DEVELOPING METHODS OF STRIP CROPPING CUCUMBERS WITH RYE/VETCH

BY

MAURICE OKENDO OGUTU

Dissertation submitted to the Faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in

Horticulture

November 20, 2000

Blacksburg, Virginia

Dr. John S. Caldwell, Chairman
Dr. Ronald D. Morse, Co-Chairman
Dr. Daniel B. Taylor, Member
Dr. James R. McKenna, Member
Dr. L. T. Kok, Member

Keywords: Cucumber beetles, beneficial insects, soil moisture, no-till, cover crops, economic analysis

DEVELOPING METHODS OF STRIP CROPPING CUCUMBER WITH RYE/VETCH

by

Maurice Okendo Ogutu

Dr. John S. Caldwell, Chairman

Horticulture Department, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

ABSTRACT

The purpose of this research carried out in 1998 and 1999 was to develop methods for strip cropping of cucumbers with rye/vetch and black plastic mulch. Effects of planting methods, weed control measures, and cover crop management techniques on pest and beneficial insects, petiole sap nitrate-nitrogen, soil moisture, yields and economic viability were assessed. Four treatments, namely cucumber direct seeded in black plastic mulch on tilled bare ground (conventional); cucumber direct seeded in black plastic mulch laid over incorporated rye/vetch residue; cucumber direct seeded into no-till rolled rye/vetch; and seedlings transplanted into no-till rolled rye/vetch, were evaluated in a randomized complete block design. Weeds were controlled in half the plot by critical manual weeding and pre-emergence herbicides applied in the other half in all treatments except the conventional system. Three-week interval staggered plantings of buckwheat to provide flowers for adult beneficial insects were also evaluated.

Results obtained indicate that rye/vetch habitat is more attractive to beneficial insects than cucumber beetles before rolling or flail mowing. There were higher densities of adult Diptera (an indicator for Tachinid parasitoids) in both years and of Pennsylvania leatherwings in 1999 in plots with rye/vetch than in plots with rye only before planting. Preferential attraction to adult Diptera was not found after planting with no differences in cumulative densities between no-till and black plastic mulch plots after rolling or flail mowing. However, adult Diptera densities were positively correlated with cucumber yield, higher densities of cucumber beetles occurred in black plastic mulch than in no-till plots in both years, and bacterial wilt, transmitted by cucumber beetles, was reduced in no-till in 1999. Similarly, rye/vetch habitat plots had a higher diversity of Carabidae species (in both habitat areas and crop rows) before rolling or flail mowing, and higher densities of Carabidae (in habitat areas), Staphylinidae (in both habitat areas and crop rows) and spiders (in crop rows) after rolling or flail mowing. Black plastic mulch plots with flail mowed, incorporated rye/vetch residues had higher petiole sap nitrate-nitrogen and higher early season cucumber plant dry weights than in conventional plots; later in the season, the highest petiole sap nitrate-nitrogen occurred in no-till plots. No-till had higher marketable cucumber yield than plastic systems. The profitability of these production systems depended more on differences in marketable yield than on cost differences. The plastic with incorporated rye/vetch and no-till transplant systems were more profitable during early harvests in late July, while no-till direct seeded and transplant systems were more profitable from early August onwards. The three-week interval staggered planting of buckwheat led to conservation of beneficial insects, and the second and third seeded buckwheat flowering periods coincided with the period vetch had lost flowers.

DEDICATION

This dissertation is dedicated to my parents, the late Carilus Ogutu Omolo and late Joyce Okinda Ogutu, whose wise guidance and counseling made me learn about the importance of education.

ACKNOWLEDGEMENTS

I would like to thank my major advisor Dr. John S. Caldwell for his wise guidance, financial support and advice, which carried me through this program. I wish also to thank Dr. Ron Morse for agreeing to act as co-chair in Dr Caldwell's absence, as well as serve as a member of my committee. I likewise thank Dr. L.T. Kok, Dr. D. B. Taylor and Dr. J. R. McKenna for serving as members of my committee and for their valuable advice. I also wish to thank Dr G. I. Holtzman for assistance in data analysis and interpretation.

I would also like to thank Mr. John Wooge and the Kentland farm staff for their assistance during my research, Laura Hill and Patrick Teague for helping me with fieldwork and data collection, my friend James Okeyo and his wife Ruphina for staying with me when I came to Blacksburg, and all members of the Horticulture Department.

I wish to thank my wife Roseline, my daughter Joyce and my son Roy for their patience and creating an enabling environment for me to complete this work. More thanks to my brother Omolo and my sisters Mrs. Ahera Onditi and Mrs. Olum Miyare for their prayers and encouragements during this time. I also extend my appreciation to my cousins Fabian Aluoch and Joseph Magadi for their good wishes. Lastly I would like to thank all my friends in Blacksburg for their assistance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

CUCUMBERS

Importance in the United States of America and botany

Cucumbers (*Cucumis sativus* L.) are both a leading commercial crop and a popular home garden vegetable. They are grown all over the world, mainly for the fresh market. China is the leading producer of fresh cucumbers, followed by India, and the United States is number three. In addition to the above, there is considerable greenhouse production in northern Europe and Japan, and lesser production in United States and Middle East (Swiader et al., 1996).

Commercial cucumber production in the United States includes processing types for pickling and fresh market types for slicing. Cucumbers were planted on 25,940 hectares (64,100 acres) out of 806,560 hectares (1,993,020 acres) of land under vegetables in the United States, in 1999 producing 540,720 mt valued at $ 217 million. During the same year, Georgia had the largest area in fresh market cucumbers, followed by Florida, Michigan, California, North Carolina, and Virginia (USDA, 2000). The major portion of the commercial crop in the United States is for processing, with Michigan, North Carolina, Texas, California, and Wisconsin the leading states for pickle production. Processing cucumber yields average about 5.6 $t.ha^{-1}$ (5 $t.ac^{-1}$) in the United States, and range from about 4.5 $t.ha^{-1}$ (4 $t.ac^{-1}$) in the East to over 20.2 $t.ha^{-1}$ (18 $t.ac^{-1}$) in California. Cucumbers for pickling are usually grown under contract, so profits are directly related to yield per acre (Swiader et al., 1996).

Average yields for fresh market slicers picked by hand range from 3.4 to 6.7 $t.ha^{-1}$ (3 - 6 $t.ac^{-1}$). Fresh market cucumbers produced early in the marketing season are a high-value crop in most areas of the United States (Swiader et al., 1996). In Virginia, the area under cucumber in 1999 was 2,307 hectares (5,700 acres), out of the total area in vegetable production of 8,903 hectares (22,000 acres), and Virginia cucumber production was valued at $ 3,900,000, out of total vegetable revenue of $ 53,887,000. This represents 7.2% of the total revenue from vegetable sales that year, making cucumbers second to tomatoes, which netted 77% of the total revenue (Virginia Agricultural Statistics Service, 2000). This indicates that fresh market cucumbers are a very important vegetable in the Virginia economy.

Cucumber (*Cucumis sativus* L.) belongs to the Cucurbitaceae family, or gourd family. Members of this family are commonly called cucurbits or vine crops. The Cucurbitaceae consist of 96 genera, but only three are of commercial importance in the United States, *Cucumis* (cucumber and muskmelon), *Citrullis* (watermelon), and *Cucurbita* (pumpkin and squash). The genus *Cucumis* consists of forty species.

Cucurbits are sub-tropical annuals that are sensitive to cold weather. Most cucurbits are grown for their fruits, but the flowers and leaves of some species are used as food in some parts of the world. Cucurbits bear different kinds of flowers on the same plant. The fruits are derived from a single ovary containing many ovules or seeds. Insects are the main pollinators of cucumbers, particularly bumble bees in the United States.

There are two types of cucumbers: slicing and pickling. Pickling cultivars are smaller and have darkish green skin with protruding warts or spines. Most pickling cucumber fruits are less than 10 cm (4 inches) long. The principal pickling cultivars grown in Virginia as well as other states are the gynoecious hybrids 'Lafayette' and 'Vlaspik,' and the monoecious cultivars Magik and Eureka. Slicing cucumbers can either be grown commercially outdoors or in greenhouse. Outdoor cultivars have smooth, dark green skin, are about 20 cm (8 inches) long and 3.75 cm (1½ inches) wide, and have seeds. Greenhouse cultivars are longer, 30-37.5 cm (12 to 15 inches), are thin-skinned and have few seeds. The principal slicing cucumber cultivars grown in Virginia as well as other states are the hybrid gynoecious cultivars Encore, Raider, Speedway, Dasher II, Thunder, Turbo, Meteor, and Striker, and the monoecious cultivars – Medalist, Cyclone, and Marketmore 76. All these cultivars have resistance to most cucurbit diseases (O'Dell et al., 2000).

Current production systems

Cucumber producers often use black plastic mulch laid on tilled bare ground. Black plastic mulch has the advantages of weed control, warming up cold soils in early spring, and conserving moisture supplied through trickle lines placed under the plastic. White transparent plastic is less suitable than black plastic mulch because it permits the growth of weeds under the mulch. Cucumbers are planted in the field by either direct seeding or transplanting seedlings not more than three weeks old. Seedlings less than three weeks old are at a critical stage when weed competition can drastically reduce their growth. Weed, insect pest, and disease control is usually done based on state recommendations for pesticide application.

NEED FOR ALTERNATIVE VEGETABLE PEST MANAGEMENT STRATEGIES

Pesticides are widely used today in the production of vegetables and other foods to control insect pests, diseases and weeds, but concerns about the effects of their residues on human health and the environment have increased among consumers and agencies of the U.S. Federal government that regulate their use. These concerns may lead to reduced availability of pesticides for vegetable growers who use them today. Other vegetable growers, both organic and non-organic, are seeking to meet increasing consumer demand for pesticide-free vegetables but need better production techniques that do not depend on pesticides.

Pesticides used on foods contain active ingredients harmful to humans. Some of these active ingredients break down into compounds harmless to humans within the period of time specified on the label after application before they may be harvested for sale and consumption. However, tolerance levels are set for many active ingredients that allow them to remain on foods after harvest at low concentrations considered to be safe for human health. Many consumers are nevertheless uncertain of the long-term effects of consuming foods with sub-lethal levels of pesticide residues, particularly because of the possibility of long-term exposure to carcinogenic compounds, potential cancer causing agents, in the human body. This concern of consumers has been supported by findings associating long-term exposure to pesticides and their residues with several diseases (Metcalf, 1994; Metcalf and Luckman, 1994; Kuchler et al., 2000).

Reflecting both consumer concerns and the above research findings, the U.S. Federal government enacted Food Quality Protection Act (FQPA) in 1996 with the purpose of ensuring the safety of food for consumers. Under the FQPA, tolerances for currently registered pesticides are to be reviewed based on their mode of actions. Organophosphates and carbamates, which belong to human carcinogenic chemical groups, are on the priority list to be reviewed first based on the maximum allowable risks set by the Environment Protection Agency (EPA). Organophosphates and carbamates are widely used for insect control. If insecticides in this group used for vegetable production are found to pose a risk to consumers above the EPA acceptable risk levels, some of the currently registered pesticides in the group will be removed from the market. This may happen even before effective alternative substitutes can be developed.

Pesticides also have environmental risks. Many pesticides, and particularly most insecticides, may be harmful to non-target beneficial organisms in the agroecosystem. Some pesticide residues pollute surface and groundwater resources, reducing the quality of those resources for human use and marine life and affecting areas beyond the immediate production agroecosystem. In addition, the manufacture of pesticides requires the use of fossil fuels, which are causes of global warming and air pollution (Pimentel et al., 1980; Debach and Rosen, 1991).

The organic vegetable industry is growing in Virginia as well as other states, and more farmers are certified annually under state laws. The conditions set in the certification programs limit the use of synthetic farm inputs, including pesticides and chemical fertilizers. In the transition period before certification, a field must be free of pesticides for a fixed period time. In Virginia, this period is one year (Virginia Association of Biological Farmers Manual, 1995); in other states, the period may be longer, such as three years in California (California Certified Organic Farmer Handbook, 2000). To meet certification requirements, pest management practices must use naturally occurring compounds. From the grower's perspective, availability of naturally occurring products is only a first condition; the necessary condition for successful transition is that alternative production systems provide adequate pest control to insure economic viability.

In order to meet the needs of organic growers and other growers who would like to eliminate pesticide use and to provide alternatives for growers who may lose registered pesticides and need alternatives in the future, insect pest control methods that do not depend on pesticides need to be developed. Research to develop alternative vegetable production techniques that reduce pesticide use while ensuring economic viability for producers can help meet the demand for food produced with less synthetic chemicals.

OPTIONS FOR ALTERNATIVE PEST MANAGEMENT STRATEGIES FOR CUCUMBER PRODUCTION

In Virginia, cucumbers are attacked by a number of insect pests, including cucumber beetles (spotted and striped), squash vine borers, squash bugs, aphids, spider mites, seed corn maggots, cutworms, and pickleworms. Among these, striped and spotted cucumber beetles rank highest for organic and other vegetable growers interested in sustainable production (Amirault and Caldwell, 1995).

Striped (*Acalymma vittata* Fabricus) and spotted (*Diabrotica undecimpunctata howardii* Barber) cucumber beetles cause several types of damage to cucumbers. Adult beetles feed on the foliage, and in the seeding stage may cause crop loss. Later, they feed on the fruit, reducing its quality. Both species can transmit bacterial wilt, and the striped cucumber beetle can also spread cucumber mosaic virus. Larvae feed on roots and stems.

Adult beetles of both species are similar in size, about 6.25 mm (0.25 inch) long. The striped cucumber beetle has a black head and black- and yellow-striped wings, while the spotted cucumber beetle has a black head and a yellowish-green body with twelve black spots on its back. Further details on the biology and damage to cucumbers of these pests are discussed in the next chapter.

Pest management strategy in conventional vegetable production is based on state recommendations for application of federally labeled pesticides. The control of cucumber beetles and bacterial wilt in cucumbers is based on the application of pesticides shortly after plant emergence and repeat applications at weekly intervals (O'Dell et al., 2000). Current recommendations are based on prevention rather than assessment of pest densities in relation to the level of damage, which would make pesticide application economically justified. Effective control under this program may require 6-8 applications. Alternative pest management strategies for growers that could reduce the number of applications are use of economic thresholds, biological control, and agroecosystem diversity.

The economic threshold is defined by Stern et al (1959) as "the pest density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level." The economic injury level is "the lowest population density of a pest that will cause economic damage" (Stern et al., 1959). An economic threshold is a decision strategy in which the growers apply insecticides only when the population of the insect pests (cucumber beetles) approaches an economically damaging level. It involves visual counts of insect pests per plant, assessment of leaf damage, or use of insect pest counts on sticky cards to determine pest densities in relation to thresholds. The thresholds for muskmelons of 0.5 beetles per plant (Brust et al., 1996) and cantaloupes of 1 beetle per plant (Brust and Foster, 1999) have been developed and used in the Midwest states to control bacterial wilt and feeding damage caused by cucumber beetles. Since spraying is done only when the threshold is reached, the number of pesticide applications per season has been reduced from 6-8 to 2-4, which is more economical for growers. This control measure can benefit conventional, sustainable, and organic vegetable growers. A threshold of 15 cucumber beetles per yellow sticky card per week has been proposed for Virginia, derived from correlations of counts on sticky cards with visual observations of one beetle per plant (Caldwell et al., 1998).

