before the parasitoid can suppress the pest population, as has been observed in southern Africa (Jack, 1913; Taylor, 1958, 1980).

Parasitization by *Sphegigaster* spp. varied with seeding dates but there were no consistent trends. These pteromalids and other Chalcidoidea contributed only about 5% of the total bean fly parasitism. These parasitoids may not play a major role in bean fly management.

The differences in the estimated numbers of bean flies between plant dissection and emergence method can be explained by the facts that adult counts did not include larvae and puparia, and that mortalities occurring during the pupal period (Greathead, 1969) are not included in counts of adults. Even so, counts of adult bean flies at emergence can be useful, especially when a large number of samples is involved, as in preliminary screening of several hundred entries; the emergence method is less laborious and less costly to use than the one requiring dissection of plants. It also facilitates estimation of parasitism because there is no need to dissect immature bean flies to determine parasitism levels (Allen & Smithson, 1986). The two methods yield comparable data.

The high correlations between seedling mortality and adult bean fly emergence/10 plants suggest that either method of sampling could be used in assessing the effects of various treatments on bean fly population levels. However, use of the emergence counts may be preferred over seedling mortality since the latter is dependent on weather conditions, and hence may not be adequate for evaluating treatments against bean fly at times of sufficient moisture and little crop damage. The lack of correlation between percent infestation and seedling mortality or dry-seed yield implies that estimates based on infestation do not provide a reliable measure of bean fly damage.

In conclusion, it was shown by experimentation that, by manipulating seeding dates and plant densities, bean fly numbers, and hence its damage to the crop, can be reduced and bean yields increased significantly. As seeding date and plant density interact, the best strategy for farmers to minimize bean fly damage is to plant fields with 300,000 to 500,000 seeds/ha. In areas where the duration of rainfall is long, such as Awassa, the optimum time for seeding is about 2 weeks after the rains have started. But at Melkassa, which has a short rainy period, seeding should take place at the beginning of the rainy season.

CHAPTER IV

STUDIES ON HABITAT DIVERSITY

INTRODUCTION

Habitat diversity, intercropping in particular, is an age-old practice that has been used by farmers to suppress pests and to increase crop yield, especially in subsistence agriculture (Perrin, 1977; Perrin & Phillips, 1978; Altieri *et al.*, 1978). In recent years, attempts have been made to extend this method into commercial agriculture in developed countries (Fordham, 1983; Speight, 1983; Capinara *et al.*, 1985; Horwith, 1985). Diverse environments can influence pest populations either by interfering with the pest's search for its host plant(s) or by providing shelter and other food sources for natural enemies (Root, 1973).

Speight & Lawton (1976) found that the numbers of predatory carabid and staphylinid beetles were correlated with the frequency and the density of annual meadow grass, *Poa annua* L. Altieri & Whitcomb (1980) showed that predator diversity and density were higher in plots surrounded by mature, complex vegetation than in those surrounded by annual crops. Similarly, Horn (1981) demonstrated that the density of predators of the green peach aphid, *Myzus persicae* (Sulzer), was higher in weedy than in weedless plots. Later, he showed (Horn, 1984) that aphid parasitoids, *Aphidius* spp., were most common in weedy plots whereas parasitism by *Diaeretiella rapae* (M'Intosh) was highest in weedless plots; secondary parasitism was always lower in plots with weeds than in those without weeds. Letourneau & Altieri (1983) reported that the predatory minute pirate bug, *Orius tristicolor* (White), showed a more rapid colonization rate in squash-maize-cowpea triculture than in squash monoculture. Experiments by Shelton & Edwards (1983) showed that predators were more abundant in weedy than in weed-free soybean fields. Barney *et al*. (1984) showed that the presence of grass weeds in particular, and weedy systems in general, contributed to a significant increase in the numbers of several major predators found in alfalfa fields. Reports by Dempster (1969), Dempster & Coaker (1974), Smith (1969, 1976a,b) and Tahvanainen & Root (1972) show that, in general, pest populations are smaller and natural enemy populations are greater in weedy than weedless plots of *Brassica* spp.

There is little information available on the effects on bean fly of multiple cropping systems. Van der Goot (1930) planted haricot bean intermixed with maize (*Zea mays*), but he obtained no reduction in bean fly numbers, a fact that he attributed to the slow initial growth of maize. Ruhendi & Litsinger (1979, 1983) and Litsinger & Ruhendi (1984) reported that the sowing of cowpea among standing rice stubble reduced colonization of this crop by bean fly. In Ethiopia, haricot bean strip-cropped with maize suffered significantly less damage by *Heliothis armigera* (Hübner) than did monocropped beans (Abate, 1988); in fact, subsistence farmers in Ethiopia rarely weed their bean fields.

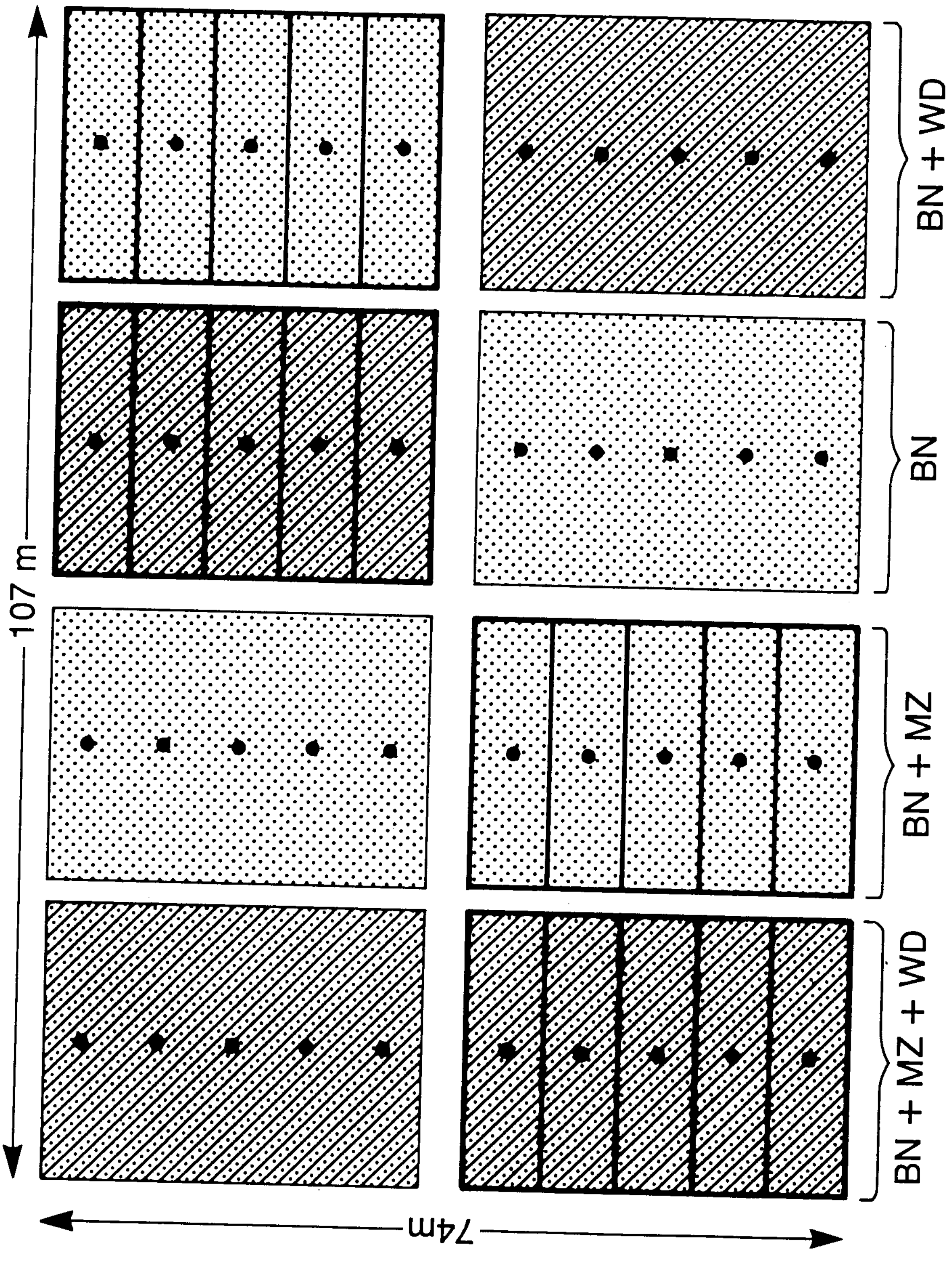
The objective of the experiment described below was to determine the effects of habitat diversity on bean fly, on beneficial insects, and on the yield of haricot bean.

MATERIALS AND METHODS

This experiment was conducted at Awassa in southern Ethiopia. The experiment was laid out in a RCBD 2-factor factorial with splits, with two levels of strip-cropping (no strip-cropping *vs* strip-cropping with maize cv. 'Katumani') as main treatments and two levels of weeding practices (subplots weeded continually until crop maturity *vs* plots in which weeds were only trimmed to the height of the bean crop) as subplot treatments (Fig. 4.1). The experiment was replicated twice in each of 1987 and 1988.

Each replicate block was 107 m x 35 m, with subplots of 25 m x 35 m, so that the total area of the experiment was 107 x 74 m or 7918 m^2. To minimize interference among treatments subplots, mainplots and replications were separated by unplanted alleys that were 2, 3, and 4 m wide, respectively. Replicates with strip-crops were surrounded by 2 rows of maize planted at 75 cm between rows and 25 cm between plants; the maize strips were repeated at approximately 5-m intervals so that there was a total of six 2-row horizontal strips in each replicate. Seeds of the commercial haricot bean (cv. 'Mexican 142') were sown in

Figure 4.1: A schematic diagram of field layout for the habitat diversity experiment (BN=beans, MZ=maize, WD=weedy; heavy lines=maize strips; heavy dots=water traps).



107 m
74m
BN + WD
BN
BN + MZ
BN + MZ + WD

rows 40 cm apart, 15 cm between seeds. Seeding took place on June 20 in 1987 and on June 30 in 1988. Maize was planted 10 days earlier than haricot bean No fertilizer or pesticides were applied.

Plants were counted 2 weeks after seeding. I counted adult bean flies visiting seedlings one day after the stand count on bean rows adjacent to maize strips and then on the middle two rows so that a total of 20 rows were sampled in each subplot; in plots without strip-crops, the insects were counted on rows corresponding to those in the strip-cropped plots. The adult flies were counted on a bright day between 10:00 and 12:00 hr, as they are most active during this time of day (Hassan, 1947). Dead seedlings were counted in each plot after the stand count. Seedlings killed by bean fly were rogued to avoid double counting. In 1987, at 35 days after seedling emergence, 25 of the dead plants, separately for each subplot, were selected and taken to the laboratory where they were sealed in pollination bags for 4 weeks; at that time any of adult bean flies and *Opius phaseoli* and other parasitoids that had emerged were counted and levels of parasitism were thus determined. In 1988, 25 dead and 25 living haricot bean plants were sampled from bean rows in plots with maize strips, and from the corresponding rows in plots without maize strips, by uprooting one plant each from even- and odd-numbered rows across the two diagonals. Thus, 125 dead and 125 living plants from each subplot, or a total of 1000 plants from the whole experimental field, were collected.

Numbers of entomophagous insects (other than *Opius phaseoli*) present in the field were estimated from yellow plastic traps (26.0 x 19.5 x 7.5 cm), filled with water and placed at about 5 m intervals in the centre of each subplot so that there were five traps for each subplot or 20 per replicate (Fig. 4.1). A few drops of liquid soap were added to the water to prevent the escape of insects landing in the trap. During the first 45 days after planting, the traps were kept 25 cm above the ground until canopy closure and then they were raised to a height of 50 cm. Entomophagous insects were counted every 2 days, when the traps were emptied, cleaned and refilled with water. Samples were taken over a period of 5 weeks. Bean yields were determined at harvest; the yields were adjusted to 10% moisture. Analysis of variance was carried out on the various data with the statistical package MSTAT Version 4.

Weed population and composition were estimated by sampling the plots on a diagonal with a 25 x 25 cm metal quadrat. Ten quadrat readings were taken per replicate.

RESULTS

Weed species

The species of weeds found at Awassa and their relative abundance in the weedy plots are listed in Table 4.1. *Galinsoga parviflora*, *Amaranthus hybridus*, *Nicandra physalodes*, *Eragrostis* sp. and *Digitaria scalarum* were the most common species of weeds

Table 4.1: Density (plants/m^2) and identity of weeds in the habitat diversity experiment field, Awassa.

Weed taxon	1987		1988	
	Density	Percent	Density	Percent
BROAD-LEAVED WEEDS				
Galinsoga parviflora	226	53.8	58	6.1
Amaranthus hybridus	66	15.7	5	0.5
Nicandra physalodes	62	14.8	3	0.3
Tagetes minuta	21	5.0	0	0.0
Conyza sp.	0	0.0	70	7.6
Solanum nigrum	4	1.0	7	0.8
Erucastrum sp.	9	2.1	2	0.2
Others	3	0.7	85	9.2
GRASSES/SEDGE				
Setaria pallidefusca	27	6.4	37	4.0
Cyperus rotundus	1	0.2	31	3.4
Sorghum sp.	1	0.2	0	0.0
Eragrostis sp.	0	0.0	370	40.0
Digitaria scalarum	0	0.0	259	28.0

found. There was a shift from broad-leaved weeds in 1987 to grassy weeds in 1988. This change may have resulted from clipping; most broad-leaved weeds do not form tillers when clipped whereas grass weeds form tillers and therefore their seed production may not have been greatly reduced.

