Abstract

FOREHAND, LISA McNICOL. Evaluation of Commercial Beneficial Insect Habitat Seed Mixtures for Organic Insect Pest Management (Under the direction of David B. Orr and H. M. Linker).

A laboratory study conducted in 2003 evaluated the purity, composition and germination of three commercial mixes: Border Patrol™ (BP), Beneficial Insect Mix (BIM), and Good Bug Blend (GBB). Regarding seed purity, BP had two weed species present and live beetles (Coleoptera: Bostrichidae) were present and actively feeding on seeds, BIM had one weed species present and one advertised species missing and GBB had fourteen different weed species present and three advertised species missing. The composition of BP found buckwheat and nasturtium to be the largest proportion by weight, while yarrow and evening primrose had the greatest seed numerical abundance. In BIM, the largest proportion of seeds by weight were coriander and candytuft, but numerically candytuft and Siberian wallflower were most abundant. The majority of seeds in GBB by both weight and numerical abundance, were clovers and alfalfa. Germination of seeds in BP was variable with two species having 0% germination, most likely due to seed feeding and pathogen growth from insect frass. BIM demonstrated good overall germination, with the exception of gayfeather. All seeds in GBB, except fennel, germinated at or above test values provided by the supplier.

A field study was conducted in 2003 to evaluate three commonly grown flowers (*Zinnia*, *Celosia* and fennel) and three commercially available beneficial insect habitat seed blends (Peaceful Valley's Good Bug Blend, (GBB) Clyde Robin's Border Patrol™ (BP) and Heirloom Seed's Beneficial Insect Mix (BIM)) to determine what insects were present in each of these different plant communities. Three experiments were conducted

to evaluate mixes: 1) insect samples were collected using a D-vac, identified to family and evaluated by feeding guilds; 2) pitfall traps were collected to monitor ground beetle and ground-dwelling spider populations; and 3) dusk observations recorded visits by noctuid and hornworm moths. *Celosia* offered the largest diversity and abundance of predators and parasitoids in the flower plots, although the specimens collected were not found to be significant in the control of agronomic pests. Fennel, although not flowering until late summer, had the lowest overall abundance and diversity of all flowering blocks. The BP plantings had the highest diversity and abundance of herbivore crop pests as well as the highest instances of Lepidoptera pests during night observations. GBB had the highest abundance and diversity of beneficial parasitoids and predators.

A field study was conducted in 2003 and 2004 to evaluate the effectiveness of a commercially available beneficial insect habitat (BIH) in decreasing pest caterpillar populations. Six pairs of organically managed tomato plots were established and Peaceful Valley's Good Bug Blend transplanted around the perimeter of treatment plots, while a brown-top millet border was planted around the controls. *Helicoverpa zea* and *Manduca spp*. eggs were monitored and categorized based on the fate of each egg after one week. When analyzed for the effect from year, treatment, year by treatment, date within year and treatment by date within year, the only significant difference seen was in parasitism by date within year. Plots were scouted weekly and the fates of hornworm larvae (*Manduca spp*.) were evaluated to determine if the beneficial insect habitat had an effect on larval parasitism by the braconid wasp *Cotesia congregata*. There was no significant difference when data were analyzed for the effect from year, treatment, year by treatment and treatment by date within year for either 2003 or 2004. However, a significant difference was seen when evaluating date within year for larval populations. This study indicates that natural enemy populations were not amplified by the presence of a commercially available BIH.

EVALUATION OF COMMERCIAL BENEFICIAL INSECT HABITAT SEED MIXTURES FOR ORGANIC INSECT PEST MANAGEMENT

by
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DEDICATION

To my wonderful husband, Hersey. I would never have been able to complete this without your love and support. Thank you.

BIOGRAPHY

Lisa Rene' McNicol Forehand was born May 23rd, 1974 in Fairfax, Virginia but relocated to Ft. Myers, Florida in 1980 with her family. In 1993, she moved to North Carolina and eventually received a Bachelor's of Science Degree from the Biology Department at the University of North Carolina at Wilmington in 2002. That same year, she and her husband relocated to Raleigh where she began work on a Master's of Science program in the Entomology department under the direction of Dr. David Orr and Dr. H.M. Linker.

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TABLE OF CONTENTS

LIST OF TABLES:

LIST OF FIGURES

Evaluation of Seed Purity, Composition and Germination of Three

Commercially Available Beneficial Insect Habits

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Abstract

Many organic growers subscribe to the idea of providing resources for natural enemies in cropping systems. However, because little research exists to guide their decision-making, farmers are frequently left to experiment with various plant species or more often resort to commercially available beneficial insect habitat (BIH) seed mixtures. Companies selling these mixtures, often make unsupported claims that their product can reduce or eliminate insect pest problems. As part of a larger project examining the usefulness of BIH seed mixes, the goal of this study was to evaluate the purity, composition consistency and germination of seed from three commercial mixes: Border Patrol™ (BP), Beneficial Insect Mix (BIM), and Good Bug Blend (GBB). When examined, it was found that BP had two weed species present and live beetles (Coleoptera: Bostrichidae) actively feeding on seeds. While evaluating seed mixtures for purity, BIM was found to have one weed species present and one advertised flower species missing, while GBB had fourteen weed species present and three advertised species missing from their mix. In BP, buckwheat and nasturtium had the largest proportion by weight, while yarrow and evening primrose had the greatest seed numerical abundance. For BIM, the largest proportion of seeds by weight was coriander and candytuft, but numerically candytuft and Siberian wallflower were most abundant. The vast majority of seeds in GBB by both weight and numerical abundance were clovers and alfalfa. Germination of seeds in BP was variable with two species having 0% germination, most likely due to seed feeding and pathogen growth from insect frass. BIM demonstrated good overall germination, with the exception of gayfeather. All seeds in GBB, except fennel, germinated at or above test values provided by the supplier.

Introduction

For centuries, growers have relied on natural enemies to partially control insect pest populations (Orr and Suh 1998). Some growers have even established plant communities that offer some of the life sustaining resources that attract and nourish beneficial insects (Beane and Bugg 1998, Jervis and Kidd 1996 and Barbosa and Benrey 1998). This practice, commonly referred to as habitat manipulation, is thought to both preserve and enhance natural enemy populations (Gurr et al. 1998). This concept has received a great deal of attention over the last few years (For summary of work see Pickett and Bugg 1998, Landis et al. 2000 and Barbosa 1998).

Little attention, however, has been given to the practical implications associated with habitat manipulation or the establishment of beneficial insect habitats (BIH). Very few recommendations regarding the effectiveness of BIH or its use in organic insect pest management are available to growers. As a result, some growers develop their own habitat based on anecdotal information, while others turn to purchased, pre-packaged seed mixtures. Companies offering these commercially available mixtures often make claims as to the specific natural enemies that are attracted to their plantings. And although these purchased mixtures may offer some of the resources beneficial insects need, there is no data demonstrating their attractiveness for insects. Likewise, no studies have been conducted to evaluate seed quality issues associated with these mixtures. Most of the commercially available BIH seed blends are offered by companies located in California and many species included in theses mixtures are unsuited to the growing conditions of North Carolina or the other areas of the United States (DuFour 2000).

Because commercially available BIH seed blends are considered neither vegetables nor agricultural commodities, they fall outside the jurisdiction of national and state seed regulations (Martin 2004). According to Martin, companies are required to label all seeds in the mixture present in a quantity greater than 5%, however, no official tests are required to verify truth in labeling of the components. As a result, growers are unaware of what is actually present in these blends and can inadvertently introduce unwanted insect and noxious weed pests.

The objective of this study was to evaluate the quality of three BIH seed mixtures. This study is part of a larger project evaluating the usefulness of commercially available BIH in organic cropping systems. Three factors were examined as measures of seed quality: 1) presence or absence of seeds advertised in each mixture, 2) presence or absence of species not advertised as being part of the seed mixtures, 3) consistency of composition between containers of the same seed mixtures, and 4) germination percentage of each seed species. Results of this study will help growers more critically evaluate commercial seed mixtures for application in organic insect pest management.

Materials and Methods

Commercial Sources. Three seed mixes were purchased anonymously in January 2003: Border Patrol™ (BP) (Clyde Robin Seed Company, P.O. Box 2366, Castro Valley, CA 94546-0366), Beneficial Insect Mix (BIM) (Heirloom Seeds, P.O. Box 245, W. Elizabeth, PA 15088-0245), Good Bug Blend (GBB) (Peaceful Valley, P.O. Box 2209, Grass Valley, CA 95945).

Each of the three BP packages arrived in 170 g cylindrical cardboard canisters (20.4 by 7.8 cm) with one metal and one plastic endcap. The three BIM packages contained 28.4 g of seed mixture sold in paper envelopes (12.4 cm by 10.1 cm) and GBB was packaged in brown-paper bag secured with packing tape and contained 2.27kg of seed mixture.

Seed Separation and Identification. An air column seed separator (South Dakota Seed Blower (model 757), Seedburo Equipment Co., 1022 West Jackson Boulevard, Chicago, IL 60607.) was employed in order to roughly separate seeds by weight. Various sized sieves (300-600 micrometer) (Hoffman Manufacturing, Inc., P.O. Box 547, Albany, OR 97321) were employed to further separate seeds by size and the final separation was completed by hand using a camel hair paint brush and fine tipped forceps. Each component was weighed separately and the percentage of each species calculated by weight and by relative numerical abundance. Samples from all companies were sent to the North Carolina Department of Agriculture & Consumer Services, Plant Industry Division - Seed Section for identification.

Germination. Germination tests were conducted on 100 randomly selected seeds of each species from each of three containers of BP and BIM and two subsamples from the one bag of GBB. If less than 100 seeds of a species were present in a mixture, all seeds were subjected to germination tests. For seeds less than 5 mm in length, two pieces of germination blotter paper (Steel Blue Germination Blotter Paper, Anchor Paper Company, 480 Broadway, St. Paul, MN 55165-0648) were placed in the bottom of 100 by 15 mm plastic petri dishes (Fisher Scientific, P.O. Box 4829, Norcross, GA 30091) and moistened with 10 ml of distilled water. Seeds greater than 5 mm in length were placed in hinged acrylic boxes (18.5 by 13.5 by 5.0 cm) with two pieces of germination blotter paper covering the bottom and moistened with 60 ml of distilled water. Excess water was drained off prior to seed placement.

Up to six petri dishes were labeled and randomly placed on plastic trays (30 by 41 cm). Each tray or hinged acrylic box was enclosed in a plastic bag (25.4 by 61.0 cm) to prevent excess water loss and placed into a seed germinator. Germinators were set on a 12-hour photoperiod and at 15^{o}C, 20^{o}C or 20/30^{o}C (with 16-hours at 20^{o}C). Germination testing procedures for each species followed recommendations in the Association of Official Seed Analysts – Rules for Seed Testing (2002). Each species germination requirements are listed in Appendix 1.6.

Seeds were considered germinated if the radicle was twice the length of the seed. Seeds recorded as germinated, were removed from dishes. Seeds that failed to germinate and could not be classified as dead were placed in a 1.0% solution of 2, 3, 5-triphenyl-tetrazolium-chloride (Grabe 1970) and soaked for 24-hours at 30^{o}C to determine if seeds were viable or dead.

Data Analysis. Seed data were recorded using the following parameters. Percentage of seeds by weight = (Weight of individual seed species/ Total weight of seed for one container)*100. Average weight of one seed of each species = Sub-sample weight of 50 seeds/ 50. Percentage of seeds based on numerical abundance = [(Total weight of each seed species/ weight of individual seed)/ Total number of seeds in the container)] *100. Percent germination = (Number of germinated seeds/ Total number of seeds tested) *100. Comparison of three seed species shared between BIM and BP were analyzed with an analysis of variance (PROC ANOVA, SAS Institute 2002).

Results

Seed Purity. Truth in labeling is an important issue with nonregulated seed mixtures. BP advertised candytuft as being a component in the seed mixture; however, it was found in only one of the three seed containers (Table 1.1). Although the manufacturer clearly states on the outside of each canister that no weed seeds were present, Siberian wallflower and Mexican hat appeared in two different containers and were not advertised as part of the seed mixture. Initial examination of the seed contents also led to the discovery of all life stages of seed-feeding beetles (Coleoptera: Bostrichidae) actively feeding within sealed canisters.

New England aster seeds were not present in the three BIM packets examined, although it was advertised by Heirloom Seeds as being a component in the seed mix Table 1.2). Evening primrose, although not advertised as being a component in the seed mixture, was found in two of three packets analyzed.

Peaceful Valley's GBB did not have three of the advertised species present: rose clover, sweet clover and buckwheat (Table 1.3). In addition, fourteen weed species were identified from this mixture (Appendix 1.7).

Composition by Weight. BP contained between 29.9% to 54.8% inert matter with an average value of 44.6% ± 13.0% (Table 1.1). Seeds of evening primrose, buckwheat, bishop's flower, strawflower and nasturtium were all present in quantities greater that 5.0% by weight. Buckwheat and nasturtium seeds accounted for an average of 10.9% and 9.2% of the total weights of seeds, respectively.

There was high variability seen between the three canisters of BP (Table 1.1). Percentage by weight of baby blue eyes seeds ranged from 0.0% to 3.8% and averaged

1.4% ± 2.1% and bishop's flower ranged from 1.6% to 20.5% with an average of 8.7% ± 10.3%. In both cases standard deviations were greater than average values. Strawflower, yarrow and evening primrose also showed significant variation between packages, with averages and standard deviations of 6.4% ± 5.7%, 2.9% ± 2.5% and 7.0% ± 5.7%, respectively.

Evaluation of BIM found the percentage of seeds based on weight was fairly consistent across the three packets (Table 1.2). Sweet alyssum had the greatest variation, with values ranging from 0.9% to 2.0% with an average and standard deviation of 1.7% ± 0.8%. Candytuft and coriander were the two species present in the greatest quantities, averaging 14.0 ± 1.6 and 13.9 ± 3.0, respectively.

In the GBB mixture, all of the clover seeds were coated, therefore clover and alfalfa seeds were separated and categorized as one component. This generic clover category comprised over 77% of the seed mixture based on weight, and was by far the largest component present (Table 1.3). The remaining twelve species accounted for approximately 22% of the total weight of the seed mix. The daikon/ radish group and the carrot family are the two most prevalent non-clover groups at 6.45% and 4.56% of the total weight, respectively. Inert matter made up 0.83% and weed species accounted for 0.64% of the total weight of the package.

Composition by Numerical Abundance. Over 90% of BP seeds were from five seed species: yarrow (25.2%), evening primrose (22.4%), blackeyed susan (19.4%), bishop's flower (14.2%) and strawflower (11.7%) (Table 1.1). Baby blue eyes showed the greatest variability with values ranging from 0.0% to 1.8% with an average and standard deviation of 0.6% ± 1.0%. Strawflower and nasturtium also demonstrated great variability with average values of 11.7% ± 11.0% and 0.1% ± 0.1% respectively.

The approximate percentage of seed species in BIM based on their relative abundance was fairly consistent (Table 1.2). Three seed species comprised approximately 36% of the total seed mixture based on numerical abundance: candytuft (12.8% ± 5.9%), Siberian wallflower (12.2% ± 3.5%) and California poppy (10.9% ± 0.8%). Sweet alyssum had the greatest variation in numerical abundance, which ranged from 3.7% to 11.2% with an average value of 8.3% ± 4.0% and in candytuft, which ranged from 9.6% to 17.9%, with an average of 12.8% ± 5.9%.

In GBB the clover group was by far the most numerically abundant at 75.69% of the total mixture (Table 1.3). The carrot family and dill are the next most common seeds present at 7.67% and 5.07%, respectively. Fennel and alyssum had the fewest numbers of seeds represented, at 0.24% and 0.53%, respectively.

Germination. Of the ten seed species that were advertised in the BP seed mixture, only four species had germination rates greater than 80%: evening primrose (98.0 ± 1.0%), bishop's flower (93.3% ± 2.9%), baby blue eyes (91.4% ± 9.0%) and blackeyed susan (88.3% ± 0.6%) (Table 1.1). Germination between canisters was fairly consistent, with the exception of yarrow, which ranged from 6.0% to 94.0% with an average of 49.3% ± 44.0%. The two non-advertised species that appeared in seed canisters, Siberian wallflower and Mexican hat, also demonstrated poor germination, averaging 48.0% and 42.0%, respectively. Angelica and strawflower, from all three containers had 0% germination. Forty seeds from each replicate of the germination study were subjected to a tetrazolium test and were found to be dead (Table 1.4). Three samples of 50 randomly selected angelica seeds from each canister were subjected to a visual evaluation for damage from seed-feeding insects. The results demonstrated that 56.0% ± 10.6% of the seeds in each canister had significant insect damage.

Heirloom Seed's BIM demonstrated fairly consistent germination results across the three replicates, with all but one species averaging over 75% germination (Table 1.2). Gayfeather ranged from 18.0% to 56.0% with an average of 32.0% ± 20.9%. Forget-me-not initially demonstrated poor germination, but after subjecting 40 seeds to a tetrazolium test, 100% proved to be viable (Table 1.4).

A comparison of seed species shared between BIM and BP found no difference in the germination rates of baby blue eyes, bishop's flower or blackeyed susan when comparing between companies (Appendix 1.11).

Germination tests were performed on two sub-samples of each of the species present in GBB. All species were found to be within the germination levels provided by the manufacturer with the exception of fennel, which averaged 68.0% ± 2.8% (Table 1.3). Due to initial poor germination results in chervil, tetrazolium tests were performed on 75 seeds, yielding an average of 84.0% viability. Forty seeds in one replicate of dill, which demonstrated poor germination, were subjected to a tetrazolium test, yielding an average of 90.0% viability (Table 1.4).

Discussion

All three canisters of BP were marked as coming from the same seed lot, however, because candytuft, Siberian wallflower and Mexican hat all occurred in only one of the three packages, one might question whether the seed lot was uniform throughout. Additional questions of quality analysis were raised when both immature and adult live seed-feeding bostrichid beetles were identified in all three BP canisters upon receipt. If these canisters had remained untouched until spring, it is likely germination of most seed species would have been zero.

Evening primrose was present in two of the three BIM seed packets, but was not advertised. Due to the invasive nature of this weed, its introduction onto a farm could have a significant economic impact for farmers and might even adversely affect commodity quality. In addition, since this weed begins to bloom at dusk, when moth activity is heaviest, it is possible that by planting this species growers might inadvertently increase pest pressure, rather than decrease it.

Although weeds comprised a small percentage of the total weight of GBB, a large number of weed species were present (Appendix 1.7). While none of the weeds present in the seed mixture are on the Federal (Plant Protection and Quarantine 2002) or the North Carolina Noxious Weed Lists (North Carolina Department of Agriculture 2003), introduction of any weeds onto farms could pose a significant problem for farmers. In addition, GBB had a large proportion of clovers, which could result in possible competition problems in the field. Most of the other plants in this seed mixture would not able to compete with the clovers, especially after the cool season when their growth outstrips warmer season species. Thus, it is possible that after one season a farmer may be left with only a habitat of clovers (See Chapter 3).

BP was the only seed mix selected which included an inert packing material to "help evenly distribute seed and create a mulch". However, the website does not mention that roughly 50% of their seed mixture is inert material (Clyde Robins 2004). Thus, a grower might be disappointed at the contents upon receipt. Also, because of the inert material, the presence of live insects might be overlooked if casually examined.

BP also clearly states on the outside of each canister that no “species is present in quantities greater that 5% of the total mixture” which suggests a roughly equal distribution among the seed species. However, five of the ten seed species, yarrow, evening primrose, blackeyed susan, bishop’s flower, and strawflower were found in quantities significantly higher than 5%. Together, those five seed species account for 93% of the total number of seeds. In the field, it may be difficult to get an even stand of all species. Again, due to the invasive nature of evening primrose, growers might be inadvertently introducing a much larger weed problem.

Heirloom Seed’s supplies the common names of the seeds included, but they offer no information regarding the percent composition or germination statistics of their product. BIM offered a consistent product across the three packages that were analyzed and there was little variation when comparing the seeds by weight or by numerical abundance. There was very little inert matter and no insects present in the packages examined.

The vast majority of the seeds in GBB were clovers and alfalfa. Because all clover seeds were coated with a rhizobacteria/ clay mixture, it added a significant amount of weight and volume to the packaged seeds. Thus, a farmer might be discouraged upon arrival if they were expecting 2.2 kg of pure seed.

BP demonstrated very poor germination in the laboratory and in fact, live insects could be seen emerging from seeds while the germination tests were being conducted (Appendix 1.8 and 1.9). Insect feeding appears to be the primary cause of poor germination in some species, especially buckwheat and angelica. High levels of pathogen growth were also observed during the germination tests. It is possible that this is the result of the presence of nutrient-rich insect frass left behind from foraging within each canister or physical injury to the seeds themselves by the insects.

This study was designed to test the germination of each seed species under their individual ideal conditions. With such poor germination of some of the species in the laboratory setting, one must question how well these seeds would germinate if planted according to manufacturer's recommendations. It is highly likely that the BP planting would contain only a few species, which would quickly be overtaken by the evening primrose. Because of the invasive nature of this weed, it could have significant negative impacts for farmers, not only for weed management, but also for moth pest pressure.

BIM demonstrated very good germination results for all seed species with only one of 16 species reporting less than 75%. Gayfeather had the lowest germination, perhaps due to the fact that many of the seeds were damaged. Thus, a grower could expect a fairly good germination and an even distribution of all the flowering types.

Peaceful Valley was the only company to provide seed germination rates with their GBB product and thus is the only company our results can be compared to. Overall, there was good germination and our results are in line with the data provided by the manufacturer, the only exception being that of fennel.

Each of these BIH seed mixes undoubtedly provide some of the life sustaining products that insects, both beneficial and otherwise, need to survive in an agricultural landscape. However, all three seed mixes analyzed had species absent which were advertised as being part of the mix and species present which were not advertised by the manufacturer. If growers are faced with increased weed pressure from a species that was introduced in one of these seed mixes or increased pest pressure from certain plants acting as food sources, they might question the additional value of these products. Clearly more work needs to be done examining the quality and effectiveness of these and other plantings. But it is our hope that this study illustrates for growers the need to evaluate each product on an individual basis and to be wary of products making promises of “silver bullets”.

References Cited

Association of Official Seed Analyst. 2002. Rules for Seed Testing. Journal of Seed Technology (Revised) 16:1-166.

Barbosa, P., [ed.] 1998. Conservation Biological Control. Academic Press, New York, NY. pp. 396.

Barbosa, P.and B. Benrey. 1998. the influence of plants on insect parasitoids: implications for conservation biological control, pp. 55-82. *In* P. Barbosa [ed.] Conservation Biological Control. Academic Press, New York, NY. pp. 396.

Beane, K.A. and R.l. Bugg 1998. Natural and artificial shelter to enhance arthropod biological control agents, pp. 239-254. *In* Pickett and Bugg [eds.] Enhancing Biological Control. University of California Press, Berkeley, CA. pp. 422.

Clyde Robins. 2002. Border Patrol™: Mother Nature's Perfect Natural Pesticide. http://www.clyderobin.com/mixes/pkg_borderpatrol.html. Accessed 6 December, 2004.

Dufour, R. 2000. Farmscaping to Enhance Biological Control. Appropriate Technology Transfer for Rural Areas (ATTRA) publication. http://www.attra.org/attra-pub/farmscape.html. December. pp. 39.

(PPQ) Plant Protection and Quarantine. 2002. Federal Noxious Weed List (http://www.aphis.usda.gov/ppq/bats/noxweed.html, accessed December 3, 2004). USDA Animal and Plant Health Inspection Service. Washington, DC. 2 pp.

Grabe, D.F. 1970. Tetrazolium testing handbook for agricultural seeds. *In* Handbook on Seed Testing. Contrib. 29. Association of Official Seed Analysts. pp. 62.

Gurr, G.M., H.F. van Emden and S.D. Wratten. 1998. Habitat manipulation and natural enemy efficiency: implications for the control of pests, pp. 155-184. *In* P. Barbosa (ed.), Conservation Biological Control. Academic Press, New York, NY. pp. 396.

Jervis, M.A. and N.A.C. Kidd 1996. Phytophagy, pp. 375-394. *In* Jervis and Kidd [eds.] Insect Natural Enemies: Parctical Approaches to Their Study and Evaluation. Chapman and Hall, London, U.K. pp. 491.

Landis, D. A., S.D. Wratten, and G. M. Gurr. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu. Rev. Entomol. 45: 175-201.

Martin, E. 2004. Personal communication, December 8, 2004. Seed Administrator for NCDA & CS – Seed Section, Raleigh, NC.

(NCDA) North Carolina Department of Agriculture. 2003. Regulations for State Noxious Weeds (http://plants.usda.gov/cgi_bin/state_noxious.cgi?statefips=37, December 3, 2004). North Carolina Department of Agriculture.

Orr, D.B. and C.P.-C. Suh. 1998. Parasitoids and predators, pp. 3-34. *In* J.E. Rechcigl and N.A. Rechcigl [eds.], Biological and Biotechnological Control of Insect Pests. Lewis Publishers, New York, NY. pp. 374.

Pickett, C.H. and R.L. Bugg [eds]. 1998. Enhancing Biological Control. UC Press, Berkeley, CA. pp. 422.

SAS Institute. 2002. PROC user's manual, version 9.1. SAS Institute, Cary, NC.

Table 1.1 Composition by weight and numerical abundance and germination rates of beneficial insect habitat seed mix received from Clyde Robin's Border Patrol™, 2003.

