Plant Diversity and its Effects on Populations of Cucumber Beetles

and Their Natural Enemies in a Cucurbit Agroecosystem

by

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PLANT DIVERSITY AND ITS EFFECTS ON POPULATIONS OF CUCUMBER BEETLES AND THEIR NATURAL ENEMIES IN A CUCURBIT AGROECOSYSTEM

by

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Horticulture

(Abstract)

Populations of striped cucumber beetles (*Acalymma vittatum* Fabr.), spotted cucumber beetles (*Diabrotica undecimpunctata howardi* Barber), western cucumber beetles (*Acalymma trivittatum* Mann.), Pennsylvania leatherwings (*Chauliognathus pennsylvanicus* DeGeer), Diptera (Order: Diptera), lady beetles (Order: Coleoptera, Family: Coccinellidae), hymenoptera (Order: Hymenoptera), and spiders (Order: Araneae) in a cucumber field and a bordering field of uncultivated vegetation were assessed using yellow sticky traps to determine: 1) the relative abundances of target insects across the uncultivated vegetation and the crop field, 2) relationships between target insects and plant species. In both years populations striped and spotted cucumber beetles and Pennsylvania leatherwings (only in 1995) increased significantly and Diptera decreased significantly in the

direction of the crop. The strength of these relationships increased over the season to a peak in August in 1995 and July in 1996 and then decreased in September in both years. There were significant correlations between Diptera and sweet-vernal grass in 1995. In 1996, cucumber beetles were correlated with wild violet (*Viola* spp.) and white clover (*Trifolium repens*); Diptera with wild violets; and the lady beetle *Coleomegilla maculata* with goldenrod (*Solidago* spp.), English plantain (P*lantago lanceolatta*), and marjoram (*Origanum* spp.) in 1996. This study demonstrated the potential value of increasing the diversity of a cucumber field to control insect pests (and thus reduce pesticide useage) as well as suggested specific plants that influenced insect populations.

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Background

In his 1958 book, *The Ecology of Invasions by Animals and Plants*, Charles Elton submitted the hypothesis that more diverse communities are more stable (fewer and smaller population fluctuations and thus fewer and less severe outbreaks). It was an idea based upon observation and intuitive reasoning that for quite some time was widely accepted by ecologists. Subsequently, though, the mathematical models of May (1973) and Pimm (1979) have brought Elton's hypothesis under question and launched a debate that has yet to be resolved (Tilman, 1996).

When it was first put forth, Elton's diversity/stability hypothesis drew a great deal of interest from the fields of forestry and agriculture. At the time, standard production practices used large monoculture forests and fields, the most unstable situation possible according to Elton's hypothesis. It was noted (particularly among foresters) that areas of monoculture production had more severe pest problems than areas with polycultures (Pimental, 1961; Altieri and Letourneau, 1982). Forestry and agriculture researchers hoped that by increasing the diversity of the tree or crop environment, they could reduce or eliminate pest outbreaks.

Much of the early work and early success with incorporating diversity into production was in the field of forestry. In fact, foresters were experimenting with increased diversity as early as 1920 (Pimentel, 1961), decades before the diversity/stability hypothesis was proposed. Repeatedly, foresters demonstrated that mixing two or more tree species within a managed stand resulted in a reduction in the frequency or severity of pest outbreaks (for a summary of the successes, see Pimentel, 1961). Today, planting mixed stands to control pests is a common practice. Agriculturalists, however, were slow to adopt this approach and it was not until the 1960's that extensive research began (Altieri and Letourneau, 1982; Risch, 1983; Kemp and Barrett, 1989).

To increase the diversity of an agricultural system researchers have experimented with two systems: polycultures of crops and areas of uncultivated growth ("weeds") within and around a field. A polyculture is a production system where the grower plants two or more crops within a field (often in alternating strips). Each of the crops may be of economic value or one may serve as an unharvested trap, drawing the pest insect away from the main crop, or serve as a habitat for beneficial insects. Risch (1981) demonstrated that a polyculture of squash, corn, and beans had significantly lower populations of herbivorous beetles than monocultures of those crops. Tahavanainen and Root (1972) reduced flea beetle populations on tobacco with a polyculture of tomato, tobacco, and cabbage.

Utilization of natural vegetation within the field has shown similar results. Pimentel (1961) demonstrated that cabbage grown interspersed with the natural vegetation of a fallow field had fewer herbivorous taxa and smaller herbivore populations than monocultures of cabbage. Smith (1976) reduced damage to brussels sprouts from the imported cabbage butterfly and aphids by incorporating naturally occurring "weed" complex as strips within the field.

Such successes are common but not necessarily the rule. Risch et al. (1983) summarized 150 studies where the effects of increased community diversity on herbivorous insects had been observed. Among the 150 studies, 53% showed a decrease in herbivore populations, 18% showed an increase, and 28% showed either variable response or no response at all. Complicating matters are sometimes contradictory results. Pimentel (1961) successfully controlled insect pests of cabbage with successional vegetation, yet Kemp and Barrett (1989) found that for soybeans, successional vegetation actually increased crop damage whereas strips of planted grasses provided effective control. Such contradictions may be the result of differences in the biology and search strategy of the various pests as well as differences in the microclimates of the fields due to the plants utilized.

Several hypotheses have been proposed to investigate the mechanisms of insect population changes in these systems. The first, the natural enemy hypothesis, states that populations of predators and parasites will be "augmented" in more complex systems and thus suppress herbivore insects (Altieri and Letourneau, 1982; Risch, 1983; Russel, 1989). The reasoning behind this hypothesis is that increased diversity increases the likelihood that the food and habitat resources of beneficial insects will be present. Crop systems in which weeds were allowed to persist within the crop field have shown higher populations of predatory insects in the "weed diverse" fields (Pimentel, 1961; Flaherty, 1969; Root, 1973; Shelton and Edwards, 1983).

The second hypothesis, resource concentration, states that in diverse systems the crop species is less concentrated and the visual and olfactory cues of other plant species may serve to mask the crop species (Altieri and Letourneau, 1982; Risch, 1983). Risch (1981) and Bach (1980) showed that populations of adult diabroticite beetles were lower in diversified systems and were more influenced by the difficulties of moving into, through, and out of diversified systems. Tahvanainen and Root (1972) demonstrated that the olfactory stimuli of tomato and tobacco were responsible for reduced incidence of flea beetles on tobacco.

The third hypothesis, associational resistance (Altieri and Letourneau, 1982), states that in a diverse system, the complex structure and the widely different and highly fragmented microclimates make it difficult for the pest to find and remain in "favorable spots" (Altieri and Letourneau, 1982). Bach (1980) found that the movements of the striped cucumber beetle (*Acalymma vittatum* Fabr.) were hindered by planting cucumbers with corn and broccoli.

The effects of diversity on pest insects are still not fully understood. The following study attempts to clarify some of the influences plant diversity has on populations of pest and beneficial insects by assessing their populations in a natural, uncultivated field adjacent to a managed cucumber field. Cucumbers were selected on the basis of a survey of biological and sustainable agriculture farmers in Virginia who were interested in reducing insecticide usage. The survey indicated that in the absence of insecticides, cucurbit crops were difficult to grow in Virginia due to pest pressure, and of the pests, cucumber beetles (striped, *Acalymma vittatum* Fabr.; spotted, *Diabrotica undecimpunctata howardi* Barber) and the squash vine borer (*Melittia cucurbitae* Harris) comprised 74% of the cucurbit pests (Caldwell et al., 1995). A paper presenting the results of two years of research follows. After the paper, some additional observations are made on possible future directions.

Plant Diversity and its Effects on Populations of Beneficial and Pest Insects

Introduction

Charles Elton (1958) proposed the hypothesis that increased diversity leads to increased stability (fewer and smaller population fluctuations and thus fewer and less severe outbreaks). This ecological concept has attracted much interest from agricultural researchers as a possible guide for restructuring farming practices to reduce pest insect outbreaks, maintain pest insect populations below economic thresholds, and thereby decrease or eliminate insecticide usage (Pimentel, 1961; Altieri and Letourneau, 1982; Risch, 1983).

Tests of the effects of increasing the plant diversity in a crop field have yielded variable results, with reduced herbivore populations in only 53% of 150 studies (Risch, 1981). One reason for these varying results is the inadequate understanding of the relationships between pests, beneficial insects, and the non-crop plant species (Risch, 1983). A greater understanding of these relationships is necessary before increased plant diversity in a crop system can become a useful means of pest control.

The objectives of this research were to determine:

1) The vegetative composition of uncultivated vegetation (uncultivated vegetation was defined as the naturally occuring plants in the study area);

2) The relative abundances of pest and potentially beneficial insects along a transect running from the uncultivated vegetation into the crop field;

3) Relationships between pest and potentially beneficial insects and plant species in the uncultivated vegetation.

The operating hypotheses of the study were:

1) Pest populations would increase in the uncultivated vegetation as one approached the crop field and continue to increase as one moved further into the crop field away from the uncultivated vegetation.

2) Beneficial insect populations would decrease in the uncultivated vegetation as one approached the crop field and continue to decrease as one moved further into the crop field away from the uncultivated vegetation.

3) Populations of pest and beneficial insects would vary with plant species diversity within the field, with beneficial insect populations increasing with increasing plant diversity and pest populations increasing with decreasing plant diversity.

4) Specific plant species would be identified that had higher or lower populations of target insects associated with them.

Cucumbers were selected as the study crop on the basis of a survey of biological and sustainable agriculture farmers in Virginia who were interested in reducing insecticide useage. The survey indicated that in the absence of insecticides, cucurbit crops were difficult to grow in Virginia due to pest pressure, and of the pests, cucumber beetles (striped, *Acalymma vittatum* Fabr.; spotted, *Diabrotica undecimpunctata howardi* Barber) and the squash vine borer (*Melittia cucurbitae* Harris) comprised 74% of the cucurbit pests (Caldwell et al., 1995). The striped cucumber beetle was of particular interest since feeding damage can kill new seedlings, and later in the season, feeding can spred bacterial wilt and mosaic virus (Foster and Flood 1996).

Methods

Site selection and plot placement. A site was selected for establishment of a research plot consisting of a cucumber planting next to natural vegetation. Selection criteria were:

1) The site should be remote from areas of pesticide

usage.

2) The site should have been in a natural state for several years.

3) The site should have a relatively high abundance of natural vegetation.

On the basis of these criteria, a site was selected at Virginia Tech's Kentland farm consisting of a fallow field surrounded on three sides by forest. A 50 m by 60 m research plot was located on the eastern side of the site bordering one of the three forested sides (Fig. 1).

The plot was divided into two 25 m X 60 m halves. The half closest to the forest was left in its natural state. The other half served as the cucumber field and was mowed and tilled in preparation for planting cucumbers. The plot was further divided into three 10 m X 50 m replications.

Sampling squares. In 1995 thirty-three 2 m X 2 m sampling squares were established within the plot, with each replication having 11 squares. Within each replication the squares were laid out in two parallel rows containing five plots each, with one square between the two rows at the forest end of the replication (Fig. 1a). The center square was origninally to be part of a marked-release study that was subsequently dropped. Rows were 4 m apart within a replication and 7 m apart between replications. Squares within a row were 5 m apart (as measured from the end of one square to the beginning of the next). Total vegetative area sampled was 60 m^2 (8% of area).