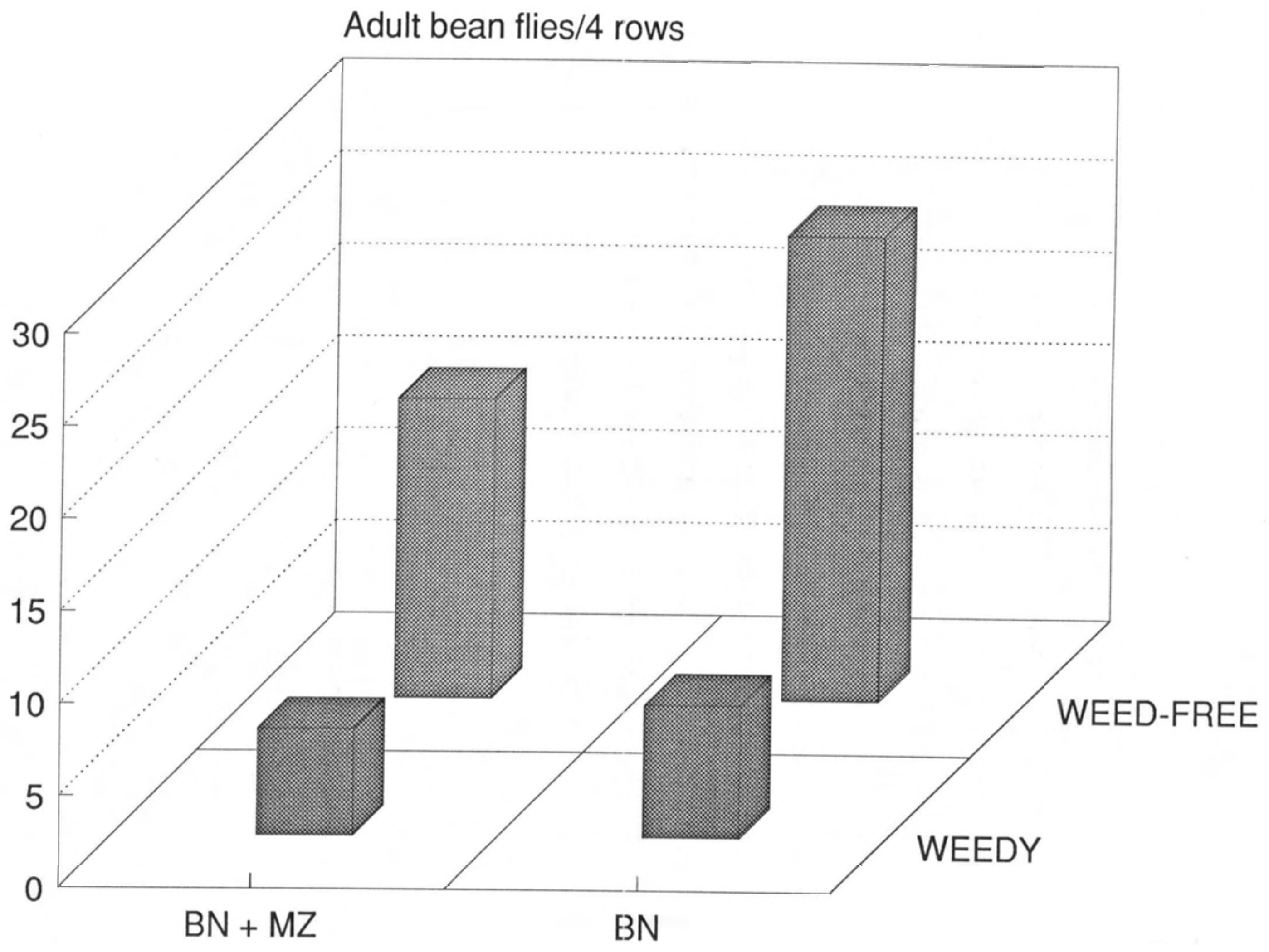
Adult flies visiting seedlings

Strip-cropping with maize did not have a significant effect on the numbers of adult bean flies in the experimental plots, but there were significant differences between weedy and weed-free plots in both seasons (Appendix 4.1). Adult bean fly numbers declined with the increase in habitat diversity. For instance, the average numbers of bean flies in weedy bean-maize intercrop, weedy bean, weed-free bean-maize intercrop, and bean monoculture plots in 1987 were 5.8, 7.2, 16.2, and 25.2, respectively. Data for 1988 are presented in Fig. 4.2.

Adult emergence

As was the case with respect to the numbers of adult bean flies visiting seedlings (see above), the mean numbers of bean fly that emerged from dead bean plants did not differ significantly for strip-cropping whereas differences between weedy and weed-free plots were significant (Appendix 4.2). The patterns of response of bean fly numbers to habitat diversity in 1988 were similar to those observed in 1987; that is, bean fly numbers tended to decline with the increasing habitat diversity. For example, the average numbers ($\bar{x} \pm$ se) of adult bean flies

Figure 4.2: Mean number of adult bean flies/4 rows of *Phaseolus vulgaris* seedlings grown with and without strip-crop under weedy and weed-free conditions, Awassa, 1988.


Adult bean flies/4 rows
30
25
20
15
10
5
0
BN + MZ
BN
WEED-FREE
WEEDY

emerging per 25 plants in weedy bean-maize intercrop, weedy bean without maize, bean monoculture, and weed-free bean-maize intercrop were 41.9 ± 3.9, 60.4 ± 6.5, 62.4 ± 2.9, and 72.7 ± 7.3, respectively.

Seedling mortality

Differences in seedling mortality among treatments were non-significant in both years; however, in 1987, seedling mortality tended to be lower in diverse plots. For example, the average percentage mortality in plots without strip-crop was 11.1 ± 1.8 as compared with 8.0 ± 1.2 in strip-cropped plots; similarly, 11.4 ± 1.5 and 7.7 ± 1.4 were recorded in weed-free and weedy plots, respectively. The observed mean values for weedy bean-maize intercrop, weedy bean without maize, weed-free intercrop, and bean monoculture in 1987 were 6.5%, 9.0%, 9.6%, and 13.2%, respectively. Seedling mortality in 1988 was relatively low and therefore differences among the means were negligible.

Parasitization by Opius phaseoli

Opius phaseoli Fischer is the main parasitoid of bean fly, and attempts were made to determine the influence of habitat diversity on parasitoid numbers. Differences among treatments in average percentages of parasitization were non-significant in both seasons (Appendix 4.3). Mean percentages of parasitization were generally high, ranging between 77.3 and 91.4 ($\bar{x}$=84.2 ± 4.8) in 1987 and between 73.0 and 78.1 ($\bar{x}$=75.4 ± 4.2) in 1988.

Average percentages of parasitization in bean plots with and without strip-crop and in weedy and weed-free plots in 1987 were 78.0 ± 5.4, 90.4 ± 2.0, 85.1 ± 6.6, and 83.4 ± 3.8, respectively. Corresponding values for the 1988 season were 75.6 ± 1.2, 75.3 ± 1.4, 76.4 ± 1.6, and 74.5 ± 0.8.

Other entomophagous insects

Surveys, using water traps, of entomophagous insects occurring in haricot bean fields with different treatments revealed more than 30 genera of parasitic and predaceous insects representing nine families of Hymenoptera, two of Diptera and one family each of Heteroptera and Coleoptera (Appendix 4.4). Of these, the tiphiid wasp *Tiphia* sp., the scoliids *Capsomeriella*, *Micromeriella* and related species, and three species of tachinid flies were most common. *Tiphia* spp., and other scoliids together constituted roughly 61% of all wasps counted in 1987 (n=1490). In 1988, 46.6%, 27.2%, and 9.5% of the total wasps were *Tiphia* sp., scoliids, and *Netelia* sp., respectively (n=1016). It should be noted that these entomophages do not attack bean fly, but they are important predators or parasitoids of the African bollworm, *Heliothis armigera* (Hübner), which is another major insect pest of haricot bean in Ethiopia.

Dry-seed yields

Strip-cropping did not have a significant effect on bean yields either in 1987 or in 1988. In contrast, weeds had highly significant effects (P<0.01) on bean yields (Appendix 4.5);

interactions between seasons, seasons and weeding, and between strip-cropping and weeding were also significant.

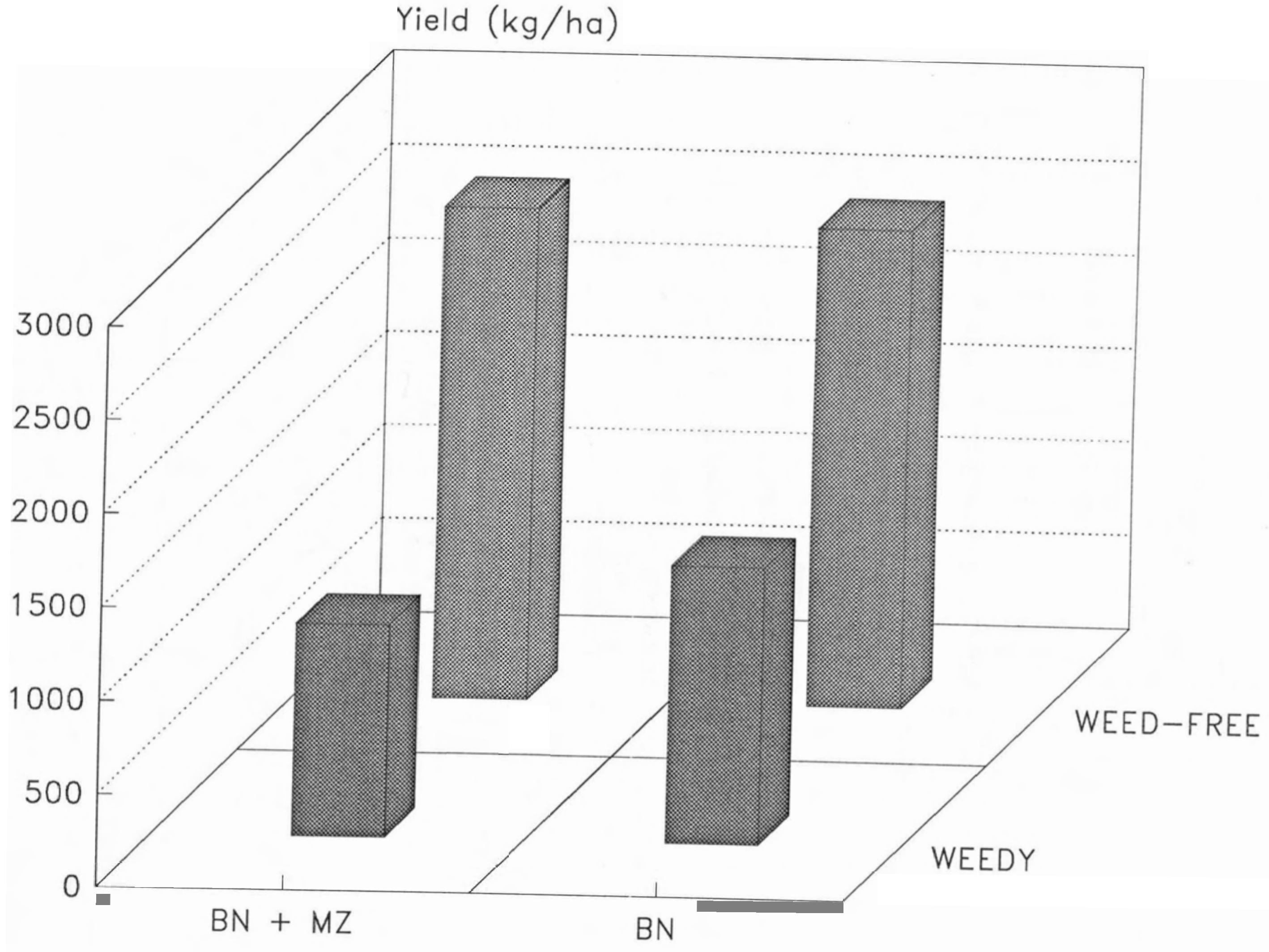
Dry-seed yields in weed-free plots were significantly greater than those in weedy plots (Fig. 4.3). Average yields in weed-free and weedy plots, respectively, were 1044 ± 38.9 and 447 ± 96.2 kg/ha in 1987, and 2590 ± 65.1 and 1307 ± 106.3 kg/ha in 1988. Seed yields declined with increasing habitat diversity. For instance, average yields in strip-cropped weedy bean, weedy bean without strip-crop, weed-free bean with strip-crop, and bean monoculture plots in 1987 were 286, 608, 1001, and 1086 kg/ha, respectively. Yield responses in the 1988 season followed a similar pattern to those in 1987. The overall mean seed yield in 1988 was significantly greater than in 1987.

DISCUSSION

In this chapter, I considered the effects of strip-cropping haricot bean with maize *vs* no strip-cropping and of weedy *vs* weed-free treatments, on the abundance of bean fly, and of entomophagous insects, and on dry-seed yield of beans during 1987 and 1988. Broad-leaf weeds, including *Galinsoga parviflora*, *Amaranthus hybridus*, and *Nicandra physalodes*, constituted approximately 93.1% of the total weed population in 1987, as compared with 24.7% in 1988 when grass weeds, such as *Eragrostis* sp. and *Digitaria scalaram* were the predominant species. However, this change in weed composition did not have

Figure 4.3 Dry-seed yield (kg/ha) of *Phaseolus vulgaris* grown with and without strip-crop under weedy and weed-free conditions, Awassa, 1988.

1988



Yield (kg/ha)
3000
2500
2000
1500
1000
500
0
BN + MZ
BN
WEED-FREE
WEEDY

appreciable effects on the responses of bean fly and *Opius phaseoli* or on bean yields; patterns of their responses were similar in both years. Bean flies were 2.26- and 3.18-times more abundant in weed-free than in weedy bean plots with or without strip-crop in 1987 and in 1988, respectively. In general, bean fly numbers tended to decrease with the increase in habitat diversity; under no conditions were bean fly numbers higher in diverse plots than in monocultures. Similar findings have been reported by Ruhendi & Litsinger (1977, 1979) and Litsinger & Ruhendi (1984) on the effects of rice stubble on the reduction of bean fly population in cowpea (*Vigna unguiculata* (L.) Walp) fields in the Philippines.

It is possible that the presence of weeds interfered with the search by bean fly for its host plant, as was hypothesized by Root (1973) for insect pests in general. The numbers of adult bean flies emerging per 25 plant samples followed a similar pattern to the numbers of adult bean flies visiting bean seedlings in the field; there were significant positive correlations of $r=0.957$ ($df=2$; $P<0.05$) and $r=0.997$ ($df=2$; $P<0.01$) between the two parameters in 1987 and 1988, respectively. These results suggest that counts of either adult bean flies visiting bean seedlings in the field or adult emergence/plant can be used to estimate bean fly populations in bean fields. However, use of the latter method is preferred over the former because adult counts in the field could vary with weather conditions, time of day (Hassan, 1947), or bean variety

(Talekar *et al*, 1988).

Habitat diversity had no effect on parasitization levels by *Opius phaseoli* of bean fly. These results confirm the point that different insects respond differently to habitat diversity (Cromartie, 1975; Levins & Wilson, 1980).