Common Name	Scientific Name	Average by weight ± SD	Average by relative abundance ± SD	Average germination ± SD
		------%------	-------%-------	-------%-------
Evening Primrose	*Oenotheria argillicola* Mackenzie	7.0 ± 5.7	22.4 ± 3.2	98.0 ± 1.0
Buckwheat	*Fagopyrum convolvulis* Moench.	10.9 ± 4.2	1.3 ± 1.0	49.7 ± 12.4
Baby Blue Eyes	*Nemophilia menziesii* Hook. & Arn.	1.4 ± 2.1	0.6 ± 1.0	91.4 ± 9.0
Bishops Flower	*Ammi majus* L.	8.7 ± 10.3	14.2 ± 8.9	93.3 ± 2.9
Blackeyed Susan	*Rudbeckia hirta* L.	4.3 ± 2.3	19.4 ± 12.6	88.3 ± 0.6
Strawflower	*Helichrysum ssp.* P. Mill.	6.4 ± 5.7	11.7 ± 11.0	0
Nasturtium	*Tropaeolum majus* L.	9.2 ± 3.0	0.1 ± 0.1	67.4 ± 25.9
Angelica	*Angelica atropurpurea* L.	2.0 ± 1.1	0.7 ± 0.5	0
Yarrow	*Achillea millefolium* L.	2.9 ± 2.5	25.2 ± 16.2	49.3 ± 44.0
Candytuft [a]	*Iberis sempervirens* L.	1.5 ± 2.7	2.4 ± 4.1	2.0 ± 0
Siberian Wallflower [ab]	*Erysimum hieraciifolium* L.	1.1 ± 2.0	2.0 ± 3.5	48.0 ± 0
Mexican Hat [ab]	*Ratibida columnifera* (Nutt.) Woot. & Standl.	<0.1 ± 0.1	<0.1± 0.1	42.0 ± 0
	Debris	44.6 ± 13.0	--	--

[a] Seed only present in one container
[b] Seed not advertised in mix, but present

Table 1.2. Composition by weight and relative abundance and germination rates of beneficial insect habitat seed mix received from Heirloom Seeds Beneficial Insect Mix, 2003.

Common Seed Name	Scientific Seed Name	Average by weight ± SD	Average by relative abundance ± SD	Average germination ± SD
		-------%-------	-------%-------	-------%-------
Sweet Alyssum	*Lobularia maritime* (L.) Desv.	1.7 ± 0.8	8.3 ± 4.0	96.0 ± 5.3
Baby Blue Eyes	*Nemophila menziesii* Hook. & Arn.	10.7 ± 1.7	9.7 ± 2.2	97.0 ± 2.6
Bishops Flower	*Ammi majus* L.	1.9 ± 0.6	4.8 ± 1.0	90.0 ± 5.0
Blackeyed Susan	*Rudbeckia hirta* L.	1.2 ± 0.2	5.5 ± 0.7	89.0 ± 6.0
Candytuft	*Iberis sempervirens* L.	14.0 ± 1.6	12.8 ± 5.9	93.7 ± 3.2
Coriander	*Coriandrum sativum* L.	13.9 ± 3.0	1.6 ± 0.3	89.3 ± 2.1
Purple Prairie Clover	*Dalea purpurea* Vent.	1.6 ± 0.2	2.0 ± 0.8	93.0 ± 2.6
Lance-Leaved Coreopsis	*Coreopsis lanceolata* L.	8.6 ± 1.4	6.1 ± 2.2	88.3 ± 6.7
Shasta Daisy	*Leucanthemum x superbum* (J.W. Ingram) Berg. ex Kent.	3.7 ± 0.1	6.5 ± 2.6	85.7 ± 2.3
Forget-me-not	*Myosotis sylvatica* Ehrh. ex Hoffmann	0.8 ± 0.1	3.6 ± 0.5	93.3 ± 6.4
Blanket Flower	*Gaillardia spp.* Foug.	8.5 ± 0.9	7.8 ± 2.1	76.0 ± 7.2
Gayfeather	*Liatris spp.* Gaertn. ex Schreb.	8.4 ± 0.5	4.2 ± 0.7	32.0 ± 20.9
California Poppy	*Eschscholzia californica* Cham.	11.3 ± 0.8	10.9 ± 0.8	92.0 ± 2.6
Dill	*Anethum graveolens* L.	1.9 ± 0.1	2.3 ± 0.3	96.0 ± 1.0
Siberian Wallflower	*Erysimum hieraciifolium* L.	10.8 ± 1.3	12.2 ± 3.5	90.3 ± 6.0
Evening Primrose [a]	*Oenothera spp.* L.	0.6 ± 0.5	1.4 ± 1.2	92.0 ± 53.1
New England Aster [b]	*Aster novae angliae* L.	--	--	--
Debris & Weed Seeds		0.4 ± 0.2	--	

[a] Seed not advertised in mix, but present
[b] Seed advertised in mix, but not present

Table 1.3. Composition by weight and numerical abundance and germination rates of beneficial insect habitat seed mix received from Peaceful Valley's Good Bug Blend, 2003.

Common name	Scientific Name	Seeds by weight	Seeds by relative abundance	Average germination ± SD
		-------%------	-------%-------	-------%-------
Alyssum (White)	*Lobularia maritime* (L.) Desv.	0.06	0.53	94.5 ± 0.7
Buckwheat [a]	*Fagopyrum spp.* P. Mill.	--	--	--
Caraway	*Carum carvi* L.	0.93	0.94	82.5 ± 3.5
Carrot	*Apiaceae*	4.56	7.67	91.0 ± 1.4
Celery	*Apium graveolens* L.	0.19	1.52	93.0 ± 4.2
Chervil	*Anthriscus cerefolium* (L.) Hoffmann	0.43	0.67	94.0 ± 7.1
Alfalfa	*Medicago sativa* L.			93.0 ± 0.0
Clover, Crimson	*Trifolium incarnatum* L.			
Clover, Rose [a]	* *Trifolium hirtum* All.	77.89	75.69	
Clover, Sub-	*Trifolium subterraneum* L.			97.0 ± 1.4
Clover, Sweet [a]	*Melilotus spp.* P. Mill.			
Clover, White	*Trifolium repens* L.			
Coriander	*Coriandrum sativum* L.	2.73	0.94	94.0 ± 2.8
Daikon/ Radish	*Raphanus sativus* L.	6.45	1.10	98.5 ± 0.7
Dill	*Anethum graveolens* L.	3.23	5.07	93.0 ± 2.8
Fennel	*Foeniculum foeniculum* (L.) Karst.	0.50	0.24	68.0 ± 2.8
Gypsophila	*Gypsophila spp.* L.	0.44	1.29	94.5 ± 6.4
Nasturtium	*Tropaeolum majus* L.	0.98	1.12	81.3 ± 8.8
Yarrow	*Achillea spp.* L.	0.15	3.20	89.0 ± 1.4
	Debris	0.83	--	--
	Weed seeds	0.64	--	--

[a] Seeds advertised in mix, but not present

Table 1.4. **Results of tetrazolium tests on seeds demonstrating poor germintation.**

Seed Company	Common Name	Scientific Name	No. Seeds Tested	No. Viable Seeds	Pct. Viable
			----#----	----#----	----%----
Border Patrol™	Strawflower	*Helichrysum ssp.* P. Mill..	120	0	0.0
Border Patrol™	Angelica	*Angelica atropurpurea* L.	120	0	0.0
Heirloom Seeds	Forget-me-not	*Myosotis sylvatica* Ehrh. ex Hoffmann	40	40	100.0
Peaceful Valley	Chervil	*Anthriscus cerefolium* (L.) Hoffmann	75	63	84.0
Peaceful Valley	Dill	*Anethum graveolens* L.	40	36	90.0

Evaluation of Insect Communities Associated with Cut Flowers/ Herbs and Commercially Available Beneficial Insect Habits Seed Mixtures

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Abstract

Organic growers in the piedmont region of North Carolina usually maintain a wide assortment of agricultural crops and typically produce cut flowers. This study was conducted to determine the insect communities present in three commonly grown cut flower/ herbs (*Zinnia*, *Celosia* and fennel) as well as three commercially available beneficial insect habitat seed blends (Peaceful Valley's Good Bug Blend, (GBB) Clyde Robin's Border Patrol™ (BP) and Heirloom Seed's Beneficial Insect Mix (BIM)). Insect communities were evaluated three ways: 1) collections were made using a D-vac, and insects identified to family and assigned to feeding guilds; 2) pitfall traps were used to collect ground beetles and ground-dwelling spiders; and 3) evening observations recorded visits by noctuid (Lepidoptera: Noctuidae) and hornworm (Lepidoptera: Sphingidae) moths to flowers. *Celosia* had the highest abundance and diversity of the cut flowers, however, the feeding guilds observed would be of little consequence for agronomic pest control. Fennel, although not flowering until late summer, had the lowest overall abundance and diversity of all flowering plots. The BP plantings had the highest diversity and abundance of insect herbivore crop pests as well as the highest instances of moth pest species during night observations. This is likely do to the fact that the mixture included evening primrose which blooms at dusk, when moths are most active. Overall, the best planting analyzed was GBB, which had the highest abundance and diversity of beneficial parasitoids and predators.

Introduction

Many farmers and researchers alike believe that an increase in plant diversity around commercial agronomic crops will improve their biological control of pests (Landis et al. 2000). This idea of conserving natural enemies through the provisioning of resources is commonly referred to as habitat manipulation (Pickett & Bugg 1998), although other pseudonyms include interculture, mixed farming and polycropping (Coll 1998). Numerous studies have tried to evaluate habitat manipulation in agroecosystems, however, due to the complex and numerous underlying ecological principles, data collection, which can be difficult at best to interpret, has been slow (Wratten et al. 1998).

Most scientists agree that in order for these beneficial insect habitats (BIH) to be considered in a pest management strategy, there must be a net gain in beneficial and a net reduction in pest insects species; however, this relationship is often difficult to determine (Landis et al. 2000). van Emden (1990) reported that the provisioning of ground cover, alternate hosts, and crop diversity can significantly increase the natural enemy diversity in a cropping system. However, it is the idea of providing a direct floral food source, which has received the greatest attention (Barbosa and Benrey, 1998).

While little research exists in this area to assist growers, a study by Braman et al. (2002) evaluated two commercially available seed mixtures on pest suppression in turf grass. They found the number of beneficial arthropods in the flower plots to be consistently lower than in that of the control. However, predation levels in plots adjacent to these flower plots were significantly higher than those of the controls. These results reflect the need for further research to demonstrate to growers how these plants will perform.

While the idea of providing additional floral resources may seem simple enough, it is important to keep in mind that all floral resources are not created equal. Nectar accessibility can vary greatly with the specific floral architecture of a single flower and very little research exists demonstrating the availability of nectar to specific parasitoids (Gurr et al. 1999). Patt et al. (1997) evaluated the foraging effectiveness of two small parasitic wasps (Hymenoptera: Eulophidae) on 24 real and four artificial flowers. Research indicated that flowers with open nectaries, such as fennel (Apiaceae: *Foeniculum vulgare* P. Mill.) and dill (Apiaceae: *Anethum graveolens* L.) offered these parasitoids the greatest nectar and pollen availability. In addition, Baggen et al (1999) found that nasturtiums and *Phacelia* benefited only the parasitoid and not its host. Thus, in order for these plantings to be successful, a complete understanding of the biology, behavior and multitrophic interactions of these natural enemies as well as an understanding of the floral resources must be obtained. But is it possible for researchers to attain a complete understanding of an entire ecosystem and simplify the results into an applicable system for farmers?

Because there exists a significant time delay from when researchers publish their results to when growers are made aware of them, farmers are often left to manage on little more than anecdotal information. Thus, when growers do not have unbiased information guiding their decisions, they can fall prey to the false promises of commercially available BIH seed mixtures. And in fact, several commercial companies offer these seed blends for the purpose of increasing natural enemies on their farm. They claim that by planting their flowering plant mix, specific pests can be significantly reduced or eradicated, thereby completely eliminating the need for chemicals. For example, Clyde Robin claims that its Border Patrol™ (BP) seed mixture "contains specially chosen flower varieties known to attract beneficial insects, which will help rid your garden of destructive insect pests — the organic way" (Clyde Robin 2002). Such claims are largely unfounded because little research exists evaluating the quality and effectiveness of these seeds mixes under field conditions.

This study is part of a larger project (See Chapters 1 and 3) evaluating the claims of three commercially available BIH seed mixes. The purpose of this study was to survey insects associated with several commercially available BIH seed mixes and commonly grown cut flowers in North Carolina. This will establish basic information about the insect communities these plants harbor and allow us to make recommendations to organic growers in this area as to the effectiveness of such practices.

Material and Methods

Commercial Sources. All seeds were purchased in February of 2003. The three commercial habitat sources were: Border Patrol™ (BP) (Clyde Robin Seed Company, P.O. Box 2366, Castro Valley, CA 94546-0366), Beneficial Insect Mix (BIM) (Heirloom Seeds, P.O. Box 245, W. Elizabeth, PA 15088-0245), Good Bug Blend (GBB) (Peaceful Valley, P.O. Box 2209, Grass Valley, CA 95945), *Foeniculum vulgare* var. bronze fennel, *Zinnia elegans* var. pastel dreams, *Celosia cristata* var. cockscomb amaranth and *Fagopyrum convolvulis* (buckwheat) (Peaceful Valley, P.O. Box 2209, Grass Valley, CA 95945).

Experimental Design. This study was conducted in 2003 at the Center for Environmental Farming Systems (CEFS) in Goldsboro, NC. All plot areas were pesticide free for at least three years prior to this study and were transitioning towards organic certification.

This study was set up using a complete block design with selective placement of treatments and three replications (blocks) (Figure 2.1). All blocks were planted from northeast to southwest. From the most northeasterly direction, each block was planted in the same order with the following seven treatment plots: *Celosia*, fennel, BP, GBB, *Zinnia*, buckwheat and BIM. A 1.5m buffer area around each plot was planted with brown-top millet (Wyatt Quarles, P.O. box 739, Garner, NC 27529) and mulched. The first block was located at the edge of a field, bordered on one side by a grassy roadway and on the other side various solanaceous crops. The northeast end of the second block was offset from the first by a distance of 58.4 m to the southeast. The study was established in a separate field planted with various brassicas, which were later used onsite as forage for swine and chickens. The third flower strip was located in another field parallel to the second one at a distance of 38 m, planted amongst corn and clovers.

Each plot with *Celosia*, fennel and *Zinnia* was 6.1 by 2.1 m and was planted in a pure stand consisting of three rows, with 76 cm between rows and 30.5 cm between each plant. Buckwheat was direct seeded on 76 cm rows, using an Earthway Seeder (Earthway Products, 1009 Maple St., Bristol, Indiana), however, it was not analyzed as part of this study because of the difficulty of sample sorting.

An entire package each of BP, GBB and BIM was separated and an estimate of the numerical abundance of each species calculated (Appendix 2.1). This numerical abundance of each seed species was used to create a planting design for each seed mixture. Planting boards were constructed as described below by cutting two 10.2 cm circles into the plywood every 0.09 m^2 (See Figures 2.2 to 2.4). Thus, one transplant could be placed through each hole into prepared soil.

For BP, a 0.6 m by 1.5 m sheet of plywood was employed to aid as a planting template for the 10 plant species (Figure 2.2). Two transplants of each species were used per planting board, with the exception of angelica and strawflower, which were left blank due to 0% germination. This pattern was repeated 12 times per plot; four times lengthwise and three times across, so that each plot measured 6.1 by 1.8 m.

For BIM, a 0.9 m by 1.5 m sheet of plywood was employed as a planting template for the 15 plant species present (Figure 2.3). All species were transplanted on a 1:1 ratio, with two transplants of each species being used per planting template, with the exception of purple prairie clover, where only one plant was transplanted. This pattern was repeated 8 times per plot, four times lengthwise and two times across so each plot measured 6.1 by 1.8 m.

The planting design utilized for GBB employed two 0.6 m by 3.0 m plywood planting boards to accommodate the 14 plant species (Figure 2.4). Plant usage varied considerably based on relative abundance (Appendix 2.2). Planting board one was used three times while planting board two was used twice.

Ten-22.9 m soaker hoses (Aquapore Moisture Systems, Inc., A Fiskars Co., 610 S. 80th Ave., Phoenix, AZ 85043) per block were linked together and run the entire length of each flower strip. Each hose was placed adjacent to the center of each row of *Celosia*, fennel, *Zinnia* and buckwheat. For BIM and BP, one hose was placed in the center of each block and two hoses set 0.5 m in from each edge of each block and placed adjacent to plants. For GBB, one hose was placed in the center of each block and two hoses set in 0.3 m from each edge of each block and placed adjacent to plants.

Crop Management. All transplants were started in the Biological Control Greenhouse at North Carolina State University (NCSU) in late March. Ninety-six cell plug trays (Hummert International, 4500 Earth City Expressway, Earth City, MO 63045), each round cell measuring 3.8 by 3.9 cm, were filled with moistened Metro-Mix 200 potting soil (Scotts-Sierra Horticultural Products Co., The Scotts Company. 14111 Scottslawn Road, Marysville, Ohio 43041) and several seeds were placed per cell. Plug trays were placed under grow lights on a 12-hour photophase and a misting bed, which watered twice a day for 5 minutes. Plants were supplementally watered as needed and fertilized once every 2 weeks with Omega 6-6-6 (Peaceful Valley, P.O. Box 2209, Grass Valley, CA 95945). Once plants were approximately 25 cm in height, they were transplanted into 266 ml plastic beverage cups (Food Lion, LLC., Salisbury, NC 28144) with a hole drilled in the bottom using a 1.3 cm drill bit.

Prior to field transplanting, in April of 2003, untreated soybean meal (Wyatt Quarles, P.O. box 739, Garner, NC 27529) was applied to each plot at a rate of 78.5 kg/ha and incorporated in using hand rakes. All plants were transplanted 15-18 May, 2003 using planting boards, hand trowels and bulb diggers. All plants were supplementally watered as needed and mulched using pesticide free wheat straw. For two weeks following transplanting, any dead plants were replaced. Weed management consisted of hand-weeding within plot and string-trimmers or lawnmowers around and between plot.

One treatment of Surround® (Engelhard Corporation, 101 Wood Avenue, Iselin, NJ 08830) was applied on 28 May, 2003 to one plot of BIM and all candytuft plants in BIM and BP, due to large numbers of spotted cucumber beetles (Coleoptera: Chyrsomelidae) at the time of transplant. In addition, each candytuft plant was covered in a cheesecloth cage supported on three sides by stakes as further protection from beetle damage. All cages were removed one week later.

Sampling. On eight dates in 2003 (19 June, 25 June, 3 July, 9 July, 16 July, 23 July, 30 July, 6 August), insect samples were collected from each plot using a D-vac (D-vac, Inc., 3891 N. Ventura Ave., Ventura, CA 93001) vacuum sampler and aerial nets (Bioquip, 321 Gladwick Street Rancho, Dominguez, CA 90220). Sampling was conducted between 11:00 am and 2:00 pm, when insect populations were expected to be greatest (Jervis and Kidd 1996). Samples were collected from one of the outside rows of *Celosia*, fennel and *Zinnia* and down one side of the three habitat mixes. In order to allow plants to recover, sides were alternated each week so that no side was sampled more often than every two weeks. Insect samples collected were transferred into glass kill jars (Bioquip, 321 Gladwick Street, Rancho Dominguez, CA 90220) treated with ethyl acetate. Insects were then placed in plastic bags (3.75 L, Ziploc®, S.C. Johnson & Co., Racine, WI) and stored in a cooler until transported to the laboratory where they were placed in a freezer at –20^{o}C.

All contents of plastic bags were later transferred to 50% ethyl alcohol, and any large plant material or seeds were removed and discarded. All insects larger than 3 mm were removed from the samples and placed into 125 ml wide-mouth polypropylene vials (Fisher Scientific, P.O. Box 4829, Norcross, GA 30091) containing 50% ethyl alcohol.

The remaining insects, those smaller than 3mm, were placed in a 1 L beaker and the entire liquid contents brought up to 600 ml using 50% ethyl alcohol. The contents were then poured into a tray measuring 29.2 by 34.3 cm, thoroughly mixed and allowed to settle, until a relatively equal distribution was achieved. Three subsamples were selected from each tray by randomly placing the rim of a 7.6 cm petri dish (Fisher Scientific, P.O. Box 4829, Norcross, GA 30091) on the bottom of the tray, then pipetting all insects within the rim into a 125 ml plastic vial (Fisher Scientific, P.O. Box 4829, Norcross, GA 30091).

Insect Identification. Insects were observed using a binocular microscope (Bausch and Lomb, 1 Bausch & Lomb Place, Rochester, NY 14604) and all identifications were made using at least one of the following sources: Bland & Jaques 1978, Borror et al. 1989, Borrer & White 1970, Flint & Dreistadt 1998, Gibson et al. 1997, Grissell & Schauff 1990, McAlpine 1981, McAlpine 1987, Mitchell 1962a. Mitchell 1962b. Mullen & Durden 2002. Stehr 1987. Stehr 1991, White 1983. Reference collections were assembled and verified by one of the following: David Stephan, Robert Blinn, Dr. Brian Wiegmann of NCSU or Dr. Ken Ahlstrom.

Moth Sampling. Observations of flower visits by adult Lepidoptera were made on four dates in 2003: 24 July, 30 July, 6 August, and 13 August. Observations began at dusk (approximately 18:30 hours) and continued until total darkness, approximately 1 hour later. Each plot was observed three times for one minute using one-million candle powered flashlights covered with red cellophane (Garrity Industries, Inc., Madison, CT 06443). The total number of noctuid moths (Lepidoptera: Noctuidae) and hornworm moths (Lepidoptera: Sphingidae) visiting each plot was recorded. If a moth moved between two plants in the same plot, without leaving the plot, it was counted only one time. If a moth visited a plant, left the plot then returned, it was counted as a second visit. Moths were collected on 24 July using aerial nets and identified to family. A reference collection was later verified by David Stephan of NCSU.

Pitfall Traps. In order to sample ground beetles (Coleoptera: Carabidae) and ground spiders (Acarina: Araneidae), pitfall traps were placed into each of the different plant communities on seven dates in 2003: 26 June, 10 July, 17 July, 25 July, 231 July, 7 August and 14 August. Pitfall traps were constructed using two 473 ml plastic cups (Solo Cup Co., 1700 Old Deerfield Road, Highland Park, IL 60035) set inside of each other. The outer cup had holes in the bottom while the inner cup had holes in the sides, set approximately 6 cm from the top. Using a garden bulb digger, cups were randomly placed in the ground so that the upper lip of the cup was even with the soil surface. Each pitfall trap was set out and collected from the same site each week. Approximately 2.5 cm of 50% antifreeze (Honeywell International Inc., 101 Columbia Rd., Morristown, NJ 07962) was poured into the inside cup (approximately 10:00 am), then samples were collected 24 hours later and transferred into glass canning jars for transport to the laboratory. All carabid beetles and spiders were transferred into 125 ml plastic vials filled with 50% ethanol and stored until identified.

Data Analysis. Simpson’s Index, Shannon-Wiener’s Index (often called Shannon’s Index), Hill’s N1 and N2 diversity numbers, species evenness and species richness were calculated for each individual planting by feeding guild. These data were subjected to an analysis of variance using the General Linear Model Procedure (PROC

GLM, SAS Institute 2002) and means separated using Student's t-test (PROC TTEST, SAS Institute 2002) and LS means (SAS Institute 2002).

Species richness refers to the number of species found in a sample of a given area, while species evenness refers to the distribution of those individuals (Barbour et al. 1987). Together, species richness and evenness can be useful in measuring species diversity (Smith and Smith 2000).

Calculation of Simpson's Index is based on consideration of the number of times one would have to select random pairs of individuals to get two of the same species (Smith and Smith 2000). This index is used to reflect dominance, because it weighs the most abundant species heavier than the more rare ones (Barbour et al. 1987). Values for Simpson's Index vary from zero (high diversity) to one (low diversity) (Ludwig and Reynolds 1988).

Shannon-Wiener's Index is used to measure the uncertainty in a community. Thus, in a community with low diversity, the probability of randomly picking an individual of a particular species is high and vice versa (Smith and Smith 2000). A value of zero applies to communities with only one species and increases as the total number of species increases (Barbour et al. 1987).

Hill's diversity numbers, N1 and N2 refer to the "effective number of species present and differ only in their tendency to include or to ignore the relatively rarer species" (Hill 1973). N1, the exponent of Shannon's Index, provides a measure of the number of abundant species in a given sample. N2, the reciprocal of Simpson's Index, provides a measure of the number of very abundant species present in a given sample (Hill 1973 and Ludwig and Reynolds 1988). In both indices, because less weight is placed on rare species, as the value increases fewer species are present (Ludwig and Reynolds 1988). See Appendix 2.4 for SAS input.

The mean value for noctuid and hornworm moth visits was calculated as follows: [total number of visits to each of six different flowering plots in one night/ three flower blocks]/ four observation dates. The mean value for ground beetles and spiders was calculated as follows: [total number of specimens of each kind in each of six different flowering plots in one night/ three flower blocks]/ seven observation dates.

Results

Mix, Date, Repetition. The six different plant communities ('mix' in analysis) had a significant effect on the abundance and diversity indices estimated from all sample plots (Appendix 2.3). Analysis of the effect of repetition within the different flowering communities did not prove to be significant with the exception of species richness. All abundance and diversity indices showed a significant difference when comparing the different flower plant mixes by date. In addition, there was a significant difference when comparing the different flowering plant communities by mix by date, with the exception of species richness.