Biological control of insect pests is achieved by use of natural enemies to reduce pest populations (Metcalf and Luckman, 1994). The classical biological control is defined by Hoy (1994) as "importation of known natural enemies against exotic insect pests from their areas of origin, assuming that they will keep the pest population below threshold in the area of introduction." A natural enemy is "any organism feeding on another organism. They are referred to as parasites, predators and pathogens" (Debach and Rosen, 1991). The above natural enemies can be used for effective biological control of pests. Parasites attacking insect pests are referred to as parasitoids and they are generally ranked first because the parasitoid completes its entire life cycle on a single host (egg, larvae, pupa or adult); hence, it kills the host. Most of the parasitoids are found in the orders Diptera and Hymenoptera. Some parasitoids can parasitize a broad range of hosts, but most of them are host specific and each may attack a different stage of the host. Parasitoids can be introduced to control a foreign pest (Hoy, 1994). Predators are ranked second since they may consume many prey individuals during their development to adulthood, but others are predators as immatures and feed on alternative foods as adults. Some predators may feed on pollen, nectar and other alternative food sources. Predatory insects are more prevalent in nature than parasitoids and most of them are found in the orders Coleoptera, Hemiptera, Hymenoptera, and Neuroptera. Predators have also been used successfully in insect pest management programs (Hoy, 1994; Debach and Rosen, 1991). The term "beneficial insect" is often used as a synonym for natural enemies of agricultural pests, and this study follows this convention also.

Biological control can also be defined in terms of augmentation and conservation of natural enemies. Augmentation was defined by Rabb et al (1976) as "efforts to increase populations or beneficial effects of natural enemies of both native and exotic pests." This can be achieved through periodic release and environmental manipulation. It is used when indigenous natural enemies cannot control pests (Hoy, 1994). There are companies that rear and sell natural enemies for certain pests. Conservation is defined as "the protection and maintenance of natural enemy populations in agricultural cropping systems" by Hoy (1994), which is essential for either native or introduced natural enemies. Conservation of natural enemies can be achieved by using pesticides which are not harmful to natural enemies, plants resistant to pests which allow natural enemies to flourish, and crops which act as shelters, alternate hosts and nectar for parasitoids (Hoy, 1994). Augmentation and conservation can lead to successful control of the pest, but preliminary studies need to be carried out before natural enemy release is commenced, and the purchase of natural enemies is an added cost to the farmer; hence, biological control is only applicable if it is cheaper than pesticide application for the conventional grower. Sustainable and organic vegetable growers utilize this method as a means of controlling insect pests when it is biologically feasible.

The utilization of agroecosystem diversity is another option for pest management in vegetables (Risch, 1979). Agroecosystem diversity makes use of two relationships between natural enemies, pest insects, and plant food material. One relationship involves the feeding behavior of natural enemies. During some stages of their life cycle, natural enemies of insect pests also feed on plants. A diverse agroecosystem can support greater numbers of natural enemies, by providing nectar and pollen of different plant species for them to feed on. The presence of adequate numbers of natural enemies reduces population densities of the pest below threshold levels; hence, the damage caused to host crop plants is less and higher yields can be achieved.

The second relationship in a diversified agroecosystem involves the ability of the insect pest to find and colonize the crop plant. In a more diversified agroecosystem, non-host plant species emit chemical cues, which makes it difficult for the pest insect to locate the host plant. The pest insect approaching a mixed stand may initially not pick up the chemical or visual cues of the host plant in a mixed stand. If a flight path of the pest insect nevertheless continues into the field and it lands on a non-host plant, it tends to move and continue searching for host plants, but it may take several attempts before it finds the host plant. In contrast, in monoculture, where only the host crop plants are grown in the field, the pest insect receives unmixed chemical and visual cues, and the probability that it will find and colonize the host crop is greater. Overall, in this manner agroecosystem diversity leads to reduced tenure time in mixed stands compared to pure stands (Bach, 1981). This effect should in theory translate into consequent reduced damage to plants and lower incidence of insect-transmitted diseases such as bacterial wilt. Agroecosystem diversity can be implemented in sustainable and organic vegetable production systems by the establishment of habitat borders and strip cropping, as explained in the following section.

The adoption of alternative pest management techniques by farmers may vary depending on the problems to be solved in a farm, the farm size, economic incentives such as premium prices for the vegetable produced using alternative techniques, achievement of comparable or higher yield than the conventional system and the economic viability of the practice (Glynn et al., 1995).

STRIP CROPPING

Strip cropping is the technique of planting different crops in alternate strips in the same field. The alternate strips may be planted simultaneously, or they may be planted so that part of their growth cycle overlaps with that of the economic crop. Strip cropping can include cover crops planted earlier in the season than the economic crop. Strips have traditionally been used for wind and water erosion control, but they may also be grown as a habitat for natural enemies of an insect pest of the economic crop. A habitat refers to an area with plant species that serve as a food source for natural enemies. Crop planting strips can be made in the fields where cover crops have been planted by either mowing and tilling, flailing, or rolling narrow seedbed strips while leaving the cover crops in areas between the seedbed strips in the field. It is important to ensure that competition between the main crop and the cover crop is minimized.

Cucurbits can be strip cropped in a rye/vetch cover crop mixture by making strips earmarked for crop planting in several different ways. One option is to apply herbicides to kill the cover crops, followed by rolling and seeding or transplanting using a no-till planter. Other options are: 1) killing the rye/vetch by flail mowing it and rototilling the residues into the soil leaving standing rye/vetch between the strips to act as a habitat for natural enemies; and 2) rolling rye/vetch in strips leaving unrolled habitat between the crop strips to act as food sources for adult natural enemies. Rolling breaks the rye stalk and effectively kills most of the rye plants, and much of the vetch is also killed by crushing. Seeding or transplanting is done in the rolled areas after cutting furrows with a coulter and opened up with a chisel. The rolled rye/vetch acts as a no-till mulch along the crop strips.

These strip cropping methods have been developed over the last six years (1994-1999) by Amirault and Caldwell (1998) and Ogutu and Caldwell (1999). Earlier research focused on identification of cover crops appropriate for conservation of natural enemies and development of cover crop and cucumber row arrangements and spacing, cover crop management, and cucumber planting techniques to reduce competition between cover crops and cucumbers. This study builds on the earlier results, adding assessment of weed control, water management, and nitrogen status, and economic comparison of strip cropping and conventional production systems. It represents the culmination of this research on strip cropping.

COVER CROPS

A cover crop is defined as a crop grown to benefit soil, other crops, or both, but not intended for harvest and economic sale (Clark, 1998). The benefits of using cover crops may include: improved soil fertility, particularly if nitrogen fixing legumes are grown; provision of mulch for weed control; reduction of groundwater contamination by grasses removing excess nitrogen from the soil profile; and reduction in disease and nematode problems, particularly if the cover crop is a non host plant. Cover crops are an important component of a sustainable agricultural system because they enhance biological processes and reduce reliance on chemical and fossil fuel inputs, which in turn can reduce fertilizer and pesticide costs (Creamer et al., 1996).

The potential negative effects of cover crops are: depletion of soil moisture during their growth period; reduction of soil temperatures in early spring, since they cover the ground from direct solar radiation; disruption of field operations, either due to difficulty in incorporating or plowing under prior to planting, or to restrictions on tractor movement if left in strips between the economic crop; reduction in the percentage of germination of vegetable seeds due to allelopathy; and attraction by some cover crops of pests or diseases of the main crop (Doll and Bauer, 1991; Stivers-Young and Tucker, 1999).

There are both constraints and opportunities in using cover crops in vegetable production (Clark, 1998). The constraints include: increased management due to differing planting times, nutrient and water needs, etc., of cover crops; possible negative effects of the previous economic crop on establishment of cover crops (such as plastic mulch or row covers); possible negative effects of the cover crops on subsequent economic crops (such as reduced soil moisture or nitrogen status after grass cover crops); and the consequent need to plan rotations and land use to minimize negative effects of cover crops and the economic crop on each other.

Despite these constraints, many opportunities exist for effective use of cover crops in vegetable production systems. Most cover crops have short cropping periods that can allow for multiple cropping that includes vegetable crops. Many cover crops can be grown at times of the year when they do not compete with the economic crop. Many cover crops can help improve soil nutrient and water status for subsequent economic crops. Cover crops can increase diversity of the agroecosystem, with potential reductions in pest (Clark, 1998).

Grain rye (*Secale cereale* L.) and hairy vetch (*Vicia villosa* Roth)

Grain rye is a winter hardy annual grass that does better in clayey loam soils. It does not require fertilizer or lime in soils whose fertility is maintained for cash crops. It is well adapted to the southern United States. It can be successfully planted in October, overwinter, and grow rapidly in the following spring. It is an effective weed suppressing mulch and is allelopathic to some weeds. It is tolerant to atrazine. It can utilize excess nitrogen left over from harvesting main crop. Rye should be killed early when it is still in the vegetative growth phase before seeding. Constraints are that if it becomes over mature, it becomes stemmy and very hard to decompose, hence interfering with seedbed preparation or no-till planting. It is also allelopathic to some small seeded plants, which may be a constraint in the germination of vegetables like carrots (http://www.sare.org 2000).

Hairy vetch is the most widely used winter annual legume cover crop in the United States. It is adapted to the southern United States, fixes nitrogen, can overwinter, and produces a large amount of biomass in the spring. It is resistant to root rot and competes well with weeds. It also possesses some allelopathic properties. It can make phosphorus and micronutrients available to the subsequent crops. Vetch mulch as compared to rye mulch, decomposes very quickly, releasing inorganic nitrogen into the soil solution (http://www.sare.org 2000).

A rye/vetch mixture can be grown to utilize the differing advantages of these two cover crops. They can be planted at the same time with a high success, and improve the survivability of vetch in the winter when the rye covers the vetch during snowfall. In the spring, vetch climbs on the rye stems, resulting in less matting on the ground and allowing for easier rolling or flail mowing. The mixture produces high biomass in the spring. Vetch residue is high in nitrogen, and its rapid decomposition also speeds up rye residue breakdown with less risk of nitrogen tie-up. Rye mulch can provide better weed control for a longer period of time, since its decomposition rate as a mulch, is slower than vetch. The mixture can also provide adult beneficial insects with pollen and nectar during the first month after planting in the late spring. Hairy vetch loses its flowers midway in the season when some adult beneficial insects are still feeding and mating, so they may move from the habitat area into the crop rows in search of food resources.

The use of rye/vetch mixture in vegetable production provides an opportunity to reduce the use of chemical inputs in production of vegetables and thereby help meet the objectives of the Food Quality Protection Act (FQPA) of 1996. This may provide an alternative to the use of pesticides, which are currently used in vegetable production but may be banned in the near future before effective substitutes are developed. It can offer weed control, insect pest control and soil fertility improvement opportunities for the organic vegetable industry.

GOALS AND OVERALL OBJECTIVES OF THIS STUDY

The goal of this study is to reduce pesticide use in cucumber production by developing cover crop management methods for strip cropping cucumbers. The specific objectives are to: achieve good weed control and stand establishment; conserve below ground and above ground beneficial insects that can control cucumber beetles; produce no-till mulch for soil moisture conservation; increase soil organic matter and fertility through decomposition of rye/vetch; and evaluate the economic viabilities of these systems. The expected result is equal or higher yields in alternative systems compared to conventional practices.

To achieve these objectives, two studies were carried out in 1998 and 1999: a comparison of methods of strip cropping of rye/vetch and cucumbers with conventional cucumber production using black plastic mulch and chemical pest control; and a companion study assessing the potential of buckwheat for extended conservation of natural enemies of cucumber beetles over the entire crop season.

In the strip cropping experiments, this research established and tested hypotheses for insect management, weed control, crop plant nitrogen status, and soil water management. There were two main hypotheses for insect management. The first is the associational resistance hypothesis, which states that the presence of non-host plants in a field will lead to difficulty in locating host plants by cucumber beetles, resulting in lower densities of cucumber beetles than in pure stands. The second is the natural enemies hypothesis, which states that the presence of a diversified habitat will provide increased nectar and pollen for the adult natural enemies of cucumber beetles, leading to lower densities of cucumber beetles than in pure stands of cucumbers.

Weed control measures in no-till systems were assessed based on the hypothesis that critical manual weeding would enable the crop to achieve growth and yields equal to the growth and yields obtained with chemical weed control. Effects on soil fertility are examined based on the hypothesis that vetch residue rich in nitrogen will supply most of the cucumber nitrogen requirements. The hypothesis for soil moisture is that soil moisture conservation will be similar in plastic and no-till.

The economic viabilities of these systems were assessed based on the hypothesis that all the systems are equally profitable when prices in a terminal market were the same. Three-week interval buckwheat seeding were evaluated in the companion study as an alternative means for providing habitats for beneficial insects based on the hypothesis that densities of beneficial insects will be constant in all the buckwheat seeded different on different dates and also in each sampling date.

The specific objectives, and hypotheses for each aspect of the study are discussed in the following five chapters. Chapters 2 and 3 present methods and results for the testing of hypothesis involving insect management in strip cropping. Chapter 4 presents methods and results for the testing of hypotheses involving crop plant sap nitrogen and soil moisture status. Chapter 5 presents methods and results for the testing of hypotheses involving economic viability. Chapter 6 presents methods and results for the companion testing of hypotheses involving conservation of natural enemies using buckwheat. Finally, Chapter 7 provides a synthesis of the results of the entire research, and concludes with some suggested directions for future research and application of results.

LITERATURE CITED

Amirault, J. P. and J. S. Caldwell. 1998. Living mulch strips as habitats for beneficial insects in the production of cucurbits. HortScience. 33(3): 524.

Bach, C. E. 1981. Host plant growth form and diversity: Effects of abundance and feeding preference of a specialist herbivore, the striped cucumber beetle *Acalymma vittata* (Fab.). Oecologia. 50: 370-375.

Brust, G. E. and R. E. Foster. 1999. New economic threshold for striped cucumber beetle (Coleoptera: Chrysomelidae) in Cantaloupe in the Midwest. Journal of Economic Entomology. 92(4): 936-940.

Brust, G. E., R. E. Foster and W. C. Buhler. 1996. Comparison of insecticide use programs for managing the striped cucumber beetles (Coleoptera: Chrysomelidae) in muskmelon. Journal of Economic Entomology. 89(4): 981-986.

Caldwell, J. S., J-P. Amirault, and A. H. Christian. 1995. Insect pests, beneficial insects, and cover crops of biological farmers. HortScience. 30(4): 806.

Caldwell, J. S., S. Johnson, M. LaChance, and S. Stockton. 1998. Threshold monitoring, trap cropping, and aluminium mulch repulsion for management of cucumber beetles on cucurbits. HortScience. 33(2): 475 (Abstract).

California Certified Organic Farmers, Inc. (CCOF). 2000. Organic certification handbook. Santa Cruz, CA. Website: http://www.ccof.org

Clark, A. (ed.). 1998. Managing cover crops profitably. Second eition. Sustainable Agriculture Network (SAN). Beltsville, Maryland.

Creamer, N. G., M. A. Bennett, B. R. Stinner and J. Cardina. 1996. A comparison of four processing tomato production systems differing in cover crop and chemical inputs. Journal of the American Society for Horticultural Sciences. 121: 559-568.

Debach, P. and D. Rosen. 1991. Biological control by natural enemies. Cambridge University Press, Cambridge. 440 pp.

Doll, J. and T. Bauer. 1991. Rye more than a mulch for weed control. Illinois Agricultural Pesticides Conference presentation summaries. Pp. 146-149. Urbana, Illinois.

Glynn, C. J., D. G. McDonald and J. P. Tette. 1995. Integrated pest management and conservation behavior. Journal of Soil and Water Conservation. 50(1): 25-29.

Hoy, M. A. 1994. Parasitoids and predators in management of arthropod pests. Pages 129-198. in: R. L. Metcalf and W. H. Luckman, eds., Introduction to insect pest management. John Wiley and Sons, Inc. New York.

Metcalf, R. L. 1994. Insecticides in pest management. Pages 245-314. in: R. L. Metcalf and W. H. Luckman, eds., Introduction to insect pest management. John Wiley and Sons, Inc. New York.