In 1996, sampling square size was reduced to 1 m X 1 m to facilitate sampling operations, and the number of squares was increased to 90. Three rows were established in a replication with 10 squares per row (Fig. 1b). Sample squares were 3.5 m apart within and between rows, and 5 m apart between replications. Total vegetative area sampled was 45 m^2 (6% of area).

A 122 cm tall wooden tomato stake was placed in the center of each square for attachment of sticky traps.

Vegetation Sampling. Two methods of monthly vegetation sampling were used: visual sampling and frame sampling. Vegetation sampling was only done in the uncultivated vegetation portion of the research plot.

Visual sampling consisted of visual estimates of the percent ground cover of all species of plants in each square. In 1995, bedstraws (*Galium* spp.), wild violets (*Viola* spp.) and goldenrods (*Solidago* spp.) were counted as groups. In 1996 grasses (Family: Poaceae) were counted as a group in addition to bedstraws, wild violets, and goldenrods. This provided both a count of the number of species present (richness) as well as an estimate of their dominance within a square (evenness) (Magurran, 1985). Each square was visually subdivided into four sections, percent coverage in each section was estimated separately, and the four estimates were summed to obtain an average for the square. For taller and less dense species a count was made of the total number of individuals of a species within a square. Dead or dead-standing plant material was not counted. In 1995, visual sampling dates were June 7-9, July 10-12, and August 14-16. In 1996 visual sampling dates were April 25-29, May 27-29, June 24-26, July 22-24, August 21-23, and September 22-25.

Frame sampling used an elaboration of the point intercept method of Murdoch (1972). The frame was 2 m tall by 1 m wide frame with four cross bars at 0.5 m, 1.0 m, 1.5 m, and 2.0 m (Fig. 2a). The frame was constructed of 2.54 cm diameter PVC tubing and crossbars used 1.27 cm diameter PVC tubing. The lower two 1.27 cm diameter cross bars were made of two pieces held together by a loose joint and duct-tape. Each cross bar was marked in ten centimeter increments to aid in sampling.

In 1995, one vertical pole was inserted at the center of the plot and the other was inserted towards one of the corners of the plot. When the vegetation was dense the two lower cross poles were removed and then reinserted after the frame was in place to reduce bending or breaking of the foliage. For each species that contacted the cross-poles, an estimate of the percent cover in each 10 cm section was made and those estimates tallied to give a percentage for the sample transect at each height. Four samples were made in each plot (one for each center-corner transect) (Fig. 2 b.). Frame sampling was done on June 12-14, July 13-14, and August 17-18.

In 1996, two more levels were added for frame sampling: 0.75 m and 1.25 m. The frame was placed on the diagonal between corners and two corner-to-corner measurements were taken (Fig. 2c). Sampling dates were: May 30, June 26-27, July 25, August 26-27, and September 30 - October 1.

Insect Counts. Insect populations were sampled using 30.48 cm by 15.24 cm yellow sticky traps (Olsen Products, through Great Lakes IPM, Vestaburg, Michigan). The sticky traps were stapled vertically to the tomato stakes of each plot, 0.91 m from the ground on the side facing the forest (Bach, 1980; Southwood, 1978). After one week the traps were collected, placed between wax paper, and stored in a freezer for counting during the winter.

Counts were made of striped cucumber beetles (*Acalymma vittatum* Fabr.), spotted cucumber beetles (*Diabrotica* *undecimpunctata howardi* Barber), western cucumber beetle (*Acalymma trivittatum* Mann.) and Pennsylvania leatherwings (*Chauliognathus pennsylvanicus* DeGeer) [a predator of cucumber beetles (Houser and Balduf, 1925)]. Diptera (Order: Diptera) were counted as a group as an indicator of the possible presence of Tachinid flies (Family: Tachinidae) a known parasitoid, and syrphid flies (Family: Syrphidae) a potential predator of ccumber beetles (Hoffman and Frodsham, 1993). Hymenoptera (Order: Hymenoptera) similarly were counted as a group as an indicator of the possible presence of the braconid wasp *Syrrhizus diabroticae* (Family: Braconidae), also a known parasitoid (Hoffman and Frodsham, 1993). Lady beetles (Order: Coleoptera, Family: Coccinellidae) and spiders (Order: Araneae) were counted as groups and were included since they are generalist predators. The seven spotted lady beetle (*Coccinella septempunctata*) and *Coleomegilla maculata* (another lady beetle) were counted independently due to reports that they will consume beetle eggs and larvae if aphids are lacking (Hoffman and Frodsham, 1993).

In 1995, sticky traps were put out on August 9 and September 19. In 1996 sticky traps were put out on April 26, June 28, July 29, September 1, and October 2 (the September 1 sample was subsequently lost due to high winds).

Cucumber planting. In 1995, prior to planting, 83.92 kg of complete ferttilizer(10N-4.4P-8.3K) and a supplement of potassium (0N-0P-29.1K) was applied in granular form.

The cultivar Arkansas Little Leaf (a pickling cucumber) was direct seeded on June 2 with a row spacing of 1.52 m. After the seed germination and the appearance of the second pair of true leaves, the plants were thinned to one plant every 20-30 cm.

In 1995 an application of 1,1'-dimethyl-4,4'-biphridinium salts was made on June 23 between rows to control the weeds. Within the rows hand weeding was done as needed.

In fall of 1995 a rye cover was planted into the cucumber field. On May 15th of 1996 the rye was flail-mowed and left in the field as a mulch. However, due to heavy rain prior to planting, weeds broke through the mulch and an application of 1,1'-dimethyl-4,4'-biphridinium salts was made on June 7.

Cucumbers were planted on June 13 using a modified no-till planter pulled by a tractor. A double row system was used with 0.6 m between rows within a pair, and 2.4 m between pairs. After seed germination and development of the second pair of true leaves, plants were thinned to one plant every 20-30 cm.

On July 9 N-(phosphomethyl)glycine,isopropylamine salt of glyphosate was applied between rows. Weeding in the rows was done by hand as needed.

In 1995, cucumbers were harvested twice weekly from August 8 to August 31. In 1996, cucumbers were harvested twice weekly from August 19 to September 20.

Statistical Methods. For purposes of analysis, the distance from the forest to the furthest edge of the cucumber field was viewed as a potential pest population gradient, with the gradient moving across the uncultivated vegetation into the cucumber field.

Diversity was estimated by: counting species (richness), Shannon evenness index (a measure of the relative abundance of each species in the sampling plot), and the Shannon index (a overall diversity measure that combines richness and evenness) (Magguran, 1985). To assess the effects of diversity and individual plant species on insect populations three steps were taken. The first step was to determine potentially important plant species (a maximum of eight was the cutoff). Potential importance was decided on the basis of two components: frequency (was it in many or few sampling squares?) and abundance (when present was it in large percentages or small?). A separate list of potentially important plant species was generated for each month and each sampling frame height.

The second step was to do a maximum R^2 regression (Proc REG, SAS Institute, 1989) on the selected factors (species richness, evenness, and the selected plant species) with the principal target insects: cucumber beetles, Diptera, and *Coleomegilla maculata*. Hymenoptera, sevenspotted ladybeetle, other lady beetles, and spiders were excluded due to low numbers and/or lack of significant gradient regressions. The results of the maximum R^2 were used identify the factors that might be contributing to these differences. The number of factors retained was determined by examining the degree of improvement in R^2 values as additional factors were added. When the improvement in the R^2 became less than 0.05, the last level was used as the highest level.

The third step was to determine the correlation of populations of these insects with each of the individual factors retained in the model. In addition, separate correlations between insect population densities and Shannon index were calculated, but there were no significant correlations between insect populations and the Shannon index in 1995 or 1996 (data not shown).

In all statistical analyses, effects at probabilities between 0.05 and 0.10 were examined as possible indicators of trends that might be detectable at statistically significant levels with higher insect populations. Actual probabilities are reported in the tables, and tendencies are distinguished from statistically significant effects by use of the words "tendency" or "trends" in the text.

Results and Discussion

Insect Populations

1995. Insect populations varied across the uncultivated vegetation-crop gradient more in September than in August (Table 1). Only populations of striped cucumber beetles and lady beetles showed significant linear or quadratic effects in August. In September, populations of striped and spotted cucumber beetles, Diptera, and Pennsylvania leatherwings showed significant linear and/or quadratic effects. Similar though non-significant linear or quadratic trends were observed in populations of lady beetles and spiders in September.

In both months, the population of striped cucumber beetles fit the operating hypothesis for pest species, with the population lowest in the uncultivated vegetation closest to the forest and increasing linearly to their highest value furthest out into the crop field (from 0.3 to 6.0 beetles in

August; from 0.8 to 4.1 beetles in September) (Fig. 3). The population of spotted cucumber beetles in September also fit the operating hypothesis for pest species, again with the population lowest in the uncultivated vegetation closest to the forest and increasing to its highest value furthest out in the crop field (from 5.3 to 11.3 beetles) (Fig. 4). When projected as a quadratic effect, the population showed a slight depression in the middle of the uncultivated vegetation (4.5 beetles at 19 m) before increasing more sharply to its highest value furthest out in the cucumber field (data not shown). This depression, however, appears to be an artifact of the data and the linear model was favored.

The population of Diptera in September fit the operating hypothesis for beneficial insects, with the population highest in the uncultivated vegetation closest to the forest and decreasing to its lowest value furthest out in the crop field (from 40.0 to 15.3 insects)(Fig. 5). The population of Pennsylvania leatherwings in this month was contrary to the operating hypothesis for beneficial insects. It was lowest in the vegetation closest to the forest and increased to its highest value furthest out in the cucumber field (3.7 to 9.5 leatherwings) (Fig. 6). The depression near the edge of the cucumber field may represent the population of Pennsylvania leatherwings in the center of the uncultivated vegetation with neither the forest edge effect nor spillover effects from the cucumber field.

1996. The population of striped cucumber beetles showed significant linear effects across the gradient in June and July, and a significant cubic effect in September (Table 2). As in 1995 striped cucumber beetles fit the operating hypothesis for pest species in June and July, with the population lowest in the uncultivated vegetation closest to the forest and increasing to their highest values furthest out in the crop field (from 0.3 and 0.1 beetles to 6.8 and 7.1 beetles for June and July respectively)(Figure 7). The slope of the regression increased from June to July. In September the regression was cubic though linear in appearance with the population highest in the uncultivated vegetation closest to the forest and decreasing to its lowest value furthest out in the crop field (from 0.6 to 0 beetles). The overall shape was essentially flat. These changes in the slope parallel changes observed in the vegetation of the research plot. In the June sample, the cucumbers had only recently germinated while the uncultivated vegetation was starting to flower and became increasingly tall and dense. In the July sample the cucumbers were flowering and the uncultivated vegetation had also reached its peak flowering and was near its peak height and density. In September, the cucumbers and uncultivated vegetation were both dying back.

The population of spotted cucumber beetles showed significant linear effects across the gradient in April, June, and July and a significant cubic effect in September (Table 2). Again the operating hypothesis for pest species was fit with the population lowest in the uncultivated vegetation and increasing to its highest values in the crop field (from 0, 0.11, 0.11, and 0.44 beetles to 0.2, 0.4, 3.8, and 2.5 beetles for April, June, July, and September respectively) (Fig. 8). The slope of the regression in April was virtually flat, increased in June, and reached its steepest in July. Again in September the regression was cubic though linear in appearance, and again the overall shape was flat. As with the striped cucumber beetles the changes in the slope of the regression parallel changes in the crop and uncultivated vegetation.