Because there was a significant difference in planting mixes, each of the different plantings was evaluated separately (Table 2.1). The multiple means comparison test for all diversity and abundance indices were significant. Fennel had significantly lower mean values for all diversity, abundance and richness indices with the exception of species evenness. *Celosia* and BP had the highest overall diversity for Simpson's Index, Shannon's Index and Hill's N1 and N2 diversity numbers. BP had the highest species richness while *Celosia* had the highest mean value for species evenness.

Feeding Guilds. There was a significant difference in all abundance and diversity indices for the decomposer/ fungal-feeder feeding guild (Table 2.2). The overall trend, based on Simpson's Index, Shannon's Index and Hill's N1 and N2 diversity numbers found the highest means present in the BP and *Zinnia* plantings. By contrast, fennel had the lowest overall mean values for species diversity and richness, but the highest mean value for species evenness. The least evenly distributed species were found in of GBB and BP.

There was a significant difference for all of the abundance and diversity indices for the herbivores of crop plants feeding guild (Table 2.2). BP and GBB had significantly higher indices than all others for Simpson's Index, Shannon's Index, Hill's N1 and N2 diversity numbers. While for the same indices fennel had the lowest mean values. *Zinnia* was the least even plant community while BP was the most even, although results were not significant.

There was a significant difference for all abundance and diversity indices for herbivores of non-crop plants (Table 2.2). The overall trend found BIM and GBB to have the highest abundance and diversity indices based on Simpson's Index, Shannon's Index and Hill's N1 and N2 diversity numbers, although values were not significantly different. In contrast, fennel had the lowest abundance and diversity mean values based on the same indices, although values for t-tests were not significant. GBB had the highest overall species richness but the most uneven species distribution, while the inverse was true for fennel.

Pollinator diversity did not differ between the different flower plantings with the exception of species richness, in which case, BP and BIM had the highest mean values

(Table 2.2). Fennel had the lowest mean values for abundance and diversity indices while maintaining the highest mean value for species evenness.

Beneficial parasitoid diversity was found to be significant for Hill's N1 diversity number, species evenness and richness (Table 2.2). The overall trend found GBB and BP to have the highest overall mean values of species diversity and richness, although results were not significantly different based on t-tests. Fennel had the lowest mean values for diversity and abundance, but the highest mean value for species evenness. BP had the highest mean value for species evenness.

The mixed parasitoid feeding guild found species diversity to be significant only for Shannon's Index and Hill's N1 diversity number (Table 2.2). Based on the t-tests, there was no difference between the plantings, the overall trend demonstrates that fennel has the lowest diversity of taxa present, while *Celosia* has the highest.

There was no significant difference in the non-crop parasitoid feeding guild, with the exception of species richness BIM had the highest mean value (Table 2.2). Fennel had the lowest mean values abundance, diversity and richness, but the most even species distribution. BIM and *Zinnia* had the overall highest species abundance and diversity based on the Simpson's Index, Shannon's Index, Hill's N1 and N2 diversity numbers, although results were not significantly different based on t-tests.

All of the abundance and diversity indices for the beneficial predator feeding guild were found to be significant (Table 2.2). Again, fennel followed the trend of having the lowest mean values for species abundance and diversity, but the highest mean value for species evenness. GBB and *Celosia* had the highest mean values for diversity and abundance, although results were not significant based on t-tests.

Only species evenness and richness were found to be significant for inconsequential predators (Table 2.2). Again, the overall trend found fennel to have the lowest overall species abundance and diversity, but the highest species evenness. *Celosia* and BIM had the highest species diversity according to Simpson's Index, Shannon's Index and Hill's N1 and diversity number.

Moth Sampling. Visits by noctuid moths to each of the flower plots were consistent over the averaged four observation dates (Table 2.3 and Figure 2.5). The two highest mean value for visits were recorded in BP and *Celosia*. The lowest mean values for visits were seen in fennel and GBB. Hornworm moth visits heavily favored BP, averaging nearly 2.5 times more visits than any other plot (Table 2.3 and 2.6). The only other visits were observed in *Zinnia* and BIM.

Pitfall Traps. The largest average values of ground beetles were found in GBB and fennel while the fewest were found in *Zinnia* and *Celosia* (Table 2.4 and Figure 2.7). The greatest average values of spiders were seen in GBB and fennel. It should also be noted that one outlier was dropped for *Zinnia* on one date, in which 72 spiders (1 adult female and 72 spiderlings) were observed.

Discussion

The purpose of this study was to evaluate the insect feeding guilds associated with several commercially available BIHs and commonly grown cut flowers and herbs in order to supply organic growers with recommendations for this region of North Carolina. We wanted to investigate the possibility that these flowering monocultures, already regularly grown on organic farms, might actually harbor the beneficial insect populations that the commercially available products purportedly attract.

Fennel is commonly used to attract beneficial organisms in an agricultural landscape and there are several papers documenting the effectiveness of this and other umbelliferous plants for feeding parasitic Hymenoptera (Al-Doghairi and Crenshaw 1999, Baggen and Gurr 1998, Baggen et al. 2000, DuFour 2000, Hodgson and Lovei 1993, Maingay et al. 1991, Patt et al. 1997, Poncavage 1991). However, our analysis of fennel found it to have the lowest species diversity and abundance for all indices and for all feeding guilds. Thus, these results proved contrary to what we were expecting. One hypothesis is that because these perennial plants were only a few months old, they lacked the resources to begin flowering early in the season. In fact, the plants did not begin flowering until late summer, and although the seed packet states “55-80 days”, it is unclear whether this timeline is for harvesting or flowering. Therefore, if the plants were not flowering, little insect activity would be expected. In addition, these plantings were among the lowest mean values of pest moth visits, which further supports our hypothesis that because there were no pollen or nectar sources available at the time of sampling, expected insect populations would be minimal. However, fennel demonstrated a comparatively high average value of ground beetles and spiders. Carmona and Landis (1999) showed that ground beetle populations can be conserved when they are provided with adequate moisture and shelter, such as would be found in a heavily mulched cropping situation, like these plants were.

Zinnia (Family: Asteraceae) is a very well known and commonly grown cut flower in this region of the United States (Greer 2000). The large, daisy-like flower-heads are born on solitary long stems and bloom throughout the summer months (Brickell and Zuk 1997). *Zinnias*, which are in the same family as sunflowers, are alleged to attract various kinds of beneficial insects from many different feeding guilds (DuFour 2000). However, this study found these plants to be one of the lowest in terms of insect abundance and diversity. It is a commonly held belief that a more diverse a vegetative ecosystem supports more diverse and abundant beneficial insects (Banks 2003). The results of this study suggest that a *Zinnia* monoculture, while well suited for a cut flower cash crop, it is not effective in increasing beneficial insect populations.

The floral structure of the *Celosia cristata* (Family: Amaranthaceae) inflorescence is that of very tightly clustered, cauliflower-like flowerheads, containing up to thousands of individual flowers (Brickell and Zuk 1997). Each individual flower is relatively shallow, with easily accessible pollen (Moore et al. 1988). Overall, the *Celosia* planting ranked among the highest insect abundance and diversity values seen. A large proportion of predators, both beneficial and those of no agronomic consequence were seen in these plots as well as parasitoids that demonstrate varied life histories. This could be due to the fact that because each inflorescence is so large, it can accommodate a significant number of insects at any given time, thus, they can easily withstand several large predatory wasps at once without being structurally compromised. While *Celosia* was the most effective of the three cut flower plantings at attracting several different feeding guilds of predators and parasitoids, the families attracted have not been shown to be effective in the control agronomic pests. Therefore, it is unlikely that *Celosia* would be useful in conserving beneficial organisms in a farm setting.

Over the last few decades, the major paradigm for increasing natural enemy populations has focused on a diverse agroecosystem (Banks 2003, Pickett and Bugg 1998 and Barbosa 1998). Perhaps none have accepted this idea more so than organic growers.

Often, they grow a large assortment of crops in a relatively small area and thus, a highly diverse system is easily adopted. In addition, the idea of naturally reducing pest pressures can often be portrayed as the "silver bullet" approach that some agriculturalists have been searching for. In addition to some commonly grown cut flowers and herbs, we evaluated three commercially available seed mixes specifically marketed for increasing beneficial insect populations. Thus, the flowering mixes chosen ranged from one with large, "showy" cut flowers to one with predominantly small flowers and one in between.

The BP seed mixture offered the greatest variety of flower types, including evening primrose. This plant has large cup-shaped flowers with a long, tubular corolla, which, as its name suggests, open at dusk (Brickell and Zuk 1997). Typically, the only insects with mouthparts specialized enough to feed from these flowers are adult Lepidoptera (Borror et al. 1989). Since most pest moth species are active at night, it seems that this seed mixture might actually attract and benefit pest species. As expected, the greatest overall occurrence of noctuid and hornworm moths as well as the highest abundance and diversity of crop feeding herbivores and decomposers were collected in BP.

Heirloom Seed's BIM was chosen for this study because the species present in this mixture represented types of flowers typically associated with "showy", cut-flowers. These flowers prove to be adequate for large pollinators such as honey bees and bumble bees, as was found to be the case in this study. In addition, because of the large number of plant species found in this mix, it was expected that a high diversity of insects was to be observed. Although the greatest overall abundance and diversity for non-crop herbivores and parasitoids was greatest in this seed mixture, that is of little help in an agricultural system. While this blend did not seem to attract many undesirable pest species, neither did it seem to improve the beneficial insect population. It is possible that the relatively large flowers that benefited the pollinators were unable to feed the microscopic hymenopterous parasitoids (Patt et al. 1997).

Peaceful Valley's GBB was chosen because of the high proportion of plant species with small, easily accessible nectaries, which are purported to benefit small parasitoids (Al-Doghairi and Crenshaw 1999, Baggen and Gurr 1998, Baggen et al. 2000, Colley and Luna 1999, DuFour 2000, Hickman et al 1995, Hodgson and Lovei 1993, Luna and Jepson 2002, MacLeod 1992, Maingay et al. 1991, Patt et al. 1997, Poncavage 1991, Ruppert and Klingauf 1988). This study supports previous research in that this planting had both the highest abundance and diversity for both beneficial predators and parasitoids. Again, since this mix was composed of relatively small, shallow flowered plants, Lepidoptera were unable to feed and few pest moths were seen. GBB also had the highest average number of ground beetles and spiders, which further strengthen the opinion that it is the best mix at attracting beneficial insects.

It is important to remember that even though insect samples were obtained from these plantings, it is unclear whether they were feeding within the particular plant communities. Clearly, more work needs to be done in order to demonstrate specific pollen and nectar preferences among the various natural enemies. Even though GBB had the highest diversity of beneficial parasitoids and predators, as seen in Chapter 3, its presence did not increase the management of pest moth populations in an organic tomato cropping system. Thus, there are clearly other factors involved in regulating these natural enemy populations besides the provisioning of habitat. It is our hope that this study will help demonstrate to organic growers the difficulty in interpreting complex data at the agroecosystem level and to warn against the promise of a silver bullet in the control of pest insect populations.

References Cited

Al-Doghairi, M.A. and W.S. Crenshaw. 1999. Surveys on visitation of flowering landscape plants by common biological agents in Colorado. Journal of the Kansas Entomological Society, 72(2): 190-196.

Baggen, L.R. and G.M. 1998. The influence of food on *Copidosoma koehleri* (Hymenoptera; Encyrtidae) and the use of flowering plants as a habitat management tool to enhance biological control of the potato moth, *Phthorimaea operculella* (Lepidoptera: Gelechiidae). Biological Control, 11: 9-17).

Baggen, L.R., G.M. Gurr, and A. Meats. 1999. Flowers in tri-trophic systems: mechanisms allowing selective exploitation by insect natural enemies for conservation biological control. Entomologia Experimentalis et Applicata, 91: 155-161.

Baggen, L.R., G.M. Gurr, and A. Meats. 2000. Field observations on selective food plants in habitat manipulation for biological control of potato moth by *Copidosoma koehleri* (Hymenoptera; Encyrtidae). Fourth International hymenoptera Conference, held in Canberra, Australia, in January 1999. pp. 388-395.

Banks, J.E. 2003. Influence of plant diversity on herbivores and natural enemies. pp. 111-120. *In* O. Koul and G.S. Dhaliwal [eds.], Predators and Parasitoids. Taylor and Francis, London, UK. pp. 191.

Barbosa, P. and B. Benrey. 1998. The influence of plants on insect parasitoids: implications for conservation biological control. pp. 55-82. *In* P. Barbosa [ed.], Conservation Biological Control. pp. 396.

Barbour, M.G., J.H. Burk and W.D. Pitts. 1987. Terrestrial Plant Ecology, second ed. Benjamin Cummings Publishing Co., Inc. Menlo Park, CA. pp. 634.

Bland, R.G. and H.E. Jaques. 1978. How to Know the Insects, third edition. McGraw-Hill, New York. pp. 409.

Borror, D.J., C.A. Triplehorn, and N.F. Johnson. 1989. An Introduction to the Study of Insects, sixth ed. Saunders, Philadelphia. pp. 875.

Borror, D.J. and R.E. White. 1970. Peterson Field Guide: Insects. Houghton Mifflin Co., New York. pp. 404.

Braman, S.K., A.F. Pendley, and W. Corley. 2002. Influence of commercially available wildflower mixes on beneficial arthropod abundance and predation in turfgrass. Environmental Entomology 31(3): 564-572.

Brickell, C. and J.D. Zuk [eds.]. 1997. The American Horticultural Society A-Z Encyclopedia of Garden Plants. DK Publishing, Inc. New York, NY. pp. 1095.

Carmona, D.M., and D.A. Landis. 1999. Influence of refuge habitats and covers crops on seasonal activity-density of ground beetles (Coleoptera: Carabidae) in field crops. Environ. Entomol. 28: 1145-53.

Clyde Robins. 2002. Border Patrol®: Mother Nature's Perfect Natural Pesticide. http://www.clyderobin.com/mixes/pkg_borderpatrol.html. accessed December 6, 2004).

Coll, M. 1998. Parasitoid activity and plant species composition in intercropped systems. pp. 85-119. In Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. pp. 423.

Colley, M.R. and J.M. Luna. 1999. Relative attractiveness of potential beneficial insectary plants to aphidophagous hoverflies (Diptera; Syrphidae). Environmental Entomology, 29(5): 1054-1059.

Dufour, R. 2000. Farmscaping to Enhance Biological Control. Appropriate Technology Transfer for Rural Areas (ATTRA) publication. http://www.attra.org/attra-pub/farmscape.html. December. pp. 39.

Flint, M.L. and S.H. Dreistadt. 1998. Natural Enemies Handbook: the Illustrated Guide to Biological Pest Control. University of California Press, Berkeley. pp. 154.

Gibson, G.A.P., J.T. Huber, and J.B. Woolley, [eds.]. 1997. Annotated Keys to the Genera of Nearctic Chalcidoidea (Hymenoptera). NRC Research Press, Ottawa, Ontario, Canada. pp. 794.

Greer, L. 2000. Sustainable Cut Flower Production. Appropriate Technology Transfer for Rural Areas (ATTRA) publication. www.attra.org/attra-pub/cutflower.html. February. pp. 24.

Grissell, E.E. and M.E. Schauff. 1990. A Handbook of the Families of Nearctic Chalcidoidea (Hymenoptera). Cushing-Malloy, Ann Arbor, Michigan. pp. 75.

Gurr, G.M., H.F. van Emden, and S.D. Wratten. 1998. Habitat manipulation and natural enemy efficiency: Implications for the control of pests. pp. 155-184. *In* P. Barbosa [ed.], Conservation Biological Control. pp. 396.

Hickman, J.M., G.L. Lovei and S.D. Wratten. 1995. Pollen feeding by adults of the hoverfly *Melanostoma fasciatum* (Diptera: Syrphidae). New Zealand journal of Zoology, 22(4): 387-392.

Hill, M.O. 1973. Diversity and evenness: a unifying notation and its consequences. Ecology 54(2): 427-432.

Hodgson, D.J. and G.L. Lovei. 1993. Novel crops in cereal fields: habitat refuges for arthropod natural enemies. Proceedings of the Forty-Sixth New Zealand Plant Protection Conference, Christchurch, New Zealand, 10-12 august 1993. pp. 329-333.

Jervis, M. and N. Kidd [eds.]. 1996. Insect Natural Enemies: Practical Approach to Their Study and Evaluation. Chapman and Hall, London, UK. pp. 491.

Landis, D. A., S.D. Wratten, and G. M. Gurr. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu. Rev. Entomol. 45: 175-201.

Ludwig, J.A. and J.F. Reynolds. 1988. Stastical Ecology: A Primer on Methods and Computing. John wiley & Sons, New York, NY. pp. 337.

Luna, J. and P. Jepson. 2002. Enhancement of biological control with insectary plantings. Organic Farming Research Foundation, 11: 27-28.

MacLeod, A. 1992. Alternative crops as floral resources for beneficial hoverflies (Diptera; Syrphidae). Brighton Crop Protection Conferences – Pests and Diseases, 23-26 November, 1992. pp. 997-1002.

Maingay, H.M., R.L. Bugg, R.W. Carlson and N.A. Davidson. 1991. Predatory and parasitic wasps (Hymenoptera) feeding at flowers of sweet fennel (*Foeniculum vulgare* Miller var. dulce Battandier & Trabut, Apiaceae) and Spearmint (*Mentha sicata* L., Lamiaceae) in Massachusetts. Biological Agriculture and Horticulture, 7(4):363-383.

McAlpine, J.F., B.V. Peterson, G.E. Shewell, H.J. Teskey, J.R. Vockeroth and D.M. Wood [eds.]. 1981. Manual of Nearctic Diptera. Volume 1, Monograph 27. Can. Gov't. Publ. Centre, Hull, Quebec. pp. 674.

McAlpine, J.F., B.V. Peterson, G.E. Shewell, H.J. Teskey, J.R. Vockeroth and D.M. Wood [eds.]. 1987. Manual of Nearctic Diptera. Volume 2, Monograph 28. Can. Gov’t. Publ. Centre, Hull, Quebec. pp. 1332.

Mitchell, T.B. 1960. Bees of the Eastern United States, Vol. 1. North Carolina Agricultural Experiment Station, Raleigh, North Carolina. 141:[1]-538.

Mitchell, T.B. 1962. Bees of the Eastern United States, Vol. 2. North Carolina Agricultural Experiment Station, Raleigh, North Carolina. 152:[1]-557

Moore, R., W.D. Clark and D.S. Vodopich. 1998. Botany, second ed. The McGraw-Hill Co. New York, NY. pp. 919.

Mullen, G. and L. Durden [eds.]. 2002. Medical and Veterinary Entomology. Academic Press, Boston. pp. 597.

Patt, J.M., G.C. Hamilton, and J.H. Lashomb. 1997. Foraging success of parasitoid wasps on flowers: interplay of insect morphology, floral architecture and searching behavior. Entomologia Experimentalis et Applicata. 83: 21-30.

Pickett, C.H. and R.L. Bugg, (eds). 1998. Enhancing Biological Control. Berkley: UC Press. pp. 422.

Poncavage, P. 1991. Beneficial Borders. Organic Gardening, 38(5): 42-46.

Ruppert, V. and F. Klingauu. 1988. The attractiveness of some flowering plants for beneficial insects as exemplified by Syrphinae (Diptera: Syrphidae). [Abstract only]. Mitteilungen der Deutschen Gesellschauft fur Allgemeine und Angewandte Entomologie, 6(1-3): 255-261).

SAS Institute. 2002. PROC user's manual, version 9.1. SAS Institute, Cary, NC.

Smith, R.L. and T.M. Smith. 2000. Elements of Ecology, fourth ed. Addison Wesley Longman, Inc. San Francisco, CA. pp. 567

Stehr, F.W. [ed.]. 1987. Immature Insects, vol.1. Kendall Hunt, Dubuque, Iowa. pp. 754.

Stehr, F.W. [ed.]. 1991. Immature Insects, vol.2. Kendall Hunt, Dubuque, Iowa. pp. 975.

van Emden, H. F. 1990. Plant diversity and natural enemy efficiency in agroecosystems. pp. 63-80. Intercept, Ltd. *In* Critical Issues in Biological Control. pp. 330.

White, R.E. 1983. A Field Guide to the Beetles of North America. Houghton Mifflin Co., New York. pp. 368.

Wratten, S.D., H.F. van Emden, and M.B. Thomas. 1998. Within-field and border refugia for the enhancement of natural enemies. pp. 375-403. University of California Press. In Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. pp. 423.

Table 2.1. Average value ± SD for each of the different flowering plots, 2003.

Mix	**Simpson**	**Shannon**	**N1**	**N2**	**Evenness**	**Richness**
BP	0.1091 ± 0.0682 $_{C}$	2.7750 ± 0.3837 $_{A}$	17.0215 ± 5.1749 $_{A}$	11.4410 ± 4.3224 $_{A}$	0.4154 ± 0.0797 $_{A}$	41.7500 ± 12.3684 $_{A}$
Celosia	0.1032 ± 0.0268 $_{C}$	2.6532 ± 0.2239 $_{AB}$	14.5362 ± 3.1538 $_{B}$	10.2772 ± 2.4406 $_{AB}$	0.4648 ± 0.1065 $_{A}$	32.8333 ± 9.8053 $_{BC}$
Fennel	0.3230 ± 0.1542 $_{A}$	1.7249 ± 0.4317 $_{D}$	6.1207 ± 2.5855 $_{D}$	3.8386 ± 1.8166 $_{D}$	0.3077 ± 0.1070 $_{B}$	20.5833 ± 7.1196 $_{D}$
BIM	0.1532 ± 0.0554 $_{B}$	2.4954 ± 0.3102 $_{BC}$	12.6705 ± 3.6907 $_{BC}$	7.3808 ± 2.6111 $_{C}$	0.3369 ± 0.0683 $_{B}$	38.1667 ± 9.9024 $_{ABC}$
GBB	0.1274 ± 0.0557 $_{BC}$	2.6126 ± 0.3408 $_{ABC}$	14.3566 ± 4.4098 $_{B}$	9.1746 ± 3.3871 $_{B}$	0.3562 ± 0.0644 $_{B}$	40.7083 ± 11.4188 $_{AB}$
Zinnia	0.1463 ± 0.0563 $_{B}$	2.4780 ± 0.2994 $_{A}$	12.4110 ± 3.4267 $_{C}$	7.6739 ± 2.4417 $_{C}$	0.4167 ± 0.1410 $_{A}$	32.0417 ± 10.1873 $_{C}$
LSD	0.0349	0.1662	1.9002	1.3806	0.0584	7.9334
F (model)	11.24	12.93	8.82	5.93	3.07	9.49
Df (model)	59	59	59	59	59	59
P (model)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Table 2.2 Analysis of diversity and abundance indices by feeding guild for each of the six different flowering plots, 2003.