Metcalf, R. L. and W. H. Luckman. 1994. The pest-management concept. Pages 1-34. in: R. L. Metcalf and W. H. Luckman, eds., Introduction to insect pest management. Wiley-interscience publication, John Wiley and sons, Inc. New York.

Kuchler, F., K. Ralston, and J. R. Tomerlin. 2000. Do health benefits explain the price premiums for organic foods? American Journal of Alternative Agriculture. 15(1): 9-19.

O' Dell, C.R., S.A. Alexander, J. S. Caldwell, H. E. Holt, B. A. Nault, and S. B. Sterret. 2000. Commercial vegetable production recommendations - Virginia. Publication Number 456-420. 176 pages.

Ogutu, M. O. and J. S. Caldwell. 1999. Stand differences in no-till direct seeded and plasticulture direct seeded and transplanted cucumbers (*Cucumis sativus* L.). Acta Horticulturae. 505:129-134.

Pimentel, D., D. Andow, D. Gallahan, I. Schreiner, T. E. Thompson, R. Dyson-Hudson, S. N. Jacobson, M. A Irish, S. F. Kroop, A. M. Moss, M. D. Shepard and B. G. Vinzant. 1980. Pesticides: Environmental and social costs. Pages 99-158. in: D. Pimentel and J. H. Perkins, eds., Pest Control: Cultural and environmental aspects, AAAS selected symposium 43. Westview Press, Boulder, Colorado.

Rabb, R. L., R. E. Stinner, and R. van den Bosch. 1976. Conservation and augmentation of natural enemies. Pages 233-254. in: C. B. Huffaker and P. S. Messenger, eds., Theory and practice of biological control. Academic Press, New York.

Risch, S. J. 1979. Effect of plant diversity on the population dynamics of several beetle pests in monocultures and polycultures of corn, beans, and squash in Costa Rica. PhD dissertation. University of Michigan, Ann Arbor, Michigan.

Stern, V. M., R.F. Smith, R. van den Bosch, and K. S. Hagen. 1959. The integrated control concept. Hilgardia. 29(2): 81-101.

Stivers-Young, L. J. and F. A. Tucker. 1999. Cover cropping practices of vegetable producers in western New York. HortTechnology. 9(3): 459-465.

Sustainable Agriculture Research Program (SARE). 2000. Website. http://www.sare.org.

Swiader, J.M., G.W. Ware, and J.P. MacCollum. Danville. 1996. Illinois: Commercial Cucumber Production. Producing Vegetable Crops. Interstate Publishers Inc. Chapter 17, cucumbers. http://www.lpl.arizona.edu/~bcohen/cucumbers/commercial.html#prod

United States Department of Agriculture (USDA), National Agricultural Statistics Service. 2000. Vegetables and Fruits. USDA, Washington, DC.

Virginia Agricultural Statistics. 2000. Vegetable and Fruits. Virginia Department of Agriculture and Consumer Services, Richmond, Virginia.

Virginia Association of Biological Farmers Inc. (VABF). 1995. Virginia organic operations certification manual. VABF, Louisa, VA.
Website: http://www.vvac.org/bgvp/vaorg/certifmanual.html

CHAPTER 2

DENSITIES OF CUCUMBER BEETLES AND THEIR NATURAL ENEMIES IN RELATION TO YIELD IN DIFFERENT CUCUMBER CROPPING SYSTEMS

I. ABOVE GROUND INSECTS

ABSTRACT

Densities of cucumber beetles [striped, *Acalymma vittata* Fabricus and spotted, *Diabrotica undecimpunctata howardii* Barber) (Coleoptera: Chrysomelidae), Pennsylvania leatherwings *Chauliognathus pennsylvanicus* DeG. (Coleoptera: Cantharidae), and Diptera were assessed using yellow sticky cards in plots before and after planting of cucumber in 1998 and 1999. Cucumbers were planted in four treatments (production systems): direct seeded in black plastic mulch strips laid on bare ground (conventional), direct seeded in black plastic mulch laid over incorporated rye/vetch residue, direct seeded in no-till rolled rye/vetch, and transplanted in no-till rolled rye/vetch. Rye/vetch strips were left between the strips in which cucumbers were planted in all treatments except the conventional.

There was less than one striped and spotted cucumber beetle per sticky trap card in all treatments before planting. In 1999, higher densities of adult Diptera and Pennsylvania leatherwings were present in rolled rye/vetch treatments compared with conventional plots. After planting, densities of cucumber beetles increased in all plots until the first peak density in early July, followed by a second peak in mid August in both years, with lower densities in no-till than in plastic mulch plots. Pennsylvania leatherwing densities were low throughout the season, with two peaks in the first weeks of July and September. No-till plots had higher densities of adult Diptera.

Densities of cucumber beetles were negatively correlated with yield in both years, while densities of adult Diptera were positively correlated with yield in both years. These results indicate that rye/vetch habitat (area of uncut live plants used as refuge and food source by beneficial insects) attracts more beneficial insects than plots without habitats, while cucumber beetles are

present at lower densities in plots with habitats. The variation in correlations between cucumber beetle and adult Diptera densities with yield suggests that the presence of pest and beneficial insects may be more critical at some stages than others in each production system. The value of rye/vetch habitats was further supported in 1999 by an over 60% incidence of bacterial wilt in plots with plastic mulch compared to less than 18% incidence in no-till plots.

Key words: *Chauliognathus pennsylvanicus*, no-till, habitats, Diptera, black plastic mulch

INTRODUCTION

Cucumber beetles (striped, *Acalymma vittata* Fabricus and spotted, *Diabrotica undecimpunctata howardii* Barber) and squash vine borer (*Melittia cucurbitae* Harris) are the most important pests for cucurbit growers in Virginia (Caldwell et al., 1995). The adult beetles feed preferentially on shoots while larvae feed on roots and develop in the soil. Adult spotted cucumber beetles feed on corn silk and beans as well (Houser and Balduf, 1925; Gould, 1944; Godfrey et al., 1998). The adult striped and spotted cucumber beetles are vectors of the bacterial wilt disease causing organism *Erwinia tracheiphilia* (E.F. Smith) Holland (Rand and Enlows, 1916; Gould, 1944; Brust, 1997). The pathogen overwinters in the guts of these pests and comes out with the feces (Gould, 1944). Temporary and long-term retention of this pathogen occurs in the spines and numerous folds in the fore and hind guts of *Acalymma vittata* Fabricus, although further studies are needed to confirm this association (Garcia-Salazar, 2000). Before cucurbits are planted, these beetles can feed on a wide host range such as plants of the Compositae, Rosae (serviceberry, wild plums), dandelions, willows and wild cucumbers. Cucumber beetles move progressively from the forest habitat in early spring to shrubs and grassland areas near cucurbit agroecosystems. The beetles attack squash first followed by cucumbers and finally melons. This transition occurs because the beetles are able to track chemical cues from the cucurbits (Houser and Balduf, 1925; Gould, 1944; Bach, 1980a). Most of their feeding is confined to cucurbits in summer (Bach, 1980a; Bach, 1980b; Bach, 1981). In the fall when cucurbits are mature and vines dry up, the overwintering adults migrate to other succulent vegetables and fall blooming plants such as goldenrod and asters. Since most of these wild plants grow along rivers and in forests, the cucumber beetles tend to migrate to these areas where they eventually overwinter (Gould, 1944).

Habitat is defined as a place or niche occupied by an organism. Some ecologists consider habitat to be synonymous with environment (Lindeman, 1942). Habitat diversity is important for both insect pests and natural enemies, since in a diverse habitat plant species serve as nectar and pollen sources for different categories of insects (Altieri and Letourneau, 1982; Altieri, 1991; Baggen et al., 1999). Habitat diversity is synonymous with biodiversity when we are considering species richness and abundance. This is usually a measure of the number of species of plants, animals, and microorganisms living in a habitat.

Strip cropping is a production system where crop strips are alternated with uncultivated patches of weeds or cover crops, which act as habitat for beneficial insects. It brings species diversity into agroecosystems that are dominated by single plant species (monoculture), which are centers of attraction for pests (Thomas et al., 1991). Some weeds and cover crops serve as nectar and pollen sources for beneficial insects. This in turn enhances establishment of potential insect pest predators closer to the crop strips before planting. Several cover crops have been associated with beneficial insects. Nine cover crops (rye/vetch mixture, buckwheat, faba beans, annual white sweet clover, grain sorghum, Canadian field pea, cowpea, sunflower and canola) have shown attraction to natural enemies. Hairy vetch and buckwheat harbored many insidious flower bugs while others recorded high numbers of Coccinellidae and syrphidae (Bugg and Ellis, 1990). In some cases trap crops such as alfalfa (Godfrey and Leigh, 1994) and squash (Pair, 1997) can be used to attract pests, which may be controlled early in the season by spraying (Pair, 1997) or natural enemies (Pickett et al., 1996) before attacking the main crop.

Natural systems contain different plant species that can provide alternative food sources for pests and beneficial insects (Baggen et al., 1999). This synergy coupled with the scarcity of preferred foods leads to stable populations of pests below threshold levels in most perennial cropping systems. However, Wiedenmann and Smith (1997) in their review of augmentation of natural enemies in annual cropping systems suggested that the time the crops are in the field and types of natural enemies that can achieve high pest mortality at low natural enemy population densities need to be considered. Habitat diversity brings more plant and animal species into the agroecosystem, which creates an environment similar to natural systems where both pests and beneficial insects exist in the same habitat. This alternative pest control method is an important tactic for the reduction of pesticide usage, which would be more environmentally friendly and economical for farmers.

Several natural enemies of cucumber beetles have been studied both under laboratory and field conditions. Major natural enemies are found in two families of insect predators, Cantharidae (soldier beetles) and Carabidae (ground beetles), and a family of parasitoids, Tachinidae (tachinids). The predators can feed on larvae or eggs of cucumber beetles while the Tachinidae parasitoids deposit their larvae into adult striped cucumber beetles (Houser and Balduf, 1925; Gould, 1944). Other potential natural enemies are the entomopathogenic nematodes, – *Steinernema* species (Rhabditus: Steinernematidae), which attack the larvae of cucumber beetles (Ellers-Kirk et al., 2000). Pennsylvania leatherwings, carabidae and Tachinidae were reported in 1994-1998 cucurbit trials in Virginia (Amirault and Caldwell, 1998; Platt, 1997).

Ladybird beetles are one of the most important group of beneficial insects predaceous on pests such as aphids in agroecosystems. Aphids can flourish to economic injury levels in the absence of these predators. The generalist predator ladybird beetles *Coleomegilla maculata* DeGeer and *Coccinella septempunctata* L. prefer to forage in agroecosystems and alfalfa fields in search of prey (aphids) while the individual preferences of other species depend on food availability and habitat characteristics (Maredia et al., 1992). Both the adults and larvae are predaceous.

Various statistical models have been used to predict yield under field and laboratory conditions using different crop production parameters (Boote et al., 1996). One model used root zone water quality to predict corn and soybean yield based on soil solution nitrate percolating around the root zone. Exclusion of insect and disease led to reduction of its predictive ability, and area specificity deters its wider application (Jaynes and Miller, 1999). Organic nitrogen and carbon have been used to predict the yield of rye under controlled environmental conditions. However, this model cannot be used under field conditions due to variation in climatic and biotic factors (Stenberg, 1998). The effect of weed pressure based on relative ground cover, weed biomass, and growth stages of rice was used to predict yield loss in rice. Various weed species compete with the crop at different growth stages, hence lumping them together reduced the predictive ability of the model. This model was later improved by incorporating the leaf area index of each weed species at different growth stages of rice, while insect and disease damage were assumed to be minimal (Florez et al., 1999). Much plant growth modeling in horticulture deals with water balance and nutrient uptake and utilization while very few articles have been published on pest and disease interaction with crops. However, a number of achievements in insect pest modeling have been made in orchards (Gary et al., 1998). Other models have been developed to predict length of cultivation and yield of vegetable crops (Lentz, 1998). Development of models that may predict yield of vegetable crops based on agroecosystem parameters of plant diversity, pest and beneficial insect densities, and weed pressure was not reported in these reviews (Lentz, 1998; Gary et al., 1998). One objective of this study is to explore the prediction of cucumber yield by evaluating relationships between pests and beneficial insect densities with cucumber yield in black plastic mulch and no-till production systems.

The main objective of this study was to compare the effect of habitats and no-till production systems with conventional plasticulture on the abundance of pests (cucumber beetles) and their natural enemies [Pennsylvania leatherwings and adult Diptera as indicators for Tachinidae (Negm et al., 1997)]. This study was carried out based on the natural enemy and associational resistance hypotheses. The natural enemy hypothesis predicts higher numbers of natural enemies in a diversified habitat due to high plant species diversity providing nectar and pollen for the adult natural enemies. The number of encounters of natural enemies with the pest will be high, mortality increased, and pest population reduced to below economic threshold level (Root, 1973; Altieri and Letourneau, 1982). The null hypothesis is that the natural enemy population will be the same in all treatments before and after planting; the alternative hypothesis is that there will be more natural enemies in no-till than in plastic and conventional plots. The other hypothesis investigated in this experiment is associational resistance, which states that the presence of the cover crop habitat strips dilutes the concentration of the desired food for the pest. The cover crops also emit chemical cues, which are different from the desired host, thereby creating an environment which leads to difficulty in locating host plants and reduced tenure time on the crop when the pest lands on a non-host plant (such as rye/vetch). The null hypothesis is that both pest and natural enemies will be attracted to all the treatments equally with an alternative hypothesis of more cucumber beetles attracted to plastic plot treatments and more beneficial insects attracted to no-till plot treatments.

MATERIALS AND METHODS

Location and experimental design

The experiment was carried out at the Virginia Polytechnic Institute and State University Kentland Farm near Blacksburg, Virginia, from 1 October 1997 to 10 September 1998 and 14 October 1998 to 13 September 1999. No-till potato had been planted on the sites prior to the experiments in 1997 and 1998. The soil type is classified as a Shottower silt loam (Virginia Polytechnic Institute and State University- Soil Survey, 1990) for both sites.

Four main plot treatments combining rye/vetch management and cucumber planting methods were compared with black plastic mulch covered strips for cucumber production with or without rye/vetch habitats for beneficial insects between the cucumber strips:

Conventional – direct seeding of cucumber into black plastic mulch, with bare ground between plastic strips (plastic on soil, direct seeded, no habitat);

Flail mowed rye/vetch residue rototilled into the soil, and black plastic mulch laid on top and cucumber direct seeded (plastic on rototilled rye/vetch, direct seeded, with habitat; RTDS);

Cucumber direct seeded into rolled rye/vetch strips using no-till equipment, with rye/vetch habitats left between no-till strips (no-till direct seeded – rye/vetch no-till, direct seeded, with habitat; NTDS);

Cucumber seedlings transplanted into rolled rye/vetch in strips using no-till equipment with rye/vetch habitat between no-till strips (no-till transplanted-rye/vetch no-till, transplanted, with habitat; NTTP).