Strip-cropping beans with maize had little effect on dry seed yield whereas weeds significantly reduced bean yields. Yield reductions due to weeds were 57.2% in 1987 and 49.5% in 1988. Beans in weedy plots produced fewer pods (15.2 ± 1.1 in 1987 and 17.1 ± 0.7 in 1988) than those in weed-free plots (22.1 ± 1.0; 26.6 ± 0.6). That is, weedy plots reduced the number of pods/plant by 31.2% and 35.7% in 1987 and 1988, respectively. These results demonstrate that reductions in bean fly numbers, brought about by presence of weeds, were not enough to offset the yield loss caused by their competition with the crop. Hence, while strip-cropping beans with maize may reduce *H. armigera* populations in beans (Abate, 1988), there is no advantage to the farmer of not weeding his bean plots.

CHAPTER V

SEED DRESSING EXPERIMENTS

INTRODUCTION

Early attempts at insecticidal control of bean fly relied on the use of spray mixtures containing derris, or inorganic compounds, such as lead arsenate (van der Goot, 1930; AVRDC, 1984), tobacco extracts (Hutson, 1932), nicotine sulphate with or without white oil (Morgan, 1938a,b; Caldwell, 1945), and diesel oil with or without clay (Moutia, 1941, 1942). None of these treatments gave satisfactory control; they were replaced by DDT, which was effective (Hely, 1948; Smith, 1945) and was used widely between the mid- 1940s and early 1960s.

Effective control of bean fly was also achieved by the application of seed dressings of chlorinated hydrocarbons, such as aldrin, dieldrin or endrin (Walker, 1960; Wickramasinghe & Fernando, 1963; Jones, 1965; Abul-Nasr & Assem, 1968; El-Sayed *et al.*, 1968; Chang, 1969; Swaine, 1969; El-Kifl *et al.*, 1973; El-Nahal & Assem, 1970). The use of these insecticides has declined over the last decade because of concerns with their persistence in the crop and in the environment.

Recently, carbamate and organophosphate insecticides, such as aldicarb, carbofuran, disulfoton, and phorate (as granular soil treatments or as liquid seed dressing) and omethoate, diazinon, dimethoate and monocrotophos (as foliar sprays), have been used (Naresh & Thakur, 1972; Bhalla *et al*., 1975; Hussein, 1978; Singh *et al*., 1978; Litsinger *et al*., 1980a,b; Gupta & Singh, 1984b; Wijeratne Banda, 1984; Krishna Moorthy & Srinivasan, 1989). Although some degree of control could be achieved with these insecticides, especially at high doses and with repeated applications, they are phytotoxic (Abate *et al*., 1986) and many of them have high mammalian toxicity. In addition, they are imported, costly and hence their use cannot be justified in subsistence agriculture.

In Ethiopia, seed dressing with aldrin has been recommended as a routine practice (Crowe & Shitaye, 1977) in commercial bean production. However, the persistence of this compound in the crop makes it unacceptable, especially when the beans are grown for export. Seed treatment with endosulfan reportedly gives effective control of bean fly in Zambia (Allen & Smithson, 1986) and in the Great Lakes region of Africa (Lays & Autrique, 1987). Seed dressing with less persistent insecticides provides perhaps the best short-term alternative to the use of aldrin for bean fly control. The objective of my studies was therefore to identify an effective, non-persistent insecticide that could replace aldrin.

MATERIALS AND METHODS

Six seed dressing insecticides (Table 5.1) together with an untreated control were tested for their efficacy against bean

Table 5.1: Seed dressing insecticides used against *Ophiomyia phaseoli* in 1987 and 1988.

Common name	Brand name	Formulation	Group*	Dosage (g ai/kg seed)
Aldrin	Aldrex	40% WP	OC	5.00
Endosulfan	Thiodan	50% WP	OC	5.00
Flutriafol + Lindane	Vincit	22.5% L	OC	2.50**
Furathiocarb	Promet	50% DS	CB	9.00***
Thiodicarb	Larvin	37.5% L	CB	11.25
Propetamphos	Safrotin	20% WP	OP	5.00

*OC=organochlorine, CB=carbamate, OP=organophosphate.
**Dosage was doubled at Awassa, in 1988.
***Zeolex was added as a sticker.

fly in the 1987 and 1988 crop-growing seasons at the Awassa and Melkassa research centres of the Institute of Agricultural Research (IAR) in southern and central Ethiopia, respectively. The rates and use of insecticides (other than endosulfan and aldrin) tested here were as recommended by their respective manufacturers. The experiments were laid out in a RCBD, replicated five times. Plots were 5 m x 4 m (20 m^2) large; plots and blocks were separated by unplanted alleys that were 1 m and 2 m wide, respectively, so that the total gross area of the experiment was 41 m x 28 m (1148 m^2).

Measured amounts of seeds of the commercial haricot bean (cv. 'Mexican 142') were placed in plastic bags, together with the respective insecticides and the whole was thoroughly mixed by shaking for 5 min. Water was added to the wettable powder formulations at the rate of 3 ml/kg seeds, to enhance adherence of the insecticides to the seed. The seeds were then sown in rows of 40 cm apart (10 rows/plot), with 15 cm between seeds so that there were approximately 330 seeds in each plot (or 165,000 plants/ha). Seeding dates for Awassa and Melkassa in 1987 (and 1988) were 26 June (10 June) and 22 July (27 July), respectively. No fertilizer was used and no other pesticides were applied. The experimental fields were kept weed-free by hand-weeding. Stand counts were recorded about 2 weeks after seeding, at which time the numbers of seedlings killed by bean fly were counted until the canopy closed. Dead seedlings were rogued to avoid double counting. In addition in 1988, 20 living plants were sampled from each plot by uprooting one plant from each row, selected by walking along a diagonal. Each plant sample was closely examined for symptoms of bean fly damage, such as mines or cracked stems, to determine the number of infested plants. The samples were taken to the laboratory, sealed in paper bags, and adult bean flies that emerged were counted after 4 weeks. When plots were harvested the yield of clean, dry seed from each plot was measured and adjusted to 10% moisture. Analysis of variance was made on the various measurements thus recorded with the statistical package MSTAT, Version 4.

RESULTS

Phytotoxic effects

Stand counts of seedlings were used as the criteria for assessing phytotoxic effects of the insecticides tested. Analysis of variance showed highly significant differences among treatments at both locations and in both years (Appendix 5.1). Table 5.2 summarizes stand counts/plot. At Awassa, seed dressing with furathiocarb and propetamphos reduced seedling numbers by, respectively, 22.3% and 25.3%, as compared with untreated controls in 1987 (Table 5.2); means for the rest of the treatments were not different from the untreated control. At Melkassa, only the thiodicarb mean was significantly different from all other treatments and showed a 12.7% reduction in seedling emergence below control values.

Table 5.2: Influence of seed dressing insecticides on seedling emergence (numbers/plot) of *Phaseolus vulgaris* (2 wks after treatment)*

Treatments	Awassa		Melkassa	
	1987	1988	1987	1988
Control (untreated)	273a	297ab	307a	317ab
Endosulfan	280a	313a	312a	323ab
Aldrin	264a	300ab	299a	330a
Flutriafol + Lindane	273a	150d	309a	306b
Thiodicarb	268a	296ab	268b	323ab
Furathiocarb	212b	258c	308a	317ab
Propetamphos	204b	275bc	306a	275c
Mean	253.5	269.9	301.3	312.9
SE	14.1	10.1	7.1	5.3

*Means, within a column, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test).

In the 1988 season, flutriafol + lindane, furathiocarb, and propetamphos had significant phytotoxic effects at Awassa; the first product, which caused nearly 50% reduction in seedling emergence relative to control values, was the most phytotoxic, followed by furathiocarb (13.1%) and propetamphos (9.3%). At Melkassa also flutriafol + lindane and propetamphos, with seedling emergence reductions of 3.5% and 13.2% respectively, were significantly different from the control. In addition to reducing seedling emergence, these two insecticides scorched those seedlings that did emerge. The overal mean seedling emergence in 1988 was significantly greater than that of 1987 (Table 5.2).

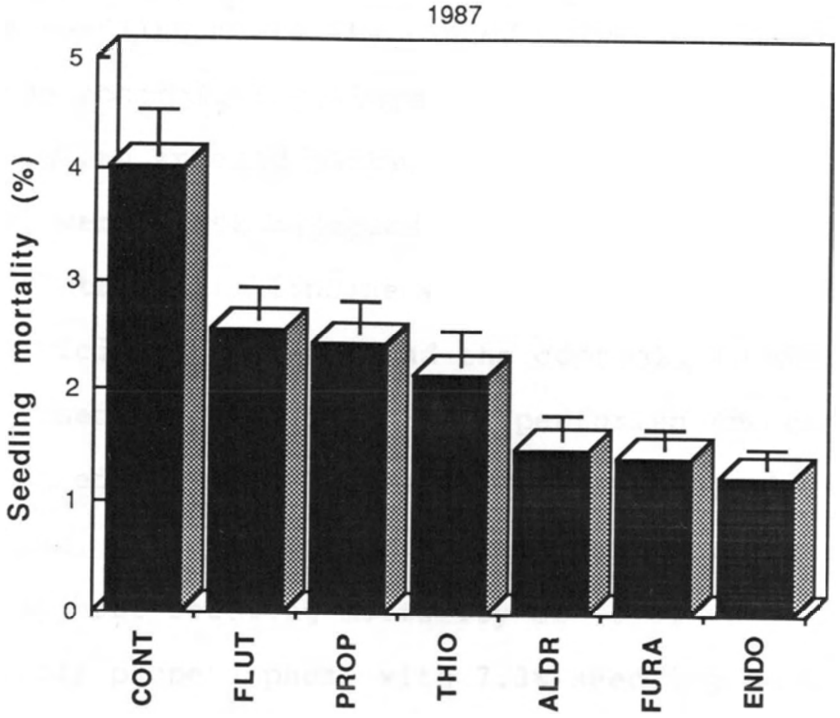
Effects on bean fly

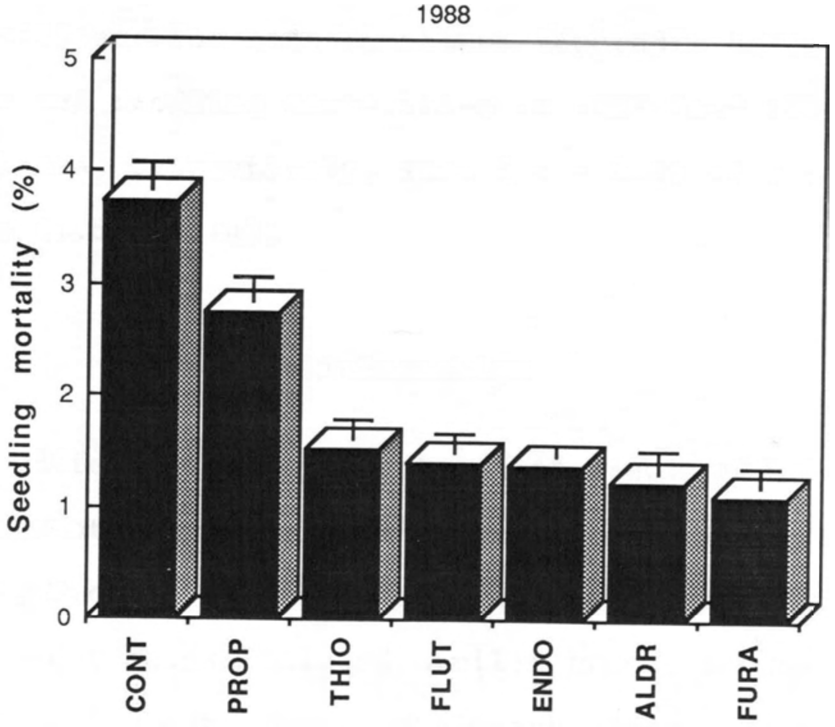
The efficacy of the six seed dressing treatments was measured on the basis of seedling mortality, damage symptoms, number of bean fly adults emerging per 20 plants, and dry-seed yield.

Seedling mortality

Analysis of variance of the original data showed significant non-additivity and hence the data were transformed to their square roots ($\sqrt{x + .5}$), as suggested by Gomez & Gomez (1984). Differences in percentages of seedling mortality among treatments were highly significant at Awassa but non-significant at Melkassa in both years (Appendix 5.2). Seedling mortality data for Awassa are summarized in Figure 5.1.

Figure 5.1: Seedling mortality caused by bean fly in *Phaseolus vulgaris* treated with various seed dressing insecticides, Awassa [Y axis values are square root ($\sqrt{x + .5}$) transformations; treatments on the X axis are shown by their first four letters; arrow bars are $\bar{x} \pm$ se].