	Simpson †	Shannon	N1	N2	Evenness	Richness
Decomposers & Fungus Feeders						
BP	0.3395 ± 0.1494 $_{B}$	1.3106 ± 0.4534 $_{A}$	4.0361 ±1.5101 $_{A}$	3.4760 ± 1.3365 $_{A}$	0.6210 ± 0.1899 $_{BC}$	6.9167 ± 2.5524 $_{A}$
Celosia	0.3564 ± 0.1608 $_{B}$	1.2126 ± 0.3782 $_{A}$	3.5908 ± 1.3064 $_{A}$	3.3314 ± 1.3427 $_{A}$	0.7686 ± 0.1719 $_{AB}$	4.8333 ±1.8098 $_{B}$
Fennel	0.5768 ± 0.3061 $_{A}$	0.6905 ± 0.5771 $_{B}$	2.3542 ± 1.4741 $_{B}$	2.1820 ± 1.3415 $_{B}$	0.8242 ± 0.1473 $_{A}$	2.9167 ± 2.0412 $_{C}$
BIM	0.4270 ± 0.1944 $_{AB}$	1.1101 ± 0.4385 $_{A}$	3.3208 ± 1. 4318 $_{AB}$	2.8829 ± 1.3568 $_{AB}$	0.6306 ± 0.1944 $_{BC}$	5.5417 ± 2.1865 $_{AB}$
GBB	0.4687 ± 0.2449 $_{AB}$	1.0309 ± 0.5232 $_{AB}$	3.1405 ± 1.3502 $_{AB}$	2.6652 ± 1.1491 $_{AB}$	0.5970 ± 0.2460 $_{C}$	6.000 ± 2.4495 $_{AB}$
Zinnia	0.3324 ± 0.1206 $_{B}$	1.2833 ± 0.3247 $_{A}$	3.7951 ± 1.2399 $_{A}$	3.4355 ± 1.2943 $_{A}$	0.6964 ± 0.1865 $_{ABC}$	5.500 ± 2.2650 $_{AB}$
LSD	0.1938	0.3659	1.0157	0.9488	0.155	1.5915
F (model)	2.34	2.77	1.98	1.48	2.62	3.65
Df (model)	59	59	59	59	59	59
P (model)	0.0002	<0.0001	0.0022	0.0520	<0.0001	<0.0001
Herbivore – Crop Pest						
BP	0.3668 ± 0.1548 $_{C}$	1.3251 ± 0.4027 $_{A}$	4.0385 ± 1.4417 $_{A}$	3.1626 ± 1.1851 $_{A}$	0.4798 ± 0.1142 $_{A}$	8.8750 ± 3.3403 $_{A}$
Celosia	0.5025 ± 0.1487 $_{B}$	0.9992 ± 0.3143 $_{B}$	2.8391 ± 0.8122 $_{B}$	2.1539 ± 0.5931 $_{B}$	0.4333 ± 0.1466 $_{AB}$	7.2917 ± 2.8204 $_{B}$
Fennel	0.6942 ± 0.1516 $_{A}$	0.5594 ± 0.2400 $_{D}$	1.7983 ± 0.4297 $_{C}$	1.5133 ± 0.3557 $_{C}$	0.4299 ± 0.1378 $_{ABC}$	4.5417 ± 1.5317 $_{C}$
BIM	0.4941 ± 0.1492 $_{B}$	1.0291 ± 0.3109 $_{B}$	2.9280 ± 0.8940 $_{B}$	2.2069 ± 0.6665 $_{B}$	0.3970 ± 0.1495 $_{BC}$	8.0833 ± 2.7333 $_{AB}$
GBB	0.3842 ± 0.1365 $_{C}$	1.2564 ± 0.3399 $_{A}$	3.6877 ± 1.0467 $_{A}$	2.8457 ± 0.7607 $_{A}$	0.4476 ± 0.0897 $_{AB}$	8.5417 ± 2.7659 $_{A}$
Zinnia	0.6381 ± 0.1412 $_{A}$	0.7220 ± 0.2333 $_{C}$	2.1122 ± 0.4876 $_{C}$	1.6436 ± 0.3700 $_{C}$	0.3599 ± 0.2119 $_{C}$	7.0417 ± 2.7104 $_{B}$
LSD	0.0766	0.1603	0.4846	0.3532	0.0728	1.165
F (model)	6.92	9.65	8.54	6.17	2.98	7.11
Df (model)	59	59	59	59	59	59
P (model)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Herbivore – Non-crop pest						
BP	0.4648 ± 0.1717 $_{B}$	1.0111 ± 0.2758 $_{A}$	2.8443 ± 0.7253 $_{A}$	2.2129 ± 0.5678 $_{AB}$	0.3918 ± 0.1616 $_{A}$	7.8333 ± 2.3530 $_{AB}$
Celosia	0.4895 ± 0.1297 $_{AB}$	0.9206 ± 0.2440 $_{AB}$	2.5774 ± 0.5631 $_{AB}$	2.1538 ± 0.4623 $_{AB}$	0.4853 ± 0.1800 $_{A}$	6.0000 ± 2.3956 $_{BC}$
Fennel	0.5743 ± 0.1775 $_{A}$	0.7760 ± 0.2931 $_{B}$	2.2602 ± 0.6294 $_{B}$	1.8989 ± 0.5565 $_{B}$	0.5051 ± 0.2203 $_{A}$	5.1250 ± 2.1931 $_{C}$
BIM	0.4470 ± 0.1226 $_{B}$	1.0614 ± 0.2644 $_{A}$	2.9850 ± 0.7452 $_{A}$	2.3795 ± 0.5566 $_{A}$	0.4218 ± 0.1371 $_{A}$	7.5833 ± 2.1451 $_{AB}$
GBB	0.4633 ± 0.1309 $_{B}$	1.0211 ± 0.2748 $_{A}$	2.8711 ± 0.7163 $_{A}$	2.2924 ± 0.5197 $_{A}$	0.3688 ± 0.0991 $_{A}$	8.3333 ± 2.9879 $_{A}$
Zinnia	0.5074 ± 0.1545 $_{AB}$	0.9411 ± 0.3011 $_{AB}$	2.6717 ± 0.7654 $_{AB}$	2.1456 ± 0.6310 $_{AB}$	0.4722 ± 0.1306 $_{A}$	6.0417 ± 2.0951 $_{BC}$
LSD	0.0958	0.1927	0.4921	0.367	0.1373	2.2039
F (model)	1.85	3.29	3.18	2.22	2.24	4.39
Df (model)	59	59	59	59	59	59
P (model)	0.0046	<0.0001	<0.0001	0.0004	<0.0001	<0.0001

Table 2.2 continued. Analysis of diversity and abundance indices by feeding guild for each of the six different flowering plots, 2003.

Pollinators

	Simpson †	Shannon	N1	N2	Evenness	Richness
BP	0.6354 ± 0.3860 $_{A}$	0.2968 ± 0.3106 $_{AB}$	1.4079 ± 0.4323 $_{AB}$	1.4231 ± 0.4935 $_{A}$	0.9540 ± 0.0701 $_{A}$	1.1250 ± 0.7974 $_{A}$
Celosia	0.7917 ± 0.3959 $_{A}$	0.1209 ± 0.2692 $_{AB}$	1.1718 ± 0.3830 $_{AB}$	1.2857 ± 0.7559 $_{A}$	0.9950 ± 0.0166 $_{A}$	0.5417 ± 0.6580 $_{B}$
Fennel	1.0000 ± 0.0000 $_{A}$	0.0000 ± 0.0000 $_{B}$	1.0000 ± 0.0000 $_{B}$	1.0000 ± 0.0000 $_{A}$	1.0000 ± 0.0000 $_{A}$	0.2500 ± 0.4423 $_{B}$
BIM	0.6422 ± 0.3337 $_{A}$	0.3476 ± 0.3210 $_{A}$	1.4833 ± 0.4500 $_{A}$	1.7602 ± 0.8070 $_{A}$	0.9604 ± 0.0588 $_{A}$	1.0417 ± 0.8587 $_{A}$
GBB	0.6224 ± 0.3923 $_{A}$	0.2264 ± 0.3156 $_{AB}$	1.3149 ± 0.4406 $_{AB}$	1.6515 ± 0.8099 $_{A}$	0.9756 ± 0.0444 $_{A}$	0.6250 ± 0.7697 $_{B}$
Zinnia	0.8333 ± 0.3333 $_{A}$	0.0490 ± 0.1765 $_{AB}$	1.0685 ± 0.2468 $_{AB}$	1.5000 ± 1.0000 $_{A}$	0.9958 ± 0.0153 $_{A}$	0.5833 ± 0.5836 $_{B}$
LSD	0.5872	0.3182	0.4397	1.2298	0.05	0.3852
F (model)	1.30	1.42	1.42	0.76	0.74	2.65
Df (model)	34	48	48	32	48	59
P (model)	0.2920	0.1682	0.1715	0.7378	0.8194	<0.0001

Parasitoid - Beneficial

	Simpson †	Shannon	N1	N2	Evenness	Richness
BP	0.4204 ± 0.1403 $_{C}$	1.0852 ± 0.2977 $_{AB}$	3.0760 ± 0.8150 $_{AB}$	2.5785 ± 0.7009 $_{AB}$	0.6911 ± 0.1089 $_{C}$	4.3333 ± 1.5512 $_{A}$
Celosia	0.4475 ± 0.1842 $_{BC}$	0.9355 ± 0.3450 $_{BC}$	2.6736 ± 0.7288 $_{BC}$	2.4671 ± 0.6517 $_{B}$	0.8222 ± 0.1345 $_{B}$	3.4167 ± 1.2482 $_{B}$
Fennel	0.5970 ± 0.2543 $_{A}$	0.6243 ± 0.4088 $_{D}$	2.0082 ± 0.7305 $_{D}$	1.9422 ± 0.6916 $_{C}$	0.9077 ± 0.1217 $_{A}$	1.9167 ± 1.2482 $_{C}$
BIM	0.4290 ± 0.1010 $_{BC}$	0.9704 ± 0.3079 $_{BC}$	2.7465 ± 0.7162 $_{BC}$	2.4512 ± 0.5508 $_{B}$	0.7609 ± 0.1540 $_{B}$	3.8333 ± 1.4039 $_{AB}$
GBB	0.3962 ± 0.1913 $_{C}$	1.1501 ± 0.4087 $_{A}$	3.3809 ± 1.1165 $_{A}$	2.9305 ± 0.9804 $_{A}$	0.7650 ± 0.1318 $_{B}$	4.5833 ± 1.7673 $_{A}$
Zinnia	0.5132 ± 0.2149 $_{AB}$	0.8146 ± 0.3901 $_{C}$	2.4134 ± 0.8325 $_{CD}$	2.2222 ± 0.7271 $_{C}$	0.8013 ± 0.1323 $_{B}$	3.1250 ± 1.2619 $_{B}$
LSD	0.0895	0.1732	0.4815	0.4164	0.0646	0.7897
F (model)	1.10	1.45	1.54	1.09	1.89	2.46
Df (model)	59	59	59	59	59	59
P (model)	0.3446	0.0605	0.0369	0.3637	0.0042	<0.0001

Parasitoid - Mixed

	Simpson †	Shannon	N1	N2	Evenness	Richness
BP	0.74622 ± 0.2555 $_{A}$	0.3580 ± 0.3618 $_{A}$	1.5215 ± 0.5441 $_{A}$	1.5149 ± 0.5453 $_{A}$	0.9548 ± 0.0756 $_{A}$	1.2917 ± 0.9079 $_{A}$
Celosia	0.7007 ± 0.2727 $_{A}$	0.3815 ± 0.3813 $_{A}$	1.5665 ± 0.5919 $_{A}$	1.6488 ± 0.6290 $_{A}$	0.9852 ± 0.0255 $_{A}$	1.0000 ± 0.9325 $_{A}$
Fennel	0.9351 ± 0.1836 $_{A}$	0.0726 ± 0.2408 $_{A}$	1.1112 ± 0.3687 $_{A}$	1.1350 ± 0.3818 $_{A}$	0.9764 ± 0.0781 $_{A}$	0.5417 ± 0.7211 $_{A}$
BIM	0.7836 ± 0.2581 $_{A}$	0.2549 ± 0.3314 $_{A}$	1.3616 ± 0.4726 $_{A}$	1.4428 ± 0.5431 $_{A}$	0.9864 ± 0.0419 $_{A}$	1.0417 ± 0.7506 $_{A}$
GBB	0.8053 ± 0.2338 $_{A}$	0.2431 ± 0.3096 $_{A}$	1.3373 ± 0.4379 $_{A}$	1.3686 ± 0.4651 $_{A}$	0.9544 ± 0.1050 $_{A}$	1.2500 ± 0.6757 $_{A}$
Zinnia	0.8074 ± 0.2333 $_{A}$	0.2649 ± 0.3041 $_{A}$	1.3624 ± 0.4331 $_{A}$	1.3706 ± 0.4990 $_{A}$	0.9312 ± 0.1290 $_{A}$	0.8750 ± 0.8502 $_{A}$
LSD	0.285	0.3731	0.5493	0.5939	0.0718	0.8565
F (model)	1.35	1.68	1.73	1.42	1.13	1.40
Df (model)	57	59	59	57	59	59
P (model)	0.1783	0.0460	0.0366	0.1417	0.3511	0.0777

Table 2.2 continued. Analysis of diversity and abundance indices by feeding guild for each of the six different flowering plots, 2003.

	Simpson †	Shannon	N1	N2	Evenness	Richness
Parasitoid – Non-crop						
BP	0.8270 ± 0.1857 $_{AB}$	0.2743 ± 0.3005 $_{AB}$	1.3778 ± 0.4607 $_{AB}$	1.2847 ± 0.3612 $_{A}$	0.8183 ± 0.2034 $_{AB}$	1.8333 ± 1.1672 $_{AB}$
Celosia	0.7757 ± 0.2287 $_{AB}$	0.3653 ± 0.3635 $_{AB}$	1.5408 ± 0.6282 $_{AB}$	1.4507 ± 0.6048 $_{A}$	0.8182 ± 0.1762 $_{AB}$	1.5000 ± 1.1795 $_{B}$
Fennel	0.8851 ± 0.2120 $_{A}$	0.1546 ± 0.2783 $_{B}$	1.2109 ± 0.3906 $_{B}$	1.2194 ± 0.4434 $_{A}$	0.9626 ± 0.0990 $_{A}$	0.3750 ± 0.6469 $_{C}$
BIM	0.7326 ± 0.2236 $_{B}$	0.4263 ± 0.3395 $_{A}$	1.6262 ± 0.6360 $_{A}$	1.5355 ± 0.6120 $_{A}$	0.7625 ± 0.1966 $_{B}$	2.1250 ± 0.8999 $_{A}$
GBB	0.8411 ± 0.2033 $_{AB}$	0.2676 ± 0.3287 $_{AB}$	1.3812 ± 0.5077 $_{AB}$	1.2856 ± 0.4319 $_{A}$	0.8058 ± 0.2026 $_{AB}$	1.5833 ± 1.1389 $_{AB}$
Zinnia	0.7307 ± 0.2302 $_{B}$	0.3905 ± 0.3212 $_{A}$	1.5490 ± 0.4722 $_{AB}$	1.5079 ± 0.4734 $_{A}$	0.8822 ± 0.1439 $_{AB}$	1.3750 ± 1.0135 $_{B}$
LSD	0.1461	0.2114	0.3756	0.3831	0.1572	0.5789
F (model)	1.32	1.32	1.17	1.10	1.52	2.52
Df (model)	55	55	55	55	55	59
P (model)	0.1586	0.1570	0.2824	0.3611	0.0643	<0.0001
Predator - Beneficial						
BP	0.3485 ± 0.1326 $_{AB}$	1.2911 ± 0.3024 $_{A}$	3.7885 ± 1.0432 $_{A}$	2.9820 ± 0.8392 $_{AB}$	0.5093 ± 0.1682 $_{C}$	8.0417 ± 2.6454 $_{A}$
Celosia	0.2923 ± 0.1276 $_{B}$	1.3555 ± 0.3021 $_{A}$	4.0261 ± 0.9740 $_{A}$	3.5358 ± 0.8016 $_{A}$	0.6305 ± 0.1430 $_{A}$	6.7083 ± 2.1158 $_{B}$
Fennel	0.4902 ± 0.1852 $_{A}$	0.9565 ± 0.3682 $_{B}$	2.7674 ± 0.9542 $_{B}$	2.3123 ± 0.8203 $_{B}$	0.6322 ± 0.1508 $_{A}$	4.5417 ± 1.6676 $_{C}$
BIM	0.3728 ± 0.1420 $_{AB}$	1.2494 ± 0.3253 $_{AB}$	3.6596 ± 1.1165 $_{AB}$	2.9993 ± 0.9662 $_{AB}$	0.5346 ± 0.1479 $_{BC}$	7.1667 ± 2.0990 $_{AB}$
GBB	0.3036 ± 0.1049 $_{B}$	1.4800 ± 0.2685 $_{A}$	4.5486 ± 1.2461 $_{A}$	3.7577 ± 1.5039 $_{A}$	0.5762 ± 0.1674 $_{ABC}$	8.1667 ± 2.0144 $_{A}$
Zinnia	0.3638 ± 0.1862 $_{AB}$	1.2822 ± 0.4218 $_{A}$	3.8777 ± 1.3355 $_{A}$	3.3055 ± 1.2764 $_{A}$	0.6264 ± 0.1535 $_{AB}$	6.4167 ± 2.1247 $_{B}$
LSD	0.16	0.3158	0.8995	0.8375	0.0951	1.2742
F (model)	2.38	3.97	3.62	2.84	1.96	4.80
Df (model)	59	59	59	59	59	59
P (model)	0.0001	<0.0001	<0.0001	<0.0001	0.0023	<0.0001
Predator – Inconsequencial						
BP	0.8127 ± 0.2958 $_{A}$	0.2038 ± 0.3127 $_{AB}$	1.2915 ± 0.4728 $_{AB}$	1.3079 ± 0.5883 $_{AB}$	0.8745 ± 0.1986 $_{AB}$	1.5000 ± 0.9780 $_{A}$
Celosia	0.6666 ± 0.3018 $_{A}$	0.3879 ± 0.3576 $_{A}$	1.5657 ± 0.5560 $_{A}$	1.6232 ± 0.6453 $_{A}$	0.8628 ± 0.1740 $_{AB}$	1.5417 ± 1.1413 $_{A}$
Fennel	0.8984 ± 0.2031 $_{A}$	0.0726 ± 0.2054 $_{B}$	1.0984 ± 0.2785 $_{B}$	1.1711 ± 0.3422 $_{B}$	0.9867 ± 0.0376 $_{A}$	0.3750 ± 0.5758 $_{B}$
BIM	0.7004 ± 0.3336 $_{A}$	0.3592 ± 0.3427 $_{A}$	1.5156 ± 0.5314 $_{A}$	1.4410 ± 0.5939 $_{AB}$	0.8042 ± 0.2207 $_{B}$	1.7500 ± 1.2247 $_{A}$
GBB	0.7584 ± 0.2507 $_{A}$	0.3336 ± 0.3851 $_{AB}$	1.5066 ± 0.6564 $_{AB}$	1.5165 ± 0.6613 $_{AB}$	0.8173 ± 0.2205 $_{B}$	1.6250 ± 1.2790 $_{A}$
Zinnia	0.8305 ± 0.2864 $_{A}$	0.1801 ± 0.2877 $_{AB}$	1.2498 ± 0.4085 $_{AB}$	1.2122 ± 0.3835 $_{AB}$	0.9493 ± 0.1135 $_{AB}$	1.0833 ± 0.7755 $_{AB}$
LSD	0.2821	0.2668	0.4099	0.426	0.1603	0.7845
F (model)	1.12	0.97	0.91	0.98	1.69	2.39
Df (model)	49	52	52	48	52	59
P (model)	0.3544	0.5394	0.6398	0.5292	0.0288	0.0001

† Means with the same letter are not significantly different.

Table 2.3. Mean dusk activity for noctuid moths (Lepidoptera: Noctuidae) and hornworm moths (Lepidoptera: Sphingidae) in each of the different flower plantings.

Plant Community	Noctuidae	Sphingidae
Celosia	1.30 ± 1.18	0.00 ± 0.00
Fennel	0.37 ± 0.42	0.00 ± 0.00
Border Patrol™	1.74 ± 1.36	2.41 ± 2.36
Good Bug Blend	0.56 ± 0.41	0.07 ± 0.15
Zinnia	0.93 ± 0.40	0.04 ± 0.11
Beneficial Insect Mix	1.96 ± 0.35	0.00 ± 0.00

Table 2.4. Mean number of ground beetles (Coleoptera: Carabidae) and spiders (Acarina: Araneidae) collected from pitfall traps.

Plant Community	Carabidae	Araneae
Celosia	0.3 ± 0.8	0.7 ± 0.7
Fennel	1.7 ± 0.9	1.0 ± 0.7
Border Patrol™	0.6 ± 0.4	0.7 ± 0.4
Good Bug Blend	2.1 ± 1.0	1.1 ± 1.2
Zinnia	0.2 ± 0.5	0.9 ± 0.9
Beneficial Insect Mix	1.0 ± 0.4	0.7 ± 0.5

Figure 2.1. Field block planting design for each of the plant communities.

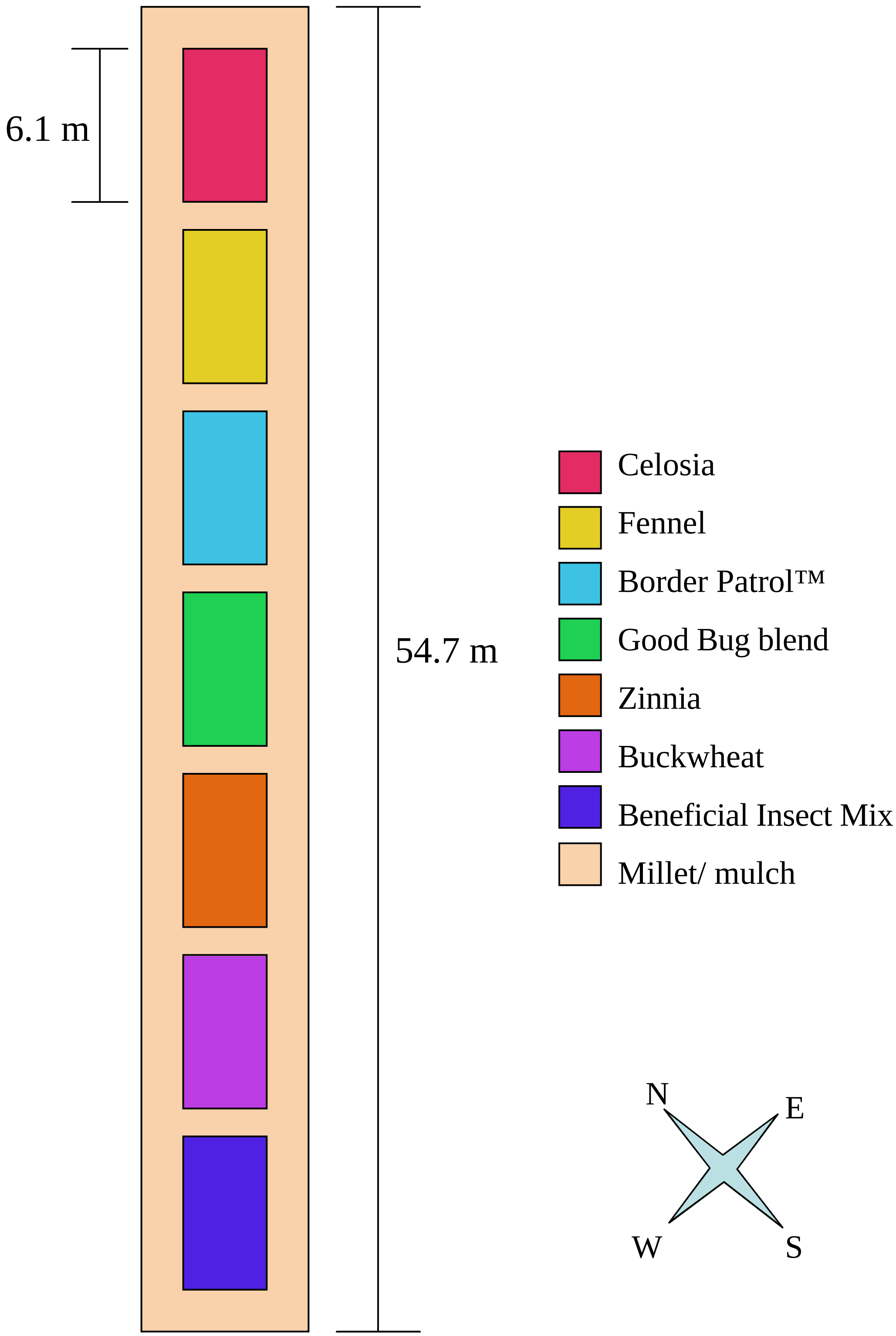


Figure 2.2. Plot planting design for Clyde Robin's Border Patrol™.

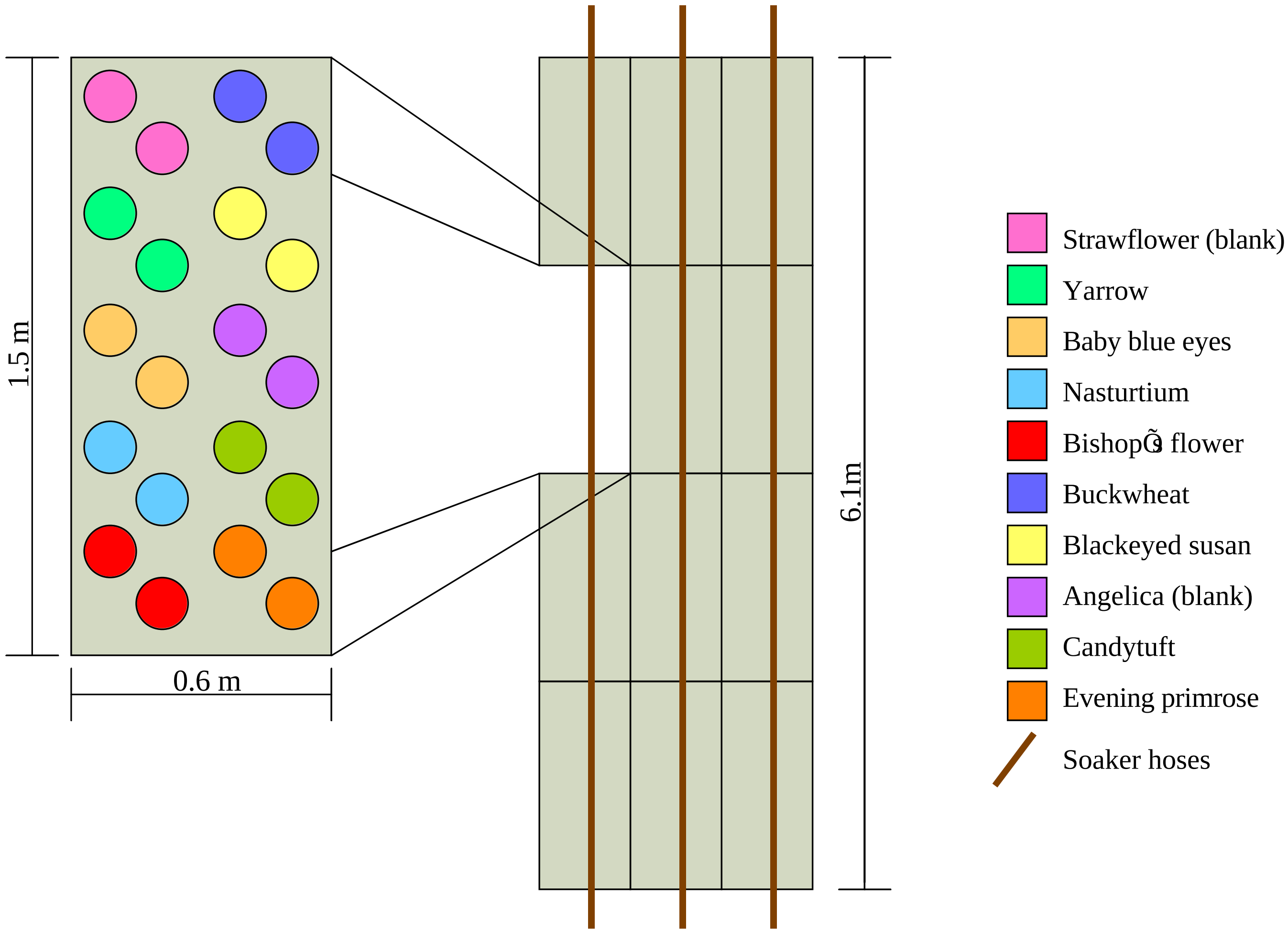


Figure 2.3. Plot planting design for Heirloom Seed's Beneficial Insect Mix.