Each main plot (9 m x 9 m) consisted of three strips (1.2 m x 9 m) of cucumbers planted in twin rows, with habitats or bare soil (1.5 m x 9 m) between the crop strips. In treatments 2–4, half of the plot was sprayed with a pre-emergence herbicide mixture of Clomazone [2-(2-Chlorophenyl) methyl-4, 4-dimethyl-3-isoxazolidinone (Command 4EC, FMC Corporation, Agricultural Products Groups, Philadelphia, PA) and Ethalfluralin [ethalfluralin N-ethyl-N (2-methyl-2-propenyl)-2,6-dinitro-4 (trifluoromethyl) benzamine, as Curbit 3E (United Agricultural Products, USA)]. Herbicides were applied pre-emergence at the rates of 0.21 kg a.i.ha^{-1} (0.19 lb a.i.ac^{-1}) and 0.42 kg a.i.ha^{-1} (0.37 lb a.i.ac^{-1}) respectively on 11 June 1998 and 6 June 1999 to half of each main plot selected at random. Placement was done at the edge of the strips covering a width of about 60 cm (2 ft) on both sides of the strip up to the edge of but not in the habitat. In the conventional plots the application was done in 60 cm (2 ft) width from the edge of the plastic strips. The application was done using a calibrated backpack sprayer at the rate of 287 liters water ha^{-1} [31 gallons per acre (GPA)]. The other half was manually weeded on 7 July 1998 and 24 June 1999 (21 days after planting). The treatments were replicated four times in a randomized complete block design with a split plot arrangement of herbicide application and manual weeding. Alley ways 4.5 m (15 ft) separated the plots.

Treatment establishment

Prior to cover crop seeding, the field was plowed into a fine seedbed. On 1 October 1997 and 14 October 1998, grain rye, *Secale cereale* L. (Poaceae), unclassified variety, and hairy vetch, *Vicia villosa* Roth (Fabaceae), unclassified variety (Supplier: Southern States Seed company, Christiansburg, Virginia), were seeded using a mechanical seeder. Grain rye served as a winter nurse crop for the hairy vetch. Only grain rye was planted in control plots. The grain rye/vetch mixture was seeded at the rate of 56 kg.ha^{-1} (50 lb.ac^{-1}) rye and 56 kg.ha^{-1} (50 lb.ac^{-1}) vetch. The vetch was inoculated with the pea/vetch strain of *Rhizobia* to facilitate proper nodulation, which is essential for nitrogen fixation.

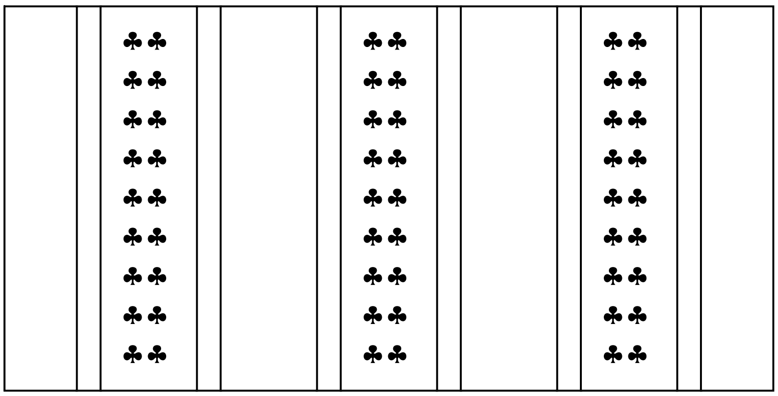
The plots were rolled (treatments 3-4) or flail mowed (treatment 2) in three planting strips alternating with habitat strips on 22 May 1998 and 22 May 1999. A habitat strip of 1.2 m (4 ft) wide was left on both sides of the center strip. The outer planting strips were bordered by a habitat strip on the outside edge of the plot 0.60 m (2 ft) wide from the edge of the planting strips on each side. After cucumber planting, 0.60 m (2 ft) of strip remained between each cucumber row and the adjacent habitat strip for tractor movement. The tractor could pass over either the habitat area or the cucumber rows using these tractor lanes.

In treatment 2, in each flail-mowed strip, rye/vetch was first raked to the edge and the strip roto-tilled; then rye/vetch mulch was raked over the tilled soil surface of the strips and incorporated. Rye/vetch mulch was raked over the center of the strips and incorporated on 25 May 1998, and 27 May 1999; finally, black plastic mulch [0.025 mm (1.25 mil) thickness, 1.2 m (4 ft) width, Huntsman Packaging, Harrington, Delaware] was laid over the plots the following day. The conventional plots mowed earlier were cultivated the same day, 25 May 1998 and black plastic mulch laid over the three strips two days later after soil drying for ease of laying. In 1999, the black plastic mulch was laid on 1 June.

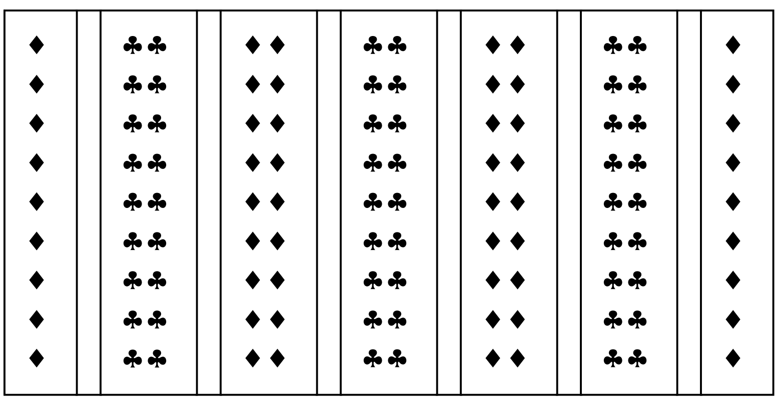
In the rolled plots (treatments 3-4), two furrows 30 cm (1 ft) apart, 3.75 cm (1.5 inches) wide, and 5 cm (2 inches) deep were made in each strip using a no-till coulter and chisel mounted on a tractor-pulled toolbar. In plots with plastic (treatments 1-2), planting holes were punched in the plastic strips at an inter-row spacing of 30 cm (1 ft) and an intra-row spacing of 22.5 cm (9 inches) between twin rows.

Layout of treatments

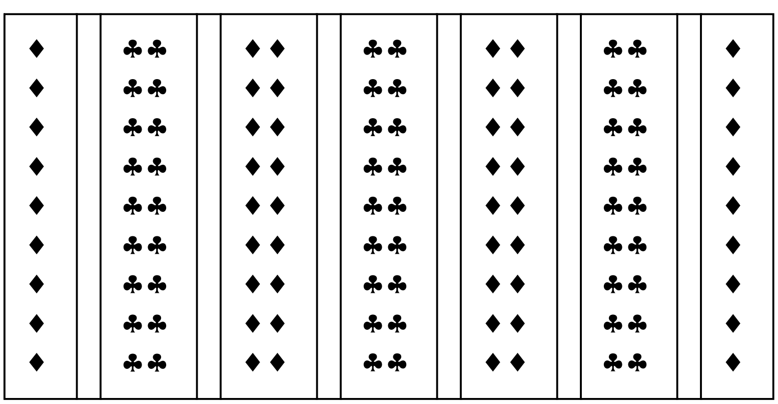
1a. Plastic laid on soil without habitat



1b. Plastic laid on rototilled rye/vetch with habitat strips



1c. No-till rye/vetch with habitat strips



♦ - habitat – 0.6 m wide; ♦ ♦ - habitat – 1.2 m wide; ♣♣ - cucumber twin row – 0.6 m wide;

- tractor lane – 0.6 m wide

Crop establishment

Hybrid cucumber cv Dasher II 194A (Stokes Seeds Inc., Buffalo, New York) for transplanting was seeded in the Virginia Tech greenhouse on 21 May 1998 and 25 May 1999, in rectangular flats filled up with Promix BX – Professional (Premier, Dorval, Quebec - Canada), and grown in the greenhouse. Hybrid cucumber cv Dasher II 194A was direct seeded in plots for treatments 1, 2 and 3 at an intra-row spacing of 22.5 cm (9 inches) and inter-row spacing of 30 cm (1 ft) on 8 June 1998 and 3 June 1999. In treatments 1 and 2, two cucumber seeds were manually drilled into the punched holes while in treatment 3, a Precision seeder (Earthway Precision Garden Seeder model 1001-B, Bristol, Indiana) with a cucumber plate was used to drill seeds into the furrow at the intra-row spacing of 22.5 cm (9 inches). Transplanting in treatment 4 was done on 16 June 1998 and 14 June 1999 respectively, one week after direct seeding, so that transplants were set in the field at the same time as the direct seeded plants emerged, and both types of plants were presented at the same time to cucumber beetles. Transplanting was done at an intra-row spacing of 22.5 cm (9 inches) in the furrows cut in the rolled rye-vetch described above. Starter solution [Soluble low N, high P fertilizer (9-45-15) was mixed in water at the rate of 0.005 kg l^{-1} (5 lb per 100 gal) and applied to each seeding hill at the rate of 6.25 l m^{-1} (½ gal ft^{-1}). Subsequently plants were watered daily until the drip system was installed to ensure survival and good establishment. Drip irrigation lines were established separately for plastic and no-till treatments. Tensiometers were used to determine when to irrigate were installed in one plastic and one no-till plot in each replicate in 1998 and 1999.

Insect monitoring

Prior to no-till plot preparation for seeding and planting, from 20 April 1998 to 11 May 1998, and from 22 April to 4 June 1999, 15 x 15 cm (6 x 6 in) yellow sticky-card traps (Olsen Products, Medina, Ohio) were attached weekly with 6 mm (1/4 inch) staples on 1.2 m (4 ft) stakes at a height 0.6 m (2 ft) above the soil line in the center of each main plot treatment to monitor above ground insects and moved up on subsequent weeks to ensure that the sticky trap cards were above the rye/vetch canopy. Trap orientation was in the wind flow direction (Stanton, 1983).

After direct seeding and transplanting of cucumbers, sticky-card traps were put up weekly from 25 June 1998 to 2 September 1998 and same dates in 1999, and removed after one week. One card was placed in the center row of cucumbers of each sub-plot at a height 0.6 m (2 ft) above the soil line throughout the sampling period. One week later, numbers of striped and spotted cucumber beetles on both sides of each trap were counted on each sampling date. Esfenvalerate (Asana, E.I. du Pont de Nemours and Co., Wilmington, Delaware) was applied at the rate of 0.035 kg a.i.ha^{-1} (0.03 lb a.i.ac$^{-1)}$ in conventional plots when densities in a given treatment exceeded 15 beetles total per card per week for both species combined. Spraying was done four times in both years. This threshold was derived by correlation of sticky card densities with visual densities in cucumber and squash in Virginia in 1996, and corresponded to a visual observation threshold of one beetle per plant (Amirault and Caldwell, 1998). The latter threshold had been established in Indiana for control of bacterial wilt (Brust et al., 1996; Foster and Flood, 1995; Brust and Foster, 1999). The above ground insects monitored were striped and spotted cucumber beetles, Pennsylvania leatherwings, adult Diptera and ladybird beetles (Coccinellidae). The adult Diptera are indicators of the two closely related tachinid fly species, *Celatoria diabroticae* (Shimer) and *C. setosa* (Coquillett) (Diptera: Tachinidae). The average proportion of adult Tachinidae family in adult Diptera populations in two complete year samples was 15.9% and higher densities occurred between April and October (Negm et al., 1997). These Tachinids deposit live larvae into some heteropterous insects and adult cucumber beetles through a larvipositor (McAlpine, 1987; Nishiyama, et al., 1995). Parasitism rates of *C. setosa* on striped cucumber beetles may reach as high as 42% (Gould, 1944; Elsey, 1988). The presence of *Celatoria* species was confirmed in Virginia in 1995-96 trials (Platt, 1997; Platt et al., 1999).

Sixteen harvests were done in the center row of each plot 90 cm (3 ft) from the end of each plot and 3.15 m (10.5 ft) long in each strip. In the conventional plots two harvest areas of equal size were established in each half. Harvesting was done twice a week on Mondays and Wednesdays from 22 July to 10 September 1998, and on Tuesdays and Thursdays from 22 July to 13 September 1999. The cucumbers were graded and weighed using the USDA Agricultural Marketing Service standards for grading cucumbers as Fancy, US No.1, US No.2, and culls (USDA, 1958). The combined weight of the first three grades is reported as total marketable yield, and this yield plus that of the culls is reported as total yield.

Differences between treatments in densities of striped (SCB) and spotted cucumber beetles (SPB), SCB and SPB combined CUK, Coccinellidae (COC), Pennsylvania leatherwings (PLW), adult Diptera (AD); and weight of cucumbers (yield) were analyzed by analysis of variance with single-degree-of-freedom contrasts. The first set of contrasts which assessed the effects of habitats on the above parameters were the following: no habitat versus habitat; no-till versus plastic with habitats; and transplants versus direct seeded for insect monitoring. The second set of contrasts which assessed the effects of no-till versus habitat on the above parameters were the following: plasticulture versus no-till; plasticulture with versus without habitats; no-till transplanted versus direct seeded. In both cases, PROC GLM of the Statistical Analysis Systems (SAS Institute, 1997) was used. Insect densities were transformed using the square root of (x +0.5) prior to analysis. Means of effects are reported using untransformed values (Gomez and Gomez, 1984).

Correlations between bi-weekly cucumber yields and insect densities were evaluated using two methods. Multivariate Analysis of Variance (MANOVA) was used with replicate, treatment, harvesting period and interactions of treatment and time, treatment and replicate (random error) all as independent variables and yield and transformed (square root of x +0.5) insect densities as dependent variables. Partial correlations of yield and insect densities were also determined. Finally, Spearman's ρ rank correlation was used to explore the association between yield and the insect densities. This method is independent of the magnitude of the parameters since ranked quantities are used to calculate the associations. This is relevant to this study because the insect densities were more skewed over time and treatments (Sokal and Rohlf, 1995). It was hypothesized that there is a negative correlation between cucumber beetle densities and yield, and a positive correlation between yield and adult Diptera, and no correlation between yield and Coccinellidae.

Cucumber yield was also analyzed for differences between herbicide and manual weeding as well as treatment and replicate, using a split plot arrangement of treatments and single-degree-of-freedom contrasts (plasticulture versus no-till; plasticulture with versus without habitats; no-till transplanted versus direct seeded) for separation of treatment differences. Individual harvest yields were grouped into two-week harvest periods and results reported for late July (harvest weeks 1-2), early August (weeks 3-4), late August (weeks 5-6), and early September (weeks 7-8) in $t.ha^{-1}$ for both 1998 and 1999.

RESULTS

2.1. Insect densities on yellow sticky card traps

2.1.1 Pre-crop densities

Prior to no-till treatment and crop establishment, densities of beneficial insects were higher in rye/vetch plots than in conventional plots with rye only (Figures 2-1, and 2-2; Tables 2-1 and 2-2). In 1998, habitat plots had higher densities of adult Diptera than the conventional plots. There were no differences in densities of Coccinellidae, Pennsylvania leatherwings, or striped and spotted cucumber beetles among the treatments.

At the first pre-crop sampling, on sticky cards removed on April 27, 1998, no striped cucumber beetles (SCB) were observed while Pennsylvania leatherwing (PLW) and spotted cucumber beetle (SPB) densities were not different. Habitat plots had higher densities of adult Diptera (AD) and Coccinellidae (COC) than the conventional treatment. At the second pre-crop sampling date one month later, from sticky cards removed on 28 May 1998, there was very low density (<1 insect / card) of SCB and SPB recorded. Both pest and beneficial insect densities were higher in rye/vetch plots, and average cucumber beetle densities increased by 1 beetle/card and beneficial insects by 1-17 insects/card. The beneficial insect densities increased in the habitat plots as follows: AD (17 insects/card), COC (3.3 insects/card) and PLW (1.4 insects/card) (Tables 2-1 and Table 2-2).

In 1999, neither CUK nor PLW were observed on yellow sticky cards removed on 29 April and 4 June 1999 while within this period (29 April – 4 June, 1999) average COC densities increased by 3 beetles/card in habitat plots. Average AD densities decreased by 53 insects/card and 21 insects/card in habitat and conventional plots respectively (Tables 2-1 and 2-2).