Diptera showed significant linear effects across the gradient at all sampling dates (Table 2). Again Diptera fit the operating hypothesis for beneficial species with the highest population in the uncultivated vegetation and decreasing to its lowest values in the crop field (10.9, 30.4, 46.7, and 42.4 insects to 7.0, 13.8, 15.5, and 31.0 insects for April, June, July, and September, respectively) (Fig. 9). The slope in April was virtually flat, increased in June, reached its steepest in July, and leveled again in September. Again the association with changes in the crop and uncultivated vegetation is present.

The population of *Coleomegilla maculata* showed significant cubic effects in April and June and a significant quadratic effect in July. *Coleomegilla maculata* did not appear to fit any of the operating hypotheses (Figure 10). It is hard to find any pattern in the changes of populations of *Coleomegilla maculata,* probably due to a small sample size (total sample size never exceeded 20 with a maximum of 3 insects per plot and most plots having only 1 insect). While the effects of the gradient were significant, this only suggests a possible relationship that would need to be investigated further with larger populations.

The population of spiders showed a significant quadratic effect in June. Spiders appeared to fit the operating hypothesis for beneficial insects, though the relationship was weak due to a small sample (total sample at any one date never exceeded 19 with a maximum of 2 spiders per plot and most plots having only 1 spider) (Fig. 11). The regression does suggest that spiders might fit the operating hypothesis for beneficial insects if a larger sample could be obtained. Since spiders tend to be more stationary predators, typically remaining associated with webs, sticky traps are probably a poor means of assessing spider populations. An alternative sampling technique is probably needed to determine the strength of this potential relationship.

Diversity and Plant Species Effects

1995 Visual Sampling. In 1995 seven plant species were selected for the maximum R^2 regression: red clover (*Trifolium pratense*), white clover (*Trifolium repens*), wild violets (*Viola* spp.), daisy fleabane (*Erigeron annuus*), marjoram (*Origanum* spp.), orchard grass (*Dactylis glomerata*), and sweet vernal grass (*Anthoxanthum odoratum*). A complete list of the plant species present in 1995 is in Table 11. The insect populations were pooled for the two sampling dates to include more insect species with significant effects of the gradient. The diversity measure evenness was selected for only one model, and richness was not selected in any model (Table 3). The R^2 was higher than 0.40 for each of the insect populations used. Significant correlations only occurred between the insect populations and specific plant species.

There was a tendency towards a positive correlation between the population of cucumber beetles and sweet vernal grass. There was a significant negative correlation between Diptera and sweet vernal grass (*Anthoxanthum odoratum*) (Table 3). The population of leatherwings showed a tendency towards positive correlation with red cover (*Trifolium campestre*) and a negative correlation with marjoram (*Origanum* spp.). Sweet vernal grass may play an opposite role for Diptera (repelling) compared to cucumber beetles (attractive).

1996 Visual Sampling. In 1996 eleven species were selected for inclusion in the maximum R^2 regression, with six of the species occurring in three or more sample dates: white clover (*Trifolium repens*), wild violets (*Viola* spp.), marjoram (*Origanum* spp.), horse nettle (*Solanum carolinense*), grasses (Family: Poaceae), and sheep sorrel (*Rumex acetosella*). Red clover (*Trifolium campestre*), goldenrods (*Solidago* spp.), and english plantain (*Plantago lanceolata*) were selected in two of the four months. The remaining plant species selected were bedstraws (*Galium* spp.) and heath aster (*Aster ericoides*). The R^2's were considerably lower than in 1995 (the largest value was 0.44), and diversity measures were included in only three models (with richness in one and evenness in all three). The lower R^2's reflect the fact that sampling dates were not

not pooled as they were in 1995. As in 1995 the only significant correlations occured between the insect populations and specific plant species.

The population of cucumber beetles had significant correlations in July with white clover (*Trifolium repens*) and wild violets (*Viola* spp.)(Table 4). Both correlations were negative suggesting that the combination of white clover and wild violets is potentially useful in reducing cucumber beetle populations. However, the R^2 was small, so potential benefits may be small. Correlations with individual factors retained in other months were non-significant.

Populations of Diptera had significant or near significant correlations with wild violets (*Viola* spp.) in April, July, and September (Table 5). There was a tendency towards correlation between populations of Diptera and sheep sorrel (*Rumex acetosella*) in June and heath aster (*Aster ericcoides*) in September. The positive correlation between Diptera and wild violet in April was highly significant, yet the regression only explained a small percentage of the variation. Interpretation of this result is complicated by the fact that wild violet in June is not present as an important factor but reappears in July and September with conflicting tendencies: negative correlation in July but positive correlation again in September. It appears, however, that wild violets have a tendency to increase the Diptera population. Sheep sorrel and heath aster are potentially useful species for increasing Diptera populations, but the p-values and fairly low R^2's for the regressions preclude any further interpretation.

Populations of *Coleomegilla maculata* had significant correlations in the month of July with goldenrod (*Solidago* spp.), English plantain (*Plantago lanceolata*), and marjoram (*Origanum* spp.) (Table 6). The correlation between *C. maculata* and goldenrod was strongly negative and this suggests that goldenrod may serve to repel *C. maculata*. *C. maculata* had low numbers, so while the correlation with goldenrod is highly significant, this would need to be confirmed with larger populations. English plantain also had a negative correlation with *C. maculata*, but the weak coefficient does not suggest an important role for this species. Marjoram was positively correlated with *C. maculata* but further study would be needed to determine how it may interact with the presence of goldenrod.

1995 Frame Sampling. There was not enough data for the 1.5 m height so it was dropped from the analysis. In 1995 only three of the seven plant species selected for inclusion in the visual sampling maximum R^2 were selected for inclusion in the frame sampling maximum R^2 (daisy fleabane, marjoram, and sweet vernal grass). The other four plant species selected from the frame sampling data were wild rose (*Rosa multiflora*), goldenrods, english plantain, and white vervain (*Verbena urticifolia*). Fewer species were selected at 1.0 m (only wild rose, goldenrods, and daisy fleabane). As with the visual sampling, diversity measures did not have significant correlations and were present in only one model (Table 7).

At both the 0.5 m and 1.0 m heights, the population of cucumber beetles had positive although non-significant correlations with wild rose (Table 7). This suggested correlation is in accordance with Howser and Balduf (1925), who reported that cucumber beetles have a preference for members of the Rosaceae in the spring before cucumbers are planted.

Populations of Diptera had a significant negative correlation with wild rose at the 0.5 m level (Table 7). This suggests that wild rose may repel Diptera, contrasting with its possible attractiveness to cucumber beetles. Inclusion of wild rose contrasts with the visual sampling, since with visual sampling wild rose was not selected by the maximum R^2 procedure, and sweet vernal grass was a important factor. This

1996 Frame sampling. There was not enough data for 1.25 m or 1.5 m so both levels were dropped from the analysis. Nine species were selected for the frame sampling maximum R^2 in 1996 with seven of the species the same as those selected for the visual smpling maximum R^2(goldenrod, sheep sorrel, english plantain, marjoram, horse nettle, grasses, and heath aster). The additional species were wild rose and hawksbeard. As in 1995 there was a distinct difference in the plants selected for the frame sampling maximum R^2 regression as compared to the species selected for visual sampling. Presumably this is due to the taller species being relatively abundant at heights 0.5 m or greater, but not abundant enough when looked at as a percent of total ground cover. The relationships were consistently strongest in July with the July sample including diversity measures for both cucumber beetles and Diptera. None of the models had significant correlations with insect populations and diversity measures.

No factors selected by the maximum R^2 regression had significant correlations with populations of cucumber beetles. In contrast with 1995, wild rose was not selected in any of the models. The R^2 values of all models were low (Table 8). In six of the nine maximum R^2 models, measures of diversity appeared, and six of eight correlation coefficients with these measures were negative although non-significant. These results suggest that cucumber beetle populations may be reduced by diversity.

The Diptera population had a significant negative correlation with goldenrod (*Solidago* spp.) at all three heights for the month of July with the correlation at its strongest at 0.75 m (Table 9). This suggests that goldenrod may repel Diptera. Since goldenrod is tall and tends to occur in clumps it may repel Diptera simply by acting as a barrier to flight. As the Diptera avoided the goldenrod in their flight path, they would be steered away from plots with high percentages of goldenrod. There was also a tendency towards a correlation in June at 0.5 m with marjoram (positive) and hawks beard (*Crepis capillaris*) (negative) and in September at 0.75 m with grasses (negative). These species might warrant further investigation. As in 1995, the frame sampling results were different from visual sampling results. Seven of the nine maximum R^2 models included richness and/or evenness. Although none of the nine correlations coefficients were significant, seven were negative. These results are contrary to the hypothesis that populations of Diptera are larger in more diverse portions of the uncultivated vegetation.

The population of *Coleomegilla maculata* had a significant positive correlation with goldenrod (*Solidago* spp.) and English plantain (*Plantago lanceolata*) in July at 0.5 m (Table

10). The positive correlation suggests that the goldenrod/English plantain combination might be attractive to *C. maculata*. Richness and/or evenness appeared in three of the nine maximum R^2 models, and all five correlation coefficients were negative, although non-significant.

Edge Effects

The vegetation was bordered on two sides by Kentucky fescue grass. The cucumber planting was bordered by this grass on three sides. The potential effects of these edges were examined by regressing insect populations on cross-directional gradients in both the uncultivated vegetation and the crop field.

In 1995 there were no significant effects of the edge. In 1996 there were significant effects of the edge in the uncultivated vegetation for spiders (P= 0.03) and lady beetles (P=0.02) in June, and striped cucumber beetles (P= 0.02), western cucumber beetles (P= 0.004), and Diptera (P= 0.01) in July (data not shown). Except for Diptera, in each case the differences between maximum and minimum population sizes on the cross-gradient were less than one insect. For Diptera, however, the difference between maximum and minimum population size was more substantial (21.3 Diptera). In the uncultivated vegetation in July, this appeared as a quadratic effect (P= 0.001) with populations lowest in the center of the uncultivated vegetation. This may be an effect of the edge between the Kentucky fescue and the uncultivated vegetation or it may be that the plant species in the center of the uncultivated vegetation are repellant to Diptera.

Cucumber Harvest

Total yield was 7.1 $t \cdot ha^{-1}$ in 1995 and 6.7 $t \cdot ha^{-1}$ in 1996. In 1995 there was a significant quadratic relationship (P= 0.01) between the cross-gradient and yield with the yield highest in the center portion of the cucumber field. In 1996 there were no significant effects of the cross-gradient on yield (data not shown).

Conclusions

Populations of cucumber beetles fit the operating hypothesis for gradient effects on pest insects, indicating that uncultivated vegetation reduces populations of cucumber beetles. The further from the vegetation, the smaller the reduction in the cucumber beetle population. The distance from vegetation at which cucumber beetle populations exceed the economic threshold would need to be established in order to use natural vegetation as a control measure. No similar effect of the Kentucky fescue was found in the cross-gradient, indicating that the insect population gradient effect is due to the uncultivated vegetation, and not an edge effect with the grass.

While the diversity in uncultivated vegetation is higher than in the crop field, populations of cucumber beetles responded less to measures of diversity within the vegetation than to specific plant species. The combination of white clover, wild violet, and horse nettle may have a repellant effect on cucumber beetle populations. The relationship between these plant species and cucumber beetles needs to be investigated further. Conversely, wild rose appears to be attractive to cucumber beetles. Further investigation would be needed to determine whether the attractive role of wild rose is positive for crop protection (serving as a trap crop) or negative (drawing cucumber beetles from the forest, before they move onto the cucumbers). The role of diversity also needs to be investigated further, as a high overall level of diversity (as compaired with the monoculture cucucumber field) was detrimental to cucumber beetles.