1987
Seedling mortality (%)
0
1
2
3
4
5
CONT
FLUT
PROP
THIO
ALDR
FURA
ENDO

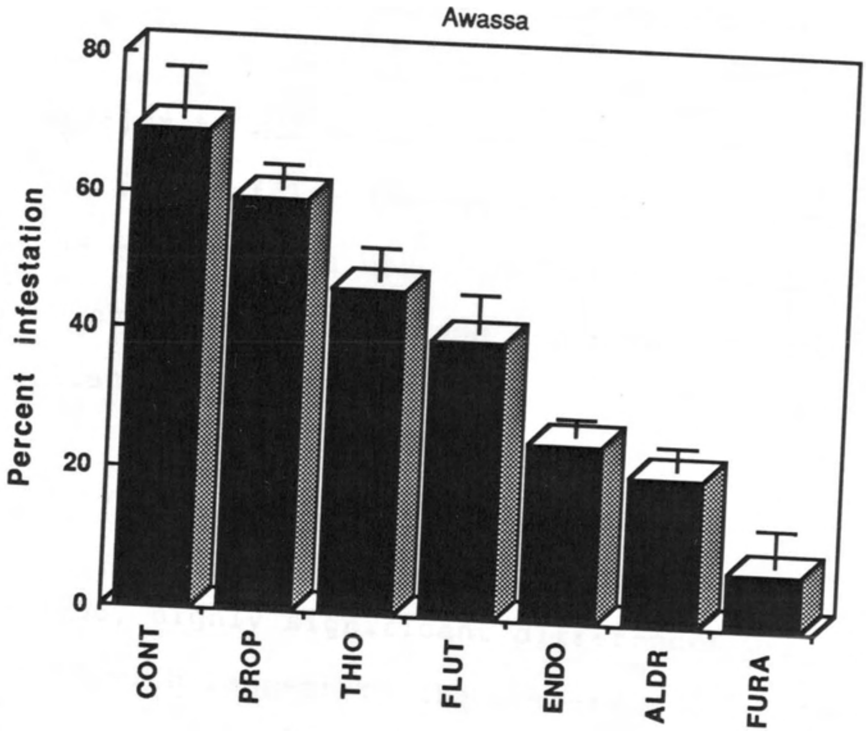

1988
Seedling mortality (%)
0
1
2
3
4
5
CONT
PROP
THIO
FLUT
ENDO
ALDR
FURA

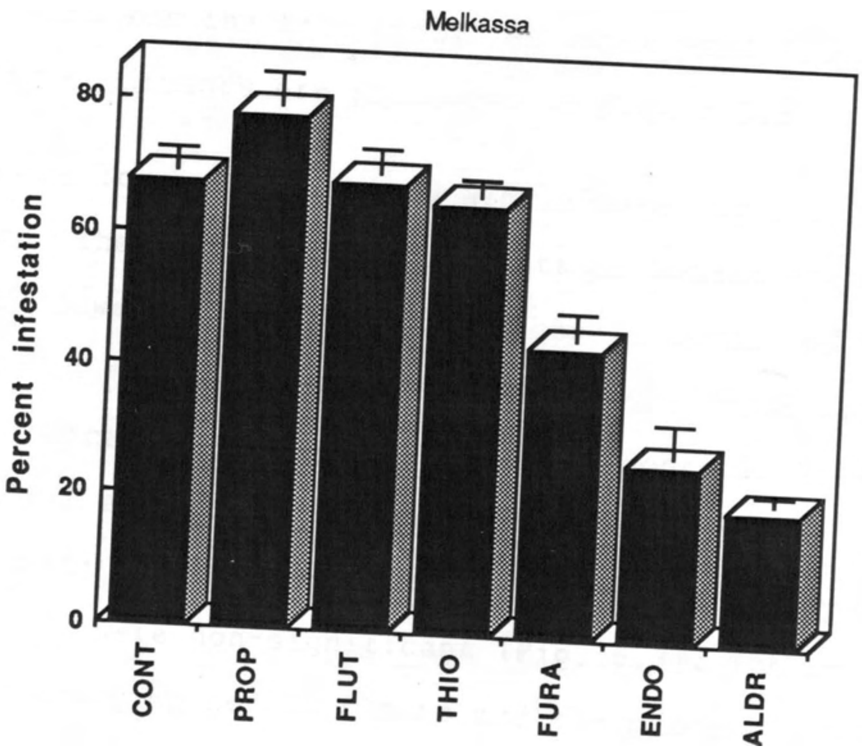
All insecticide treatments were significantly superior, in reducing bean fly damage, to the control in both years. In 1987, mean seedling mortality ranged between 1.2% in aldrin and 16.4% in the control. Seedlings in aldrin, furathiocarb, and endosulfan treated plots, with no significant differences among them, were least affected by bean fly. Thiodicarb, propetamphos, and flutriafol + lindane were intermediate between the above insecticide treatments and the control. In the 1988 season too, all insecticide treatments outperformed the control (Fig. 5.1); mean seedling mortalities for endosulfan, aldrin, flutriafol + lindane, thiodicarb, and furathiocarb were less than 2% whereas the highest seedling mortality of 13.8% was recorded in the control; propetamphos, with 7.3% seedling mortality, was intermediate between the control and the rest of the treatments. Differences in percent seedling mortality between years were significant for both locations (Appendix 5.2); the overall mean ($\bar{x} \pm$ se) seedling mortalities in 1987 (and 1988) at Awassa and Melkassa, respectively, were 5.4 ± 2.0% (4.0 ± 1.8%) and 27.5 ± 5.8% (1.5 ± 0.1%).

Percent infestation

Differences in percentages of seedling infestation among treatments were highly significant at both locations (Appendix 5.3). Figure 5.2 summarizes these data. The differences among treatment means followed similar trends at the two locations. At Awassa, for example, furathiocarb plots, followed by endosulfan

Figure 5.2: Percent infestation caused by bean fly in *Phaseolus vulgaris* treated with various seed dressing insecticides, 1988. [Y axis values are arcsine transformations of percentages; treatments on the X axis are shown by their first four letters; arrow bars are $\bar{x}$ ± se].


Awassa
Percent infestation
80
60
40
20
0
CONT
PROP
THIO
FLUT
ENDO
ALDR
FURA


Melkassa
Percent infestation
80
60
40
20
0
CONT
PROP
FLUT
THIO
FURA
ENDO
ALDR

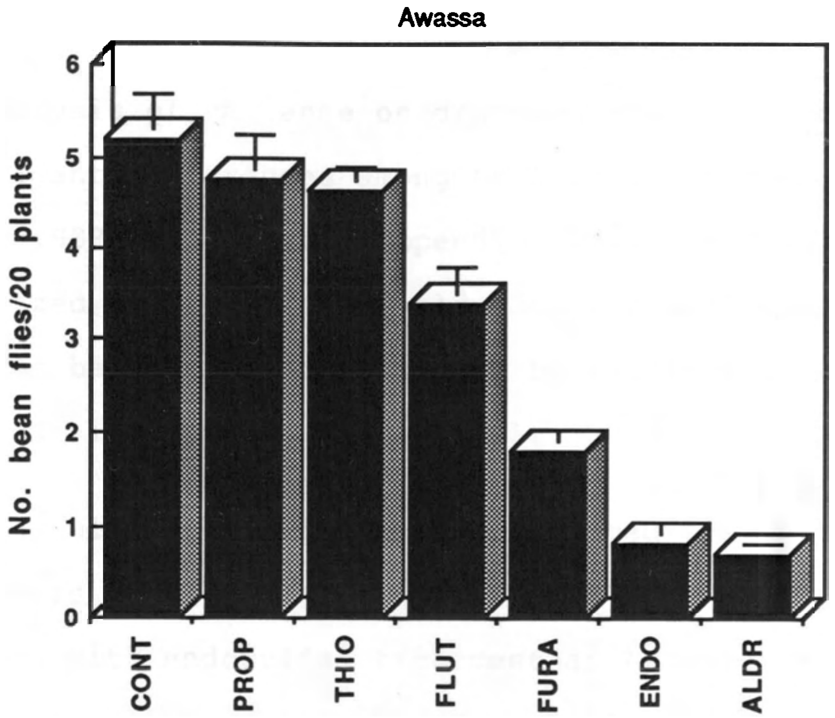
and aldrin were least damaged. Propetamphos was not significantly different from the control whereas flutriafol + lindane and thiodicarb were intermediate between the control and the rest of the treatments. At Melkassa, endosulfan and aldrin were superior to all other treatments; differences among the means for flutriafol + lindane, thiodicarb, propetamphos and the untreated control were non-significant whereas furathiocarb was intermediate between these and the remaining two insecticides (endosulfan and aldrin).

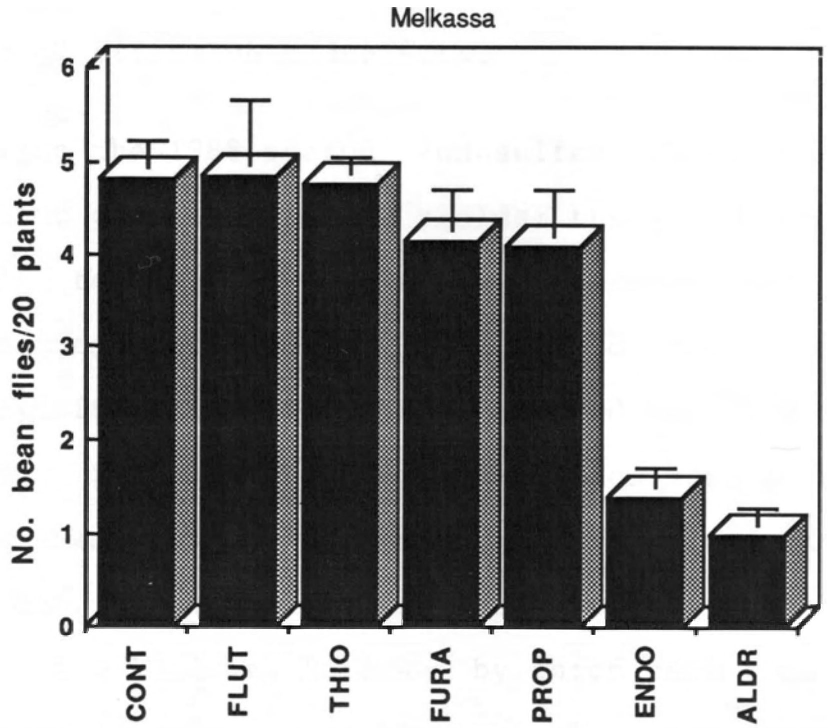
Adult emergence

In 1988, highly significant differences were found among treatments with respect to the numbers of adult bean flies that emerged per 20 plants sampled (35 days after seeding) (Appendix 5.4). Data for the mean number of adult bean flies in the various treatments are presented in Figure 5.3.

Means for endosulfan and aldrin were significantly lower than for the rest of the treatments at Awassa (Fig. 5.3). These were followed by furathiocarb which, in turn, was followed by flutriafol + lindane; no differences were found among the means for thiodicarb, propetamphos, and the control. At Melkassa, endosulfan and aldrin were significantly superior to other treatments; differences among the control and the rest of the treatments were non-significant (Fig. 5.3). The number of insects emerging per 20 plants and the percent infestation were significantly correlated with each other at Awassa (r=0.961;

Figure 5.3: Number of bean flies emerging/20 seedlings of *Phaseolus vulgaris* treated with various seed dressing insecticides, 1988. [Y axis values are square root ($\sqrt{x + .5}$) transformations; treatments on the X axis are shown by their first four letters; arrow bars are $\bar{x}$ ±se].


Awassa
No. bean flies/20 plants
0
1
2
3
4
5
6
CONT
PROP
THIO
FLUT
FURA
ENDO
ALDR


Melkassa
No. bean flies/20 plants
0
1
2
3
4
5
6
CONT
FLUT
THIO
FURA
PROP
ENDO
ALDR

df=5; P<0.001) and Melkassa (r=0.908; df=5; P<0.01).

Dry-seed yield

Analysis of variance on dry-seed yield showed highly significant differences among treatments in both years at Awassa and in 1988 at Melkassa (Appendix 5.5). Yield data are summarized in Table 5.3. Yield data for Melkassa, 1987, were excluded because of heavy damage by termites (*Microtermes* sp.) that made interpretation difficult.

Endosulfan consistently outperformed the rest of the treatments. The highest yield, in 1987, of 1930 kg/ha was obtained with endosulfan treatment at Awassa, as compared with 1225 kg/ha for the controls. This difference implies that bean fly caused an estimated maximum yield loss of 36.5% in the absence of effective protection.

During the 1988 season, endosulfan, aldrin and propetamphos treatments gave the highest yields; the yield loss at Awassa was estimated to be 16.1% in untreated controls. Here, flutriafol + lindane treatment gave the lowest yield because of its phytotoxicity. Means for thiodicarb and the control were not different; furathiocarb and propetamphos were intermediate between these and the top-performing two treatments. At Melkassa (1988) too, the highest yield was obtained with endosulfan; flutriafol + lindane, followed by thiodicarb treatment, was significantly inferior to the control, again because of

Table 5.3: Dry-seed yield (kg/ha) of haricot bean treated with various seed dressing insecticides against *Ophiomyia phaseoli**

Treatments	Awassa		Melkassa
	1987	1988	1988
Control	1225b	3156b	1931ab
Endosulfan	1930a	3761a	2102a
Aldrin	1721a	3537a	2006ab
Propetamphos	1186b	3499ab	1993ab
Furathiocarb	1535a	3376ab	1858bc
Thiodicarb	1671a	3228b	1696cd
Flutriafol + Lindane	1696a	2134c	1555d
Mean	1566.5	3241.3	1877.4
SE	125.3	132.7	58.3

*Means, within a column, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test).

phytotoxicity.

DISCUSSION

In this chapter, I described the experiments that I conducted to identify effective and safe seed dressing insecticide(s) during 1987 and 1988 at Awassa and Melkassa. I used phytotoxicity, seedling mortality, seedling infestation, number of bean flies emerging per 20 plants, and dry-seed yield as criteria for evaluating the efficacy of treatments.

Endosulfan and aldrin were the least phytotoxic and the most effective of all the seed dressing insecticides tested. These results confirm that endosulfan can be used in place of aldrin. Although endosulfan is related to organochlorines, a report by Kole *et al.* (1989) suggests that it is less persistent than aldrin and related insecticides which are banned in many countries. The rest of the insecticides tested gave variable results; bean fly control with these insecticides was comparable to those of endosulfan and aldrin, but they produced varying degrees of phytotoxicity, as measured by the numbers of seedlings that emerged 2 weeks after seeding. Even if the non-favoured insecticides were effective, liquid formulations, such as those for thiodicarb and flutriafol, will have limited use since they require more caution in handling, are inconvenient to apply, and are more toxic to humans than are wettable powders.

Significant correlations were found between infestation levels and insect numbers (1988), a fact suggesting that either of these measures can be used to evaluate treatments against bean fly, as long as only one crop variety is involved (cf. Chapter II). These (insect numbers and infestation) provide alternatives to the use of mortality levels and dry-seed yields, especially under circumstances where bean fly population does not reach damaging levels, or where seedling damage by other insects complicates seedling mortality and yield data, as in Melkassa.

Seedling mortality at Melkassa appeared to be high in 1987, ranging between 20% and 35.4%. However, this was the result not only of bean fly but also included the combined effects of heavy termite (*Microtermes* sp.) damage, and moisture stress, both of which are often confused with bean fly symptoms. The lack of differences among treatment means in 1988 was perhaps because of the availability of adequate precipitation and hence low levels of bean fly damage.

Seedling emergence and dry-seed yields were significantly higher and seedling mortalities and yield loss were lower in 1988 than in 1987. For instance, estimated maximum yield loss due to bean fly at Awassa was 36.5% in 1987 and 16.1% in 1988; the overall mean yields in 1988 at Awassa and Melkassa, respectively, were 2.08- and 2.85-fold higher than those in 1987. Increased precipitation in 1988 was probably the main cause of these changes in seedling emergence, seedling mortality, and dry-seed yields.

In summary, the experiments demonstrated that endosulfan, at the rate of 5 g a.i./kg of seeds, gave bean fly control at a level comparable with aldrin; it is hence the best seed dressing insecticide available for the control of bean fly among the six tested.

SUMMARY AND CONCLUSIONS

The bean fly, *Ophiomyia phaseoli*, is the major pest of haricot bean in Ethiopia. The maggot mines leaves upon hatching, then moves to the veins and stems where feeding by the third instar larva causes characteristic swellings and cracks; most damaged seedlings turn yellowish, wilt and die.