The next sampling date in 1999 followed treatment establishment but preceded germination of direct seeded cucumber and transplanting of seedling cucumber, with cards removed on 11 June. In this sample, the average PLW densities increased by 1.75 beetles/card and 0.25 beetles/card in habitat and conventional plots respectively. AD densities decreased by 4 insects/card in habitat plots compared to an increase of 0.8 insects/card in conventional plots. COC densities increased by 2.5 beetles/card and 5 beetles/card in habitat and conventional plots, respectively (Tables 2-1 and 2-2).

2.1.2 Post-planting densities

Overall cumulative insect density data for the whole season from 2 July to 9 September 1998 indicated that plastic (140 beetles/plot) plots had higher densities of striped and spotted cucumber beetles than no-till (117 beetles/plot) plots (p= 0.001). Higher densities of Coccinellidae were observed in no-till (62 beetles /plot) than in plastic (52 beetles/plot) plots (p= 0.03). The Pennsylvania leatherwings density of 3 insects/plot in habitat plots was not different from 1 insect/plot in plastic plots. The adult Diptera densities of 77 insects/plot in habitat plots was not different from the density of 74 insects/plot in conventional plots (Figure 2-3).

The cumulative insect densities data for 1999 (2 July to 8 September 1999) showed higher mean densities of striped and spotted cucumber beetles in plastic (92 beetles/plot) than in no-till (59/plot) plots (p= 0.0001). Higher densities of Pennsylvania leatherwings were observed in no-till (5 insects/plot) than in plastic (2 insects/plot) plots (p= 0.001); likewise Coccinellidae densities were higher in no-till (136 beetles/plot) than in plastic (122 beetles/plot) plots (p= 0.05). The RTDS treatment had the highest densities of striped and spotted cucumber beetles (98 beetles/plot). The adult Diptera density of 118 insects/plot in habitat plots was not different from the density 117 insects/plot in conventional plots, but higher densities of adult Diptera were observed in no-till direct seeded (132 insects/plot) than in transplanted (106 insects/plot) plots (p= 0.02) (Figure 2-4).

Examination of the weekly count data showed that there were two peaks of mean cucumber beetle (both species combined) densities over the course of the season from 2 July to 9 September 1998 and 2 July to 8 September 1999. The first peak in mean densities appeared on 2 July 1998 and 9 July 1999, when densities exceeding 15 beetles/plot were recorded in no-till transplants, conventional, and RTDS, with a maximum of 40 beetles/plot in RTDS (Figures 2-5 and 2-6). After this date (2 July), in 1998, mean beetle densities declined in all treatments in the next three sampling dates, with conventional (14 beetles/plot) plots recording higher densities than habitat plots in samples removed on 17 (p=0.03) and 24 (p= 0.003) July and 3 August (p= 0.008). Plastic plots had higher striped and spotted cucumber beetles than no-till plots with mean beetle densities of more than 15/plot on sampling dates 9 July (p= 0.001) and 17 July (p= 0.03) July, and 3 (p= 0.0006) August. The second peak had higher mean densities in plastic than in no-till plots on 11 August (p= 0.0001). No-till direct seeded plots had lower mean densities than no-till transplants on 2 July (p= 0.02) (Figure 2-5; Table 2-3).

There was no difference in mean Pennsylvania leatherwing densities for all comparisons. The first and second peaks occurred on 2 July and 1 September respectively (Figure 2-5; Table 2-3). Mean densities of adult Diptera were higher in habitat than in conventional plots on 17 July (p= 0.05) (Figure 2-5; Table 2-3). Coccinellidae mean densities were higher in habitat than conventional plots on 2 (p= 0.0007) and 9 (p= 0.004) July and 24 August (p= 0.04). Higher mean Coccinellidae densities were also observed in no-till than in plastic plots on 2 (p= 0.01) and 24 (p= 0.008) July, 24 August (p= 0.0002) and 9 September (p= 0.02) (Figure 2-5; Table 2-3).

Similarly in 1999, conventional plots had higher mean cucumber beetle densities than habitat plots on 16 July (p= 0.03) and 18 August (p= 0.04). Higher mean densities were observed in plastic than in no-till plots on 9 July (p= 0.0001), 16 July (p= 0.0001), 22 July (p= 0.003), 18 August (p= 0.02), and 8 September (p= 0.02) (Figure 2-6; Table 2-4).

Mean Pennsylvania leatherwings densities were higher in habitat than in conventional plots on 2 July (p= 0.05), corresponding to the first peak, and on 3 August (p= 0.01), while no-till plots had higher densities than plastic plots on 2 July (p= 0.004) and 9 July (p= 0.02). The second peak appeared on 8 September (p= 0.62) samples but there was no difference between plastic and no-till plots (Figure 2-6; Table 2-4).

Mean adult Diptera densities were higher in habitat than in conventional plots on 9 July (p= 0.04), 9 August (p= 0.02), 1 September (p= 0.01), and 8 September (p= 0.003). Higher densities were observed in no-till than in plastic plots on 9 July (p= 0.0001) and 9 August (p= 0.008). No-till direct seeded plots had higher mean densities than transplanted plots on 3 (p= 0.01) and 18 August (p= 0.0.02) (Figure 2-6; Table 2-4)

Higher mean Coccinellidae densities were observed in habitat than in conventional plots on 2 July (p= 0.01) and 9 August (p= 0.04). There were higher mean Coccinellidae densities in no-till than plastic plots on 2 (p= 0.0001) and 9 July (p= 0.0001) (Figure 2-6; Table 2-4).

Plant survivorship was higher in no-till than in plastic plots, with 60% of the plants not affected by bacterial wilt on 6 August in plastic plots while above 80% remained unaffected in no-till plots. The spread of the disease increased five weeks later, leading to less than 40% survival in plastic plots and more than 75% survival in no-till plots on 14 September (Figure 2-7).

TABLE 2-1. MEAN INSECT DENSITIES IN CONVENTIONAL AND HABITAT PLOTS BEFORE ROLLING AND FLAIL MOWING, 1998 AND 1999

		Mean insect densities				
		1998[z]		1999		
Treatments[x]	Insects[y]	4/27	5/28	4/29	6/04	6/11
Conventional	CUK	0	0	0	0	0
	COC	2	1	1	1	6
	PLW	0	0	0	0	0.3
	AD	26	45	24	3	4
RTDS	CUK	0.5	2	0	0	0
	COC	7	11	2	3	8
	PLW	0	2	0	0	1
	AD	79	81	61	17	7
NTDS	CUK	1	1	0	0	0
	COC	6	11	1	4	6
	PLW	0.3	2	0	0	3
	AD	70	88	80	18	9
NTTP	CUK	0.8	1	0	0	0
	COC	9	7	1.3	6.3	7
	PLW	0.3	2	0	0.3	2
	AD	78	108	59	4	10

y - CUK = striped + spotted cucumber beetles; PLW = Pennsylvania leatherwings; COC = Coccinellidae; AD = Adult Diptera

z - Removal dates

x - Treatments :

Conventional = Cucumber direct seeded in black plastic mulch laid on tilled bare ground, no habitat;

RTDS = Cucumber direct seeded in black plastic mulch laid on rototilled rye/vetch residues, rye/vetch habitat;

NTDS = Cucumber direct seeded into furrows in no-till rolled rye/vetch, rye/vetch habitat; and

NTTP = Cucumber transplanted into furrows in no-till rolled rye/vetch, rye/vetch habitat.

TABLE 2-2. COMPARISONS[z] OF THE EFFECTS OF HABITAT, PLASTICULTURE, NO-TILL, AND PLANTING METHODS ON INSECT[x] DENSITIES IN CUCUMBER ROWS BEFORE CUCUMBER ESTABLISHMENT, 1998 AND 1999

Removal	Habitat vs. Conventional				No-till vs. Plastic				Direct seed vs. Transplants			
Date	CUK	COC	PLW	AD	CUK	COC	PLW	AD	CUK	COC	PLW	AD
					1998							
4/27	NS	**	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
5/28	NS	**	*	**	NS	NS	NS	NS	NS	NS	NS	NS
					1999							
4/29	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS
6/04	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
6/11	NS	NS	*	*	NS	NS	NS	NS	NS	NS	NS	NS

[z] - ** - Significant at P<0.01; * - Significant at 0.05 <P< 0.01; NS – Not significant

[x] - CUK = striped + spotted cucumber beetles; PLW = Pennsylvania leatherwings; COC = Coccinellidae; AD = Adult Diptera.

TABLE 2-3. COMPARISONS[Z] OF THE EFFECTS OF HABITAT, PLASTICULTURE, NO-TILL, AND PLANTING METHODS ON INSECT[X] DENSITIES IN CUCUMBER ROWS AFTER PLANTING, 1998

Removal	Habitat vs Conventional				No-till vs. Plastic				Direct seed vs. Transplants			
Date	CUK	COC	PLW	AD	CUK	COC	PLW	AD	CUK	COC	PLW	AD
7/02	*	**	NS	NS	NS	*	NS	NS	*	NS	NS	NS
7/09	NS	**	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
7/17	**	NS	NS	*	*	NS	NS	NS	NS	NS	NS	NS
7/24	*	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS
8/03	**	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
8/11	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
8/17	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
8/24	NS	*	NS	NS	NS	**	NS	NS	NS	NS	NS	NS
9/01	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
9/09	NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS

z - ** - Significant at P<0.01; * - Significant at 0.05 <P< 0.01; NS – Not significant

x - CUK = striped + spotted cucumber beetles; PLW = Pennsylvania leatherwings; COC = Coccinellidae; AD = Adult Diptera.

TABLE 2-4. COMPARISONS[z] OF THE EFFECTS OF HABITAT, PLASTICULTURE, NO-TILL, AND PLANTING METHODS ON INSECT[x] DENSITIES IN CUCUMBER ROWS AFTER PLANTING, 1999

Removal Date	Habitat vs. Conventional				No-till vs. Plastic				Direct seed vs. Transplants			
	CUK	COC	PLW	AD	CUK	COC	PLW	AD	CUK	COC	PLW	AD
7/02	NS	**	*	NS	NS	**	**	NS	NS	NS	NS	NS
7/09	NS	NS	NS	*	**	**	*	**	NS	NS	NS	NS
7/16	*	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
7/22	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS
8/03	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	**
8/09	NS	*	NS	*	NS	NS	NS	**	NS	NS	NS	NS
8/18	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**
8/25	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
9/01	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS
9/08	NS	NS	NS	**	*	NS	NS	NS	NS	NS	NS	NS

[z] - ** - Significant at P<0.01; * - Significant at 0.05 <P< 0.01; NS – Not significant

[x] - CUK = striped + spotted cucumber beetles; PLW = Pennsylvania leatherwings; COC = Coccinellidae; AD = Adult Diptera.

TABLE 2-5. BIWEEKLY MEAN (± SE) MARKETABLE YIELD OF FRESH MARKET CUCUMBERS, 1998 AND 1999

Harvesting Dates	Treatments[Z]	Yield (t.ha^{-1})[x] 1998	1999
July 16-31	Conventional	1.3 ± 0.5	14.1 ± 1.7
	RTDS	9.8 ± 1.8	11.3 ± 0.7
	NTDS	3.2 ± 0.7	1.2 ± 0.4
	NTTP	13.2 ± 1.3	14.5 ± 1.1
August 1-15	Conventional	8.6 ± 1.2	15.2 ± 2.9
	RTDS	8.8 ± 2.7	15.4 ± 1.3
	NTDS	13.5 ± 1.8	14.9 ± 2.1
	NTTP	11.7 ± 1.6	16.3 ± 0.7
August 16-31	Conventional	13.2 ± 2.5	8.0 ± 2.3
	RTDS	6.5 ± 2.1	9.3 ± 0.9
	NTDS	18.9 ± 2.7	19.3 ± 1.7
	NTTP	13.4 ± 1.9	15.2 ± 0.7
September 1-15	Conventional	3.8 ± 0.7	1.3 ± 0.3
	RTDS	2.3 ± 0.6	1.9 ± 0.3
	NTDS	4.6 ± 0.9	8.1 ± 0.6
	NTTP	3.7 ± 0.7	5.6 ± 0.5

[z] Treatments:

Conventional = Conventional - plastic mulch/no habitat - direct seeded;

RTDS = Plastic mulch- incorporated rye/vetch with rye/vetch habitat- direct seeded;

NTDS = No-till mulch- with rye/vetch habitat- direct seeded;

NTTP = No-till mulch- with rye/vetch habitat - transplanted.

[x] Marketable yields = Total yields – Culls

FIGURE 2-1. CUMULATIVE MEAN INSECT DENSITIES IN HABITAT AND CONVENTIONAL PLOTS BEFORE PLANTING, 1998.