The population of Diptera fit the operating hypothesis for gradient effects on beneficial insects. As with the cucumber beetles, Diptera respond more to specific plant species, particularly wild violets. A high overall level of diversity does appear to create conditions favorable for Diptera, relative to monoculture. However, contrary to our hypothesis, increased diversity within uncultivated vegetation does not appear to increase Diptera populations over relatively less diverse areas within the uncultivated vegetation.

Populations of Pennsylvania leatherwing did not fit the operating hypothesis for gradient effects on beneficial insects. This may be due to sampling protocol and a difference in the ecology of adults versus larva; only the larval stage preys upon cucumber beetles. Since only adults were counted it is possible that the results may not reflect the effects of uncultivated vegetation on the larval leatherwings.

Concerning the other beneficial insects, larger populations and/or better sampling methods will be needed before any conclusions can be made. As with Diptera, increased diversity within the natural vegetation did not appear to increase populations of *C. maculata*. Spiders did show a tendency towards fitting the hypothesis for gradient effects, so perhaps with a larger sample this tendency might be detectable at statistically significant levels.

Contrary to the operating hypothesis, there did not appear to be any significant correlations between the Shannon diversity index and insect populations. Correlations between richness and evenness were also contrary to the hypothesis for beneficial insects. The relationships between specific plants and the insect populations appeared to be more important. The relationships between wild rose, wild violets, and white clover with cucumber beetles; wild rose, wild violets, and sweet vernal grass with Diptera; and goldenrod, English plantain, and marjoram with *C. maculata,* warrant further attention.

Incorporating greater plant diversity into the crop field may be an effective means of controling cucurbit insect pests. In particular, incorporation of whitw clover and wild violets into, or removal of wild rose from crop fileds and crop field borders may help in regulating cucumber beetle populations. Furthermore, adding wild violets may have the added benefit of attracting tachinid and syrphid flis which would further reduce beetle populations.

Future Directions

On the basis of this research it appears that increasing the diversity around a cucumber field will have a negative effect on populations of cucumber beetles. The specific plants necessary to obtain that control need to be investigated further. For cucumber beetles in 1995 sweet-vernal grass had a positive effect on beetle populations, and in 1996 wild violet and white clover appeared to have a negative effect on beetle populations, while wild rose appeared to be attractive. Manipulative studies should be done to investigate these relationships further. Will the effects of the gradient be enhanced if there is more white clover and wild violet present? Is a specific ratio of violet to clover necessary? Will removal of sweet-vernal grass enhance the effect of the gradient? Could wild rose be increased and used as a trap crop? Augmenting plant populations may result in plant species with non-significant trends toward correlation with insect populations to become more significant. The precise nature of the correlation between cucumber beetles and sweet vernal grass in 1995, and wild violets, clover, and wild rose in 1996, needs to be investigated as well. Is the effect due to the plants themselves (i.e. olfactory or visually repellant) or do the plants simply provide a good habitat for beneficial insects?

For spiders, lady beetles, and Hymenoptera, a larger sample may yield more interesting results. Augmenting the populations or developing better sampling techniques may result in more significant results. Enhanced populations of cucumber beetles may show a greater or less pronounced effect of the gradient. Perhaps there is a maximum population size beyond which control could no longer be maintained.

There is also the question of time. How long will the effect of the gradient persist? As of yet there have been no long term studies demonstrating that the reduction in pest populations due to increased diversity persists over time (remains stable). If increased diversity is to be used commercially as means of pest control, the long term consequence of diversity must be studied. If the positive effects of diversity only last a season or two, then the system will need to be managed (mowed or replanted periodically).

Furthermore, if the populations become unstable in time, an important factor is the magnitude of the instability. Pest populations can fluctuate, even wildly, so long as the economic threshold is not exceeded. What is more important - particularly if the enemies or resource concentration hypotheses are the predominant mechanisms - is the stability of the community. Will there be a constant pool of beneficial insects or pest-confusing plants? A recent paper by Tilman (1996) suggests that increased diversity will indeed lead to increased community stability, but not stability of individual plant or insect species. So there is hope that increasing the diversity of the agro-ecosystem surrounding a crop will prove to be a useful approach to pest control.

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Appendix

Table 1. Analysis of variance of effects[z] of uncultivated vegetation-crop gradient distance on populations of insects, summer 1995.

Insects	August	September
Striped	L P=0.02	L P=0.02 Q P=0.09
Spotted	NS	L P=0.02 Q P=0.03
Western	NS	NS
Diptera	NS	L P=0.02
Lady Beetles	L P=0.02	L P=0.09
C. mac[Y]	NS	NS
Sevenspotted	NS	NS
Hymenoptera	NS	NS
Spiders	NS	Q P=0.07
Pennsylvania Leatherwing	NS	L P=0.004 Q P=0.003

[z] Effects of gradient distance obtained by orthogonal contrasts:

L = linear

Q = quadratic

Non-significant (NS) at P ≥ 0.10

[Y] *Coleomegilla maculata*

Table 2. Analysis of variance of effects[z] of uncultivated vegetation-crop gradient distance on populations of insects, summer 1996.

Insects	April	June	July	September
Striped	NS	L P=0.008	L P=0.01	C P=0.02
Spotted	L P=0.08	L P=0.007	L P=0.01	C P=0.04
Western	NS	NS	L P=0.004 Q P=0.007	Q P=0.09
Diptera	L P=0.06	L P=0.08	L P=0.0001	L P=0.08
Lady Beetles	NS	NS	NS	NS
C. mac[y]	C P=0.05	C P=0.09	Q P=0.05	NS
Sevenspot	NS	NS	NS	NS
Hymenopt-era	NS	NS	NS	NS
Spiders	NS	Q p=0.02	NS	NS
Leather-wing	NS	NS	NS	NS

[z] Effects of gradient distance obtained by orthogonal contrasts:

L = linear

Q = quadratic

Non-significant (NS) at $P \geq 0.10$

[z] *Coleomegilla maculata*

Table 3. Factors retained by maximum R^2 regression of insect populations on measures of diversity and plant species for visual sampling and their corresponding correlations with insect populations, August-September 1995.

Insects[z]	R-square	Factors	Correlation	P-Value[y]
Cucumber Beetles (92)	0.58	Evenness	-0.33	0.27
		Red Clover	-0.26	0.40
		Orchard Grass	-0.14	0.66
		Sweet Vernal Grass	0.52	0.07
Diptera (906)	0.76	White Clover	0.20	0.50
		Wild Violet	0.38	0.21
		Daisy Fleabane	-0.26	0.39
		Sweet Vernal Grass	-0.65	0.02
Pennsylvania Leatherwing (33)	0.43	Red Clover	0.48	0.09
		Marjoram	-0.49	0.09

[z] Number in parenthesis indicates total sample size
[y] Of correlation coefficient

Table 4:
Factors retained by maximum R^2 regression of insect populations on measures of diversity and plant species for visual sampling and their corresponding correlations for cucumber beetle populations, 1996.

Month	R-square	Factors	Correlation	P-value[z]
June	0.26	Richness	-0.16	0.34
		Evenness	0.09	0.60
		English Plantain	-0.15	0.37
July	0.22	White Clover	-0.37	0.01
		Wild Violet	-0.30	0.03
		Horse Nettle	0.20	0.16
September	0.16	White Clover	-0.11	0.44
		Tall Goldenrod	-0.24	0.86
		Wild Violet	0.16	0.24
		Marjoram	-0.18	0.21

x Of correlation coefficient

Table 5. Factors retained by maximum R^2 regression of insect populations on measures of diversity and plant species for visual sampling and their corresponding correlations for Diptera populations[Z], 1996.

Month	R-square	Factors	Correlation	P-value[Y]
April	0.18	Wild Violet	0.38	0.007
		Marjoram	0.11	0.47
June	0.22	Evenness	-0.23	0.16
		Sheep Sorrel	0.28	0.09
		English Plantain	0.14	0.40
		Horse Nettle	0.06	0.72
July	0.14	Wild Violet	-0.25	0.08
		Marjoram	0.24	0.10
		Horse Nettle	0.12	0.41
September	0.23	Evenness	0.03	0.86
		Red Clover	0.14	0.34
		Wild Violet	0.26	0.07
		Grasses	-0.22	0.12
		Heath Aster	-0.26	0.08

[Z] April: 440; June: 924; July: 2457; September: 1575 Diptera
[Y] Of correlation coefficient

Table 6. Factors retained by maximum R^2 regression of insect populations on measures of diversity and plant species for visual sampling and their corresponding correlations for *Coleomegilla maculata* populations[z], 1996.

Month	R-square	Factor	Correlation	P-value[Y]
April	0.11	White Clover	0.25	0.09
		Marjoram	0.16	0.26
June	0.18	Sheep Sorrel	-0.21	0.21
		English Plantain	-0.12	0.46
		Grasses	-0.28	0.09
July	0.44	Goldenrod	-0.55	0.0001
		English Plantain	-0.06	0.02
		Marjoram	0.36	0.01

[Z] April: 15; June: 20; July: 19 *C. maculata*
[Y] Of correlation coefficient

Table 7. Factors retained by maximum R^2 regression of insect populations on measures of diversity and plant species for two heights of frame sampling (0.5 m, 1.0 m) and their corresponding correlations with insect populations[z], August-September 1995.

Insect	Height	R-square	Factors	Correlation	P-Value[Y]
Cucumber Beetles (92)	0.5 m	0.31	Wild Rose	0.42	0.12
			Goldenrod	-0.34	0.24
			Sweet Vernal Grass	-0.39	0.17
	1.0 m	0.29	Wild Rose	0.46	0.15
			Goldenrod	0.18	0.60
Diptera (906)	0.5m	0.72	Richness	0.18	0.53
			Evenness	-0.01	0.97
			Wild Rose	-0.62	0.02
			Goldenrod	0.39	0.16
	1.0 m	0.29	Wild Rose	-0.49	0.13
			Goldenrod	0.32	0.33

[Z] Number in parenthesis indicates total sample size
[Y] Of correlation coefficient

Table 8. Factors retained by maximum R^2 regression of insect populations on measures of diversity and plant species for three heights of frame sampling (0.5 m, 0.75 m, and 1.0 m) and their corresponding correlations on cucumber beetle populations[z], 1996.

0.5 m

Month	R-square	Factors	Correlation	P-value[Y]
June	0.11	Hawks Beard	-0.20	0.24
		Horse Nettle	-0.20	0.25
		Grasses	-0.16	0.33
July	0.14	Richness	0.05	0.77
		Evenness	0.12	0.42
		English Plantain	0.23	0.13
September	0.05	Richness	-0.16	0.29
		Goldenrod	-0.10	0.48

0.75 m

Month	R-square	Factors	Correlation	P-value
June	0.04	Goldenrod	-0.16	0.35
		Marjoram	-0.12	0.47
July	0.11	Richness	-0.13	0.62
		Evenness	-0.11	0.68
		Goldenrod	-0.24	0.33
September	0.04	Grasses	-0.20	0.35

1.0 m

Month	R-square	Factors	Correlation	P-value
June	0.03	Richness	-0.18	0.52
July	0.20	Evenness	-0.25	0.34
		Goldenrod	-0.37	0.16
September	0.23	Richness	-0.32	0.23
		Grasses	0.14	0.60

[z] June: 18; July: 171; September: 55 beetles
[Y] Of correlation coefficient

Table 9. Factors retained by maximum R^2 regression of insect populations on measures of diversity and plant species for three heights of frame sampling (0.5 m, 0.75 m, and 1.0m) and their corresponding correlations on Diptera populations[z], 1996.