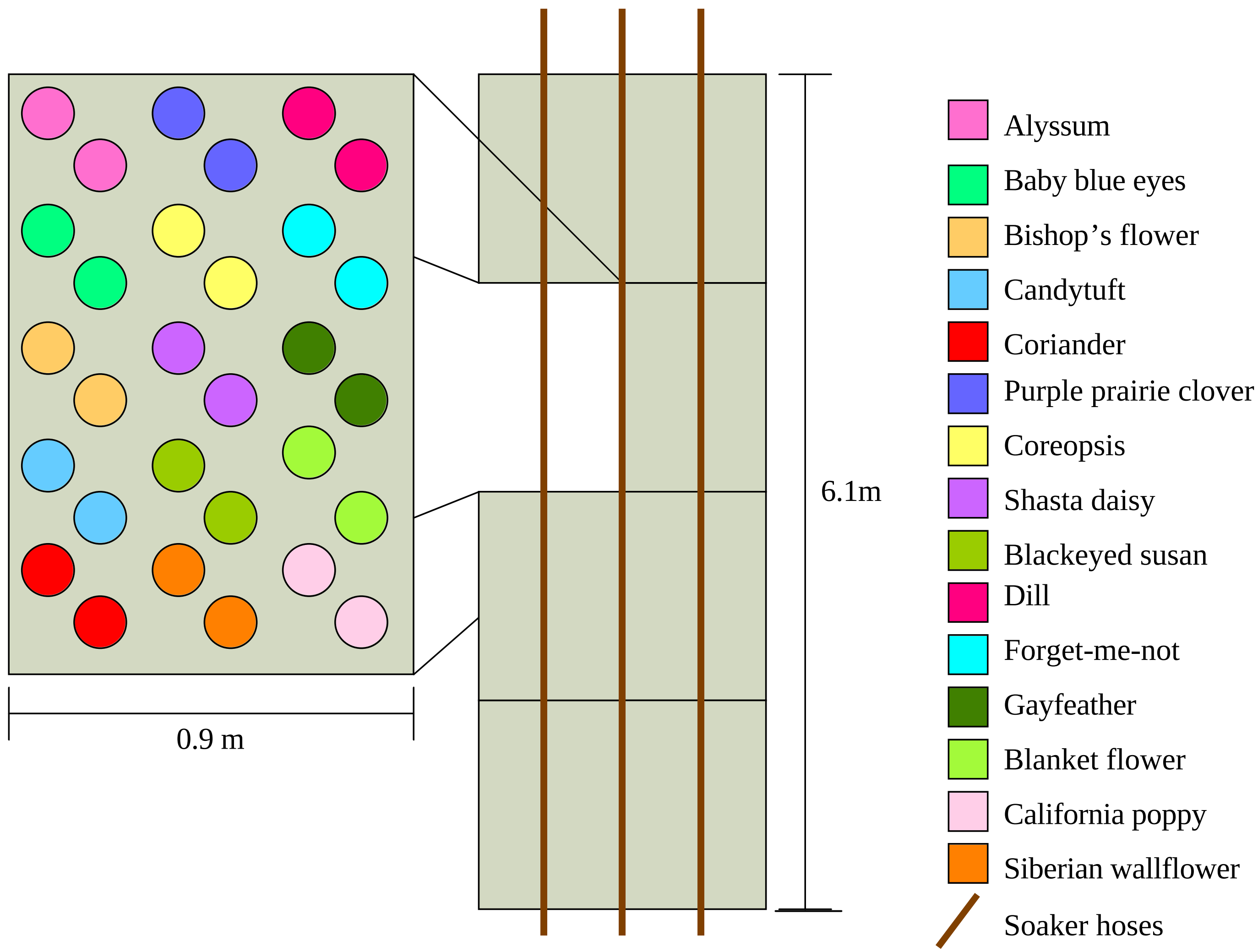


Figure 2.4. Plot planting design for Peaceful Valley's Good Bug Blend

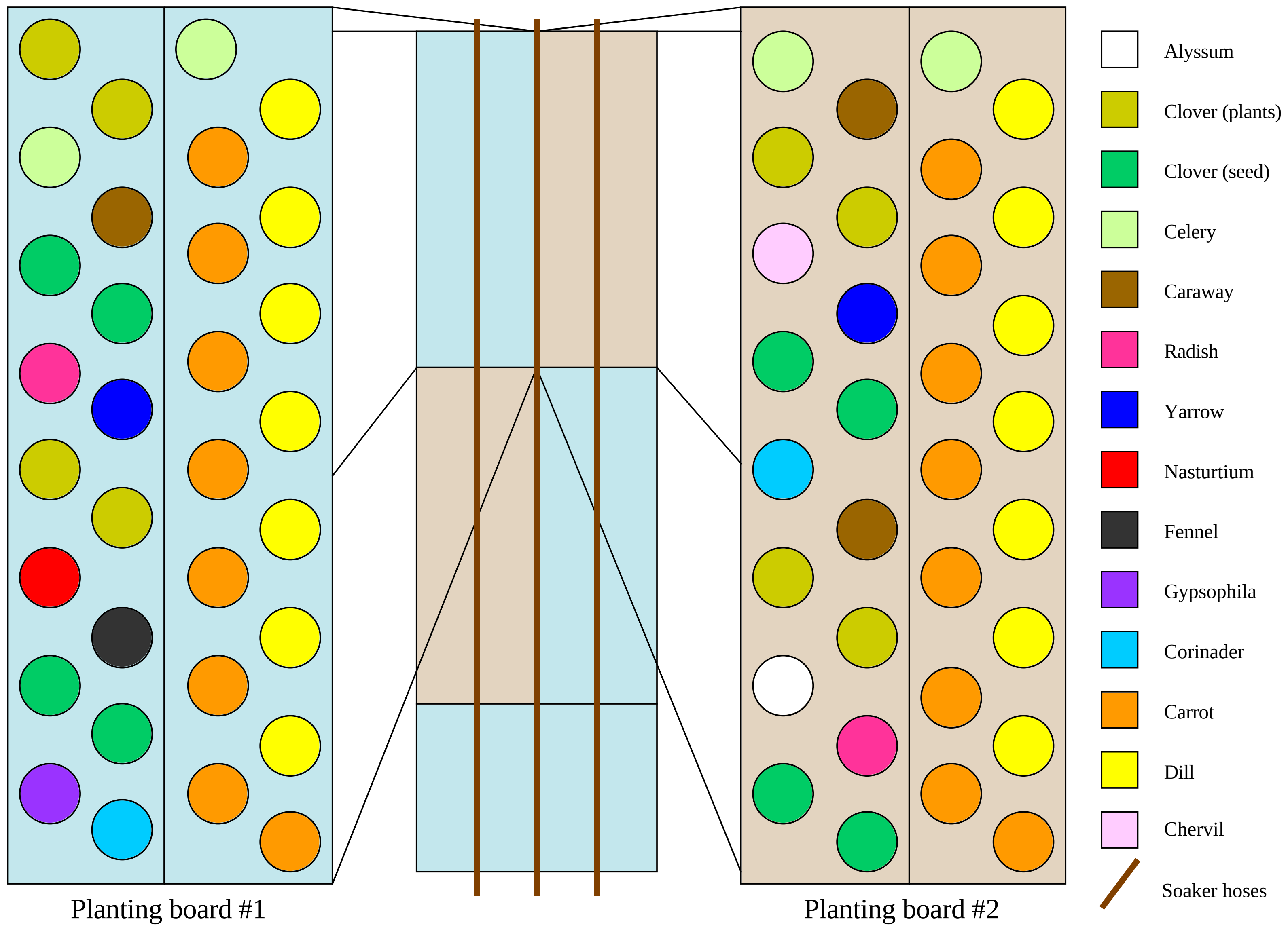


Figure 2.5. Average number ± SD of visits for noctuid moths (Lepidoptera: Noctuidae) to each of the plant plots.

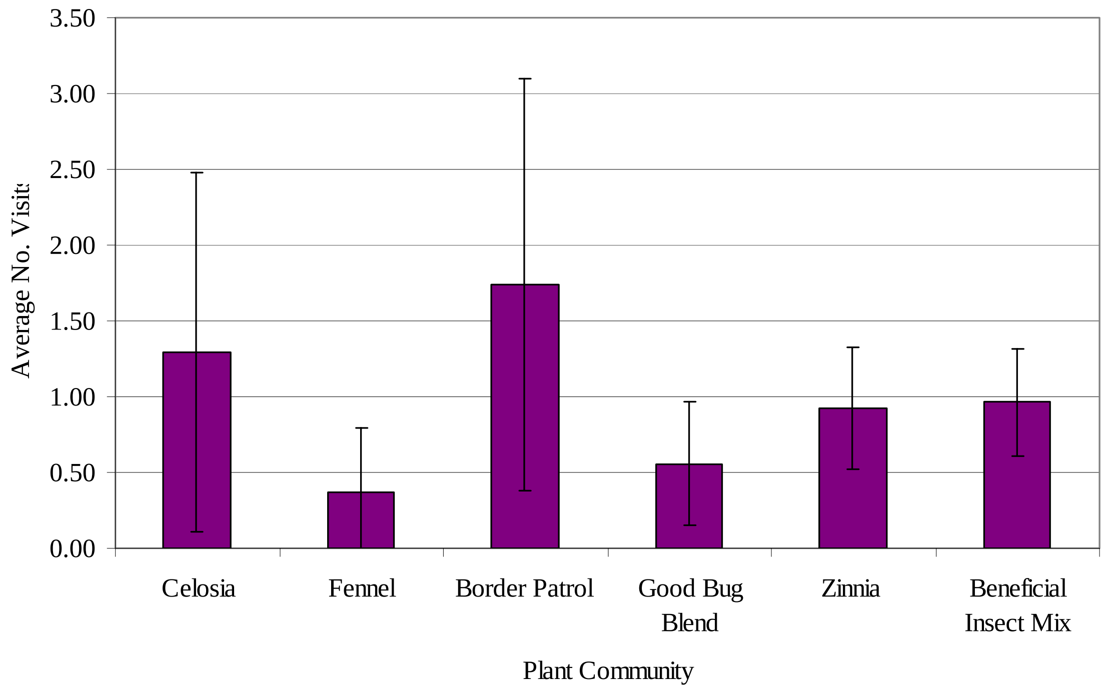


Figure 2.6. Average number ± SD of visits for hornworm moths (Lepidoptera: Sphingidae) to each of the plant plots.

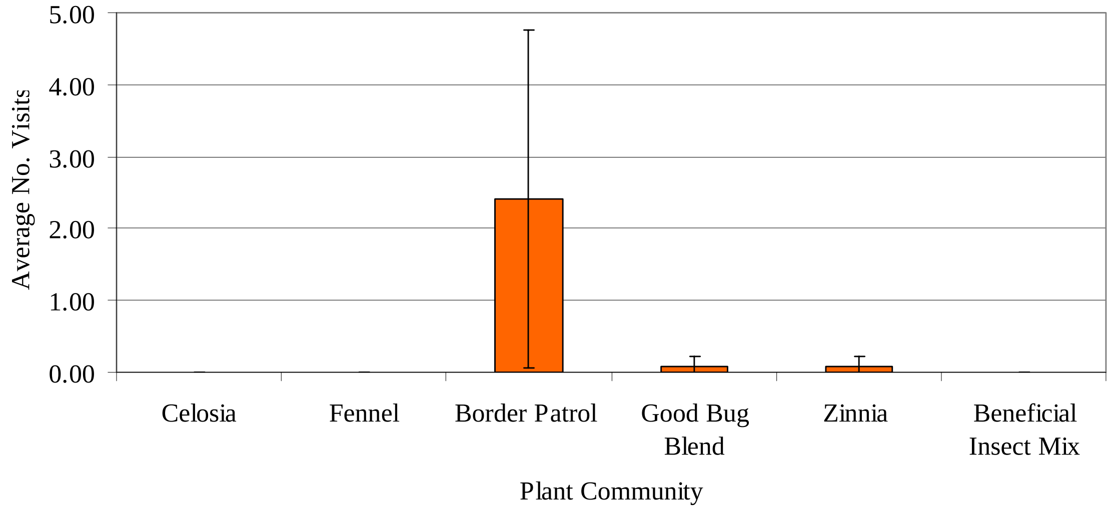
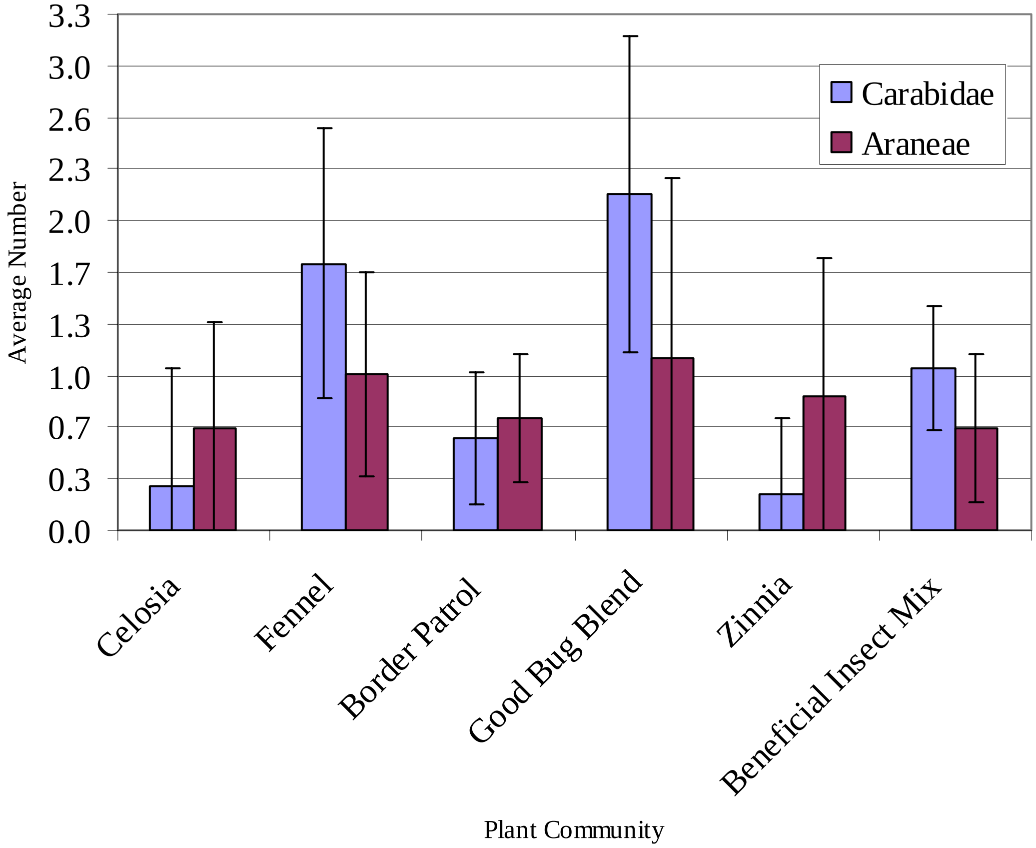


Table 2.7. Average numbers ± SD of ground beetles (Coleoptera: Carabidae) and spiders (Arachnida: Araneae) caught in pitfall traps in various plant communities.



Evaluation of a Commercially Available Beneficial Insect Habitat for Controlling Pest Populations of Tomato Fruitworms (*Helicoverpa zea*) and Hornworms (*Manduca spp.*) in an Organic Tomato Cropping System

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Abstract. A field study was conducted in 2003 and 2004 at the Center for Environmental Farming Systems (CEFS) in Goldsboro, NC to evaluate the effectiveness of a commercially available beneficial insect habitat (BIH) in decreasing pest caterpillar populations. Six pairs of organically managed tomato plots were established and Peaceful Valley's Good Bug Blend transplanted around the perimeter of treatment plots, while a brown-top millet (*Brachiaria ramosa)* border was planted around the control plots. *Helicoverpa zea* and *Manduca spp*. eggs were monitored and categorized based on the fate of each egg after one week: parasitized, chewing predator, sucking predator, hatched or unknown. When analyzed for the effect from year, treatment, year by treatment, date within year and treatment by date within year, the only significant difference seen was in parasitism by date within year. Plots were scouted weekly and the fates of hornworm larvae (*Manduca spp*.) were evaluated to determine if the BIH had an effect on larval parasitism by the braconid wasp, *Cotesia congregata*. There was no significant difference when data were analyzed for the effect from year, treatment, year by treatment and treatment by date within year for either 2003 or 2004. However, there was a significant difference when evaluating date within year for larval populations. This study indicates that natural enemy populations were not amplified by the presence of a commercially available BIH. However, due to the difficulty in favorably augmenting an entire agroecosystem, more work clearly needs to be done.

Introduction

Many organic growers believe that diversification of plants in and around commercial crops will improve biological control of pest species, and this belief is supported by research (Landis et al. 2000). The foundation of this approach is that a more complex agroecosystem will mimic the natural system that existed before agricultural disturbances. A variety of approaches have been examined to try to reach this goal. The notion of growing multiple plant varieties in close proximity to one another is commonly known as intercropping, although it has many pseudonyms including polycropping, mixed farming, interculture (Coll 1998). In recent years, a new approach to increasing agricultural diversity has been adopted by the organic community. DuFour (2000) proposed farmscaping as a "whole-farm, ecological approach to pest management", by utilizing "hedgerows, insectary plants, cover crops and water reservoirs to support populations of beneficial organisms such as insects, bats and birds of prey". It is inferred from these ideas that beneficial insects are attracted to an undisturbed and diverse landscape, resulting in more pest insects being destroyed (Pickett and Bugg 1998). However, due to the complex and numerous underlying ecological mechanisms, data collection has proven to be very slow and difficult to interpret (Wratten et al. 1998).

To be useful for pest management, any area maintained for beneficial insect habitat (BIH) must result in a net gain in beneficial insects and net reduction in pest insects; however, it is difficult to determine this relationship (Landis et al. 2000). Several characteristics should be considered when creating such a habitat; increased quantities of pollen and/ or nectar, over wintering sites, and a source of alternate prey (Carmona and Landis 1999).

Many entomophagous insects feed on nectar or pollen at some point in their lives (Jervis and Kidd 1996), but it is important to keep in mind that not all floral structures are created equal. Nectar accessibility can vary greatly with flower architecture and very little research exists looking at the availability of nectar to specific parasitoids. Patt et al. (1997) evaluated the foraging success of two parasitoids (*Edovum puttleri* Grissell and *Pediobius foveolatus* Crawford) (Hymenoptera: Eulophidae) on 24 real and four artificial flowers and offered insight into the intimate plant-insect interactions involved with feeding. Research indicated that flowers with exposed nectaries, such as fennel (Apiaceae: *Foeniculum vulgare* P. Mill.) and dill (Apiaceae: *Anethum graveolens* L.) offered the greatest nectar and pollen availability to small parasitoids. The slightly larger sized *P. foveolatus*, may have possessed enough strength to maneuver floral parts in order to gain access to the partially exposed nectaries of the coriander flowers, which *E. puttleri* was unable to access. This is further supported by work done by Idris and Grafius (1995), which demonstrated that the parasitoid *Diadegma insulare* (Hymenoptera: Ichneumonidae) was able to manipulate several flowers with hidden nectaries to obtain food because of its strength and size.

Several commercial companies currently market seed mixtures of flowering plants to organic growers, claiming they will bring in beneficial insects and help in pest management. When evaluating an agricultural landscape for BIH, it is recommended that 5-10% of the total area be removed from production (Nentwig et al. 1998). Once the designated areas have been set aside, normal plant regeneration can be allowed to take place or they can be planted with a seed mixture (Nentwig et al. 1998). Commercially available seed mixtures are intended to attract a wide variety of desirable insects and provide some of the resources that allow them to produce more offspring. Although some commercial seed producers make claims of which insects their mixture will attract, very little research exists to support this. Braman et al. (2002) evaluated two commercially available seed mixtures for pest suppression in turfgrass and found numbers of beneficial arthropods in the flower strips was consistently lower than in that of the control. However, levels of predation in plots adjacent to these flower strips were significantly higher than that of the control. This further demonstrates the need for additional research to demonstrate to growers how these plants perform under field conditions. In addition, factors such as germination rates, and noxious weed contamination of commercial seed mixtures should be examined.

In 2000, N.G. Creamer and T. Kleese conducted an unpublished survey asking organic growers in North and South Carolina what their top ten research needs were. Survey results indicated the number one response was “insect pests”. When growers were asked to prioritize needs for resolving pest problems, beneficial insects and BIH were their first and second choices, respectively.

This study assessed the value of a commercial BIH seed mix in management of two widespread pests of tomatoes: the tomato fruitworm, *Helicoverpa zea* and hornworms, *Manduca spp.* Because so few data exist on the implementation of commercial BIH, it is hoped this research will aid organic growers in the southeastern US in making informed decisions about the effectiveness of this practice.

Material and Methods

Experimental Design. This study was conducted in 2003 and 2004 at the Center for Environmental Farming Systems (CEFS) in Goldsboro, NC. All plot areas were pesticide free for at least three years prior to this study and were transitioning towards organic certification. The study was set up using a randomized block design with selective placement of treatments and five replications. The six locations were within a 2km radius and acted as blocks. All plots were kept in the same location for both years of the study, with the exception of one control plot, which was moved exactly 15.8m further away from its paired treatment plot due to high tomato disease pressure.

Each plot measured 8.2 by 15.8 m and contained four-13.7 m rows of tomato plants transplanted 0.91 m apart on a 1.52 m row spacing. Treatment plots were surrounded by a transplanted border of Good Bug Blend (Peaceful Valley, P.O. Box 2209, Grass Valley, CA 95945), while around the control plots, a border of brown-top millet was direct seeded. Control and treatment plots were separated by approximately 45 m. The planting design for the Good Bug Blend (GBB) was determined from the estimated percent abundance of each seed species present in the seed mix (See Chapter 1). A sheet of plywood (0.6 by 3.0 m) was employed as a planting template, with pairs of 10.2 cm circles cut into the plywood every 0.09 m on center (Figures 3.1, 3.2). A soaker hose (Aquapore Moisture Systems, Inc., A Fiskars Co., 610 S. 80th Ave., Phoenix AZ 85043) was set 0.30 m in from the plot edge, adjacent to the center of the habitat border.

Crop Management. Tomato seeds, variety ‘Amelia’ (Clifton See Co., P.O. Box 206, Dobson, NC 28341), were obtained in February, 2003 and 2004. Seed coatings were removed by placing seeds in a sieve and rinsing with distilled water. Seeds were planted into 96-cell (3.8 by 3.9 cm) round plug trays (Hummert International, 4500 Earth City Expressway, Earth City, MO 63045) and filled with moistened Metro-Mix 200 potting soil (Scotts-Sierra Horticultural Products Co., The Scotts Company, 14111 Scottslawn

Rd., Marysville, OH 43041). Plug trays were placed under high intensity metal halide lights on a 12-hour photoperiod and watered for five minutes twice daily under a misting bed. Plants were supplementally watered as needed and fertilized once every two weeks with Omega 6-6-6 (Peaceful Valley, P.O. Box 2209, Grass Valley, CA 95945). Once plants were approximately 25 cm tall, they were transplanted into 266 ml plastic beverage cups (Food Lion, LLC., Salisbury, NC 28144) with holes drilled in the bottom using a 1.3 cm drill bit.

Prior to transplanting in 2003, all plots were tractor tilled and left fallow for three weeks. Plots were fertilized with untreated soybean meal (1,547 kg/ha) (J. Milo Pierce Farm Center, Inc., 3626 Nahunta Road, Pikesville, NC 27863) and Solubor (7.6 kg/ha) (Borax, Inc. 26877 Tourney Road, Valencia, CA 91355-1847). Each plot was then hand-tilled and 22.9 m soaker hoses were laid out around the perimeter of each plot and adjacent to the center of where each row of tomatoes would be transplanted. The entire plot was then mulched with 10-15 cm of pesticide-free wheat straw, and tomatoes transplanted on 14-16 May, 2003. Tomato plants were supported with sisal twine (The Lehigh Group, Macungie, PA 18062) secured to wooden stakes (0.02 by 0.02 by 1.4 m) with a 2.7 m stake spacing. Plants were watered in the field as needed using either pump fed soaker hoses or hand watering. All plots had at least a 1.2 m buffer area surrounding all sides, which was planted with brown-top millet and kept mowed to aid in weed suppression.

Tomato plants, stakes and soaker hoses were removed from each plot in September, 2003. In October, each plot was hand tilled and crimson clover seed, variety ‘Au Robin’ (Wyatt Quarles, P.O. box 739, Garner, NC 27529), inoculated with *Rhizobia*

(Urbana Laboratories, 2202 Locust St, St. Joseph, MO 64501) was hand raked in at a rate of 1,547 kg/ha. In treatment plots, both the inside and outside of the habitat border was seeded with crimson clover, whereas control plots had the entire area seeded. In April, 2004, clover was mowed to ground level with a string trimmer and left for two weeks. Untreated soybean meal was applied to each plot at a rate of 1,547 kg/ha and incorporated with the clover residue using a hand tiller.