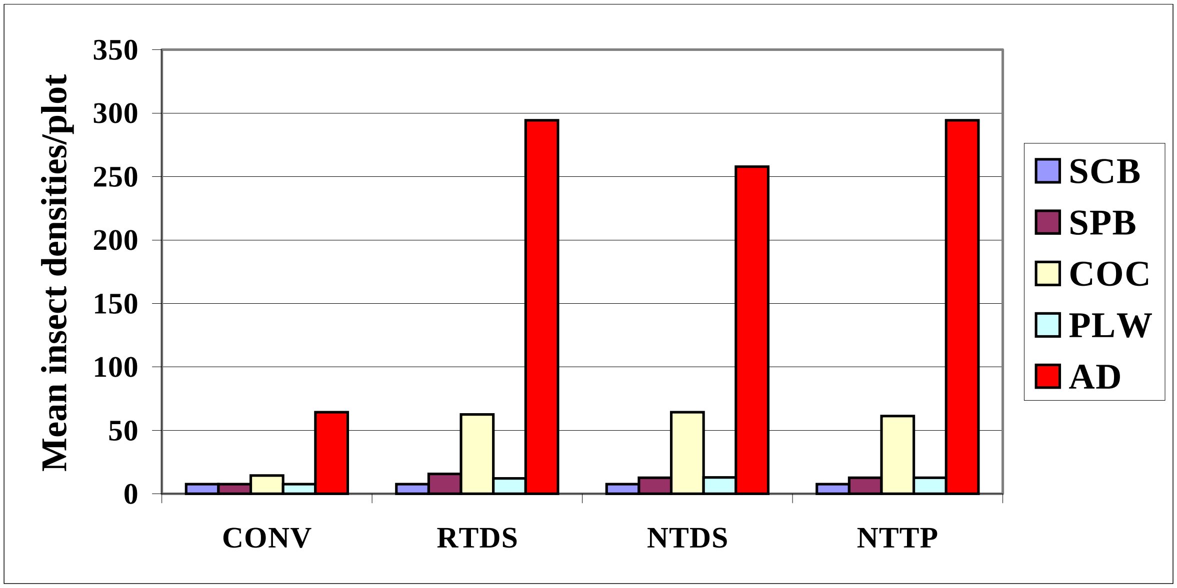


FIGURE 2-2. CUMULATIVE MEAN INSECT DENSITIES IN HABITAT AND CONVENTIONAL PLOTS BEFORE PLANTING, 1999

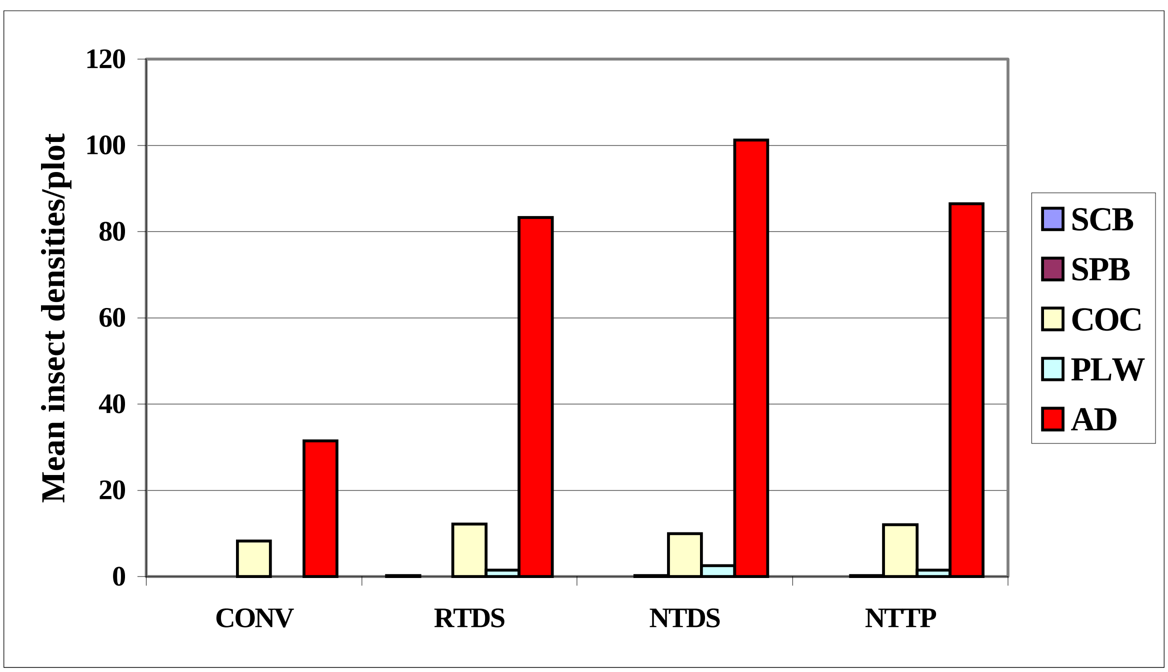


FIGURE 2-3. CUMULATIVE MEAN INSECT DENSITIES IN CUCUMBER ROWS AFTER PLANTING, 1998

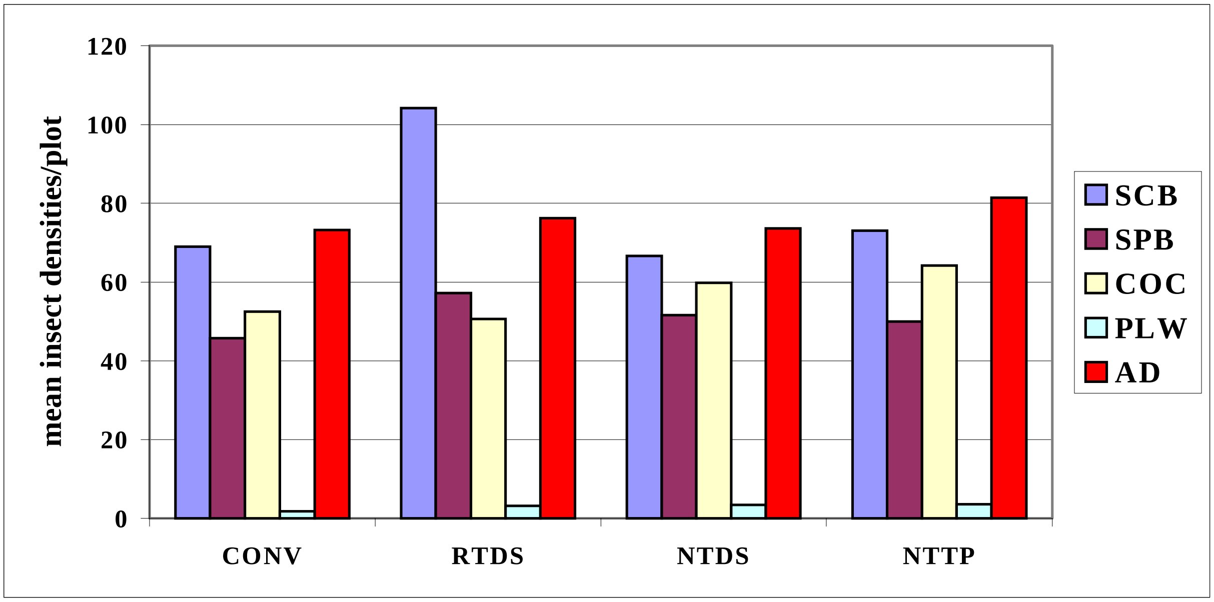


FIGURE 2-4. CUMULATIVE MEAN INSECT DENSITIES IN CUCUMBER ROWS AFTER PLANTING, 1999

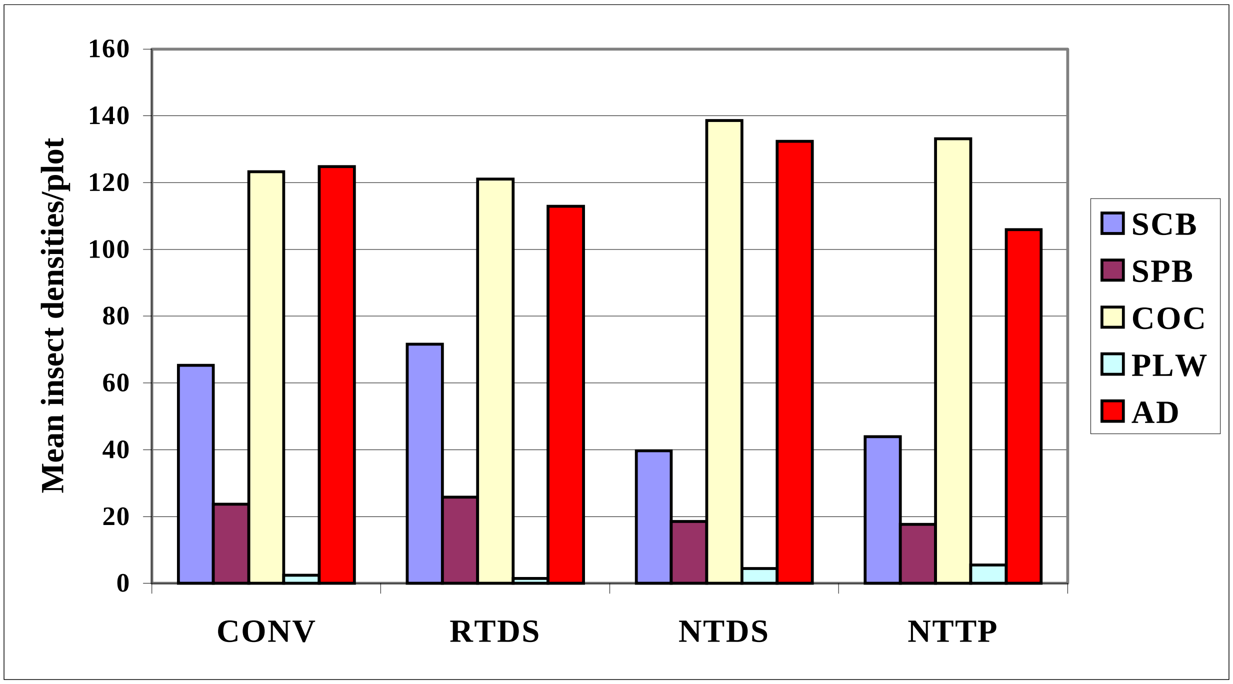


FIGURE 2-5. WEEKLY MEAN INSECT DENSITIES IN HABITAT AND CONVENTIONAL PLOTS AFTER PLANTING, 1998

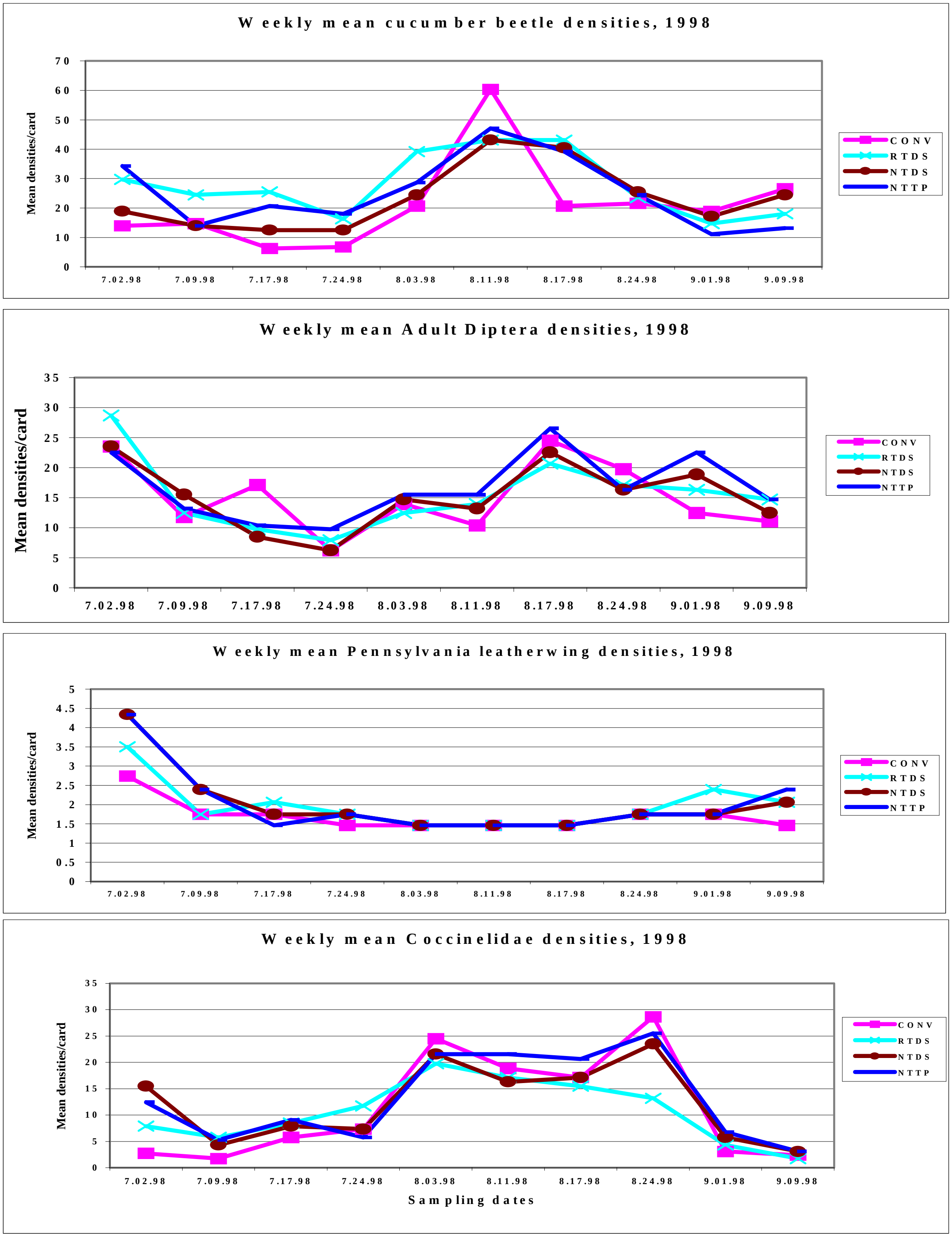


FIGURE 2-6. WEEKLY MEAN INSECT DENSITIES IN HABITAT AND CONVENTIONAL PLOTS AFTER PLANTING, 1999

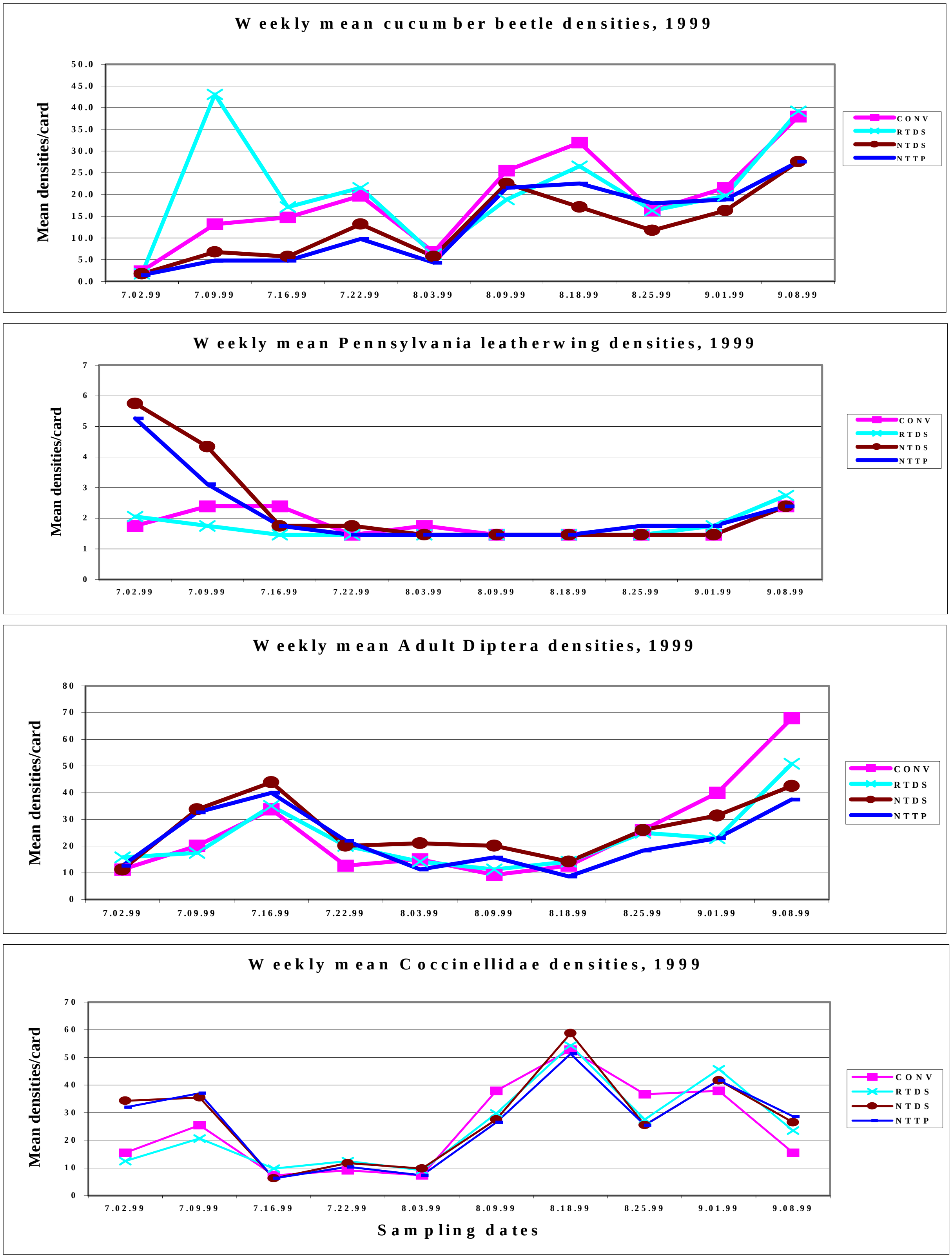
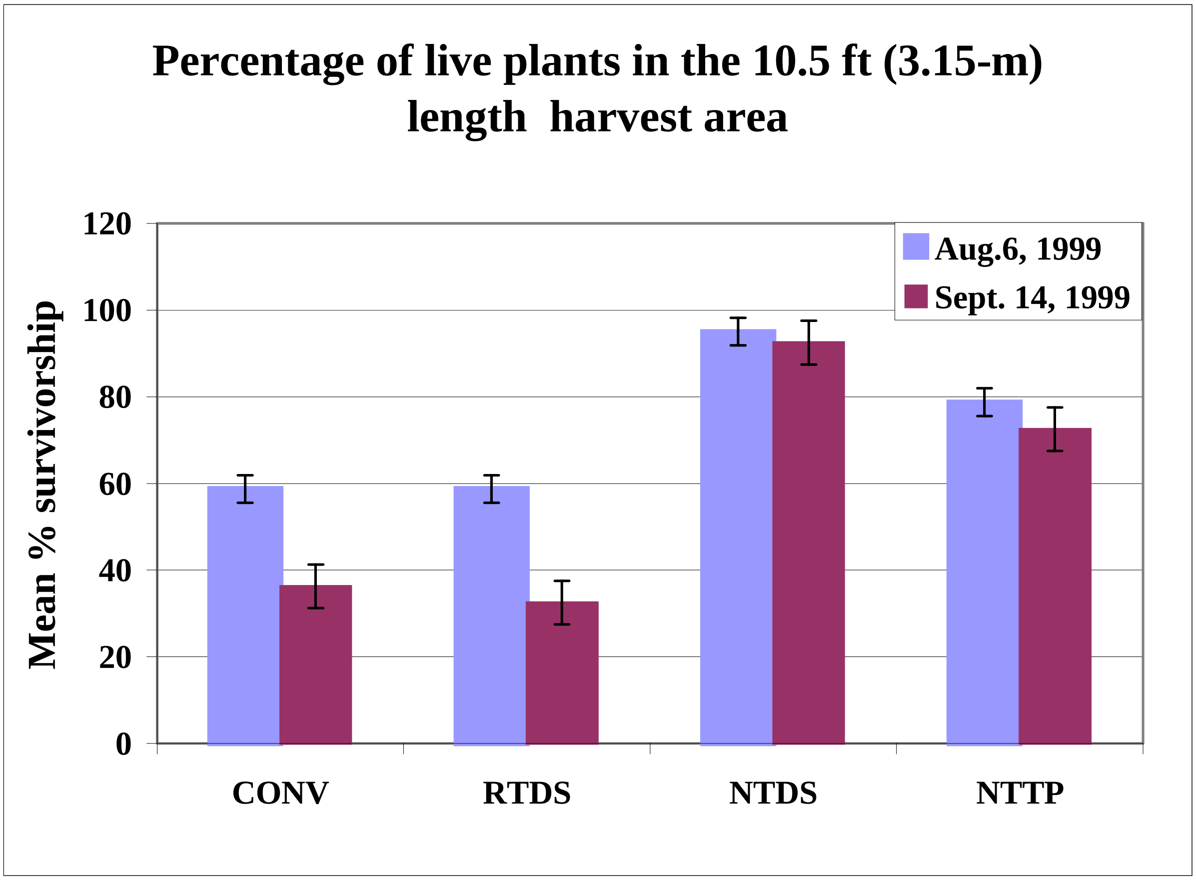