0.5 m

Month	R-square	Factors	Correlation	P-value[Y]
June	0.25	Wild Rose Marjoram Hawks Beard	0.19 0.31 -0.30	0.27 0.07 0.08
July	0.21	Richness Goldenrod Grasses	0.26 -0.31 -0.08	0.09 0.04 0.58
September	0.09	Evenness Horse Nettle	-0.26 0.04	0.09 0.77

0.75 m

Month	R-square	Factors	Correlation	P-value
June	0.12	Richness Evenness Goldenrod	-0.19 -0.10 -0.09	0.28 0.57 0.60
July	0.46	Richness Evenness Goldenrod	-0.36 -0.16 -0.59	0.14 0.53 0.01
September	0.22	Evenness Grasses Heath Aster	-0.17 -0.36 -0.16	0.27 0.09 0.46

1.0 m

Month	R-square	Factors	Correlation	P-value
June	0.08	Richness	-0.18	0.52
July	0.20	Evenness Goldenrod	0.04 -0.53	0.87 0.03
September	0.05	Grasses	0.26	0.32

[Z] June: 924; July: 2457; September: 1575 Diptera
[Y] Of correlation coefficient

Table 10. Factors retained by maximum R^2 regression of insect populations on measures of diversity and plant species for three heights of frame sampling (0.5 m, 0.75 m, and 1.0 m) and their corresponding correlations on *Coleomegilla maculata* populations[Z], 1996.

0.5 m

Month	R-square	Factors	Correlation	P-value[Y]
June	0.28	Richness	-0.05	0.75
		Eveness	-0.23	0.18
		Marjoram	0.29	0.09
July	0.21	Goldenrod	0.34	0.02
		English Plantain	0.35	0.02

0.75 m

Month	R-square	Factors	Correlation	P-value
June	0.16	Richness	-0.14	0.43
		Evenness	-0.17	0.35
		Goldenrod	0.08	0.63
July	0.27	Wild Rose	-0.17	0.49
		Goldenrod	-0.29	0.23
		Hawks Beard	-0.28	0.26

1.0 m

Month	R-square	Factors	Correlation	P-value
June	0.02	Richness	-0.18	0.52
July	0.11	Goldenrod	-0.23	0.40
		Grasses	-0.20	0.46

[Z] June: 20; July: 19 *C. maculata*
[Y] Of correlation coefficient

Table 11. Plant species present in 1995 and 1996.

Common name	Scientific name[z]	1995	1996
Bedstraw	*Galium* spp.	x	x
Bitter dock	*Rumex obtusifolius*	x	x
Bitternut hickory	*Carya cordiformis*		x
Blackberry	*Rubus* spp.		x
Black locust	*Robinia pseudoacacia*		x
Burr dock	*Arctium minus*	x	x
Boxelder	*Acer negundo*	x	x
Cherry	*Prunus* spp.		x
Chickory	*Chicorium intybus*	x	x
Cinquefoil	*Potentilla recta*	x	x
Daisy fleabane	*Erigeron annuus*	x	
Deptford pink	*Dianthus armeria*	x	x
English plantain	*Plantago lanceolata*	x	x
Evening primrose	*Oenothera spp.*		x
Goldenrod	*Solidago* spp.	x	x
Hawksbeard	*Crepis capillaris*	x	x
Heath aster	*Aster ericcoides*		x
Hop clover	*Trifolium campestre*	x	x
Horse nettle	*Solanum carolinense*	x	x
Marjoram	*Origanum* spp.	x	x
Mexican tea	Chenopodium *ambrosioides*	x	x
Milkweed	*Asclepias variegata*	x	x
Moth mullein	*Verbascum blattaria*	x	
Nodding thistle	*Carduus acanthoides*	x	
Nut sedge	*Cyperus esculentus*	x	x
Orchard grass	*Dactylis glomerata*	x	x
Oxalis spp.	*Oxalis* spp.	x	x
Ox-eye daisy	*Chrysanthemum leucanthemum*		x
Plantago spp.	*Plantago* spp.	x	x
Pennsylvania smartweed	*Polygonum pensylvanicum*		x
Pignut hickory	*Carya glabra*		x
Pokeweed	*Phryma leptostachya*		x
Queen ann's lace	*Daucus carota*		x
Red clover	*Trifolium pratense*	x	x
Sheep sorrel	*Rumex acetosella*	x	x
Sleepy catchfly	*Silene antirrhina*	x	
Staghorn sumac	*Rhus typhina*		x
St. John's wort	*Hypericum punctatum*	x	
Sweet vernal grass	*Anthoxanthum odoratum*	x	x

Common name	Scientific name[z]	1995	1996
Sycamore	*Platanus occidentalis*		x
Tulip poplar	*Liriodendron tulipifera*		x
Venus's looking-glass	*Triodanis perfoliata*	x	x
Virginia groundcherry	*Physalis virginiana*		x
Rye	*Elymus virginicus*	x	x
White clover	*Trifolium repens*	x	x
White vervain	*Verbena urticifolia*	x	x
Wild basil	*Satureja vulgaris*	x	x
Wild onion	*Allium* spp.		x
Wild rose	*Rosa multiflora*	x	x
Wild violet	*Viola* spp.	x	x

x = Indicates presence of a species for a particulr year

[z] (Wofford, 1989)

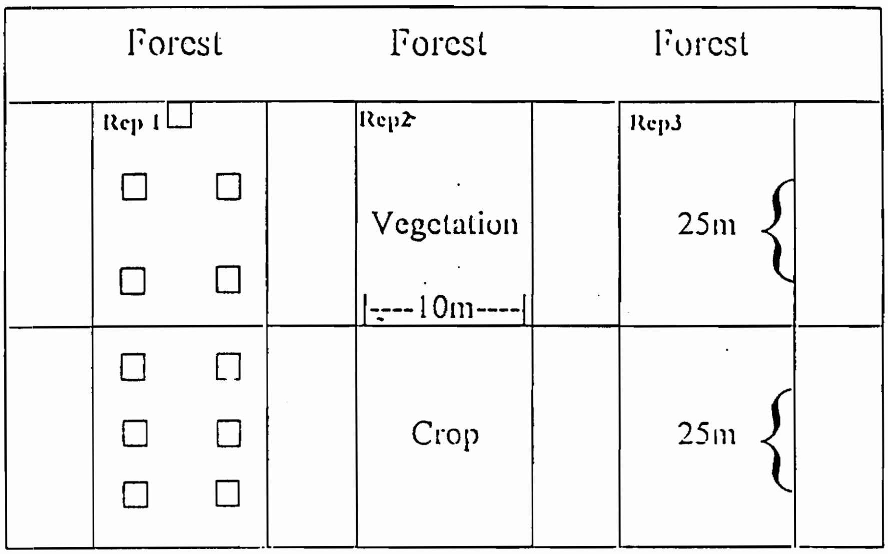

Figure 1 a. Area Sampled: 1995

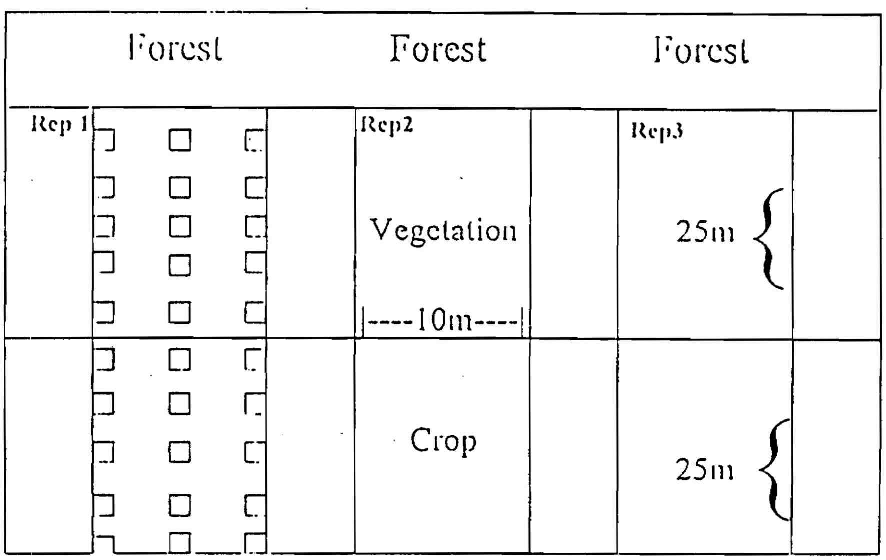

Figure 1 b.Area Sampled: 1996

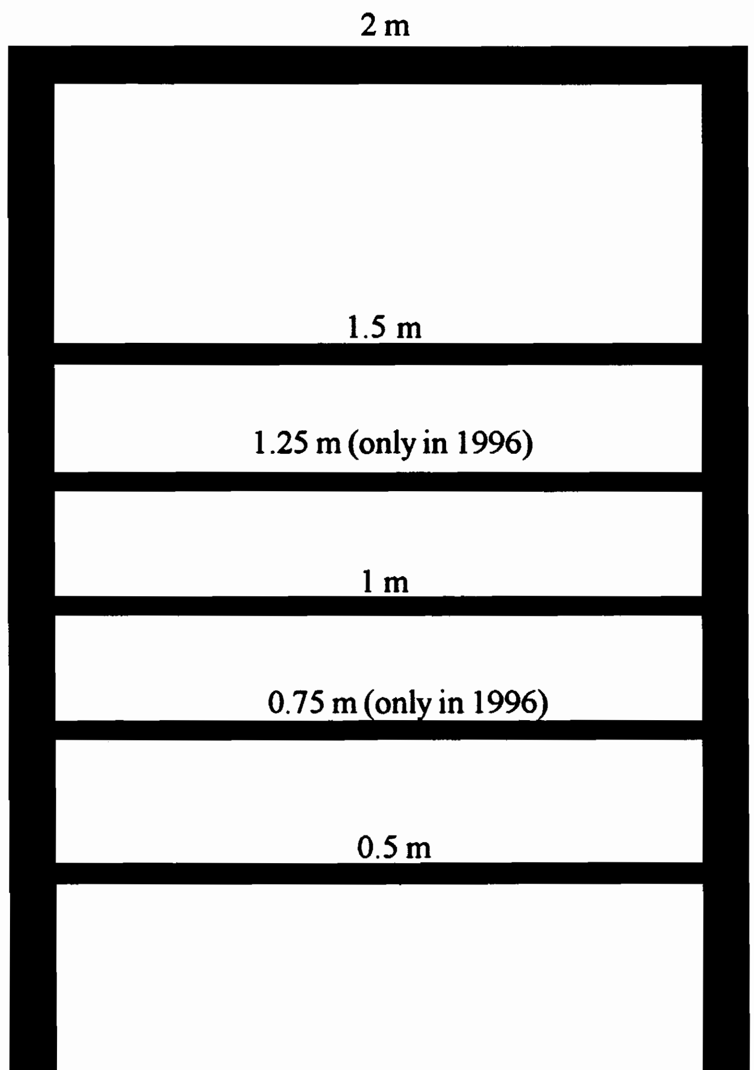

Figure 2 a. Sampling Frame

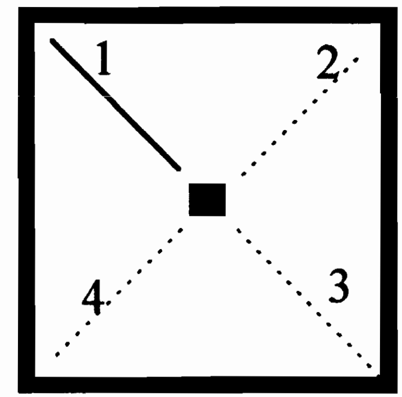

Figure 2 b. Frame sampling pattern within a sampling square in 1995.