In Ethiopia, haricot bean is grown largely by subsistence farmers. Thus, my studies were aimed at developing an integrated approach of bean fly management that is applicable to subsistence farming:

(1) to identify germplasms of beans that are resistant to bean fly;

(2) to determine the effects of seeding date and plant density on bean fly numbers, incidence of parasitoids, and crop yield;

(3) to determine the effects of habitat diversity on bean fly and natural enemy numbers; and

(4) to select effective seed dressing insecticides against bean fly.

I conducted my experiments in two agroecologically distinct environments, one at Awassa in southern Ethiopia and the other at Melkassa in central Ethiopia.

Of the more than 1500 germplasm tested, four accessions (CIAT accession no. G05253, G05773, G02005 and G02472) were highly resistant to bean fly and are recommended for use in breeding programmes. The mechanism of resistance was tolerance, a fact suggesting that breeding programmes must place emphasis on plant vigour.

Bean fly (larvae + puparia) counts and infestation levels have often been used as criteria in screening for resistance. My studies demonstrated that these parameters are not reliable measures of resistance and hence should not be used as the major sorting criteria. Once the large number of material screened at the initial stage has been reduced to a manageable size (based on a subjective damage score rating made at about 7 weeks after seeding), seedling mortality appeared to be the most useful parameter for the identification of resistant cultivars. Paired comparisons of yield losses caused by bean fly between insecticide-protected and -unprotected plots, replicated over time and space, are essential to confirm final selections.

Crop damage by bean fly can be reduced by manipulation of seeding date and plant density. Because season, seeding date and plant density interact, recommendations on seeding date should not be based on calendar dates; other factors in the local environment, such as the expected availability of moisture during the entire growth period, must be taken into consideration. Thus, the best strategy for farmers to reduce bean fly damage is to plant fields with 300,000 to 500,000 seeds/ha. In areas that have long periods of rainfall, such as Awassa, the optimum time for seeding is about 2 weeks after the rains have started; but at Melkassa, which has a short rainy period, seeding should take place at the beginning of the rainy season.

Although bean fly parasitism by *Opius phaseoli* was generally high, reaching 93% at Awassa and over 62% at Melkassa, the parasitoid did not give effective control. It is suggested that this pupal parasitoid arrives after bean fly has already caused damage.

Strip-cropping beans with maize did not affect bean fly numbers or crop yield. By contrast, bean fly numbers in weed-free plots were 2- to 3-times higher than in weedy plots. Parasitization by *Opius phaseoli* was not influenced by strip-cropping or weeding. The presence of weeds reduced bean yields by 57.2% in 1987 and by 49.5% in 1988, respectively. Thus, there is no obvious advantage to the farmer of not weeding bean fields.

Insecticides used as seed dressing significantly reduced bean fly damage. The highest yields were obtained by treatment with endosulfan, followed by aldrin (both applied at 5 g a.i./kg of seeds). Some treatments were phytotoxic and hence gave lower yields than the control. It is recommended that aldrin be replaced with endosulfan, which is less persistent in the crop and in the environment.

In conclusion, bean fly management in subsistence agriculture must be based on a combination of tactics, including the appropriate choice of seeding dates, plant density and resistant cultivars. By comparison, in commercial bean production, seed dressing with an appropriate insecticide may be useful in reducing bean fly damage.

A P P E N D I C E S

APPENDIX 1: STUDIES ON POPULATION DYNAMICS AND DISTRIBUTION

INTRODUCTION

The first records of the bean fly, *Ophiomyia phaseoli* (Tryon) (Diptera: Agromyzidae), as a major insect pest of *Phaseolus vulgaris* L. in Ethiopia, were in the Mekele and Kobo areas of Tigray and Welo administrative regions during the early 1970's (Crowe *et al*. 1977). By 1982, Abate *et al*. reported this agromyzid to be the most important insect pest of beans in the country. However, little was known about its host range, geographic distribution, natural enemies and population dynamics. Elsewhere, no less than 40 species of host plants have been recorded from different parts of the world (Talekar, ?1989). Of these, the wild hosts in the genus *Crotalaria* of the family Leguminosae have been cited as the most important sources of infestation (van der Goot, 1930; Cheu, 1944). Its parasitoid complex and the life cycles of the pest and some of its parasitoids were studied by Greathead (1969) in East Africa and by Burikam (1978) in Thailand. Waterston (1915) and Fellowes & Amarasena (1977) in Sri Lanka, Otanes y Quesales (1918) in the Philippines, van der Goot (1930) in Indonesia, Abul-Nasr and Assem (1968) in Egypt, Kleinschmidt (1970) in Australia and Gangrade (1976) and several other workers in India studied the parasitoid complex of bean fly. Raros (1975) studied the bionomics of the bean fly and the introduced braconid parasitoid, *Opius phaseoli* Fischer, in Hawaii.

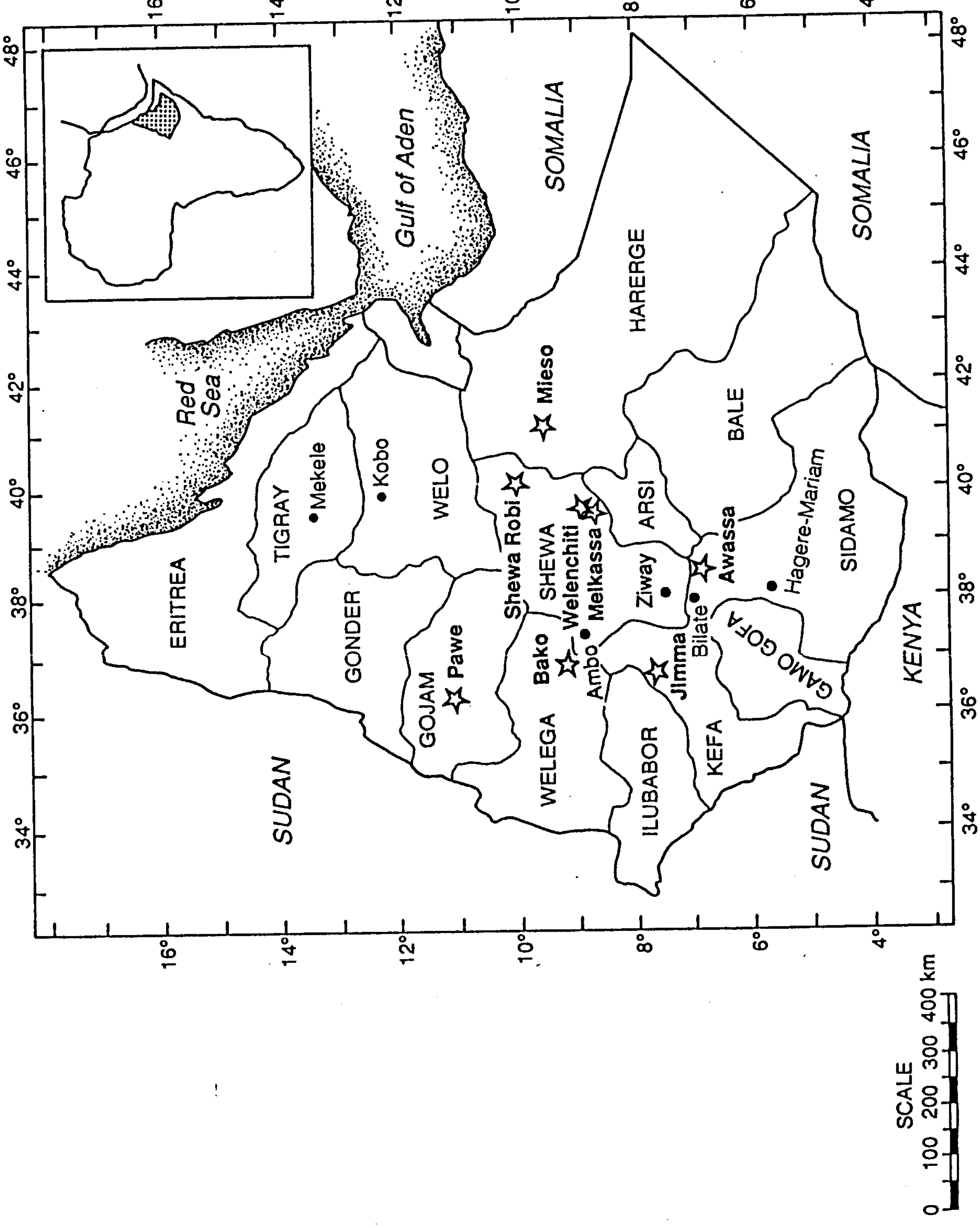
My study was undertaken to determine the host range, geographic distribution, parasitoid complex and population dynamics of the bean fly and some of its parasitoids in Ethiopia.

MATERIALS AND METHODS

Host plants and geographic distribution

Extensive surveys were made in most of the major bean-producing areas of Ethiopia, including parts of Shewa, Sidamo, Harerge, Welega and Kefa administrative regions (Fig. A.1), to determine the host plants and geographic distribution of bean fly and its parasitoids. At each site, a minimum of 25 plants of haricot bean (*Phaseolus vulgaris* L.), cowpea (*Vigna unguiculata* L.), and soybean (*Glycine max* (L.) Merr.) that showed symptoms of bean fly damage as well as up to 300 leaves of the wild bush, *Crotalaria laburnifolia* L. (Leguminosae), containing freshly formed puparia were sampled. These samples were taken to the laboratory and kept in emergence cages or pollen bags for at least 4 weeks, after which time they were opened and the emerged insects were counted and recorded. Several species of leguminous plants in the genera *Glycine*, *Desmodium*, *Indigofera* and *Cassia* were also examined for bean fly attack, but none showed symptoms of damage.

Figure A.1: Distribution of bean fly in Ethiopia (previous records are indicated by solid dots; records based on current survey are shown by stars).


Red Sea
Gulf of Aden
SOMALIA
SOMALIA
SUDAN
SUDAN
KENYA
ERITREA
TIGRAY
Mekele
Kobo
GONDER
WELO
GOJAM
Pawe
Shewa Robi
SHEWA
Welenchiti
Melkassa
Mieso
HARERGE
ARSI
Ziway
Awassa
BALE
Bako
Ambo
Bilate
Jimma
Hagere-Mariam
SIDAMO
GAMO GOFA
WELEGA
ILUBABOR
KEFA
34°
36°
38°
40°
42°
44°
46°
48°
4°
6°
8°
10°
12°
14°
16°
SCALE
0 100 200 300 400 km

Parasitoid complex and population dynamics

To determine seasonal changes in bean fly numbers and those of its parasitoids, and to determine the species composition of the latter, I made two kinds of samples from 15 June 1987 to 17 October 1988 on a 200-ha farm at the Nazareth Research Centre at Melkassa (1550 m above sea level) of the Institute of Agricultural Research (IAR), Ethiopia. In the first set of samples, three representative crotalaria plants were selected and the numbers of leaves with and without bean fly damage were counted; thus the percentages of leaves that showed evidence of bean fly damage were determined. In the second set, 100-400 leaves containing young fresh pupae were collected by the examination (2-3 hr) of several plants from different parts of the field. Samples were taken every 2 weeks, and the numbers of miners per leaf were counted in the laboratory. From these data, the percentages of leaves with more than one miner were determined; this was done to determine changes in the level of the pest's incidence during different months.

The leaf samples were placed into cylindrical cages constructed from powdered milk cans (22.5 x 15.5 cm); to avoid crowding, no more than 200 leaves were kept in each cage. For improved aeration, a circular hole was cut in the bottom of the can, sealed with two-ply black muslin cloth and wax. A hole was also cut in the lid of the can, and a test tube was inserted.

Any insects emerging were counted daily for 4 weeks, after which time the can was emptied and any insects that had died inside the can were also counted. All insects from each sample were sorted out before they were sent for identification to the CAB International Institute of Entomology.

RESULTS

Host plants and geographic distribution

Extensive surveys carried out in the major bean-growing zones of Ethiopia (Fig. A.1) showed that *Crotalaria laburnifolia* was the only wild host of bean fly. Among the cultivated plants, haricot bean, cowpea and soybean were attacked, but the pest caused economic damage only to haricot bean.

Bean fly, and its parasitoids, are widely distributed throughout the major bean-growing areas of Ethiopia (Table A.1). The braconid, *Opius phaseoli*, was the major parasitoid attacking bean fly on haricot bean and cowpea whereas species of Chalcidoidea, on the average, were more abundant on the wild host plant. The pteromalid wasps, *Sphegigaster* spp., were the most common parasitoids among the Chalcidoidea.

Population dynamics and parasitoid complex

The prevalence of bean fly, as measured by percent leaf damage, differed significantly ($P<0.001$; ANOVA, Completely Randomized Design) between months (Fig. A.2). Percentages of

Table A.1: Occurrence of bean fly and its parasitoids on various host plants and localities in Ethiopia, June 1987 - October 1988.

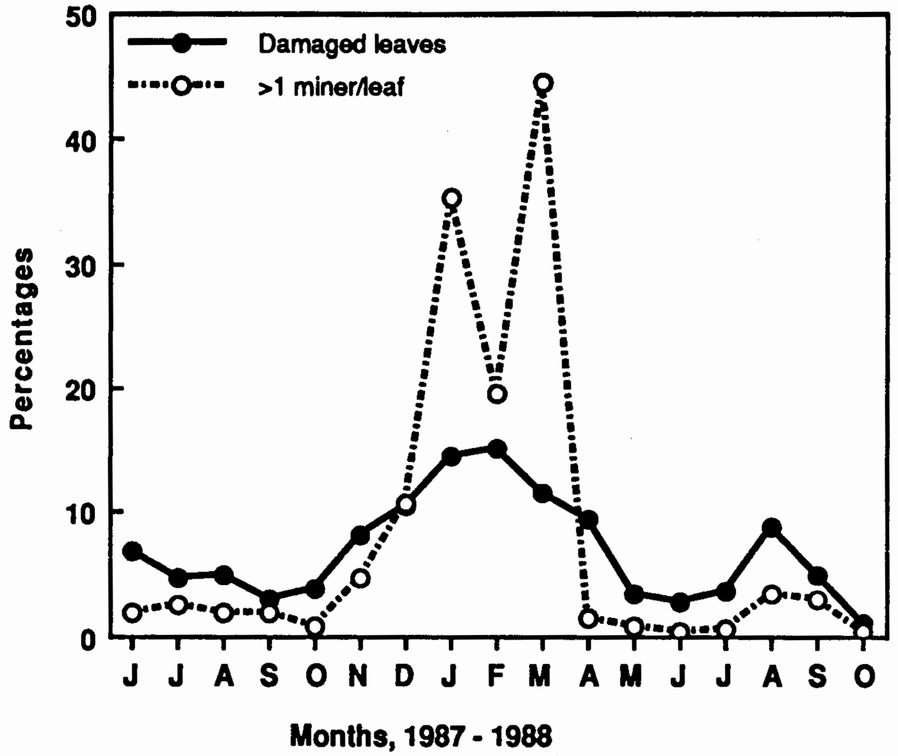
Host plant	Locality	Sampling date	Adults*	% Parasitism	
				Opius	Chalcids
Phaseolus vulgaris	Awassa	17.6.87	70	66.8	10.0
"	Awassa	12.7.87	30	83.5	6.9
"	Awassa	11.8.87	78	64.7	6.1
"	Awassa	23.7.88	78	87.2	6.3
"	Awassa	8.8.88	343	82.6	2.3
"	Awassa	19.8.88	63	69.9	8.6
"	Melkassa	24.7.87	3	22.4	4.1
"	Melkassa	17.9.87	10	42.8	5.7
"	Melkassa	29.7.88	1	20.0	20.0
"	Melkassa	1.9.88	25	87.0	0.0
"	Pawe	27.6.87	64	17.4	0.7
"	Jimma	24.8.88	25	54.5	2.3
"	Bako	25.8.88	22	46.2	3.8
"	Welenchiti	30.8.88	13	57.1	8.6
"	Shewa Robi	22.9.88	39	35.2	11.8
"	Mieso	2.9.88	0	0.0	0.0
Vigna unguiculata	Melkassa	5.10.88	33	74.0	3.1

Table A.1: cont'd.