FIGURE 2-7. EFFECT OF BACTERIAL WILT ON SURVIVORSHIP OF CUCUMBERS IN NO-TILL AND PLASTIC PLOTS, 1999



2.2 Relative contributions and associations between insect densities and yields

2.2.1 Partial correlations

2.2.1.1 Relationship between cucumber beetle densities and cucumber yield

The partial correlations between densities of cucumber beetles (pest) and cucumber yield varied depending on treatment and harvest period. There was no positive correlation in 1998 while there was negative correlation in weeks 1 and 2 in all the treatments except NTTP, in RTDS in weeks 3 and 4, conventional in weeks 5 and 6, and NTDS and NTTP in weeks 7 and 8. Overall, there were six negative correlations but no positive correlation. In 1999, positive correlations were observed in weeks 1 and 2 for NTTP and weeks 7 and 8 for conventional, respectively. Negative correlations were found in conventional and RTDS in weeks 1 and 2, NTTP in weeks 5 and 6, NTDS and NTTP at weeks 7 and 8. Overall, there were five negative correlations and only two positive correlations (Figures 2-8a and 2-8b).

2.2.1.2 Relationship between adult Diptera densities and cucumber yields

In 1998, positive partial correlations were found in NTDS in weeks 1 and 2 and conventional and NTTP in weeks 3 and 4, while negative correlations were found in RTDS in weeks 1 and 2, and 3 and 4, and also in conventional in weeks 5 and 6. Overall, there were three negative correlations and two positive correlations. In 1999, positive correlations were found in conventional in weeks 3 and 4, and conventional and NTDS in weeks 5 and 6, and also 7 and 8. Negative partial correlations were found in conventional in weeks 1 and 2, and in RTDS in weeks 7 and 8. Overall, there were two negative correlations and seven positive correlations (Figures 2-8c and 2-8d).

2.2.1.3 Relationship between Coccinellidae densities and cucumber yields

In 1998, positive correlations were found in RTDS in weeks 1 and 2, RTDS and conventional in weeks 3 and 4, and NTDS in weeks 5 and 6. Negative partial correlations were found in NTTP in weeks 3 and 4, and in conventional and RTDS at weeks 5 and 6. Overall, there were four negative correlations and four positive correlations. In 1999, there were no positive correlations while negative correlations were found in NTDS in weeks 5 and 6. Overall, there was only one negative correlation and no positive correlation (Figures 2-8e and 2-8f).

2.2.2 Non-parametric associations

2.2.2.1 Association between cucumber beetles (pest) densities and cucumber yield

A negative association between cucumber beetle densities and yield in the NTDS treatment was found in weeks 1 and 2 (Spearman's ρ =-0.71, p=0.05) was observed in 1998. Overall, there was only one negative association. The following year (1999), strong positive associations were found in NTDS (Spearman's ρ =0.82, p=0.01) and RTDS (Spearman's ρ = 0.78, p=0.02) in weeks 1 and 2, while a negative association (Spearman's ρ = -0.74, p=0.03) was found in NTTP in weeks 3 and 4. Overall, there was only one negative association, while there were two positive associations (Figures 2-9a and 2-9b).

2.2.2.2 Association between adult Diptera densities and cucumber yield

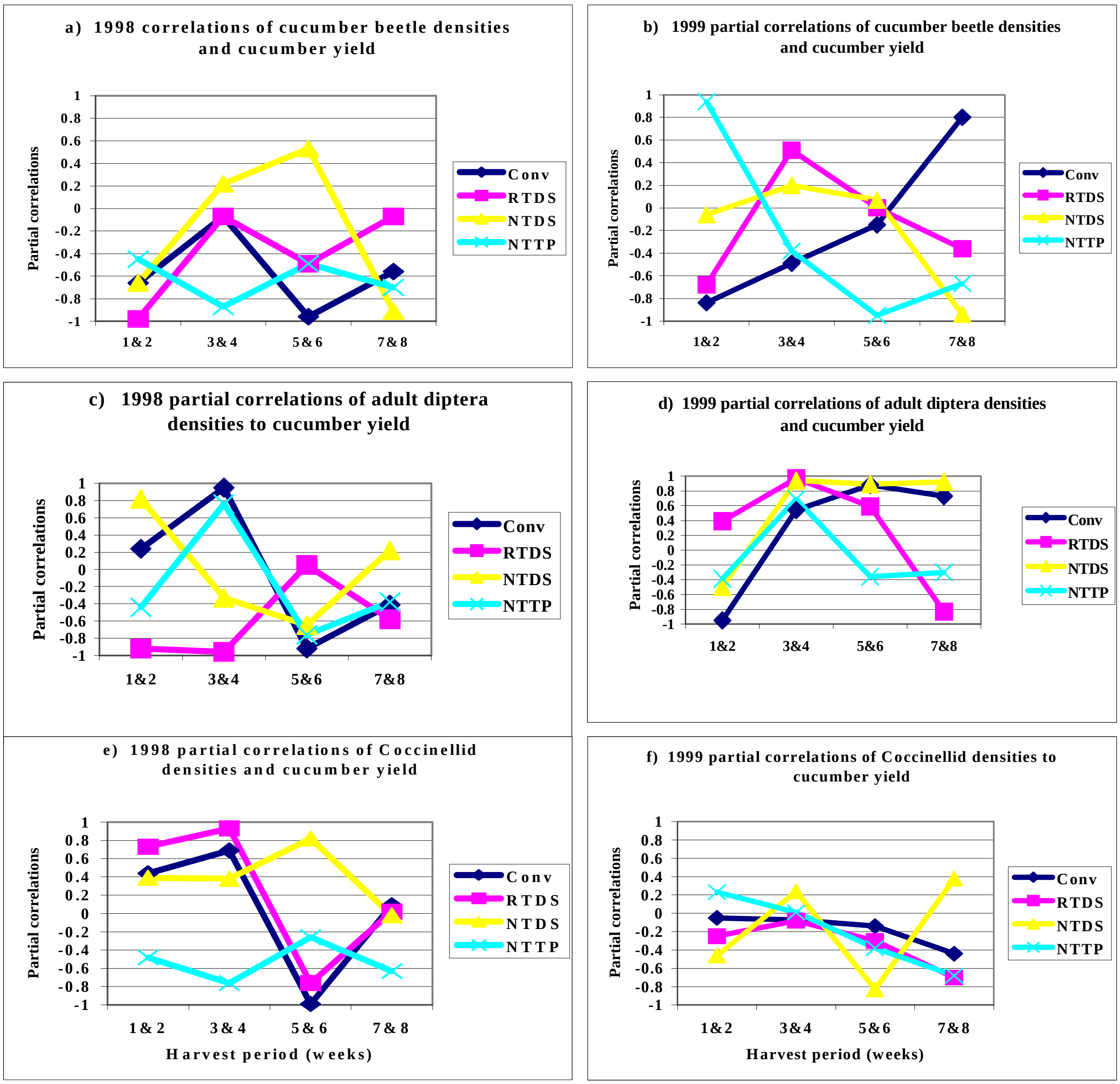
There was a negative association between adult Diptera densities and cucumber yield (Spearman's ρ = -0.74, p=0.03) in RTDS in weeks 3 and 4 in 1998. Overall, there was only one negative association, while there were no positive associations. In 1999, strong positive associations (Spearman's ρ = 0.91, p=0.002) were found in weeks 1 and 2 in NTDS and in NTTP (Spearman's ρ = 0.71, p=0.05), while positive associations were found in weeks 3 and 4 in NTTP (Spearman's ρ = 0.92, p=0.001) and in the conventional treatment (Spearman's ρ = 0.80, p=0.02). Overall, there was no negative association, while there were four positive associations (Figures 2-9c and 2-9d).

2.2.2.3 Association between Coccinellidae densities and yield

In 1998, a strong positive association (Spearman's ρ = 0.76, p=0.030) was found in weeks 1 and 2 in NTTP and a negative association (Spearman's ρ = -0.88, p=0.004) was found in weeks

7 and 8 in NTTP. Overall, there was one negative association and one positive association. In 1999, a positive association (Spearman's $\rho = 0.74$, $p=0.04$) was found in weeks 1 and 2 in RTDS. Negative associations were found in weeks 5 and 6 in conventional (Spearman's $\rho = -0.81$, $p=0.01$) and in NTTP (Spearman's $\rho = -0.81$, $p=0.01$). Overall, there were two negative associations, while there was only one positive association (Figures 2-9e and 2-9f).

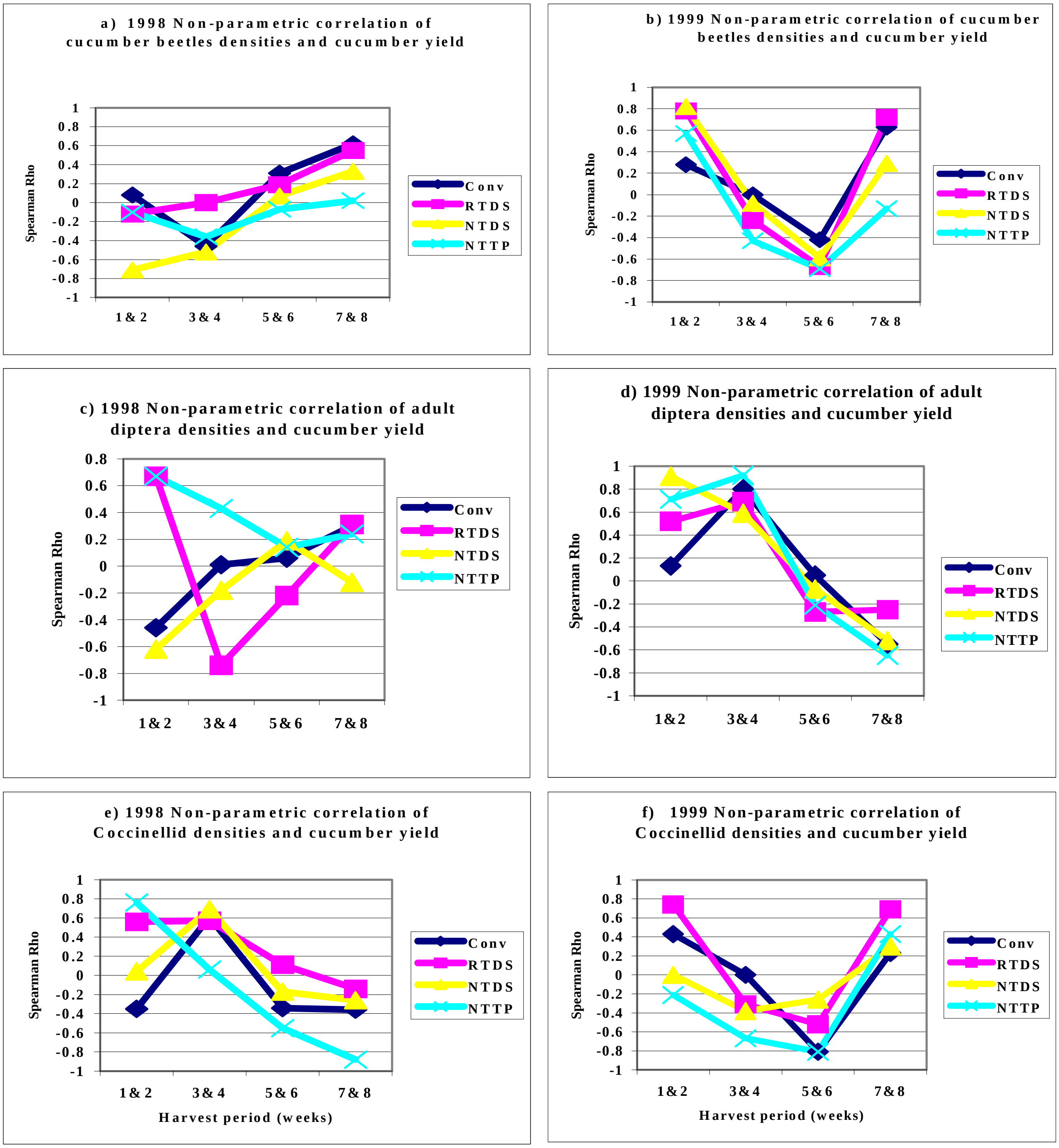
FIGURE 2-8. PARTIAL CORRELATIONS[z] OF CUCUMBER BEETLES, ADULT DIPTERA, AND COCCINELLIDAE DENSITIES WITH CUCUMBER YIELD FOR EACH TWO-WEEK HARVEST PERIOD, 1998 AND 1999



z Treatments: CONV = Conventional - plastic mulch/no habitat - direct seeded; RTDS = Plastic mulch- incorporated rye/vetch with rye/vetch habitat- direct seeded; NTDS = No-till mulch- with rye/vetch habitat- direct seeded; NTTP = No-till mulch- with rye/vetch habitat - transplanted.

Partial correlation: -0.60 to +0.60: Not significant- explained less than 40% variation. Above 0.60 - or +: Significant- explained more than 40% variation.