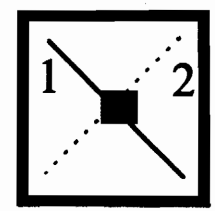

Figure 2 c. Frame Sampling pattern within a sampling square in 1996.

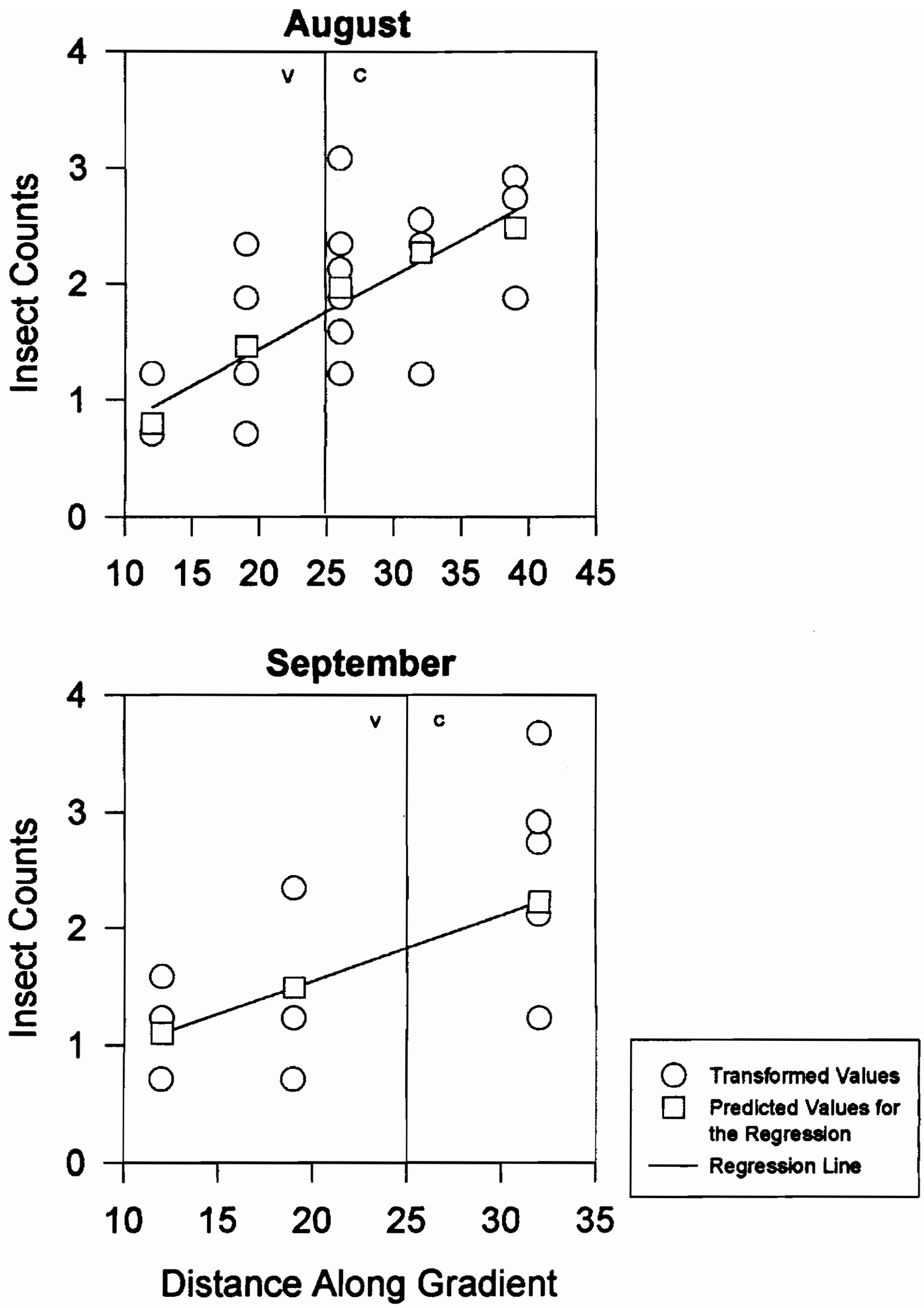

Figure 3: Effects of uncultivated vegetation / crop gradient on the striped cucumber beetle population, 1995 (August: y = 0.41 + 0.10x, R^2 = 0.63; September: y = 0.41 + 0.06x, R^2 = 0.34).

V = Uncultivated vegetation
C = Crop field

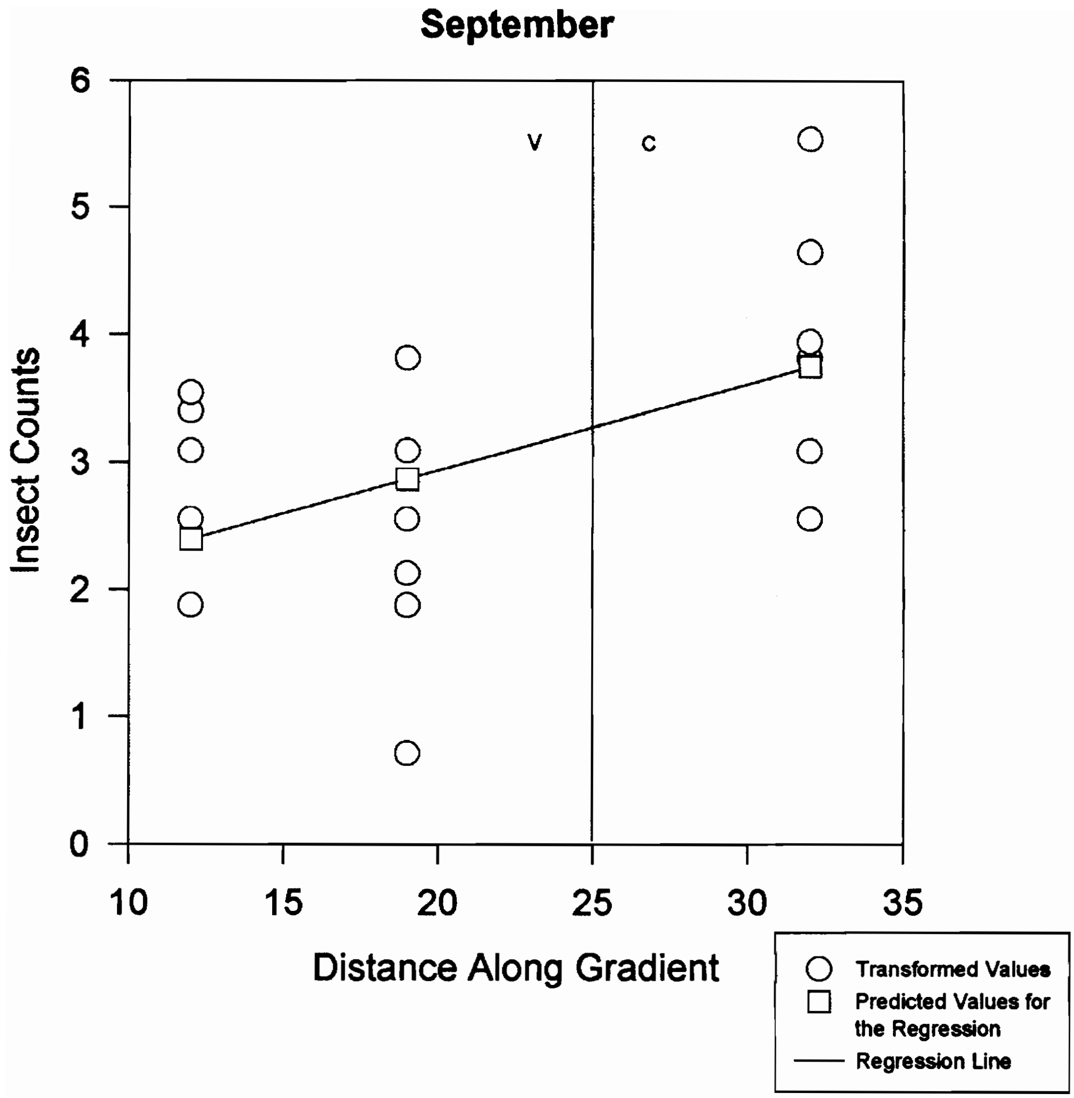

Figure 4: Effects of uncultivated vegetation / crop gradient on the spotted cucumber beetle population, 1995 ($y = 1.57 + 0.07x$, $R^2 = 0.34$).

V = Uncultivated vegetation
C = Crop field

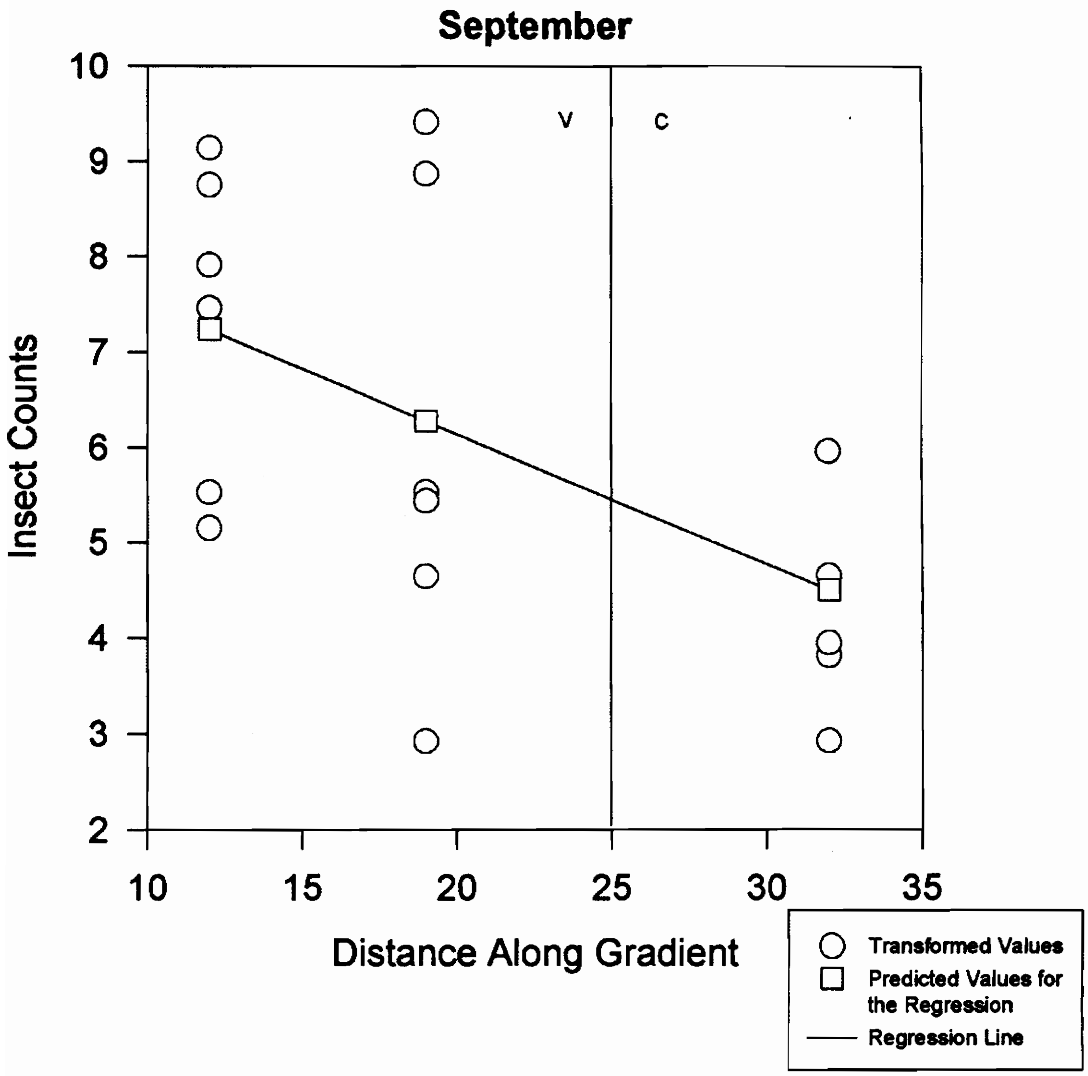

Figure 5: Effects of uncultivated vegetation / crop gradient on the Diptera population, 1995 (8.87 - 0.14x, R^2 = 0.30).