Host plant	Locality	Sampling date	Adults	% Parasitism	
				Opius	Chalcids
Glycine max	Awassa	20.8.88	2	0.0	41.9
C. laburnifolia	Melkassa	4.5.87	9	2.7	64.9
" "	Melkassa	28.7.87	18	0.2	5.3
" "	Melkassa	3.10.88	15	31.2	15.7

*Mean number of insects emerging from 25 plants or leaves.

Figure A.2: Incidence of bean fly on the wild plant host, *Crotalaria laburnifolia*, Melkassa.



Damaged leaves
>1 miner/leaf
Percentages
0
10
20
30
40
50
J J A S O N D J F M A M J J A S O
Months, 1987 - 1988

damaged leaves of *C. laburnifolia* ranged from 1.0% to 15.1% with a 17-month average of 6.8 ± 0.6% ($\bar{x}$ ± se). Percentages of leaves with more than one miner/leaf varied from month to month, ranging between 0.4 and 44.5 ($\bar{x}$=7.9 ± 3.2). Both methods of sampling, *i.e.* percentages of infested leaves and leaf miner counts, showed similar trends in seasonal changes of bean fly population, and there was a highly significant correlation ($r=0.76$; $df=15$; $P<0.01$) between them. In general, bean fly populations on the wild host were low during most of the study period. The highest numbers were recorded between December and March (Fig. A.2). At Melkassa, this is a dry period when cultivated host plants are not available to bean fly, nor are there abundant flush leaves of the wild host suitable for egg laying. Pupal survival was also low, ranging between 9.0 and 56.6% ($\bar{x}$=36.1 ± 2.7%). Parasitoids were apparently the major cause of pupal mortality as they accounted for 5.2 - 71.1% ($\bar{x}$=41.4 ± 3.7%) of bean fly parasitism in the wild plant host. Percentages of bean fly survival and parasitism were significantly correlated ($r=-0.568$; $df=15$; $P<0.05$).

The species composition and relative abundance of parasitic Hymenoptera associated with bean fly on crotalaria are shown in Table A.2. A total of 17 species were recorded between June 1987 and October 1988. Brief notes on these are presented below:

Table A.2: Hymenopterous parasitoids of bean fly on the wild plant host, *Crotalaria laburnifolia*, Melkassa, May 1987 - October 1988.

Parasitoid taxon	Status*	Relative abundance**
BRACONIDAE		
Opius phaseoli	primary	common
PTEROMALIDAE		
Sphegigaster stepicola	primary	very common
S. brunneicornis	primary	rare
Halticoptera sp. ?circulus	primary	very rare
Herbertia sp.	?primary	very rare
Callitula filicornis	uncertain	very rare
EULOPHIDAE		
Chrysonotomyia formosa	primary	very rare
Chrysonotomyia sp. *?erythraea*	primary	very rare
Meruana liriomyzae	primary	very rare
Pediobius acantha	primary	very rare
Cirrospilus sp.	uncertain	very rare
Aprostocetus sp.	uncertain	very rare

Table A.2: cont'd.

Parasitoid taxon	Status	Relative abundance
EUPELMIDAE		
Eupelmus sp.	primary	very rare
Eupelmus ?australiensis	secondary	very rare
Eupelmus sp. (*urozonus* group)	primary	very rare
EURYTOMIDAE		
Eurytoma sp.	primary	very rare
TETRACAMPIDAE		
Epiclerus sp. nr. *nomocerus*	uncertain	very rare

*From literature; **very common=maximum emergence > 30% of the total insect emergence; common=21-30%; rare=11-20%; very rare=≤10%.

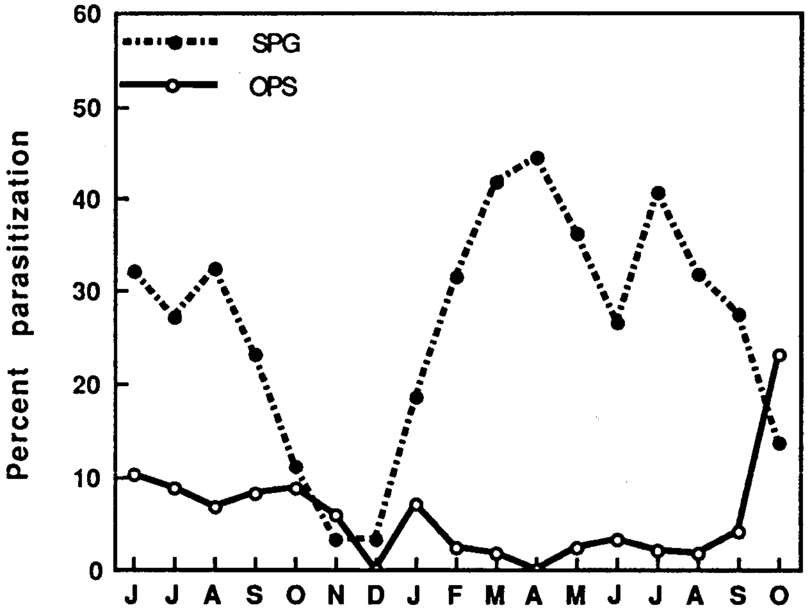
Sphegigaster spp.

Two species of this genus, *S. stepicola* Boucek and *S. brunneicornis* (Ferrière), were recorded. These were by far the most numerous parasitoids all year round (Fig. A.3). Combined parasitism by the two species ranged between 3.1% and 44.4%, with an overall average of 26.2 ± 3.1%. Of the two species, *S. stepicola* accounted for nearly 72% of the total emergence. This species is reported to have been reared from *Phytomyza albiceps* Meigen, and is known so far only from southern Europe and India (Z. Boucek, pers. comm.); *S. brunneicornis* has been reported from Sri Lanka and India (Peter & Balasubramanian, 1984) and has been reared only from bean fly. Hassan (1947), in Egypt, reared a related species, *S. agromyzae* Dodd, also from bean fly.

Opius phaseoli Fischer

Apparently the pest density and the percent parasitism are both influenced by planting dates (see Chapter III). Parasitism by *O. phaseoli* varied from 0% in some months to 23.2% (Fig. A.3), with a 17-month average of 5.6 ± 1.3%. These percentages are much lower than the levels I observed on haricot bean in my general surveys (Table A.1) or in seeding date experiments (see Chapter III) or those reported by Greathead (1969, 1975) and Raros (1975). Greathead (1969) reported parasitism levels of over 50%, sometimes reaching 90%, in East Africa.

Figure A.3: Parasitism levels by several Hymenoptera of bean fly on *Crotalaria laburnifolia*, Melkassa (SPG and OPS represent *Sphegigaster* spp. and *Opius phaseoli*, respectively).


SPG
OPS
Percent parasitization
60
50
40
30
20
10
0
J J A S O N D J F M A M J J A S O

Chrysonotomyia spp.

Two species of these eulophids were recorded. These are *C. formosa* (Westwood) and *C.* sp. nr *erythraea* (Silvestri). Parasitism by these ranged between 0% and 8.7%, with a mean value of 2.6 ± 0.7%. Although both species are widely distributed on bean fly attacking crotalaria in many parts of Ethiopia they usually occurred in small numbers. *Chrysonotomyia formosa* may be polyphagous as it has also been recorded on *Liriomyza trifolii* (Burgess) (Schriner *et al.*, 1986).

Other Chalcidoidea

The remaining species of the Chalcidoidea listed in Table A.2 accounted for 0.5% to 19.7% of bean fly parasitism, with a 17-month mean of 7.0 ± 1.3%.

DISCUSSION

In this chapter, I reported on geographic distribution, host plants, natural enemies and seasonal changes in their numbers.

In 1983, I first studied the bushy crotalaria, *Crotalaria laburnifolia*, that grows wild commonly in terrace bunds of farms and as a weed in fallows in bean-growing areas in central and parts of southern Ethiopia. It is an alternative host plant of *Ophiomyia phaseoli*, the identity of which was confirmed by I.M. White of CAB International Institute of Entomology (CABIIE) (CIE Coll. No. A17050 Africa). *Ophiomyia phaseoli* acts as a true leaf miner on this plant; it lays its eggs mainly on the upper surface of the leaf, in which the young maggots form serpentine mines upon hatching. The mines coalesce and form yellow blotches as the maggots grow bigger and eventually pupate within the leaf. In addition, an unknown leaf-mining agromyzid causing symptoms similar to those of *Ophiomyia phaseoli* was also collected, with a similar parasitoid complex observed from samples collected from Shewa Robi, Ziway, Bilate and Hagere-Mariam. The identity of the pest species is being studied by CABIIE specialists.

The highly significant correlations between percentages of infested leaves and percentages of leaves with greater than one leaf miner suggest that either of the two parameters can be employed for estimating bean fly numbers.

It is interesting to note here that although *Opius phaseoli* was the most numerous parasitoid of bean fly on haricot bean and cowpea, *Sphegigaster* spp. were more abundant than *O. phaseoli* on bean fly when attacking the wild host plant, *Crotalaria laburnifolia*. It is possible, therefore, that the host plant on which the pest occurs plays some role in the behaviour and performance of the parasitoid as has been demonstrated for other parasitoids (Herzog & Funderurk, 1985).

Opius phaseoli occurs naturally outside Ethiopia, *e.g.* in Kenya, Tanzania, Uganda, Botswana, Madagascar, Mauritius, India and the Philippines (Greathead, 1969; Fischer, 1971a). It was introduced from Uganda into Hawaii in 1969 (Greathead, 1969), where it is reported to have given effective biological control of bean fly (Greathead, 1975). Its introduction into Brunei was also reported to have resulted in effective control of the pest (CIBC, 1978). Fischer (1971b) identified a related species, *O. importatus* Fischer, from Hawaii.

All other Chalcidoidea occurred in small numbers. *Halticoptera ?circulus* (Walker) is said to be a widespread species parasitizing agromyzid leafminers in many parts of the world (Z. Boucek , pers. comm.). Raros (1975) recorded a related species, *H. patellana* (Dalman), on bean fly from Hawaii. *Meruana liriomyzae* Boucek is apparently polyphagous, having been reared from *Liriomyza brassicae* (Riley) on Mauritius and from *L. sativae* Blanchard on Reunion; it also occurs in Kenya, South Africa, and Australia (Boucek, pers. comm.). I also reared it from *Chromatomyia horticola* (Goureau) attacking cabbages in the Ethiopian highlands in 1983.

This is perhaps only the second or third record of the pteromalid species *Herbertia* from Africa; the first was made by Deeming (1979) from Nigeria; Greathead (1969) recorded an undetermined species of *Herbertia* from East Africa, but no species of this genus has been described from Africa so far. *Pediobius acantha* (Walker) was found very rarely; it is known to be widespread in Europe, attacking dipterous leafminers and its presence in Ethiopia is "surprising" (Z. Boucek, pers. comm.). The genera *Cirrospilus*, *Aprostocetus* and *Epiclerus* have not been recorded on bean fly in the past anywhere in the world. Z. Boucek (pers. comm.) argued that *Eupelmus ?australiensis* (Girault), formerly known as *E. popa* Gir., is a parasitoid of the sorghum midge, and it might therefore have been an accidental admixture. However, I believe that this is not the case because Greathead (1969) reared a similar species from *Ophiomyia phaseoli* in East Africa; he suggested the species was a hyperparasitoid of *Opius phaseoli*. Although undescribed species of the genus *Callitula* have been recorded from *Ophiomyia phaseoli* in many parts of the world, *C. filicormis* Delucchi may be the first specific record from Africa and perhaps for bean fly.

Casual observations suggest that seedling mortality among beans caused by the fly in areas where the wild plant host occurred was much less severe than it was in areas where there were no wild hosts. For example, crotalaria does not occur at Awassa, and seedling mortality of beans planted during the critical period of early June was 39.1% in 1987 and 36.1% in 1988, whereas at Melkassa (where crotalaria occurs) the corresponding values were 14.8% and 3.8%, respectively. It is therefore possible that the presence of the wild host may play a positive role in the integrated management of bean fly. Further research is needed to throw some light on this area; it may also be interesting to study significance of the natural enemies in different localities.

In summary, surveys carried out during two seasons showed that bean fly is widely distributed throughout Ethiopia. It was found on beans, cowpea and soybean but caused economic damage only on beans. The leguminous bush *Crotalaria laburnifolia* was the only wild host plant supporting bean fly and its parasitoid populations throughout the year in some parts of Ethiopia. Bean fly incidence on the wild host was highest between December and March. Seventeen species of parasitoids were recorded. Of these, the pteromalids *Sphegigaster stepicola* and *S. brunneicornis* were the most common species on the wild plant host, accounting for up to 44.5% ($\bar{x}$=26.2 ± 3.1%) of bean fly parasitism. Parasitism by the braconid *Opius phaseoli* was low, ranging from 0% to 23.2% ($\bar{x}$=5.6 ± 1.3%). However, on beans, it was the major parasitoid, with up to 94% of bean fly parasitism. This fact suggests the possibility that the host plant plays an important role in bean fly dynamics.