In 2004, each plot contained four rows of 14 plants, due to habitat growth within treatment plots, the second year of the study, with 0.91 m between each plant and 1.52 m between each row. One-22.86 m soaker hose was placed down the center of each tomato row and each row covered with 1.22 m polyester landscape fabric (Easy Garden Products, Ltd., 3022 Franklin Avenue, Waco, Texas 76710) to aid in weed control. Tomato plants were transplanted through holes cut in the landscape fabric. One-1.83 m metal fence stake (Lowe's Home Improvement, P.O. Box 281791, Atlanta, GA 30384-1791) was placed at the end of each row and angled at approximately 45^{o} away from plots. One-1.22 m wooden stake was placed four plants in from each end and in the center of each row and plants supported with nylon twine (The Lehigh Group, Macungie, PA 18062). Tomato plants were hand watered as needed throughout the growing season. All plots had at least a 1.2 m buffer area surrounding all sides, which was planted with brown-top millet and kept mowed to aid in weed suppression.

Habitat Management. A 0.453 kg package of Good Bug Blend was obtained anonymously in January, 2003. Seeds were separated from one another using an air column seed separator (South Dakota Seed Blower (model 757), Seedburo Equipment Co., 1022 West Jackson Boulevard, Chicago, IL 60607), various sized sieves (Precision

Eforming LLC, 839 Rte. 13, Cortland, NY 13045), and hand separation (See Chapter 1). The percentage of each seed species based on its relative numerical abundance was estimated for planting in the greenhouse and transplanting into the field.

Transplants of each seed species were started in 96-cell (3.4 by 5.3 cm) square plug flats (Hummert International, 4500 Earth City Expressway, Earth City, MO 63045) filled with moistened Metro-Mix 200 potting soil. Seeds of a single species were planted in separate trays, with the exception of the clover and alfalfa, which were planted in a mixture. Plug trays were placed under high-intensity, metal-halide lights on a 12-hour photoperiod and watered for five minutes twice daily under a misting bed. Plants were supplementally watered as needed and fertilized once every two weeks with Omega 6-6-6 (Peaceful Valley, P.O. Box 2209, Grass Valley, CA 95945). Once plugs reached approximately 25 cm in height, they were transplanted into 266 ml plastic beverage cups, with 1.3 cm holes drilled in the bottom. Plants were transplanted into the field 14-16 May, 2003 and watered using pump-fed soaker hoses or hand watering.

Throughout the summer of 2003, hand weeding was conducted within the transplanted habitat to avoid competition by weeds. The habitat was allowed to overwinter and reseed and no hand weeding was conducted within the habitat plantings in 2004. Large broadleaf weeds were removed from within the perimeter of plots to avoid crop competition.

Sampling – Egg Fate. Gravid *Helicoverpa zea* moths were obtained from the North Carolina State University (NCSU) Insectary. On six dates in 2003, moths were transported to Goldsboro, NC in plastic buckets secured with cheesecloth over the lid. Five plants per plot were randomly selected and one leaf on the upper third of the plant was used as substrate for egg laying. A cheesecloth bag (22 by 43 cm) was placed over the selected leaf and three to six gravid moths placed in each bag, closed and secured using plastic coated wire. The bags were left overnight and the following morning moths were removed from the bag and all but five eggs removed. Detailed maps of egg locations on each leaf were recorded on paper tags (12 by 6 cm, Avery-Dennison, Brea, CA 92821) and secured to the base of each leaf using wire. Eggs were left in the field for one week, after which the fate of each egg was recorded.

Due to erratic egg production by insectary-raised moths the first year of the study, eggs from field populations of *H. zea* and *Manduca spp*. as well as insectary reared *Manduca sexta* were evaluated on four dates in 2004. For field populations, plants were scouted and where possible, twenty-five randomly selected eggs were evaluated per plot. Eggs were located and a detailed map of the location of each egg on each leaf was drawn on a paper tag (4.3 by 7.0 cm, Avery-Dennison, Brea, CA 92821), secured to the base of the leaf using string. After two days, the leaves containing the eggs were removed from the plant, inserted into water pics (Syndicate Sales, 2025 N. Wabash Street, Kokomo, IN 46901) and placed in sealed 3.8 liter plastic bag, which were brought back to the Biological Control Laboratory at NCSU for continued egg development. Bags were kept at room temperature and out of direct sunlight. Seven days after eggs were located in the field, they were evaluated and the fate of each egg recorded.

For laboratory procured eggs, tomato leaves were placed in water pics (Syndicate Sales, 2025 N. Wabash Street, Kokomo, IN 46901) and secured along the inside of a wire cage (42 by 44 by 92 cm) containing gravid *M. sexta* and left overnight. The following morning, all but five eggs were removed from each leaf and a detailed map of egg locations drawn on a paper tag (4.3 by 7.0 cm) and secured to the base of each leaf. Leaves and water pics were then taken to the field and secured to five randomly selected tomato plants in each plot using rubber ties. After two days, leaves were removed from the field, placed in plastic bags and transported to the Biological Control Laboratory at NCSU where they were held at room temperature, out of direct sunlight. Seven days after eggs were deposited, the fate of each egg was recorded.

Sampling – Larval Parasitism. On six dates in 2003 (9 July, 16 July, 24 July, 30 July, 6, August and 13 August) and six dates in 2004 (9 July, 15 July, 22 July, 29 July, 4 August and 10 August) field populations of larval hornworms (*Manduca spp*.) were monitored weekly for parasitism by *Cotesia congregata* (Hymenoptera: Braconidae). Each plant in every plot was scouted and the total number of hornworms, parasitized and not, recorded. Larvae were considered parasitized if *C. congregata* coccoons were present on the dorsum of hornworms.

On three dates in 2004 (June 7, 2004 [44 larvae], June 14, 2004, [10 larvae] and June 22, 2004, [33 larvae]) all hornworm larvae were removed from each plot by hand. Plants had not yet become established and this moth flight was earlier in the season than was expected.

Sampling – Habitat Percent Cover. In August of 2004, three-1 m quadrats were sampled on three sides of the perimeter habitat for each treatment plot and all plant species that were originally transplanted were recorded based on a percent composition.

Data Analysis

Egg Fate. For each date in 2003 and 2004, the number of eggs of each fate and the total number of eggs for each date was calculated. The percentage of each egg fate, for each date was calculated as follows: total number of eggs of a particular fate/ total number of eggs recorded on that same date. For the analysis of variation within plots and variation between plots, data was subjected to an analysis of variance (ANOVA) using the Mixed Procedure (PROC MIXED), Type III Test of Fixed Effects. Treatment and control means were compared using the Least Significant Difference Test (LSD) at a significance level of 0.05 (SAS Institute 2002).

Hornworm Parasitism. The numbers of parasitized and nonparasitized larvae were summed to get a total number of larvae found for each date in 2003 and 2004. The percentage of parasitized larvae for each date was calculated by taking the total number of parasitized larvae on a specific date/ the total number of larvae for the same date. For the analysis of variation within plots and variation between plots, data was subjected to an analysis of variance (ANOVA) using the Mixed Procedure (PROC MIXED), Type III Test of Fixed Effects. Treatment and control means were separated using the Least Significant Difference Test (LSD) at a significance level of 0.05 (SAS Institute 2002).

Habitat Percent Cover. Percent cover was estimated for each habitat plant species from three locations around the perimeter of the habitat planting. Averaged values for all treatment plots were averaged for an estimate of percent cover for all habitat plantings.

Results

Egg Parasitism. There was more egg parasitism in 2004 than in 2003, whereas mean values for chewing predators, sucking predators, hatched eggs and unknown fates were higher in 2003 (Table 3.1). However, there was no significant difference when comparing the treatment and control in either year.

Of the known egg fates, parasitism and hatching were observed most often and together comprised approximately 40% of all egg fates in 2003 and over 58% in 2004. When comparing the average percentage of hatched *H. zea* eggs in treatment and control plots, there was no significant difference in either 2003 or 2004 (Figure 3.3 and 3.4). When comparing the average percentage of parasitized *H. zea* eggs by treatment, there was no significant difference in either 2003 or 2004 (Figures 3.5 and 3.6).

The fixed value and PR > F values for Type 3 Tests of Fixed Effects for all egg fates are reported in Appendix 1. Data were analyzed to examine the effect of year, treatment, year by treatment, date within year and treatment by date within year. At the 0.05 level of significance, there was no significant difference for any egg fate by treatment or treatment by date within year. Analysis of data by year found all values for egg fates to be significant with the exception of sucking predators. Analysis of data by year by treatment found only parasitism and chewing predator values to be significant, while date within year found all egg fates to be significant with the exception of chewing predators.

Larval Parasitism. In both 2003 and 2004, the mean number of parasitized hornworm larvae was higher in control plots, although results were not significant (Table 3.2). The average percentage of parasitized *Manduca spp.* larvae in 2003 did not vary significantly, with the exception of 17 July, 2003, in which parasitism levels were much higher in control plots (69%) than in treatment plots (9%) (Figure 3.7). In 2004, the average percent parasitism of hornworm larvae was much closer, with the exception of one date (5 August, 2004), in which parasitism levels were higher in the control plots (65%) than in treatment plots (25%) (Figure 3.8).

The fixed value and PR > F values for Type 3 Tests of Fixed Effects for hornworm larval parasitism are reported in Appendix 2. Data were analyzed to determine the effect of year, treatment, year by treatment, date within year and treatment by date within year. The only significant value seen in larval parasitism was for date within year.

Habitat Percent Cover. The average percent composition of the remaining GBB habitat was recorded for the six treatment plots (Figure 3.9). Only six of the original fourteen species were present at the conclusion of the 2004 field season. Yarrow, fennel and clover were the only species present in every plot with average percent cover estimates of 14.8%, 10.4% and 6.4%, respectively. Celery was found in two plots (0.7%), while only one alfalfa and one dill plant occurred in a single subsample of a single plot (both 0.1%).

Discussion

For BIH to be useful in pest management, there must be a net gain in beneficial insects and a net reduction in insect pests (Landis et al. 2000). Nectar and/or pollen, alternative hosts and a favorable microhabitat are a few of the resources required by natural enemies (Barbosa and Benrey 1998). Research conducted in 2003 compared insects collected from six different flowering plant communities, and found Peaceful Valley's GBB to have the highest populations of beneficial parasitoids and predators (See Chapter 2). However, after two years of evaluating its effectiveness in reducing pest moth egg and, ultimately larval numbers, there was no significant effect. There are two possibilities why this occurred: 1) alternative hosts/ prey in the habitat acted as a "sink" for beneficials and 2) carbohydrates and pollen sources were obtained from outside the habitat.

Because egg parasitism in tomatoes was not affected by presence of habitat, it is possible that alternative hosts were present in the vegetation surrounding the crop. If this were the case, these parasitoids would have no need to enter the plots in search of hosts. This brings up the question of whether or not the habitat is acting as a “source” or a “sink” for natural enemies (Carmona and Landis 1999). In theory, beneficial insects are intended to utilize the resources within a habitat area as needed, but then move into the crop to manage pest populations. However, if the habitat, intended to increase the population of beneficial insects is too attractive and resource-rich, there would be no need to enter the crop. In this study it is unlikely the habitat was acting as a sink. Levels of parasitism were not out of line with what Schmidt (1998) found in tomatoes on four organic farms in central North Carolina.

Predators clearly play an important role in agroecosystems (Barbosa and Wratten 1998, Helenius 1998 and DuFour 2000), however they were of little consequence in regulating pest moth egg populations in this tomato cropping system. Predation levels were lower in 2004, possibly due to adequate resources in the surrounding vegetation, thereby strengthening the hypothesis that the surrounding vegetation was acting as a “sink”. It is also possible that eggs which had been preyed upon could not be located and were recorded as “unknown”.

In May, 2003, a diverse group of flowering plants was transplanted around the perimeter of treatment plots in this study. However, many species were quick to flower and senesce. In fact, the only plants seen in all plots at the end of the 2004 field season were yarrow, fennel and clover. Little if any nectar or pollen was available from the habitat late in the season, yet parasitism levels remained high. Clearly these parasitoids were obtaining needed carbohydrate and protein sources, but it does not appear the habitat provided it. At the time of this publication, no literature is available demonstrating the nectar availability of tomato flowers, but it possible that some of the beneficial insects were able to feed successfully.

A more likely source for a carbohydrate source is from honeydew excreted by aphids (Homoptera: Aphidae). Aphids as well as other homopterans are a commonly encountered pest in tomatoes (Dodson et al 2002) and the honeydew, which they excrete has been shown to provide a carbohydrate source for parasitic Hymenoptera (Idoine and Ferro 1988 and Baggen and Gurr 1998). Because aphid colonies were present within all plots, it is likely that parasitoids benefited and were able to keep parasitism levels high even though no nectar or pollen were available in the BIH.

Clearly, more work needs to be done to evaluate the effectiveness of BIH. While this study did not prove its effectiveness in a tomato cropping system, it is important to bear in mind that this study evaluated a specific commercially available seed mixture planted around a particular crop variety. It is unclear how results would have turned out using a different seed mix or a different crop. Also, results may vary from location to location, so future work should take into consideration incorporating a wide geographic area.

References Cited

Baggen, L.R. and G.M. Gurr. 1998. The influence of *Copidosoma koehleri* (Hymenoptera: Encyrtidae) and the use of flowering plants as a habitat management tool to enhance biological control of potato moth, *Phthorimaea operculella* (Lepdoptera: Gelechiidae). Biological Control, 11:9-17.

Barbosa, P and B. Benrey. 1998. The influence of plants on insect parasitoids: Complications for conservation biological control. pp. 55-82. *In* P. Barbosa [ed.], Conservation Biological Control. Academic Press, New York, NY. pp. 396.

Barbosa, P. and S.D. Wratten. 1998. Influence of plants on invertebrate predators: implications to conserce biological control. pp. 83-100. In Barbosa [ed.], Conservation Biological Control. Academic Press, New York, NY. pp. 396.

Braman, S.K., A.F. Pendley, and W. Corley. 2002. Influence of commercially available wildflower mixes on beneficial arthropod abundance and predation in turfgrass. Environmental Entomology 31(3): 564-572.

Carmona, D.M. and D.A. Landis. 1999. Influence of refuge habitats and cover crops on seasonal activity-density of ground beetles (Coleoptera: Carabidae) in field crops. Environmental Entomology. 28(6): 1145-1153.

Coll, M. 1998. Parasitoid activity and plant species competition in intercropped systems. pp. 85-119. *In* Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, CA. pp. 423.

Dodson, M., J. Bachmann, and P. Williams. 2002. Organic Greenhouse Tomato Production. http://attra.ncat.org/attra-pub/ghtomato.html. Appropriate Technology Transfer for Rural Areas publication. March. pp. 16.

Dufour, R. 2000. Farmscaping to Enhance Biological Control. Appropriate Technology Transfer for Rural Areas (ATTRA) publication. http://www.attra.org/attra-pub/farmscape.html. December. pp. 39.

Helenius, J. 1998. Enhancement of predation through within-field diversification. pp. 121-160. *In* Pickett and Bugg [eds.] Enhancing Biological Control. University of California Press, Berkeley, CA. pp. 422.

Idris, A.B. and E. Grafius. 1995. Abstract only. Wildflowers as nectar sources for *Diadegma insulare* (Hymenoptera: Ichneumonidae), a parasitoid of diamondback moth (Lepidoptera: Yponomeutidae). Environmental Entomology, 24(6): 1726-1735.

Idoine, A.B. and D.N. Ferro. 1988. Aphid honeydew as a carbohydrate source for *Edovum puttleri* (Hymenoptera; Eulophidae) Environmental Entomology, 17:941-944.

Jervis, M.A. and N.A.C. Kidd. 1996. Phytophagy. Pp. 375-394. Chapman and Hall. *In* Jervis, M.A. and N.A.C. Kidd (eds.). Insect Natural Enemies: Practical Approaches to Their Study and Evaluation. pp. 491.

Landis, D. A., S.D. Wratten, and G. M. Gurr. 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu. Rev. Entomol. 45:175-201.

Nentwig, W., T. Frank, and C. Lethmayer. 1998. Sown weed strips: artificial ecological compensation areas as an important tool in conservation biological control. Pp. 133-153. Academic Press. *In* P. Barbosa [ed.] Conservation Biological Control. pp. 396.

Patt, J.M., G.C. Hamilton and J.L. Lashomb. 1997. Foraging success of parasitoid wasps on flowers: interplay of insect morphology, floral architecture and searching behavior. Entomologia Experimentalis et Applicata 83: 21-30.

Pickett, C.H. and R.L. Bugg, (eds). 1998. Enhancing Biological Control. Berkley: UC Press.

SAS Institute. 2002. PROC User's Manual, version 9.1. SAS Institute Inc., Cary, NC.

Schmidt, V.B. 1998. Assessing the impact of beneficial insect populations on organic farms. M.S. Thesis, North Carolina State University, Raleigh.

Wratten, S.D., H.F. van Emden, and M.B. Thomas. 1998. Within-field and border refugia for the enhancement of natural enemies. pp. 375-403. *In* Pickett and Bugg [eds.], Enhancing Biological Control: Habitat Management to Promote Natural Enemies of Agricultural Pests. University of California Press, Berkeley, CA. pp. 423.

Table 3.1. Comparison of the mean number ± standard error of *H. zea* and *Manduca spp.* eggs for each egg fate for treatment and control in 2003 and 2004.

	2003		2004	
Egg Fate	Treatment	Control	Treatment	Control
Parasitized	23.0 ± 3.5 NS	18.5 ± 3.5 NS	43.4 ± 3.7 NS	51.1 ± 3.7 NS
Chewing Predator	4.0 ± 1.1 NS	6.7 ± 1.1 NS	2.4 ± 1.2 NS	1.3± 1.2 NS
Sucking Predator	3.3 ± 0.7 NS	2.5 ± 0.7 NS	1.7 ± 0.8 NS	1.6± 0.8 NS
Hatched	17.2 ± 2.4 NS	21.2 ± 2.4 NS	12.5 ± 2.6 NS	12.8 ± 2.6 NS
Unknown	44.7 ± 3.5 NS	42.2± 3.5 NS	37.1 ± 3.7 NS	32.3 ± 3.7 NS

Table 3.2. Comparison of the mean number ± standard error of parasitized *Manduca spp*. larvae seen per treatment in 2003 and 2004.

Year	Control	Treatment
2003	52.4 ± 7.3 NS	50.3 ± 7.4 NS
2004	52.5 ± 7.0 NS	42.5 ± 7.0 NS

..

Figure 3.1. Plot design for treatment plots surrounded by border of Peaceful Valley's Good Bug Blend.

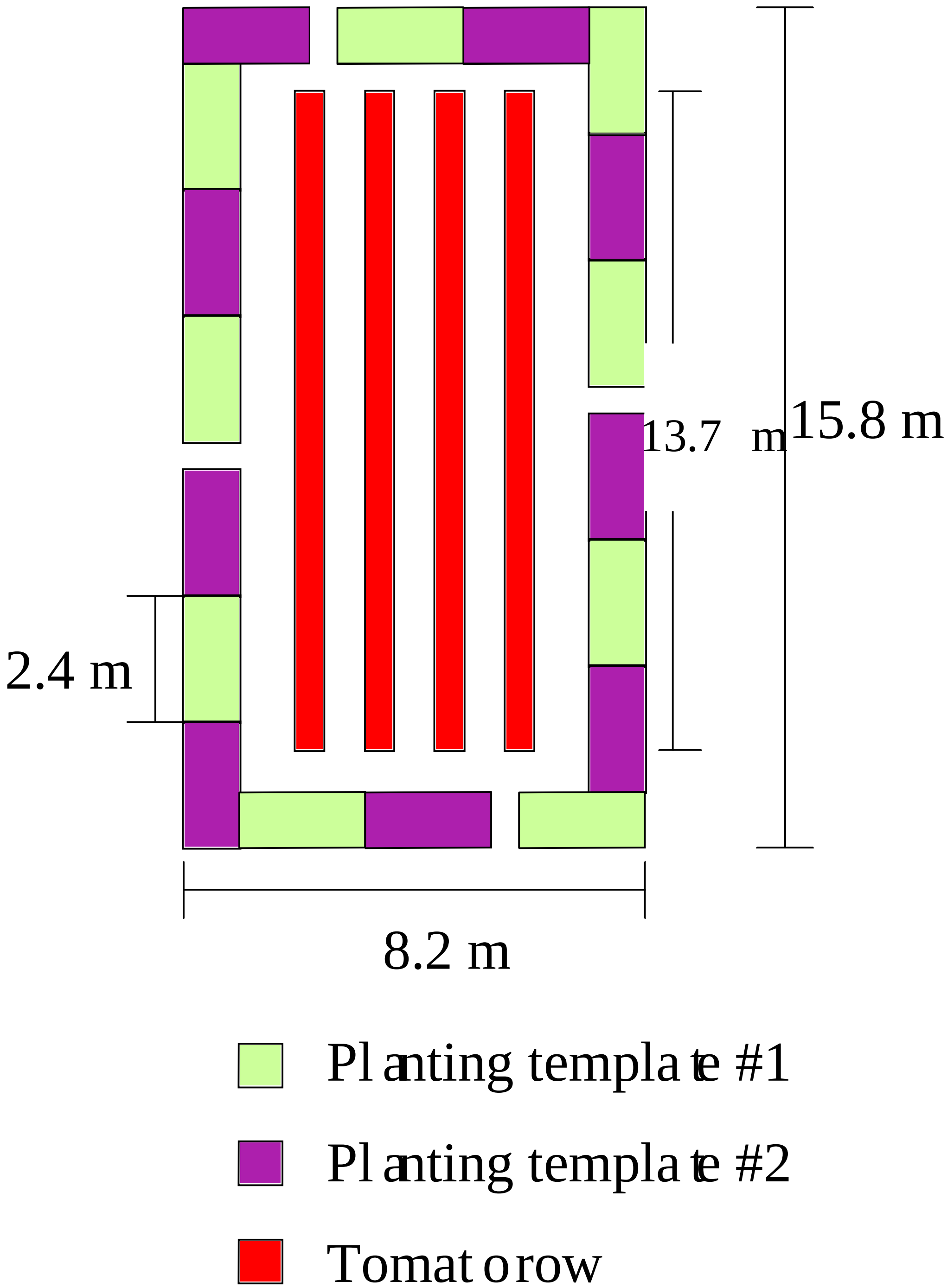


Figure 3.2. Planting design of Peaceful Valley's Good Bug Blend transplanted around treatment plots.

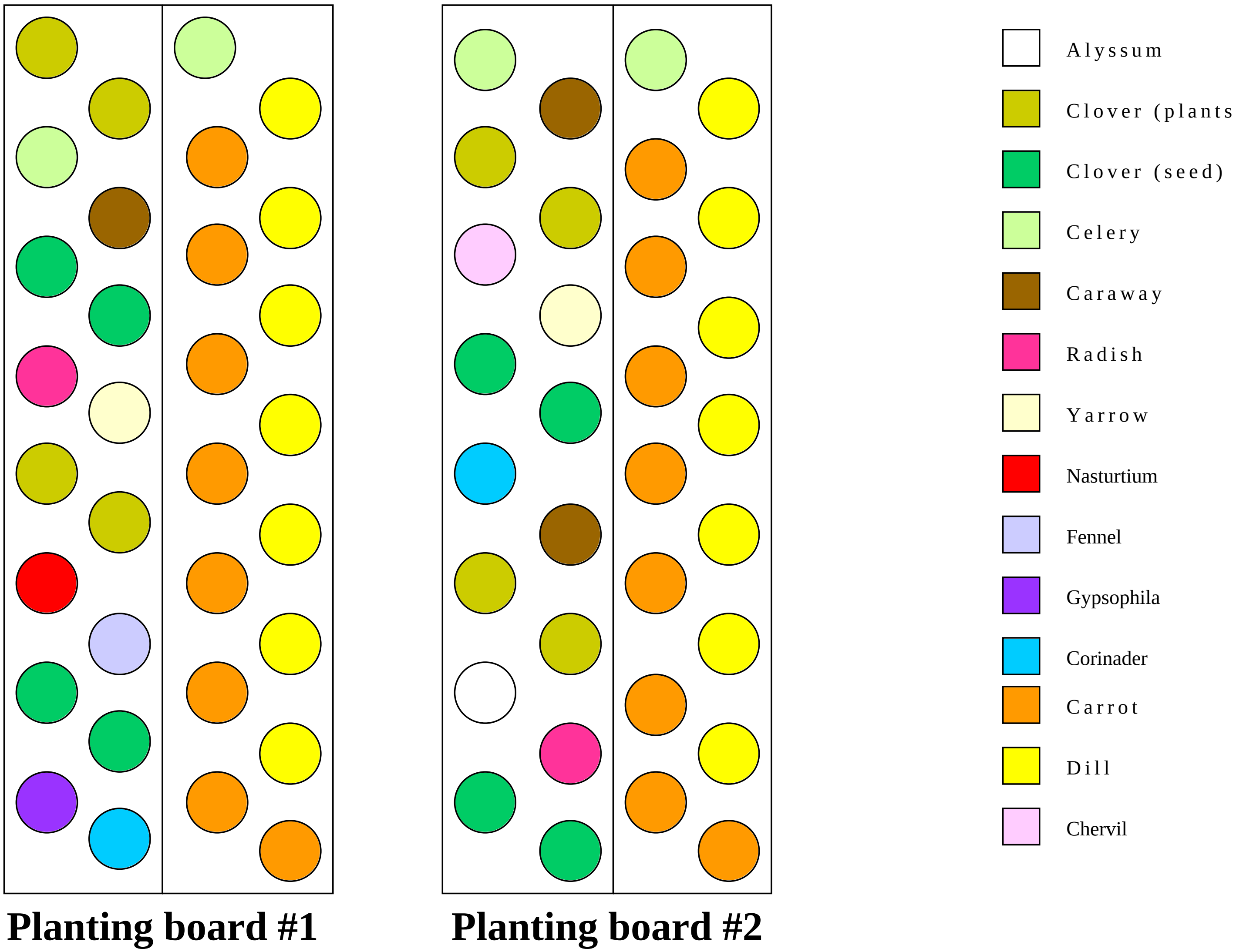


Figure 3.3. Average percentage ± SD of hatched *Helicoverpa zea* eggs for control and treatment plots in 2003.