V = Uncultivated vegetation
C = Crop field

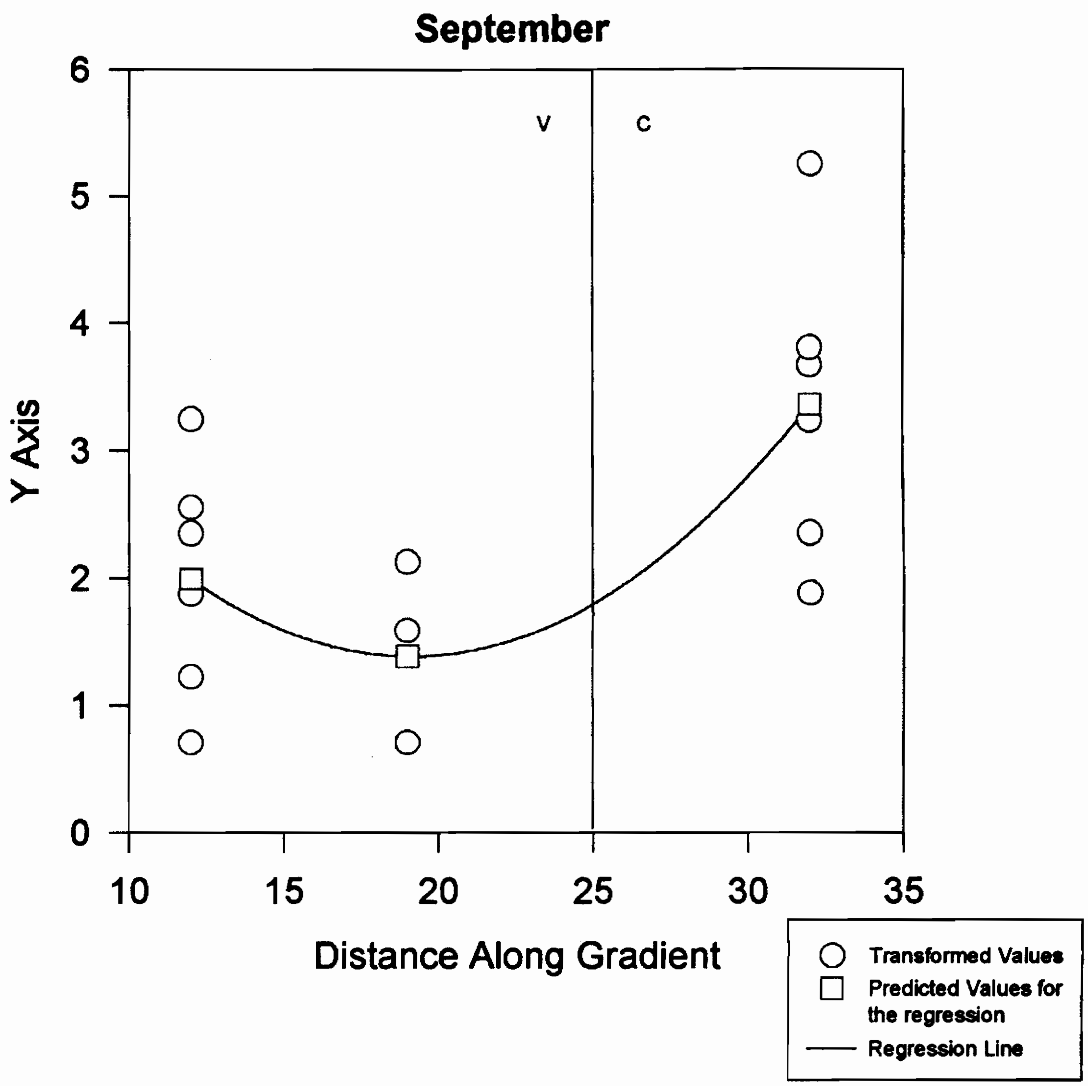

Figure 6: Effects of uncultivated vegetation / crop gradient on the leatherwing population, 1995 ($y = 5.77 -0.46x + 0.01x^2$, $R^2 = 0.48$).

V = Uncultivated vegetation
C = Crop field

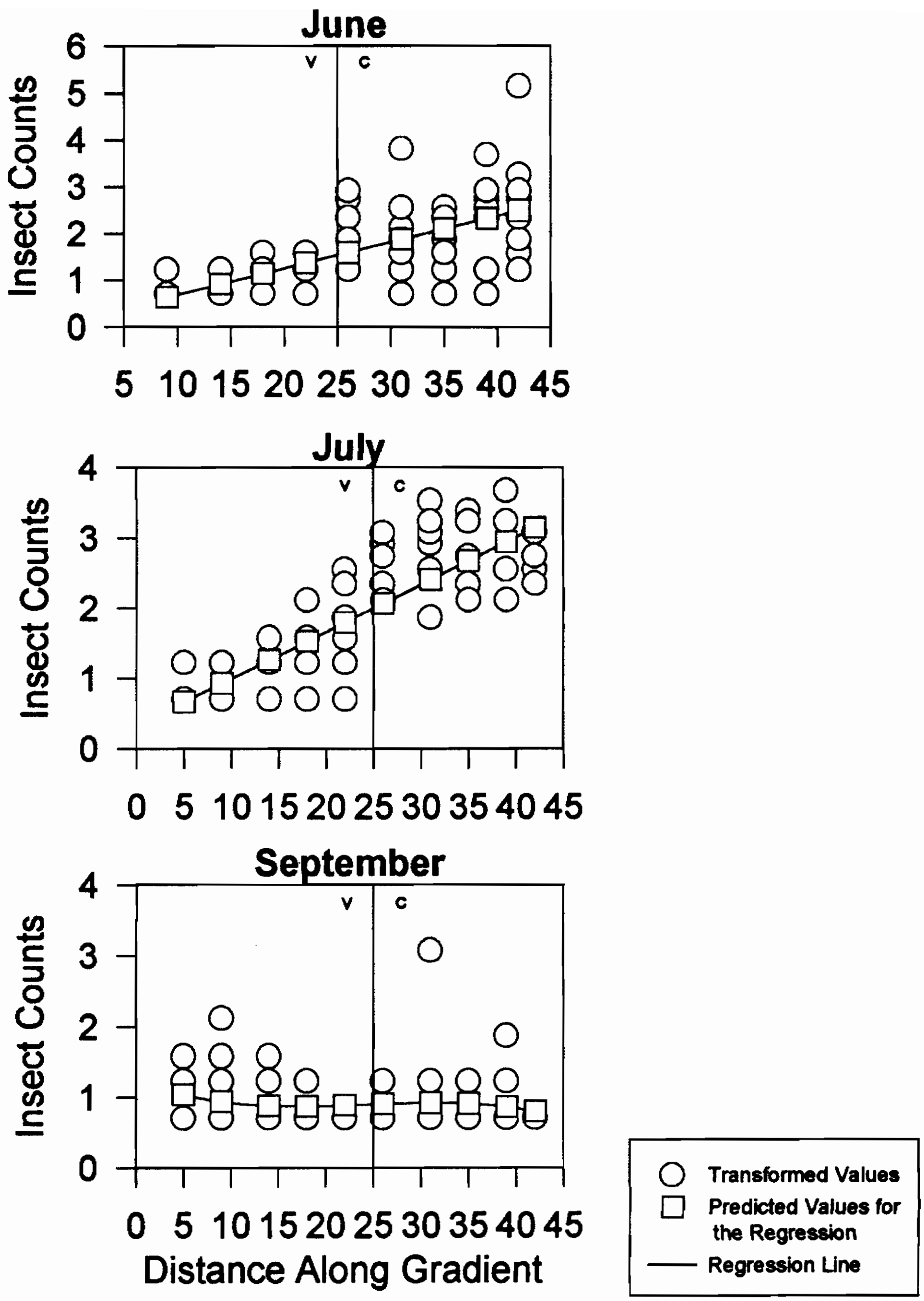

Figure 7: Effects of uncultivated vegetation / crop gradient on the striped cucumber beetle population, 1996. (June: $y = 0.12 + 0.06x$, $R^2 = 0.43$; July: $y = 0.33 + 0.07x$, $R^2 = 0.73$; September: $y = 1.26 - 0.05x + 0.002x^2 - 0.00003x^3$,$R^2 = 0.02$).