APPENDIX 2: DATA ON HOST PLANT RESISTANCE

Appendix 2.1: Two-way ANOVA of various paramters in 38 cultivars of *Phaseolus vulgaris* tested for bean fly resistance at two locations, 1987

VARIABLE	SOURCE	DF	SS	MS	F	Prob.
			Awassa			
% dead	Rep	2	678.97	339.48	6.04	0.003
seedlings	Cultivar	37	6721.11	181.65	3.23	0.000
	Error	74	4160.65	56.22		
Score	Rep	2	20.37	10.18	4.43	0.015
	Cultivar	37	170.32	4.60	2.00	0.005
	Error	74	169.96	2.30		
% pod damage	Rep	2	69.49	34.74	3.09	0.051
	Cultivar	37	956.61	25.85	2.30	0.000
	Error	74	832.36	11.25		
No. pods	Rep	2	484.37	242.18	4.95	0.009
per plant	Cultivar	37	9440.57	255.15	5.21	0.000
	Error	74	3623.67	48.97		
Yield	Rep	2	503100.02	251550.01	1.04	0.358
	Cultivar	37	65218619.27	1762665.39	7.29	0.000
	Error	74	17893380.65	241802.44		

Appendix 2.1: cont'd.

VARIABLE	SOURCE	DF	SS	MS	F	Prob.
			M e l k a s s a			
% dead	Rep	2	807.68	403.84	5.39	0.006
seedlings	Cultivar	37	3824.87	103.37	1.38	0.120
	Error	74	5544.59	74.93		
	....					
No. pods	Rep	2	131.88	65.94	2.73	0.070
per plant	Cultivar	37	756.94	20.46	0.85	
	Error	74	1784.77	24.12		
	....					
Yield	Rep	2	678185.75	339092.88	2.98	0.057
	Cultivar	37	19471377.27	526253.44	4.62	0.000
	Error	74	8433966.91	113972.53		

Appendix 2.2: Correlations between dry-seed yield and various parameters in 38 cultivars of *Phaseolus vulgaris* tested for bean fly resistance, Melkassa, 1987*

Parameters measured	Partial R^2	Total R^2	b value	F	P
		Awassa			
No. pods/plant	0.5234	0.5234	48.68	39.5372	0.0001
% dead seedlings	0.1842	0.7076	-43.65	22.0433	0.0001
% pod damage	0.0092	0.7168	-30.39	1.1021	0.3012
		Melkassa			
Leaf area	0.2419	0.2419	12.27	11.4882	0.0017
% dead seedlings	0.1327	0.3746	-22.53	7.4277	0.0100
No. pods/plant	0.0432	0.4179	35.32	2.5252	0.1213

*pod damage was negligible at Melkassa.

Appendix 2.3: ANOVA of percent seedling mortality caused by bean fly in 15 cultivars of *Phaseolus vulgaris*, Awassa, 1988

SOURCE	DF	SS	MS	F	P
4 June 1988					
Rep	3	440.42	146.81	0.87	
A (INSECTICIDE)	1	15539.91	15539.91	92.24	0.002
Error (A)	3	505.41	168.47		
B (CULTIVAR)	14	8214.13	586.72	15.07	0.000
Error (B)	42	1634.76	38.92		
AB	14	7084.13	506.01	14.00	0.000
Error (C)	42	1517.58	36.13		
18 June 1988					
Rep	3	3600.62	1200.21	0.77	
A (INSECTICIDE)	1	11653.15	11653.15	7.48	0.071
Error (A)	3	4671.49	1557.17		
B (CULTIVAR)	14	5715.41	408.24	9.57	0.000
Error (B)	42	1791.54	42.66		
AB	14	5188.85	370.63	8.01	0.000
Error (C)	42	1943.20	46.27		

Appendix 2.4: Two-way ANOVA of percent yield loss in 15 cultivars of *Phaseolus vulgaris*, Awassa, 1988

SOURCE	DF	SS	MS	F	P
June 4					
Rep	3	2717.59	905.86	6.44	0.001
Variety	14	32096.24	2292.59	16.31	0.000
Error	42	5903.35			
....					
June 18					
Rep	3	6988.48	2332.82	12.46	0.000
Variety	14	8620.48	615.75	3.29	0.001
Error	42	7864.26	187.24		

Appendix 2.5: ANOVA of dry-seed yield in 15 cultivars of *Phaseolus vulgaris*, Awassa, 1988

SOURCE	DF	SS	MS	F	P
4 June					
Rep	3	646299.99	215433.33	0.14	
INSECTICIDE	1	13290444.59	13290444.94	8.94	0.058
Error (A)	3	4461003.04	1487001.02		
CULTIVAR	14	64921653.13	4637260.94	16.13	0.000
Error (B)	42	12075062.79	287501.50		
AB	14	15183476.21	1084534.02	6.03	0.000
Error (C)	42	7551788.43	179804.49		
18 June					
Rep	3	18774800.02	6258266.67	4.18	0.135
INSECTICIDE	1	20392312.59	20392312.59	13.63	0.034
Error (A)	3	4487469.21	1495823.07		
CULTIVAR	14	65737731.93	4695552.28	9.26	0.000
Error (B)	42	21301122.04	507169.57		
AB	14	5742554.72	410182.48	2.13	0.029
Error (C)	42	8078358.01	192341.86		

Appendix 2.6: Morphological and physiological character measurements for 38 cultivars of *Phaseolus vulgaris* tested for bean fly resistance, Melkassa, 1987*

CIAT Acc. #	Cultivar name	Leaf area **	Hair density ***	%dry matter		
				Leaf	Stem	Total
G03696	Coleccion 12-D	74.7	73bc	11.2	5.9	16.8
G03844	Cascade	45.7	149abc	11.2	3.5	14.7
EMP 81	EMP 81	87.7	94bc	9.9	3.8	13.7
G02472	Guerrero 29-C	59.0	125abc	11.2	3.5	14.6
G02005	Gentry 21020	76.0	51bc	10.5	3.3	13.8
G04958	Varanic 2	90.0	60bc	10.8	4.5	15.2
G03645	Jamapa	53.7	99bc	11.3	3.8	15.1
G11292	Poroto Tropero	61.3	114abc	13.1	4.1	17.2
G05059	H6 Mulatinho	61.3	87bc	10.6	3.7	14.1
G00124	PI163557	33.7	105abc	11.3	3.9	15.3
G00404	Round Speckled Sugar	56.7	90bc	10.3	3.7	14.0
G01483	PI278672	39.0	117abc	11.4	3.9	15.3
G09409	U.S. Refugee	52.3	116abc	10.6	3.7	14.3
G00112	PI155213	53.7	147abc	10.8	3.4	14.1
G04458	27-R	38.0	89bc	11.1	3.9	15.1
G03627	S-182-N	59.0	121abc	10.1	4.2	14.3
G04017	Carioça	70.3	118abc	11.0	3.9	14.8

Appendix 2.6: cont'd.

CIAT Acc. #	Cultivar name	Leaf area **	Hair density ***	%dry matter		
				Leaf	Stem	Total
G01996	Gentry 20989	66.7	108abc	10.2	3.3	13.5
G01853	Calima	58.3	112abc	11.0	4.4	15.4
G04446	Ex-Puebla 152-Brown Seeded	64.3	65bc	10.8	3.9	14.6
G01820	Negro Iamapa	54.0	90bc	10.0	4.0	14.0
Local	Brown Speckled	53.7	128abc	10.6	3.5	14.2
G00402	White Sugar	48.7	127abc	10.4	3.6	14.0
Local	Red Wolaita	53.7	101bc	10.4	3.6	14.0
G03807	Brasil 2=Pico de Oro	56.3	92bc	11.2	3.6	14.8
G12532	PG 0036	59.3	160ab	11.0	3.5	14.1
G00056	Striped Brown	46.7	108abc	10.8	4.4	15.3
G00734	Otz K'al Tsaik	48.0	94bc	11.3	3.8	15.2
G00105	Zarzaleno de Arbor	49.7	78bc	11.5	4.0	15.5
G02548	Col. No. 12	59.3	114abc	10.9	3.3	14.2
G00011	Frijol	45.3	113abc	11.4	3.6	15.0
G01447	PI251049	38.7	210a	11.0	4.1	15.2
G13204	Cod-1213	48.3	92bc	10.8	4.4	15.2
G01540	Bakon	64.3	113abc	11.0	4.1	15.6

Appendix 2.6: cont'd.

CIAT Acc. #	Cultivar name	Leaf area **	Hair density ***	%dry matter		
				Leaf	Stem	Total
G00113	PI155307	60.7	93bc	10.2	3.7	13.8
Local	Mexican 142	59.3	129abc	10.3	4.2	14.5
G12553	PG 0063	65.3	98bc	10.2	4.2	14.5
G00158	Yer Fasulyasi	87.3	78bc	10.5	3.4	13.9
	Mean	57.9	106.6	10.8	3.9	14.7
	SE	2.0	5.0	0.1	0.1	0.1

*Means followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test; **=cm^2/plant; ***=no./cm^2).

Appendix 2.7: Correlations between bean fly damage and various plant character measurements of 38 cultivars of *Phaseolus vulgaris*, Melkassa, 1987

Variable measured	Corr. coeff. (r)	P
Leaf area	-0.204	0.220
Hair density	0.081	1.000
Dry matter (leaf)	0.024	1.000
Dry matter (stem)	0.054	1.000
Dry matter (total)	-0.005	1.000

Appendix 2.8: Two-way ANOVA of bean fly emergence/5 plants in 15 cultivars of *Phaseolus vulgaris* at two locations, 1988

SOURCE	DF	SS	MS	F	P
Awassa					
Rep	3	635.38	211.79	4.94	0.005
Cultivar	14	1419.93	101.42	2.37	0.015
Error	42	1800.87	42.88		
Melkassa					
Rep	3	28.93	9.64	0.55	
Cultivar	14	585.46	41.82	2.40	0.014
Error	42	732.94	17.45		

Appendix 2.9: Correlations between dry-seed yield and various parameters in 15 cultivars of *Phaseolus vulgaris* tested for bean fly resistance, Awassa, 1988*

Parameters measured	Partial R^2	Total R^2	b value	F	P
		4 June, 1988			
% dead seedlings	0.9015	0.9015	-68.61	118.9849	0.0001
No. pods/plant	0.0285	0.9300	41.19	4.8905	0.0472
No. seeds/pod	0.0106	0.9406	405.60	1.9594	0.1891
1000-seed wt.	0.0122	0.9528	4.91	2.5845	0.1390
% pod damage**	0.0034	0.9562	-112.61	0.7084	0.4218
		18 June, 1988			
% dead seedlings	0.4177	0.4177	-36.77	9.3234	0.0092
No. pods/plant	0.2591	0.6768	35.46	9.6200	0.0092
% plants with advent. roots	0.1049	0.7817	-13.03	5.2862	0.0421
Stem length	0.0780	0.8596	16.05	5.5549	0.0402
No. seeds/pod	0.0482	0.9078	647.35	4.7054	0.0582
% pod damage	0.0248	0.9327	-322.79	2.9513	0.1241

*Data from untreated plots; ***Heliothis armigera*.

APPENDIX 3: DATA ON SEEDING DATE AND PLANT DENSITY

Appendix 3.1: ANOVA of bean fly emergence/10 dead seedlings of *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), 1987 and 1988

SOURCE	DF	SS	MS	F	P
Awassa					
Year (Y)	1	5000.23	5000.23	74.41	0.000
Rep(Y)	4	971.87	242.97	3.62	0.037
SDt (A)	3	1836.49	612.16	9.11	0.002
YA	3	605.78	201.93	3.00	0.072
Error(A)	12	806.38	67.20		
PDt (B)	4	4487.05	1121.76	41.94	0.000
YB	4	922.56	230.64	8.62	0.000
AB	12	744.95	62.08	2.32	0.015
YAB	12	252.04	21.00	0.79	
Error(B)	64	1711.80	26.75		
Melkassa					
Y	1	94.97	94.97	69.15	0.000
Rep(Y)	4	5.54	1.38	1.01	0.444
A	3	157.48	52.49	38.22	0.000
YA	3	113.30	37.76	27.50	0.000
Error(A)	12	16.48	1.37		
B	4	142.91	35.73	17.83	0.000
YB	4	31.17	7.79	3.89	0.006
AB	12	79.62	6.63	3.31	0.000
YAB	12	70.29	5.86	2.92	0.002
Error(B)	64	128.24	2.00		

Appendix 3.2 ANOVA of percentages of seedling mortality caused by bean fly in *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), 1987 and 1988

SOURCE	DF	SS	MS	F	P
Awassa					
Year (Y)	1	1130.59	1130.59	16.67	0.001
Rep(Y)	4	846.12	211.53	3.12	0.056
SDt (A)	3	530.32	176.77	2.61	0.099
YA	3	4141.17	1380.39	20.35	0.000
Error(A)	12	813.94	67.83		
PDt (B)	4	5157.96	1289.49	70.87	0.000
YB	4	224.16	56.04	3.08	0.022
AB	12	245.57	20.46	1.12	0.356
YAB	12	1141.97	95.16	5.23	0.000
Error(B)	64	1164.54	18.20		
Melkassa					
Y	1	1488.90	1488.90	75.26	0.000
Rep(Y)	4	122.36	30.59	1.55	0.251
SDt (A)	3	936.09	312.03	15.77	0.000
YA	3	1679.81	559.94	28.30	0.000
Error(A)	12	237.41	19.78		
PDt (B)	4	1865.77	466.44	48.03	0.000
YB	4	577.13	144.28	14.86	0.000
AB	12	474.09	39.51	4.07	0.000
YAB	12	401.98	33.50	3.45	0.000
Error(B)	64	621.48	9.71		

Appendix 3.3: ANOVA of dry-seed yield of *Phaseolus vulgaris* seeded at different dates (SDt) and densities (PDt), 1987 and 1988

SOURCE	DF	SS	MS	F	P
Awassa					
Year (Y)	1	9170268.88	9170268.88	87.01	0.000
Rep(Y)	4	202335.06	50583.76	0.48	
SDt (A)	3	5060963.34	1686987.78	16.01	0.000
YA	3	4526210.00	1508736.67	14.31	0.000
Error(A)	12	1264788.88	105399.07		
PDt (B)	4	12992871.79	3248217.95	34.28	0.000
YB	4	114810.34	28702.58	0.30	
AB	12	1504873.17	125406.10	1.32	0.227
YAB	12	1062841.25	88570.10	0.93	
Error(B)	64	6065224.00	94769.12		
Melkassa					
Y	1	75501141.95	75501141.95	344.40	0.000
Rep(Y)	4	1973807.40	493451.85	2.25	0.124
A	3	12111758.52	4037252.84	18.42	0.000
YA	3	2763623.52	921207.84	4.20	0.030
Error(A)	12	2630681.62	219223.47		
B	4	8259196.90	2064799.22	20.87	0.000
YB	4	3795565.49	948891.37	9.59	0.000
AB	12	3045713.08	253809.42	2.57	0.007
YAB	12	1668866.02	139072.17	1.41	0.186
Error(B)	64	6332605.90	98947.00		

Appendix 3.4: Numbers of pods/plant in *Phaseolus vulgaris* seeded at different dates (SDt)*

SDt	Awassa		Melkassa	
	1987	1988	1987	1988
S1	36.1a	28.6c	11.2de	25.1a
S2	31.4bc	31.3bc	13.4cd	22.1b
S3	32.7ab	30.8bc	9.3e	20.0b
S4	28.5c	27.9c	10.4e	14.2c
Mean	32.2	29.7	11.1	20.3
SE	1.3	1.3	0.5	1.0

*All means, within location, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); data pooled over plant densities.