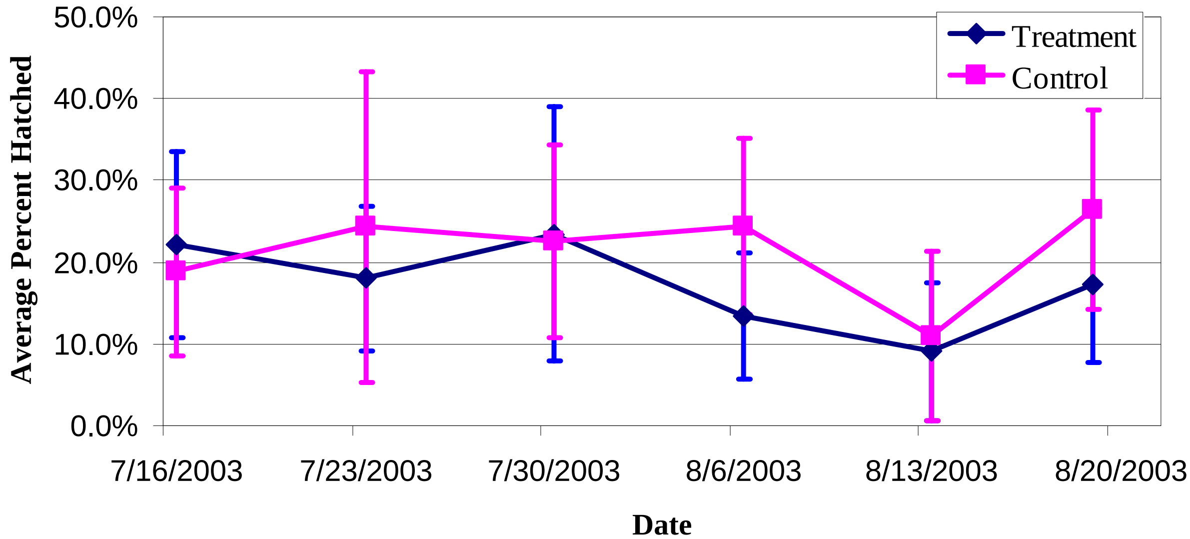


Figure 3.4. Average percentage + SD of hatched *Helicoverpa zea* eggs for control and treatment plots in 2004.

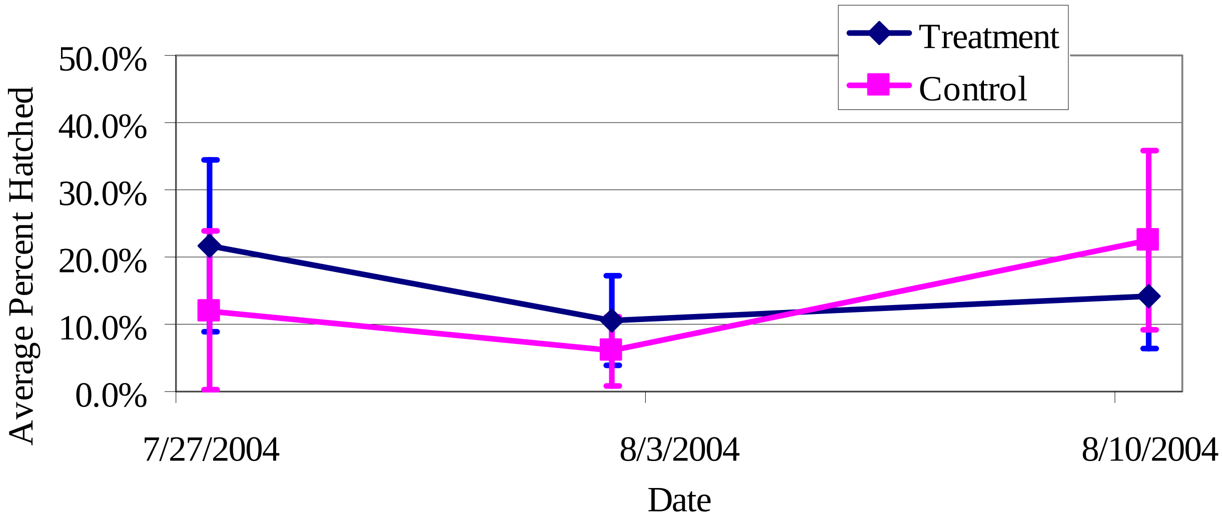


Figure 3.5. Average percentage $\underline{+}$ SD of parasitized *Helicoverpa zea* eggs for control and treatment plots in 2003.

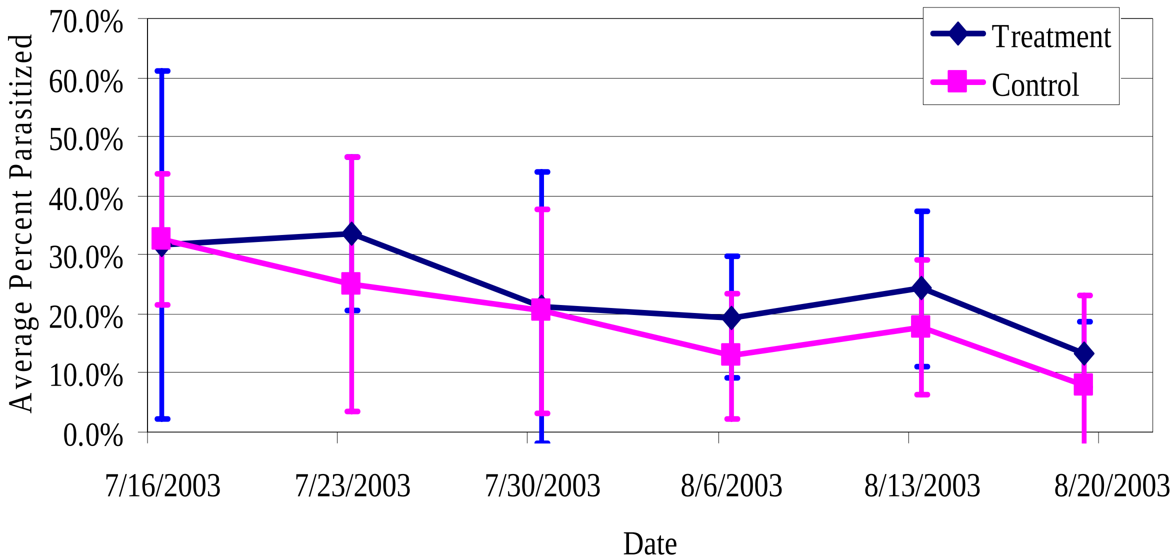


Figure 3.6. Average percentage ± SD of parasitized *Helicoverpa zea* eggs for control and treatment plots in 2004.

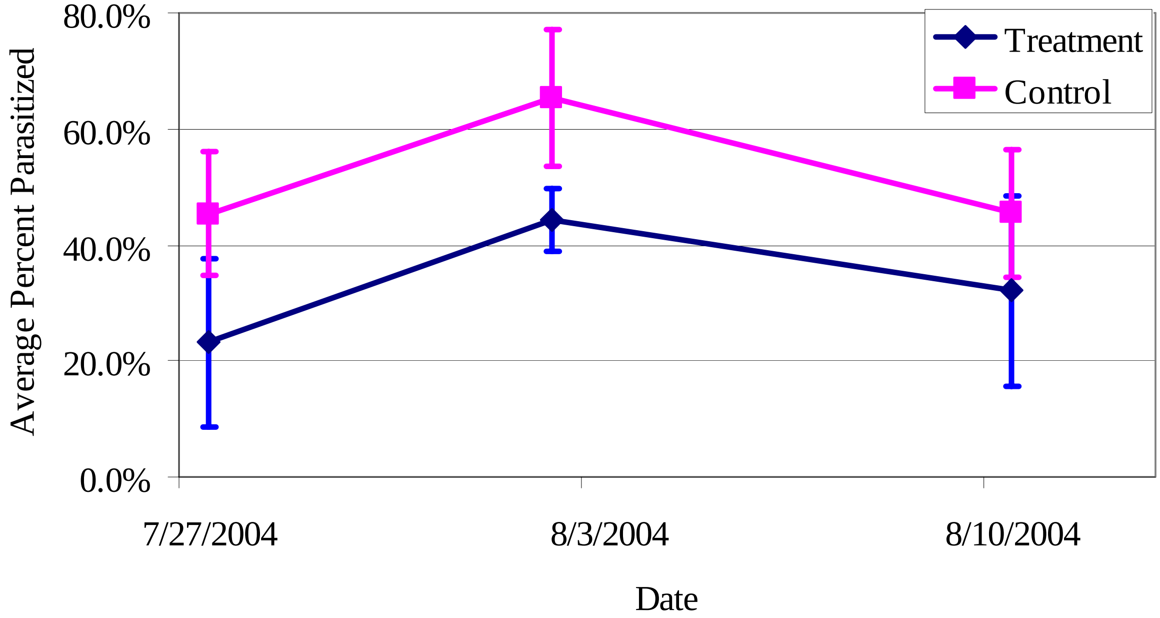


Figure 3.7. Average percentage ± SD of parasitized *Manduca spp*. larvae in 2003.

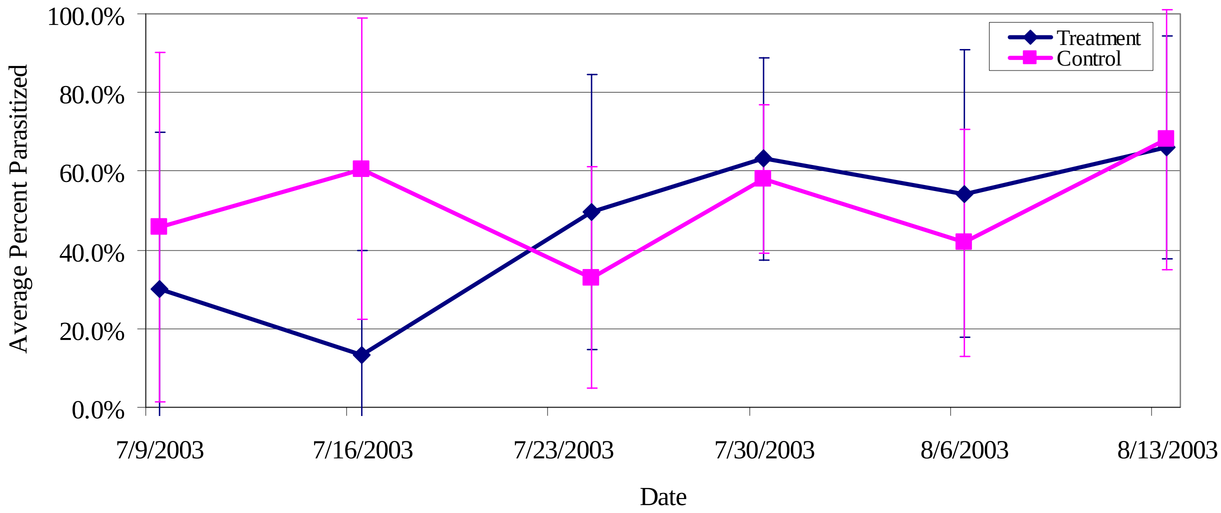


Figure 3.8. Average percentage ± SD of parasitized *Manduca spp.* larvae in 2004.

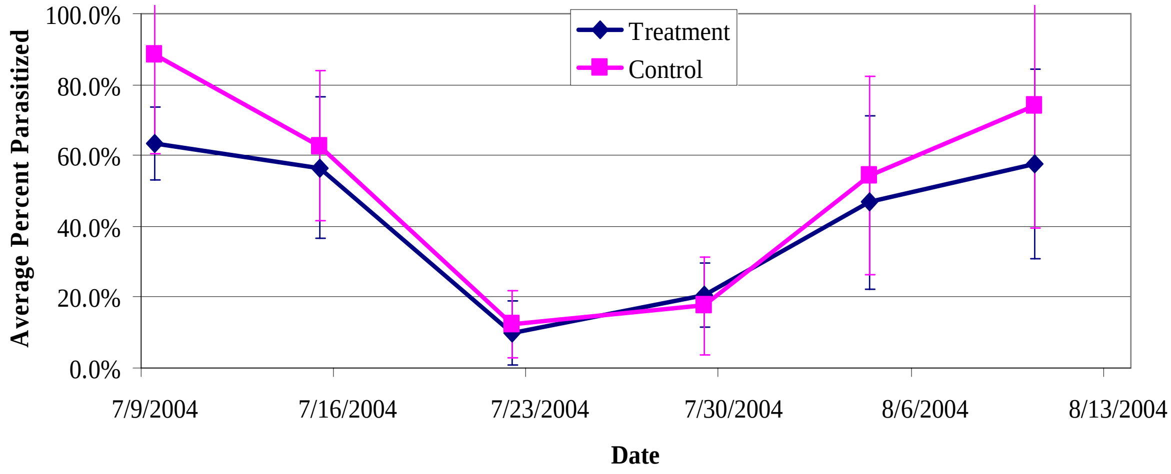
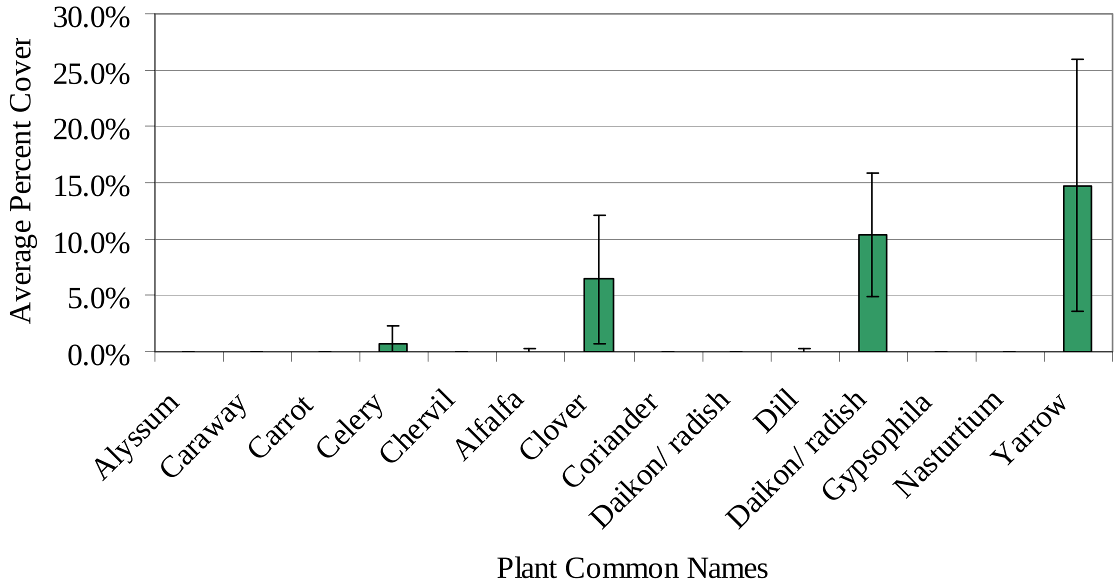


Figure 3.9. Average percent $\pm$ SD cover of beneficial insect habitat surrounding tomato plots on 10 August, 2004.



APPENDIX – CHAPTER 1

Appendix 1.1. The gross weight (g) and percentage of each seed species of by weight in Clyde Robin's Border Patrol™, 2003.

Common Name	Scientific Name	Pkg 1	Pkg 2	Pkg 3	Pkg 1	Pkg 2	Pkg 3
		----g----	----g----	----g----	----%----	----%----	----%----
Evening Primrose	*Oenotheria argillicola* Mackenzie	6.22	27.38	5.52	3.8	13.6	3.5
Buckwheat	*Fagopyrum convolvulis* Moench.	21.54	12.24	21.03	13.3	6.1	13.4
Baby Blue Eyes	*Nemophilia menziesii* Hook. & Arn.	6.09	0.57	0.04	3.8	0.3	0.0
Bishop's Flower	*Ammi majus* L.	6.33	41.28	2.46	3.9	20.5	1.6
Blackeyed Susan	*Rudbeckia hirta* L.	9.79	10.64	2.72	6.0	5.3	1.7
Strawflower	*Helichrysum ssp.* P. Mill.	12.49	22.84	0.15	7.7	11.3	0.1
Nasturtium	*Tropaeolum majus* L.	14.31	12.99	19.55	8.8	6.4	12.5
Angelica	*Angelica atropurpurea* L.	4.97	1.80	3.13	3.1	0.9	2.0
Yarrow	*Achillea millefolium* L.	1.04	11.20	3.70	0.6	5.6	2.4
Candytuft [a]	*Iberis sempervirens* L.	0.00	0.00	7.23	0.0	0.0	4.6
Siberian Wallflower [ab]	*Erysimum hieraciifolium* L.	0.00	0.00	5.34	0.0	0.0	3.4
Mexican Hat [ab]	*Ratibida columnifera* (Nutt.) Woot. & Standl.	0.00	0.30	0.00	0.0	0.1	0.0
Debris		79.45	60.20	86.06	49.0	29.9	54.8
Total weight of all seeds in package		162.23	201.44	156.93	--	--	--

[a] Seed present in only one package
[b] Seed not advertised as being part of mixture, but present

Appendix 1. 2 Estimate of the numerical abundance of each seed species based on weight and the percent composition of each seed species for Clyde Robin's Border Patrol™, 2003.

Common Name	Scientific Name	Package 1	Package 2	Package 3	Package 1	Package 2	Package 3
		----#----	----#----	----#----	----%----	----%----	----%----
Evening Primrose	*Oenotheria argillicola* Mackenzie	15,945	70,205	14,150	18.9	25.2	23.2
Buckwheat	*Fagopyrum convolvulis* Moench.	1,326	754	1,295	1.6	0.3	2.1
Baby Blue Eyes	*Nemophilia menziesii* Hook. & Arn.	1,547	145	11	1.8	0.1	0.0
Bishop's Flower	*Ammi majus* L.	10,205	66,581	3,975	12.1	23.9	6.5
Blackeyed Susan	*Rudbeckia hirta* L.	28,594	31,066	7,930	33.9	11.1	13.0
Strawflower	*Helichrysum ssp.* P. Mill.	18,898	34,562	234	22.4	12.4	0.4
Nasturtium	*Tropaeolum majus* L.	102	92	139	0.1	0.0	0.2
Angelica	*Angelica atropurpurea* L.	866	313	546	1.0	0.1	0.9
Yarrow	*Achillea millefolium* L.	6,916	74,667	24,661	8.2	26.8	40.5
Candytuft [a]	*Iberis sempervirens* L.	0	0	4,293	0.0	0.0	7.1
Siberian Wallflower [ab]	*Erysimum hieraciifolium* L.	0	0	3,648	0.0	0.0	6.0
Mexican Hat [ab]	*Ratibida columnifera* (Nutt.) Woot. & Standl.	0	346	0	0.0	0.1	0.0
Estimate of all seeds in package		84,399	278,73	60,882	--	--	--

[a] Seed present in only one package
[b] Seed not advertised as being part of mixture, but present

Appendix 1.3. The gross weight (g) and percentage of each seed species of by weight in Heirloom Seed’s Beneficial Insect Mix, 2003.

Common Seed Name	Scientific Seed Name	Package 1	Package 2	Package 3	Package 1	Package 2	Package 3
		----g----	----g----	----g----	----%----	----%----	----%----
Sweet Alyssum	*Lobularia maritime* (L.) Desv.	0.61	0.52	0.23	2.4	2.0	0.9
Baby Blue Eyes	*Nemophila menziesii* Hook. & Arn.	2.68	2.39	3.31	10.5	9.1	12.5
Bishop’s Flower	*Ammi majus* L.	0.47	0.34	0.64	1.8	1.3	2.4
Blackeyed Susan	*Rudbeckia hirta* L.	0.34	0.26	0.31	1.3	1.0	1.2
Candytuft	*Iberis sempervirens* L.	3.60	3.23	4.09	14.1	12.3	15.4
Coriander	*Coriandrum sativum* L.	3.22	4.54	3.11	12.7	17.3	11.7
Purple Prairie Clover	*Dalea purpurea* Vent.	0.44	0.35	0.47	1.7	1.3	1.8
Lance-Leaved Coreopsis	*Coreopsis lanceolata* L.	2.06	2.68	2.00	8.1	10.2	7.5
Shasta Daisy	*Leucanthemum x superbum* (J.W. Ingram) Berg. ex Kent.	0.93	0.94	1.02	3.7	3.6	3.8
Forget-me-not	*Myosotis sylvatica* Ehrh. ex Hoffmann	0.23	0.18	0.21	0.9	0.7	0.8
Blanket Flower	*Gaillardia spp.* Foug.	2.14	2.49	2.03	8.4	9.5	7.6
Gayfeather	*Liatris spp.* Gaertn. ex Schreb.	2.15	2.31	2.08	8.4	8.8	7.8
California Poppy	*Eschscholzia californica* Cham.	2.90	2.75	3.23	11.4	10.5	12.2
Dill	*Anethum graveolens* L.	0.44	0.51	0.53	1.7	1.9	2.0
Siberian Wallflower	*Erysimum hieraciifolium* L.	2.92	2.44	3.11	11.5	9.3	11.7
Evening Primrose [a]	*Oenothera spp.* L.	0.25	0.23	0.00	1.0	0.9	0.0
New England Aster [b]	*Aster novae angliae* L.	0.0	0.0	0.0	0.0	0.0	0.0
Debris		0.07	0.06	0.18	0.3	0.2	0.7
Total weight of all seeds in package		25.45	26.22	26.55	--	--	--

[a] Seed not advertised in mix, but present

[b] Seed advertised in mix but not present

Appendix 1. 4 Estimate of the numerical abundance of each seed species based on weight and the percent composition of each seed species for Heirloom Seeds Beneficial Insect Mix, 2003.

Common Seed Name	Scientific Seed Name	Package 1	Package 2	Package 3	Package 1	Package 2	Package 3
		----#----	----#----	----#----	----%----	----%----	----%----
Sweet Alyssum	*Lobularia maritime* (L.) Desv.	1,781	1,465	662	11.2	9.9	3.7
Baby Blue Eyes	*Nemophila menziesii* Hook. & Arn.	1,340	1,265	2,188	8.5	8.5	12.2
Bishop's Flower	*Ammi majus* L.	718	602	1,053	4.5	4.1	5.9
Blackeyed Susan	*Rudbeckia hirta* L.	986	703	1,000	6.2	4.7	5.6
Candytuft	*Iberis sempervirens* L.	1,519	1,367	3,518	9.6	9.2	19.7
Coriander	*Coriandrum sativum* L.	206	284	280	1.3	1.9	1.6
Purple Prairie Clover	*Dalea purpurea* Vent.	268	215	534	1.7	1.5	3.0
Lance-Leaved Coreopsis	*Coreopsis lanceolata* L.	1,015	1,211	680	6.4	8.2	3.8
Shasta Daisy	*Leucanthemum x superbum* (J.W. Ingram) Berg. ex Kent.	819	724	1,700	5.2	4.9	9.5
Forget-me-not	*Myosotis sylvatica* Ehrh. ex Hoffmann	662	533	564	4.2	3.6	3.2
Blanket Flower	*Gaillardia spp.* Foug.	1,161	1,489	1,077	7.3	10.1	6.0
Gayfeather	*Liatris spp.* Gaertn. ex Schreb.	647	740	644	4.1	5.0	3.6
California Poppy	*Eschscholzia californica* Cham.	1,664	1,549	2,118	10.5	10.5	11.8
Dill	*Anethum graveolens* L.	340	383	376	2.1	2.6	2.1
Siberian Wallflower	*Erysimum hieraciifolium* L.	2,374	1,972	1,486	15.0	13.3	8.3
Evening Primrose [a]	*Oenothera spp.* L.	350	308	--	2.2	2.1	--
New England Aster [b]	*Aster novae angliae* L.	--	--	--	--	--	--
Estimate of all seeds in package		15,850	14,809	17,881	--	--	--

[a] Seed not advertised in mix, but present
[b] Seed advertised in mix but not present

Appendix 1.5. The gross weight (g), percentage of total weight, estimated numerical abundance and percent abundance based on weight for Peaceful Valley's Good Bug Blend, 2003.