V = Uncultivated vegetation portion
C = Crop field portion

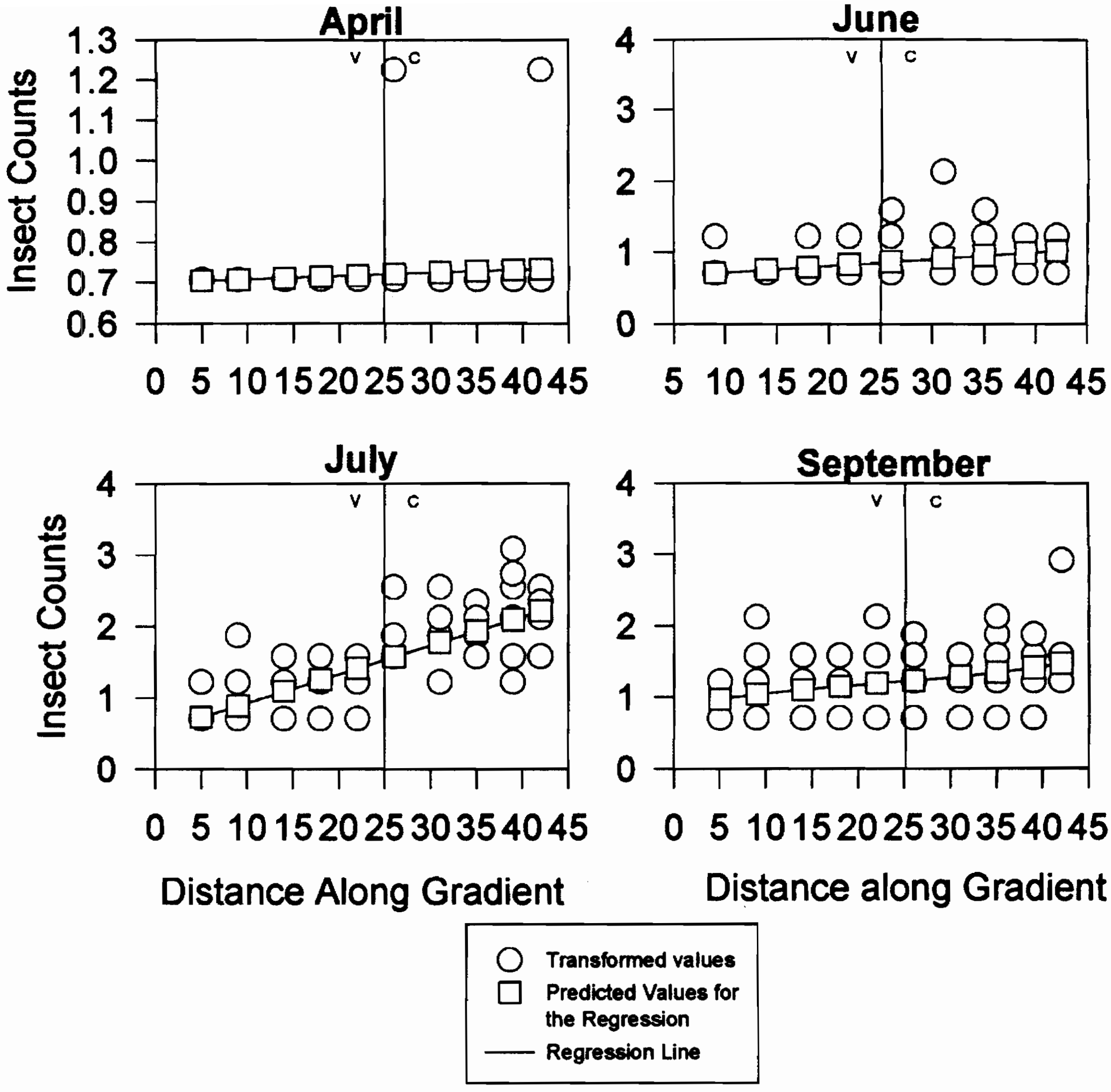

Figure 8: Effects of uncultivated vegetation / crop gradient on the spotted cucumber beetle population, 1996. (April: $y = 0.70 + 0.001x$, $R^2 = 0.02$; June: $y = 0.63 + 0.009x$, $R^2 = 0.11$; July: $y = 0.53 + 0.04x$, $R^2 = 0.59$, September: $y = 0.86 + 0.02x - 0.007x^2 + 0.00001x^3$).

V = Uncultivated vegetation
C = Crop field

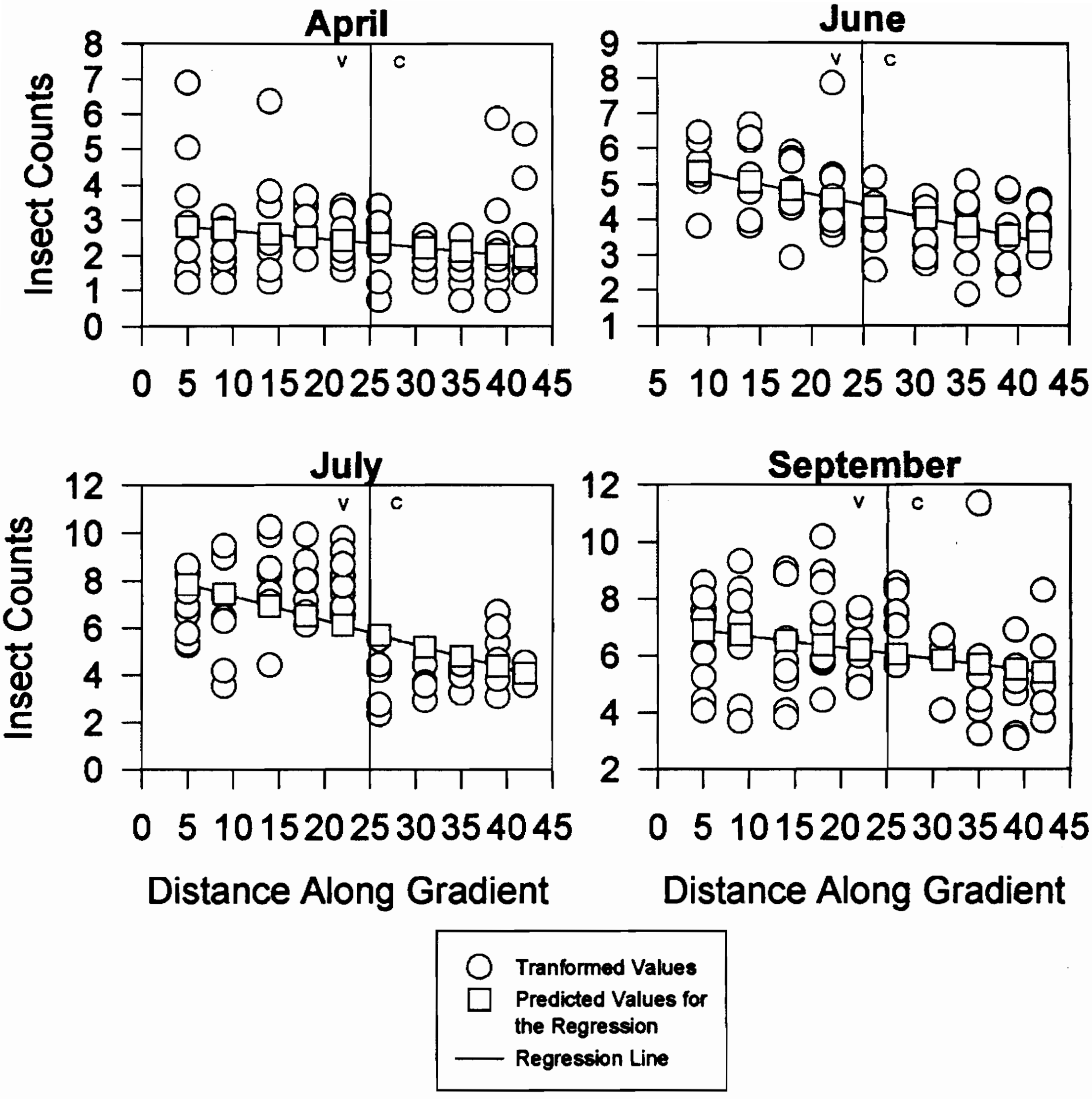

Figure 9: Effects of uncultivated vegetation / crop gradient on the Diptera population, 1996. (April: y = 2.92 - 0.023x, R^2 = 0.06; June: y = 5.89 - 0.06x, R^2 = 0.34; July: y = 8.36 - 0.10x, R^2 = 0.08; September: y = 7.09 - 0.04x).

V = Uncultivated vegetation
C = Crop field

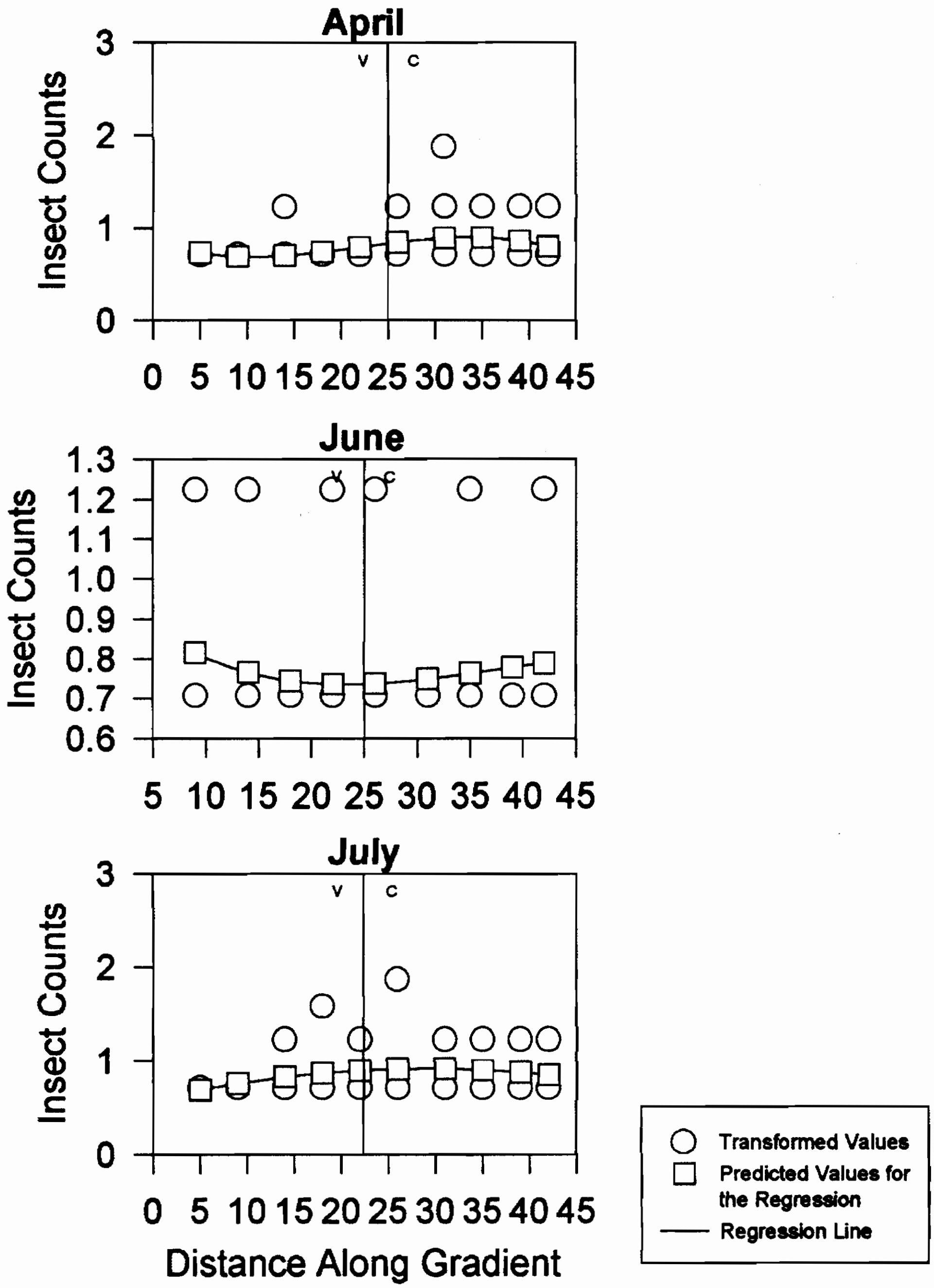

Figure 10: Effects of uncultivated vegetation / crop gradient on the *Coleomegilla maculata* population, 1996. (April: $y = 0.86 - 0.04x + 0.002x^2 + 0.00003x^3$, $R^2 = 0.11$; June: $y = 0.98 - 0.02x + 0.0008x^2 - 0.000007x^3$, $R^2 = 0.02$; July: $y = 0.58 + 0.02x - 0.0004x^2$, $R^2 = 0.08$.)

V = Uncultivated vegetation
C = Crop field

Vita

Born in Ankara, Turkey on May 19th 1971.

Graduated from Lloyd C. Bird High School, Chesterfield, Virginia, in 1989.

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