Appendix 3.5: Numbers of seeds/pod in *Phaseolus vulgaris* seeded at different dates (SDt)*

SDt	Awassa		Melkassa	
	1987	1988	1987	1988
S1	2.02c	2.39abc	3.01ab	3.14a
S2	2.18bc	2.45ab	2.40d	2.63cd
S3	2.70a	2.05bc	1.68e	2.84abc
S4	2.74a	2.26bc	1.18f	2.75bc
Mean	2.41	2.29	2.07	2.84
SE	0.09	0.08	0.10	0.07

*All means, within location, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); data pooled over plant densities.

Appendix 3.6: Thousand-seed weight (g) in *Phaseolus vulgaris* seeded at different dates (SDt)*

SDt	Awassa		Melkassa	
	1987	1988	1987	1988
S1	205.6b	240.1a	147.2d	195.3a
S2	197.5bc	204.3b	146.7d	182.0b
S3	190.7cd	202.3b	159.3c	162.9c
S4	184.5d	196.8bc	162.5c	158.8c
Mean	194.6	210.9	153.9	174.7
SE	1.7	2.7	1.1	2.1

*All means, within location, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); data pooled over plant densities.

Appendix 3.7: ANOVA of percent parasitization by *Opius phaseoli* of bean fly in haricot bean seeded at different dates (SDt) and densities (PDt), 1987 and 1988*

SOURCE	DF	SS	MS	F	P
Awassa					
Year (Y)	1	1625.09	1625.09	63.66	0.000
Rep(Y)	4	66.13	16.53	0.65	
SDt (A)	3	3227.41	1075.80	42.14	0.000
YA	3	347.19	115.73	4.53	0.024
Error(A)	12	306.34	25.53		
PDt (B)	4	168.51	42.13	5.14	0.001
YB	4	9.57	2.39	0.29	
AB	12	211.85	17.65	2.15	0.025
YAB	12	242.27	20.19	2.46	0.010
Error(B)	64	524.77	8.20		
Melkassa					
Y	1	1029.02	1029.02	4.51	0.055
Rep(Y)	4	1707.27	426.82	1.87	0.180
A	3	17829.75	5943.25	26.03	0.000
YA	3	7955.06	2651.69	11.61	0.000
Error(A)	12	2739.89	228.32		
B	4	1671.08	417.77	1.45	0.228
YB	4	2753.39	688.35	2.39	0.060
AB	12	2400.36	200.03	0.69	
YAB	12	1334.26	111.19	0.39	
Error(B)	64	18445.76	288.21		

*Arcsine transformations of percentages were used for ANOVA.

Appendix 3.8: Parameters describing relative contributions of seeding date and plant density to bean fly parasitism levels by *Opius phaseoli*, 1988*

Variables	Partial R^2	Total R^2	b value	F	P
Awassa	*(Y-intercept=88.9172;*	*df=1,37)*			
Seeding dates	0.4989	0.4989	-0.6074	37.8304	0.0001
Plant densities	0.0116	0.5105	-0.7337	0.8805	0.3541
Melkassa	*(Y-intercept=22.3288;*	*df=1,37)*			
Seeding dates	0.4820	0.4820	1.3069	35.3541	0.0001
Plant densities	0.0049	0.4869	-1.0450	0.3555	0.5546

*Values of 0, 10, 20, and 30 were assigned to S1, S2, S3 and S4, respectively, for analysis.

Appendix 3.9: Percent parasitization by *Sphegigaster* spp. and other Chalcidoidea of bean fly in haricot bean seeded at different dates (SDt)*

SDt	Awassa		Melkassa	
	1987	1988	1987	1988
S1	5.5b	1.8c	2.1cd	1.7d
S2	9.1a	5.5b	3.2cd	5.1bc
S3	5.5b	5.7b	7.9ab	3.9bcd
S4	5.3b	7.0ab	9.9a	6.4bc
Mean	6.3	5.0	5.8	4.3

*All means, within location, followed by the same letter(s) are not significantly different from each other at 5% (Duncan's New Multiple Range Test); data pooled over plant densities.

APPENDIX 4: DATA ON HABITAT DIVERSITY EXPERIMENTS

Appendix 4.1: ANOVA of the numbers of adult bean flies visiting *Phaseolus vulgaris* seedlings grown with and without strip-crop under weedy and weed-free conditions, Awassa, 1987 and 1988

SOURCE	DF	SS	MS	F	P
Year (Y)	1	49.70	49.70	1.70	0.322
Rep(Y)	2	19.13	9.56	0.33	
Strip-crop (A)	1	35.40	35.40	1.21	0.385
YA	1	19.80	19.80	0.68	
Error(A)	2	58.45	29.22		
Weeding (B)	1	753.50	753.50	80.14	0.000
YB	1	0.90	0.90	0.10	
AB	1	0.30	0.30	0.03	
YAB	1	49.70	49.70	5.29	0.083
Error(B)	4	37.61	9.40		

Appendix 4.2: ANOVA of adult bean fly emergence/25 dead seedlings of *Phaseolus vulgaris* grown with and without strip-crop under weedy and weed-free conditions, Awassa, 1987 and 1988

SOURCE	DF	SS	MS	F	P
Year (Y)	1	73.53	73.53	0.06	
Rep(Y)	2	609.98	304.99	0.27	
Strip-crop (A)	1	129.39	129.39	0.11	
YA	1	9.77	9.77	0.01	
Error(A)	2	2276.24	1138.12		
Weeding (B)	1	2670.31	2670.31	44.97	0.002
YB	1	354.38	354.38	5.97	0.070
AB	1	173.58	173.58	2.92	0.162
YAB	1	245.71	245.71	4.14	0.111
Error(B)	4	237.53	59.38		

Appendix 4.3: ANOVA of parasitism levels by *Opius phaseoli* of bean fly in bean plots grown with and without strip-crop under weedy and weed-free conditions, Awassa, 1987 and 1988

SOURCE	DF	SS	MS	F	P
Year (Y)	1	308.88	308.88	3.86	0.188
Rep(Y)	2	87.34	43.67	0.55	
Strip-crop (A)	1	147.02	147.02	1.84	0.308
YA	1	158.13	158.13	1.97	0.295
Error(A)	2	160.16	80.08		
Weeding (B)	1	12.78	12.78	0.18	
YB	1	0.03	0.03	0.00	
AB	1	9.15	9.15	0.13	
YAB	1	11.73	11.73	0.16	
Error(B)	4	290.76	72.69		

Appendix 4.4: List of commonly occurring entomophagous insects captured in water traps in *Phaseolus vulgaris* plots with and without maize strips under weedy and weed-free conditions, Awassa, 1987 and 1988*

Taxon**	Abundance***
DIPTERA	
Tachinidae	
Voria capensis Villeneuve	very common
Periscepsia carbonaria (Panzer)	common
Voria ruralis (Fallen)	rare
Syrphidae	
Ischiodon aegyptius (Wiedemann)	very rare
Betasyrphus adligatus (Wiedemann)	very rare
HYMENOPTERA	
Tiphiidae	
Tiphia sp.	very common
Scoliidae	
Capsomeriella madonensis (Buysson)	common
Aureimeris sp.	rare
Micromeriella aureola (Klug)	very rare
Micromeriella hylina (Klug)	very rare
Capsomerinae	rare
Sphecidae	
Philanthus spp.	very rare
Lara sp.	very rare

Appendix 4.4: cont'd.

Taxon**	Abundance***
Oxybelus sp. "B"	very rare
Podalonia sp.	very rare
Oxybelus sp. "A"	very rare
Ichneumonidae	
Netelia sp.	rare
Venturia sp.	rare
Vespidae	
Polistes sp.	very rare
Belonogaster sp.	very rare
Pompilidae	
Anoplius morosus	very rare
Anoplius sp.	very rare
Elaphrosyron insidiosus (Smith)	very rare
Pericnemis sp.	very rare
Cyamagena sp.	very rare
Eumenidae	
Antepipona sp.	very rare
Chalcididae	
Brachymeria kassalensis (Kirby)	very rare
Brachymeria sp.	very rare
Gen. et sp. indet. (4)	very rare
Halictidae	
Lasioglossum sp.	very rare

Appendix 4.4: cont'd.

Taxon**	Abundance***
HETEROPTERA	
Reduviidae	
Pirates (Cleptocoris) sp.	very rare
COLEOPTERA	
Coccinellidae	
Adonia variegata Goeze	very rare
Cheilomenes sulphureae (Oliver)	very rare
Cheilomenes vicinus (Mulsant)	very rare
Cheilomenes lunata (Fabricius)	very rare

*All specimens (except the coccinellids) were determined by the CABIIE (Coll. No. A20050).
**Families and genera within a family listed in descending order of occurrence.
***Very rare=< 5% of total catch; rare=6-10%; common=11-15%; very common=> 15%.

Appendix 4.5: ANOVA of dry-seed yield (kg/ha) of *Phaseolus vulgaris* grown with and without strip-crop under weedy and weed-free conditions, Awassa, 1987 and 1988

SOURCE	DF	SS	MS	F	P
Year (Y)	1	5792445.56	5792445.56	39.85	0.024
Rep(Y)	2	12586.63	6293.31	0.04	
Strip-crop (A)	1	116110.56	116110.56	0.80	
YA	1	4389.06	4389.06	0.03	
Error(A)	2	290696.63	145348.31		
Weeding (B)	1	3531580.56	3531580.56	534.07	0.000
YB	1	470939.06	470939.06	71.22	0.001
AB	1	106765.56	106765.56	16.15	0.015
YAB	1	8055.06	8055.06	1.22	0.331
Error(B)	4	26450.25	6612.56		

APPENDIX 5: DATA ON SEED DRESSING EXPERIMENTS

Appendix 5.1: ANOVA of numbers of seedling emergence/plot (2 wks after seeding) in haricot bean treated with various seed dressing insecticides against *Ophiomyia phaseoli*, 1987 and 1988

SOURCE	DF	SS	MS	F	P
		Awassa			
Year (Y)	1	4690.41	4690.41	17.39	0.003
Rep(Y)	8	2157.71	269.71		
Treatments (T)	6	62574.60	10429.10	13.90	0.000
TY	6	60577.69	10096.28	13.46	0.000
Error	48	36014.29	750.30		
		Melkassa			
Y	1	2343.21	2343.21	11.98	0.008
Rep(Y)	8	1564.86	195.61		
T	6	6271.54	1045.26	5.29	0.000
TY	6	10704.69	1784.11	9.03	0.000
Error	48	9480.34	197.51		

Appendix 5.2: ANOVA of percent seedling mortality caused by *Ophiomyia phaseoli* in haricot bean treated with various seed dressing insecticides, 1987 and 1988*

SOURCE	DF	SS	MS	F	P
		Awassa			
Year (Y)	1	1.65	1.65	5.35	0.049
Rep(Y)	8	2.46	0.31		
Treatments (T)	6	54.09	9.01	31.53	0.000
TY	6	3.52	0.59	2.05	0.076
Error	48	13.72	0.29		
		Melkassa			
Y	1	251.46	251.46	217.09	0.000
Rep(Y))	8	9.27	1.16		
T	6	5.21	0.87	1.36	0.251
TY	6	4.28	0.71	1.11	0.368
Error	48	30.73	0.64		

*Data were transformed to their square roots ($\sqrt{x + .5}$) for ANOVA.

Appendix 5.3: Two-way ANOVA of percent infestation (35 days after seeding) by *Ophiomyia phaseoli* of haricot bean treated with various seed dressing insecticides, 1988*

SOURCE	DF	SS	MS	F	P
			Awassa		
Rep	4	835.91	208.98	2.30	0.088
Treatment	6	14267.42	2377.90	26.17	0.000
Error	24	2180.70	90.86		
			Melkassa		
Rep	4	452.50	113.12	1.83	0.156
Treatment	6	15412.74	2568.79	41.55	0.000
Error	24	1483.92	61.83		

*Data are arcsine transformations of percentages.

Appendix 5.4: Two-way ANOVA of numbers of adult *Ophiomyia phaseoli* emerging/20 plants (35 days after seeding) of haricot bean treated with various seed dressing insecticides, 1988*

SOURCE	DF	SS	MS	F	P
		Awassa			
Rep	4	1.85	0.46	1.71	0.180
Treatment	6	110.86	18.48	68.34	0.000
Error	24	6.49	0.27		
		Melkassa			
Rep	4	1.80	0.45	0.56	
Treatment	6	82.91	13.82	17.24	0.000
Error	24	19.24	0.80		

*Data were transformed to their square roots ($\sqrt{x + .5}$) for ANOVA.

Appendix 5.5: ANOVA of dry-seed yield (kg/ha) of haricot bean treated with various seed dressing insecticides against *Ophiomyia phaseoli*, 1987 and 1988

SOURCE	DF	SS	MS	F	P
		Awassa			
Year (Y)	1	49100034.00	49100034.00	49.99	0.000
Rep(Y)	8	7857086.69	982135.84		
Treatments (T)	6	5520962.28	920160.38	11.05	0.000
TY	6	5084625.21	847437.54	10.18	0.000
Error	48	3995947.77	83248.91		
		Melkassa			
Y	1	26038079.36	26038079.36	357.77	0.000
Rep(Y)	8	582236.62	72779.58		
T	6	813395.94	135565.99	4.65	0.000
TY	6	769493.02	128248.84	4.40	0.001
Error	48	1397940.72	29123.76		

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