Common name	Scientific Name	Total wt. (g)	Total wt. (%)	Est. # of seeds	Est. % seeds
		----g----	----%----	----#----	----%----
Alyssum (white)	*Lobularia maritime* (L.) Desv.	1.26	0.06	3,736	0.53
Buckwheat [a]	*Fagopyrum spp.* P. Mill.	0	0	0	0
Caraway	*Carum carvi* L.	20.84	0.93	6,679	0.94
Carrot	*Apiaceae*	102.76	4.56	54,256	7.67
Celery	*Apium graveolens* L.	4.24	0.19	10,765	1.52
Chervil	*Anthriscus cerefolium* (L.) Hoffmann	9.67	0.43	4,741	0.67
Alfalfa	*Medicago sativa* L.				
Clover, Crimson	*Trifolium incarnatum* L.				
Clover, Rose [a]	* *Trifolium hirtum* All.	1,753.59	77.89	535,283	75.69
Clover, Sub-	*Trifolium subterraneum* L.				
Clover, Sweet [a]	*Melilotus spp.* P. Mill.				
Clover, White	*Trifolium repens* L.				
Coriander	*Coriandrum sativum* L.	61.35	2.73	6,644	0.94
Daikon/ Radish	*Raphanus sativus* L.	145.26	6.45	7,776	1.10
Dill	*Anethum graveolens* L.	72.78	3.23	35,889	5.07
Fennel	*Foeniculum foeniculum* (L.) Karst.	11.15	0.50	1,727	0.24
Gypsophila	*Gypsophila spp.* L.	10.01	0.44	9,098	1.29
Nasturtium	*Tropaeolum majus* L.	22.02	0.98	159	1.12
Yarrow	*Achillea spp.* L.	3.35	0.15	22,647	3.20
	Debris	18.67	0.83	--	--
	Weed seeds	14.34	0.64	--	--
	Total	2,251.30	100.00	707,189	100.00

[a] Seed advertised in mix but not present

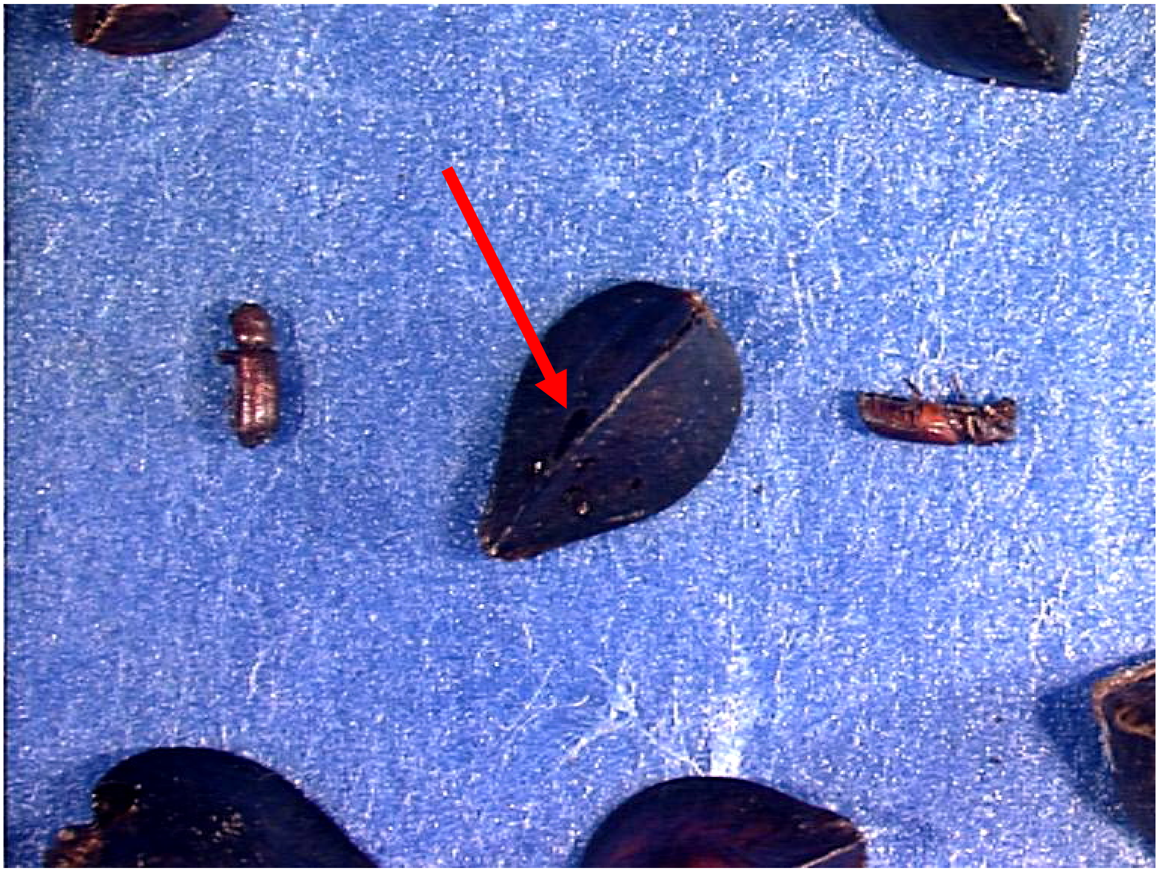
Appendix 1.6. Germination temperatures for each species of seed tested, by company.

Common Name	Scientific Name	Germination Temp.
	Border Patrol ™	---- °C ----
Evening Primrose	*Oenotheria argillicola* Mackenzie	20/30
Buckwheat	*Fagopyrum convolvulis* Moench.	20/30
Baby Blue Eyes	*Nemophilia menziesii* Hook. & Arn.	15
Bishop's Flower	*Ammi majus* L.	20/30
Blackeyed Susan	*Rudbeckia hirta* L.	20/30
Strawflower	*Helichrysum ssp.* P. Mill.	15
Nasturtium	*Tropaeolum majus* L.	20
Angelica	*Angelica atropurpurea* L.	20/30
Yarrow	*Achillea millefolium* L.	20/30
Candytuft	*Iberis sempervirens* L.	15
Siberian Wallflower	*Erysimum hieraciifolium* L.	20/30
Mexican Hat	*Ratibida columnifera* (Nutt.) Woot. & Standl.	20/30
	Beneficial Insect Mix	---- °C ----
Sweet Alyssum	*Lobularia maritime* (L.) Desv.	15
Baby Blue Eyes	*Nemophila menziesii* Hook. & Arn.	15
Bishop's Flower	*Ammi majus* L.	20/30
Blackeyed Susan	*Rudbeckia hirta* L.	20/30
Candytuft	*Iberis sempervirens* L.	15
Coriander	*Coriandrum sativum* L.	15
Purple Prairie Clover	*Dalea purpurea* Vent.	20/30
Lance-Leaved Coreopsis	*Coreopsis lanceolata* L.	20/30
Shasta Daisy	*Leucanthemum x superbum* (J.W. Ingram) Berg. ex Kent.	20/30
Forget-me-not	*Myosotis sylvatica* Ehrh. ex Hoffmann	20/30
Blanket Flower	*Gaillardia spp.* Foug.	20/30
Gayfeather	*Liatris spp.* Gaertn. ex Schreb.	20/30
California Poppy	*Eschscholzia californica* Cham.	15
Dill	*Anethum graveolens* L.	20/30
Siberian Wallflower	*Erysimum hieraciifolium* L.	20/30
Evening Primrose	*Oenothera spp.* L.	20/30
	Good Bug Blend	---- °C ----
Alyssum (white)	*Lobularia maritime* (L.) Desv.	15
Caraway	*Carum carvi* L.	20/30
Carrot	*Apiaceae*	20/30
Celery	*Apium graveolens* L.	20
Chervil	*Anthriscus cerefolium* (L.) Hoffmann	20/30
Clovers & Alfalfa	*Trifolium spp*. L. & *Medicago sativa* L.	20
Coriander	*Coriandrum sativum* L.	15
Daikon/ Radish	*Raphanus sativus* L.	20
Dill	*Anethum graveolens* L.	20/30
Fennel	*Foeniculum foeniculum* (L.) Karst.	20/30
Gypsophila	*Gypsophila spp*. L.	15
Nasturtium	*Tropaeolum majus* L.	20
Yarrow	*Achillea spp*. L.	20/30

Appendix 1.7. Identification of weed components present in all three beneficial insect habitat seed mixtures.

Scientific name	Common Name
Border Patrol™	
Siberian Wallflower	*Erysimum hieraciifolium* L.
Mexican Hat	*Ratibida columnifera* (Nutt.) Woot. & Standl.
Beneficial Insect Mix	
Evening Primrose	*Oenothera spp.* L.
Good Bug Blend	
Orchardgrass	*Dactylis glomerata* L.
Tall Fescue	*Festuca arundinacea* Schreb.
Ryegrass	*Lolium* L. spp.
Japanese Millet	*Echinochloa frumentacea* Link
Lady's Thumb	*Polygonum persicaria* L.
Chess	*Bromus* L. spp.
Oats	*Avena sativa* L.
2 different species	Apiaceae
Rye	*Secale cereale* L. subsp. c*ereale*
Barley	*Hordeum vulgare* L. subsp. *vulgare*
Pea	*Pisum* L. spp.
2 different species	Cucurbitaceae

Appendix 1.8. Photograph of buckwheat seeds damaged by bostrichid beetles (Coleoptera: Bostrichidae) which emerged during germination trials.



Appendix 1.9. Close-up photograph of bostrichid beetle (Coleoptera: Bostrichidae) during BP germination trial.

Appendix 1.10. Close-up photograph of damage to buckwheat seeds by bostrichid beetles (Coleoptera: Bostrichidae) in the BP germination trial.

Appendix 1.11. Comparison of the germination rates of shared species of Heirloom Seed's Beneficial Insect Mix and Clyde Robin's Border Patrol™.

Company	Common Name	Average
		----%----
Heirloom Seeds	Baby Blue Eyes	97.0 NS[A]
Border Patrol™	Baby Blue Eyes	91.4 NS
Heirloom Seeds	Bishop's Flower	90.0 NS
Border Patrol™	Bishop's Flower	93.3 NS
Heirloom Seeds	Blackeyed Susan	89.0 NS
Border Patrol™	Blackeyed Susan	88.3 NS

[A] NS = Not significant (PROC GLM, SAS Institute, 2002)

APPENDIX – CHAPTER 2

Appendix 2.1 Species components in each of the commercial beneficial inset habitats.

Common Name	Scientific Name	No. plants per planting board	No. plants per block
	Border Patrol ™		
Evening Primrose	*Oenotheria argillicola* Mackenzie	2	24
Buckwheat	*Fagopyrum convolvulis* Moench.	2	24
Baby Blue Eyes	*Nemophilia menziesii* Hook. & Arn.	2	24
Bishop's Flower	*Ammi majus* L.	2	24
Blackeyed Susan	*Rudbeckia hirta* L.	2	24
Strawflower	*Helichrysum ssp.* P. Mill.	2	24
Nasturtium	*Tropaeolum majus* L.	2	24
Angelica	*Angelica atropurpurea* L.	2	24
Yarrow	*Achillea millefolium* L.	2	24
Dame's Rocket	*Hesperis matronalis* L.	2	24
Siberian Wallflower	*Erysimum hieraciifolium* L.	2	24
	Beneficial Insect Mix		
Sweet Alyssum	*Lobularia maritime* (L.) Desv.	2	16
Baby Blue Eyes	*Nemophila menziesii* Hook. & Arn.	*2*	16
Bishop's Flower	*Ammi majus* L.	*2*	16
Blackeyed Susan	*Rudbeckia hirta* L.	*2*	16
Candytuft	*Iberis sempervirens* L.	*2*	16
Coriander	*Coriandrum sativum* L.	*2*	16
Purple Prairie Clover	*Dalea purpurea* Vent.	*2*	16
Lance-Leaved Coreopsis	*Coreopsis lanceolata* L.	*2*	16
Shasta Daisy	*Leucanthemum x superbum* (J.W. Ingram) Berg. ex Kent.	*2*	16
Forget-me-not	*Myosotis sylvatica* Ehrh. ex Hoffmann	*2*	16
Blanket Flower	*Gaillardia spp.* Foug.	*2*	16
Gayfeather	*Liatris spp.* Gaertn. ex Schreb.	*2*	16
California Poppy	*Eschscholzia californica* Cham.	*2*	16
Dill	*Anethum graveolens* L.	*2*	16
Siberian Wallflower	*Erysimum hieraciifolium* L.	*2*	16
	Good Bug Blend		
Alyssum (white)	*Lobularia maritime* (L.) Desv.	1	2
Caraway	*Carum carvi* L.	3	7
Carrot	*Apiaceae*	16	40
Celery	*Apium graveolens* L.	4	10
Chervil	*Anthriscus cerefolium* (L.) Hoffmann	1	2
Clovers & Alfalfa	*Trifolium spp.* L. & *Medicago sativa* L.	$_A$ 16	40
Coriander	*Coriandrum sativum* L.	2	5
Daikon/ Radish	*Raphanus sativus* L.	2	5
Dill	*Anethum graveolens* L.	14	35
Fennel	*Foeniculum foeniculum* (L.) Karst.	1	3
Gypsophila	*Gypsophila spp.* L.	1	3
Nasturtium	*Tropaeolum majus* L.	1	3
Yarrow	*Achillea spp.* L.	2	5

$_A$ Denote combined totals for clover seeds and transplants.

Appendix 2.2. List of insect families by feeding guild.

	Decomposer/ Fungus Feeder	
Lathridiidae	Lauxaniidae	Lonchopteridae
Mordellidae	Mycetophilidae	Nitidulidae
Phalacridae	Phoridae	Psocoptera [A]
Scatopsidae	Sciaridae	Sepsidae
Stratiomyidae	Sarcophagidae	
	Herbivore – Crop Pest	
Aphidae	Arctiidae	Chrysomelidae
Cicadellidae	Coreidae	Curculionidae
Elateridae	Languriidae	Lygaeidae
Membracidae	Miridae	Noctuidae
Papillionidae	Pentatomidae	Rhopalidae
Scarabaeidae	Sphingidae	Tephritidae
	Thysanoptera [A]	
	Herbivore – Non-crop Feeder	
Acrididae	Anthicidae	Berytidae
Cecidomyiidae	Cercopidae	Chloropidae
Cydnidae	Delphacidae	Drosophilidae
Geometridae	Gryllidae	Hesperiidae
Nymphalidae	Otitidae	Pieridae
Tettigoniidae	Thyreocoridae	Tipulidae
	Pollinators	
Anthophoridae	Apidae	Halictidae
	Parasitoid - Beneficial	
Bethylidae	Braconidae	Dryinidae
Encyrtidae	Eulophidae	Ichneumonidae
Mymaridae	Proctotrupidae	Scelionidae
	Trichogrammatidae	
	Parasitoid – Mixed	
Ceraphronidae	Diapriidae	Pteromalidae
	Parasitoid – Non-crop	
Eucoilidae	Meloidae	Platygasteridae
Scoliidae	Tiphiidae	
	Predator - Beneficial	
Anthocoridae	Carabidae	Chrysopidae
Coccinellidae	Dolichipodidae	Formicidae
Lygaeidae	Nabidae	Pentatomidae
Reduviidae	Araneidae	Staphylinidae
Syrphidae	Tachinidae	Vespidae
	Predator – Inconsequential	
Cantharidae	Cucujidae	Empididae
Lampyridae	Libellulidae	Sphecidae

[A] Denotes order level identification, rather than family.

Appendix 2.3 Results of analysis of variance by mix, rep within mix, date, and mix by date.

	Simpson	Shannon	N1	N2	Evenness	Richness
Mix						
df	5, 84	5, 84	5, 84	5, 84	5, 84	5, 84
F value	0.1617	87.47	53.88	36.13	12.67	43.41
Pr > F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Rep(mix)						
df	12, 84	12, 84	12, 84	12, 84	12, 84	12, 84
F value	1.35	1.81	1.51	1.02	1.31	4.68
Pr > F	0.2042	0.059	0.1381	0.4417	0.2307	<0.0001
Date						
df	7, 84	7, 84	7, 84	7, 84	7, 84	7, 84
F value	15.92	30.02	25.01	13.17	4.16	35.07
Pr > F	<0.0001	<0.0001	<0.0001	<0.0001	0.0006	<0.0001
Mix*date						
df	35, 84	35, 84	35, 84	35, 84	35, 84	35, 84
F value	5.11	2.67	1.65	13.17	2.08	1.19
Pr > F	<0.0001	0.0001	0.0329	<0.0001	0.0034	0.255

Appendix 2.4 SAS (2002) input code for data analysis.

```
PROC IMPORT OUT= WORK.big
DATAFILE= "F:\Thesis\D-vac Thesis\stastics D-vac\smallandbig.xls"
DBMS=EXCEL2000 REPLACE;
RANGE="'big-all$'";
GETNAMES=YES;
RUN;
PROC IMPORT OUT= WORK.sm
DATAFILE= "F:\Thesis\D-vac Thesis\stastics D-vac\smallandbig.xls"
DBMS=EXCEL2000 REPLACE;
RANGE="'small-all$'";
GETNAMES=YES;
RUN;

data big; set big; if date='.' then delete;
proc print data=big; run;
data sm2; set sm;
if date='.' then delete;
array s CHRYS -- SPIDR;
Do over s;
s = 6.6*s;
end;
proc print ;
run;
data both; set big sm2;
proc print ;
run;
proc sort data=both; by date mix rep;
proc means sum noprint data=both; by date mix rep;
output out= b2 sum = ;
var   ANTHI CANTHE CARAB CHRYS COCCI CUCUJ CURCU ELATE LAMPY LANGU
LATHR MELOT MORDE NITID PHALA SCARA STAPH CHLOR DOLIC DROSO EMPID LAUXA
LONCH MYCET OTITI SARCO SCIAR SEPS STRAT SYRPH TACHI TEPHR TIPUL MENIA
BERYT COREI CYDNI LYGH LYGP MIRID NABID PENTAH PENTAP REDUV RHOPA THYRE
APHID CERCO CICAD DELFA MEMBR ANTHOP APIDA BETHY BRACO DRYII EUCOI
FORMI HALIC ICHNE PTERO SCELI SCOLII SPHEC TIPHI VESPI ARCTI GEOMI
HESPE NOCTU NYMPH PAPIL PIERI SPHIN CRSOP LIBELL ACRID GRYLL TETTO
PSOCO SPIDR CECID PHORI SCATO ANTIC CERAP DIAPR  ENCYR  EULOP  MYMAR
PLATY PROCT TRICH ORTHI THYSA;
 proc print data=b2; run;
 proc means sum n data=b2;
var ANTHI CANTHE CARAB CHRYS COCCI CUCUJ CURCU ELATE LAMPY LANGU LATHR
MELOT MORDE NITID PHALA SCARA STAPH CHLOR DOLIC DROSO EMPID LAUXA LONCH
MYCET OTITI SARCO SCIAR SEPS STRAT SYRPH TACHI TEPHR TIPUL MENIA BERYT
COREI CYDNI LYGH LYGP MIRID NABID PENTAH PENTAP REDUV RHOPA THYRE APHID
CERCO CICAD DELFA MEMBR ANTHOP APIDA BETHY BRACO DRYII EUCOI FORMI
HALIC ICHNE PTERO SCELI SCOLII SPHEC TIPHI VESPI ARCTI GEOMI HESPE
NOCTU NYMPH PAPIL PIERI SPHIN CRSOP LIBELL ACRID GRYLL TETTO PSOCO
SPIDR CECID PHORI SCATO ANTIC CERAP DIAPR  ENCYR  EULOP  MYMAR PLATY
PROCT TRICH ORTHI THYSA;
run;

data b2; set b2; drop _type_ _freq_;
proc transpose data=b2 out=t; by date mix rep;
data t; set t; family=_name_;
```

```
if family='MENIA' then delete;
IF FAMILY IN ('LATHR', 'LAUXA', 'LONCH', 'MORDE', 'MYCET', 'NITID',
'PHALA', 'PHORI', 'PSOCO',
'SCATO','SCIAR', 'SEPS', 'STRAT','SARCO') THEN FG='D    ';
IF FAMILY IN ('APHID', 'ARCTI', 'CHRYS', 'CICAD', 'COREI', 'CURCU',
'ELATE', 'LANGU',
'LYGH', 'MEMBR', 'MIRID', 'NOCTU', 'PAPIL', 'PENTAH', 'RHOPA', 'SCARA',
'SPHIN', 'TEPHR',
'THYSA','ORTHI') THEN FG='HCP';
IF FAMILY IN ('ACRID', 'ANTHI', 'BERYT', 'CECID', 'CERCO', 'CHLOR',
'CYDNI', 'DELFA', 'DROSO',
'GEOMI', 'GRYLL', 'HESPE', 'NYMPH', 'OTITI', 'PAPIL', 'PIERI', 'TETTO',
'THYRE', 'TIPUL')
THEN FG='HG';
IF FAMILY IN ('ANTHOP', 'APIDA', 'HALIC') THEN FG='HPF';
IF FAMILY IN ('BETHY', 'BRACO', 'DRYII', 'ENCYR', 'EULOP', 'ICHNE',
'MYMAR', 'PROCT',
'SCELI', 'TRICH') THEN FG='PAB';
IF FAMILY IN ('CERAP', 'DIAPR', 'PTERO') THEN FG='PAM';
IF FAMILY IN ('EUCOI', 'MELOT', 'PLATY', 'SCOLII', 'TIPHI') THEN
FG='PAN';
IF FAMILY IN ('ANTIC', 'CARAB', 'CRSOP', 'COCCI', 'DOLIC', 'FORMI',
'LYGP', 'NABID', 'PENTAP',
'REDUV', 'SPIDR', 'STAPH', 'SYRPH', 'TACHI', 'VESPI') THEN FG='PBR';
IF FAMILY IN ('CANTHE', 'CUCUJ', 'EMPID', 'LAMPY', 'LIBELL', 'SPHEC')
THEN FG='PRI';
drop _name_;
proc print data=t; run;

data div; set t; count=col1;
if count>0 then present=1; else present=0;
drop col1;
proc sort data=div; by mix rep date;
proc means data=div; by mix rep date; output out=ff sum= n0;
var present;
proc print data=ff; run;

proc sort data=div; by mix rep date family;
proc means noprint; by mix rep date family;
output out=tot sum= totcount; var count;
proc print data=tot; run;
proc means data=tot noprint; by mix rep date ;
output out=all sum=totalf; var totcount;
proc print data=all; run;
data index; merge tot all;by mix rep date ;
s=(totcount-1)*(totcount)/(totalf*(totalf-1));
p=totcount/totalf;
sh=-p*log(p);
proc print data=index ; run;

proc means data=index noprint;by mix rep date ;
output out=indx sum=simpson shannon;
var s sh;
data index; set indx;
n1=exp(shannon);
n2=1/simpson;
proc print data=indx;
```

```
proc sort data=index; by mix rep date;
data even; merge index ff; by mix rep date;
even=n1/n0; richness=n0; proc print;
proc glm data=even; class mix rep date;
model simpson shannon n1 n2 even richness =mix rep(mix) date|mix;
test h=mix e=rep(mix);
means date mix;
means mix/lsd e=rep(mix);
means date/lsd;
run;

**** Calculate indeces separately by feeding guild
***************************;
data div; set t; count=col1;
if count>0 then present=1; else present=0;
drop col1;
proc sort data=div; by fg mix rep date;
proc means data=div; by fg mix rep date; output out=ff sum= n0;
var present;
proc print data=ff; run;

proc sort data=div; by fg mix rep date family;
proc means noprint; by fg mix rep date family;
output out=tot sum= totcount; var count;
proc print data=tot; run;
proc means data=tot noprint; by fg mix rep date ;
output out=all sum=totalf; var totcount;
proc print data=all; run;
data index; merge tot all; by fg mix rep date ;
s=(totcount-1)*(totcount)/(totalf*(totalf-1));
p=totcount/totalf;
sh=-p*log(p);
proc print data=index ; run;

proc means data=index noprint; by fg mix rep date ;
output out=indx sum=simpson shannon;
var s sh;
data index; set indx;
n1=exp(shannon);
n2=1/simpson;
proc print data=indx;
proc sort data=index; by fg mix rep date;
data even; merge index ff; by fg mix rep date;
even=n1/n0; richness=n0; proc print; run;

proc glm data=even; class mix rep date; by fg;
model simpson shannon n1 n2 even richness =mix rep(mix) date|mix;
test h=mix e=rep(mix);
means date mix;
means mix/lsd e=rep(mix) lines;
means date/lsd lines;
run;

proc sort; by date; proc freq; by date; tables fg*n0; run;
```

APPENDIX – CHAPTER 3

Appendix 3.1. Analysis of variance for each of the different egg fates based on year, treatment, year by treatment, date within year, and treatment by date within year.

Year

Effect	df	F value	Pr > F
Parasitized	1,4	85.21	0.0008
Hatched	1,4	8.57	0.0429
Chewing Predator	1,4	9.57	0.0364
Sucking Predator	1,4	2.80	0.1698
Unknown	1,4	8.61	0.0427

Treatment.

Effect	df	F value	Pr > F
Parasitized	1,5	0.26	0.6325
Hatched	1,5	1.03	0.3558
Chewing Predator	1,5	0.62	0.4665
Sucking Predator	1,5	0.52	0.5036
Unknown	1,5	1.55	0.2685

Year by treatment.

Effect	df	F value	Pr > F
Parasitized	1,74	4.77	0.03252
Hatched	1,74	0.73	0.3962
Chewing Predator	1,74	2.80	0.0986
Sucking Predator	1,74	0.25	0.6221
Unknown	1,74	0.15	0.7037

Date within year.

Effect	df	F value	Pr > F
Parasitized	8,74	10.79	<0.0001
Hatched	8,74	3.64	0.0013
Chewing Predator	8,74	0.66	0.7280
Sucking Predator	8,74	3.93	0.0006
Unknown	8,74	4.28	0.0003

Treatment by date within year.

Effect	df	F value	Pr > F
Parasitized	8,74	0.38	0.9259
Hatched	8,74	0.55	0.8143
Chewing Predator	8,74	0.86	0.5543
Sucking Predator	8,74	1.55	0.1554
Unknown	8,74	1.59	0.1421

Appendix 3.2: Analysis of Variance Table for *Manduca spp*. larvae based on year by treatment, date within year and treatment by date within year.

Effect	df	F value	Pr > F
Year	1,4	0.84	0.4123
Treatment	1,5	2.15	0.2021
Year * treatment	1,92	0.93	0.3369
Date (year)	10,92	8.40	<0.0001
Treatment * date (year)	10,92	1.46	0.1682