FIGURE 2-9. NON-PARAMETRIC[z] PARTIAL CORRELATION OF CUCUMBER BEETLES, ADULT DIPTERA, AND COCCINELLIDAE DENSITIES WITH CUCUMBER YIELD FOR EACH TWO-WEEK HARVEST PERIOD, 1998 AND 1999



z **Treatments**: CONV = Conventional - plastic mulch/no habitat - direct seeded; RTDS = Plastic mulch- incorporated rye/vetch with rye/vetch habitat- direct seeded; NTDS = No-till mulch- with rye/vetch habitat- direct seeded; NTTP = No-till mulch- with rye/vetch habitat - transplanted. **Non-parametric associations**: -0.70 <ρ<0.70: Not significant ρ ≥ |0.70|: Significant where P =0.05 and very significant when P< 0.01.

DISCUSSION

Habitats led to increased densities of beneficial insects before planting (Table 2-1) and also during individual sampling periods (Table 2-2) in both years. This supports the natural enemy hypothesis, which predicts increased densities of natural enemies in diversified habitats. Rye/vetch flowers can serve as food for adult natural enemies that are mainly nectar and pollen feeders (Root, 1973; Altieri and Letourneau, 1982; Bugg and Ellis, 1990; Altieri, 1991; Platt et al., 1999). The higher numbers of adult Diptera early in the season was an indication of the possibility of high densities of Tachinid flies (Negm et al., 1997; Table 2-1). Tachinids might have caused a decline in cucumber beetle densities by parasitizing over-wintering generation (McAlpine, 1987; Nishiyama et al., 1995). Rolling and flail mowing were done on 13 May and direct seeding was done on 3 June 1999, while transplanting followed 11 days later (on 14 June), hence the second pre-planting monitoring overlapped with the time some parts of the habitat had been disturbed, which might have led to reduced beneficial insect build-up in habitat areas during the last pre-plant sample. The presence of higher densities of adult Diptera in cucumber rows in habitat plots than conventional plots in 1999 suggests that these insects moved from the habitats into the cucumber crop rows after planting.

Weekly insect densities after planting indicated that the first peak density for cucumber beetles occurred in early July (Figures 2-5 and 2-6; Tables 2-3 and 2-4). The peak densities of cucumber beetles correspond to the appearance of the overwintering generation in early July and first generation in middle of August (Houser and Balduf, 1925; Gould, 1944; Foster and Flood, 1996; Brust and Foster, 1999). The appearance of increased incidence of bacterial wilt shown in the plant survivorship data taken on August 6, 1999 (Figure 2-7) suggests that plants were infected by the wilt causing organism in early to mid-July period. It takes about two weeks for the plants to show the wilt symptoms while the feeding behavior and density of the cucumber beetles influences the spread of the disease (Yao et al., 1996). It is possible that the effect of natural enemies might have led to lower cucumber beetle densities in no-till than plastic plots, which is more clearly shown in 1999 than 1998 results (Figures 2-5 and 2-6). The larval stage of the Pennsylvania leatherwing feeds on eggs and larvae of cucumber beetles (Houser and Balduf, 1925). The period between middle of July and late August may be dominated by this stage.

Hence, even though densities of adults were low or zero during this period (Figures 2-5 and 2-6; Tables 2-3 and 2-4), their role in reducing the pest population might still be important. Ground predators like Carabidae, Staphylinidae, larvae and spiders can also be very important in controlling this pest.

Correlations between cucumber beetle densities and yield were negative in most of the treatments (Figures 2-8 and 2-9). The indirect effect of adult beetle feeding is transmission of bacterial wilt causing organism. The wilt affects branches or the whole plant thereby leading to lower plant densities and consequently reduction in harvest. The effect of bacterial wilt may not show up at the beginning of the harvest period but later on (Yao et al., 1996). In this study also, bacterial wilt incidence increased in the latter half of the harvest period, and incidence was higher in plastic plots than in no-till plots, which previously had higher densities of cucumber beetles. The feeding damage and bacterial wilt (Bach, 1981; Foster and Flood, 1995; Brust and Foster, 1999) were the possible main causes of the negative correlation between cucumber beetle densities and yield.

There was a positive correlation between adult Diptera densities and yield during most of the periods in 1999.

Coccinellidae are not directly involved in controlling cucumber beetle populations but they do feed on aphids, which are secondary pests in cucurbits. Aphid damage can be serious in the absence of these natural enemies. The attractiveness of habitats to Coccinellidae is a potential second benefit also examined in this study. However, aphids were not observed in either year, so the lack of correlation between Coccinellidae densities and yield is expected.

No-till systems had higher cumulative marketable yields than black plastic systems as indicated in 1998 (Ogutu and Caldwell, 1999) results, which were confirmed in 1999 (Table 2-5).

In summary, this study has shown that rye/vetch cover crops, can attract beneficial insects and be manipulated to fit production practices while providing diversity in agroecosystems, as a technique for controlling both weeds and insect pests at the same time, while reducing the need for pesticide use. The cover crops used in these experiments are well adapted to the Southeast United

States. They accumulate substantial biomass early in the spring, which enables them to smother weeds and allow cucumber seedlings to pass through the stage when weed competition is critical. Habitat diversity should be considered as a part of the farming system in which the synergy of other factors such as nutrition, water management, field operations, and weather factors are optimized to ensure profitable vegetable production.

LITERATURE CITED

Altieri, M. A. 1991. How best can we use biodiversity in agroecosystems? Outlook on Agriculture. 20(1): 15 – 23.

Altieri, M. A. and D. K. Letourneau. 1982. Vegetation management and biological control in agroecosystems. Crop Protection. 1(4): 405 – 430.

Amirault, J. P. and J. S. Caldwell. 1998. Living mulch strips as habitats for beneficial insects in the production of cucurbits. Hortscience. 33(3): 524.

Bach, C. E. 1980a. Effects of plant diversity and time of colonization on a herbivore-plant interaction. Oecologia. 44: 319 -326.

Bach, C.E.1980b. Effects of plant density and diversity on the population dynamics of a specialist herbivore. The striped cucumber beetle *Acalymma vittata* (Fab.). Ecology. 61(6): 1515-1530.

Bach, C. E. 1981. Host plant growth form and diversity: Effects of abundance and feeding preference of a specialist herbivore, the striped cucumber beetle *Acalymma vittata* (Fab.). Oecologia. 50:370 -375.

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 et applicata. 91(1): 155-161.

Boote, K. J., J. W. Jones and N. B. Pickering. 1996. Potential uses and limitations of crop models. Agronomy Journal. 88: 704-716.

Brust, G. E. and R. E. Foster. 1999. New economic threshold for striped cucumber beetle (Coleoptera: Chrysomelidae) in Cantaloupe in the Midwest. Journal of Economic Entomology. 92(4): 936-940.

Brust, G. E., R. Foster and W. Buhler. 1996. Comparison of insecticide use programs for managing the striped cucumber beetle (Coleoptera: Chrysomelidae) in Muskmelon. Journal of Economic Entomology. 89: 981-986.

Brust, G. E. 1997. Seasonal variation in percentage of striped cucumber beetles (Coleoptera: Chrysomelidae) that vector Erwinia tracheiphilia. Environmental Entomology. 26:(3) 580-584.

Bugg, R. L. and R. T. Ellis. 1990. Insects associated with cover crops in Massachusetts. Biological Agriculture and Horticulture. 7: 47-68.

Caldwell, J.S., J-P. Amirault, and A.H. Christian. 1995. Insect pests, beneficial insects, and cover crops of biological farmers. HortScience 30(4): 806.

Ellers-Kirk, C. D., S. J. Fleischer, R. H. Snyder, and J. P. Lynch. 2000. Potential of entomopathogenic nematodes for biological control of *Acalymma vittatum* (Coleoptera: Chrysomelidae) in cucumbers grown in conventional and organic soil management systems. Journal of Economic Entomology. 93(3): 605-612.

Elsey, K.D. 1988. Cucumber beetle seasonality in coastal South Carolina. Environmental Entomology. 17(3):496-502.

Florez, J. A., A. J. Fischer, H. Ramirez and M. C. Duque. 1999. Predicting rice yield loss caused by multispecies weed competition. Agronomy Journal. 91: 87-92.

Foster, R., and B. Flood (eds.). 1995. Vegetable insect management. Meister Publishing Co., Willoughby, Ohio.

Garcia-Salazar, C., F. E. Gildow, S.J. Fleischer, D. Cox-Foster and F. L. Lukezic. 2000. Alimentary canal of adult *Acalymma vittata* (Coleoptera: Chrysomelidae): Morphology and potential role in survival of *Erwinia tracheiphila* (enterobacteriaceae). The Canadian Entomologist. 132: 1-13.

Gary, C., J. W. Jones and M. Tchamitchian. 1998. Crop modeling in horticulture: state of the art. Scientia Horticulturae. 74: 3-20.

Godfrey, L. D. and T. F. Leigh. 1994. Alfalfa harvest strategy effect on Lygus bug (Hemiptera: Miridae) and insect predator population density: Implication for use as a trap crop in cotton. Environmental entomology. 23(5):1106 – 1118.

Godfrey, L. D., R. L. Coviello, W. J. Bentley, C. G. Summers, J. J. Stapleton, M. Murray, and E. T. Natwick. 1998. University of California Pest Management Guidelines: Cucurbits. Publication No. 3339. Division of Agriculture and Natural Resources, University of California, Davis, CA.

Gomez, K. A. and A. A. Gomez. 1984. Statistical procedures for agricultural research. International Rice Research Institute, Los Banos, Phillipines.

Gould, G. E. 1944. The biology and control of the striped cucumber beetle. Bulletin of the Purdue University Agricultural Experiment Station, Lafayette, Indiana. No. 490: 1-13

Houser, J. S. and W. V. Balduf. 1925. The striped cucumber beetle. Bulletin of the Ohio Agricultural Experiment Station. No. 388: 241-364.

Jaynes, D. B. and J. G. Miller. 1999. Evaluation of the root zone water quality model using data from Iowa MSEA. Agronomy Journal. 91: 192-200.

Lentz, W. 1998. Model application in horticulture: a review. Scientia Horticulturae. 74: 151-174.

Lindeman, R. L. 1942. The trophic – dynamic aspect of ecology. Ecology. 23(4): 399-418.

Maredia, K. M., S. H. Gage, D. A. Landis and T. M. Wirth. 1992. Ecological observations on predatory Coccinellidae (Coleoptera) in southwestern Michigan. The Great Lakes

Entomologist. 25(4): 265-270.

McAlpine, J.F. (ed.). 1987. Manual of Nearctic Diptera. Vol. 2, Monograph No. 68. Biosystems Research Center, Ottawa, Canada.

Negm, F.H., M. M. Salem, and M. M. Bassiouny. 1997. Abundance and fluctuations of insect populations of the order Diptera at Al-Arish region, North of Sinai. Annals of Agricultural Science, Moshtohor. 35(2): 1005 – 1011.

Nishiyama, M., M. Iwasa, and K. Hori. 1995. Parasitism by Tachinid flies (Diptera: Tachinidae) of heteropterous insects in Tokachi, Hokkaido. Japanese Journal of Entomology, 63 (1): 159-165.

Ogutu, M. O. and J. S. Caldwell. 1999. Stand differences in no-till direct seeded and plasticulture direct seeded and transplanted cucumbers (*Cucumis sativus* L.). Acta Horticulturae. 505: 129-134.

Pair, S. D. 1997. Evaluation of systematically treated squash trap plants and attracticidal baits for early-season control of cucumber beetles (Coleoptera: Chrysomelidae) and squash bug (Hemiptera: Coreidae) in cucurbit crops. Journal of Economic Entomology. 90:1306–1314.

Platt, J. O. 1997. The use of buckwheat border habitats to attract natural enemies of cucumber beetles in a cucurbit agroecosystem. MS thesis. Virginia Tech, Blacksburg, Virginia.

Platt, J. O., J. S. Caldwell, and L. T. Kok. 1999. Effect of buckwheat as a flowering border on populations of cucumber beetles and their natural enemies in cucumber and squash. Crop Protection 18: 305-315.

Pickett, C. H., S. E. Schoeng, and M. P. Hoffman. 1996. Establishment of the squash bug parasitoid, *Tichopoda pennipes* Fabr. (Diptera: Tachinidae), in Northern California. Pan-Pacific Entomologist. 72 (4): 220-226.

Rand, F. B. and E. M. A. Enlows. 1916. Transmission and control of bacterial wilt of cucurbits. Journal of Agricultural Research. 6: 417-438.

Root, R. B. 1973. Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (*Brassica oleracreae*). Ecological Monograph. 43: 95-124.

SAS Institute. 1997. SAS/STAT user's guide 4th Edition Volume. Version 6.12. SAS Institute, Cary, North Carolina.

Sokal, R.R. and F. J. Rohlf. 1995. Biometry: The principles and practice of statistics in biological research. 3rd Edition. New York Freeman.

Stanton, M.L. 1983. Spatial patterns in the plant community and their effects upon insect search. In: S. Ahmad (ed.), Herbivorous insects. Academic Press, New York.

Stenberg, B. 1998. Soil attributes as predictors of crop production under standardized conditions. Biology and Fertility of Soils. 27: 104-112.

Thomas, M. B., S. D. Wratten, and N. W. Sotherton. 1991. Creation of 'island' habitats in farmland to manipulate populations of beneficial arthropods: predator densities and emigration. Journal of Applied Ecology. 28: 906- 917.

United States Department Agriculture (USDA), Agricultural Marketing Service. 1958. United States standards for grades of cucumbers. USDA Source 23 FR 1166.

Virginia Polytechnic Institute and State University (VPI&SU), Soil Survey. 1990 Soil map for Kentland Research Farm, Blacksburg, Virginia.

Wiedenmann, R. N., and J. W. Smith. 1997. Attributes of natural enemies in ephemeral crop habitats. Biological Control. 10(1): 16 – 22.

Yao, C., G. Zehnder, E. Bauske, and J. Kloepper. 1996.Relationship between cucumber beetle (Coleoptera: Chrysomelidae) density and incidence of bacterial wilts of cucurbits. Entomological Society of America. 89 (2): 510-514.

CHAPTER 3

DENSITIES OF CUCUMBER BEETLES AND THEIR NATURAL ENEMIES IN RELATION TO YIELD IN DIFFERENT CUCUMBER CROPPING SYSTEMS

II GROUND PREDATORS

ABSTRACT

The presence of Carabidae, Staphylinidae, and Spiders, which are potential predators for cucumber beetles [striped, *Acalymma vittata* (Fabricus) and spotted, *Diabrotica undecimpunctata howardii* Barber (Coleoptera: Chrysomelidae)] for one or another of their life stages were monitored using pitfall traps in 1998 and 1999 in plots in which cucumber was planted with and without habitats for attraction and conservation *in situ* of natural enemies. Planting treatments were: direct seeded in black plastic mulch strips laid on bare ground (conventional), direct seeded in black plastic mulch laid over incorporated rye/vetch residue, direct seeded in no-till rolled rye/vetch, and transplanted in no-till rolled rye/vetch. Rye/vetch strips were left between the strips in which cucumbers were planted in all treatments except the conventional. Pitfall traps 9.45 cm deep and 7.50 cm surface diameter were placed in the center row in each treatment buried underground with the upper edge at the level of the soil surface.

Plots with rye and vetch had higher densities of Carabidae, Staphylinidae, and Spiders before planting than conventional plots with only rye in 1999. After cucumber planting, there were higher densities of predators in middle to late August in no-till than in black plastic mulch plots in both years. There was a higher diversity of Carabidae species in rye/vetch habitat plots than in conventional plots with rye only and no vetch before rolling and flail mowing in 1999. Carabidae species recovered from pitfall traps in habitat areas before rolling and flail mowing included *Harpalus longicollis*, *Harpalus pennsylvanicus, Poecilus chalcite, Agonum rigidullum*, *Pterostichus tristis*, *Amara angustata*, *Galeritia tricolor*, and *Scarites subterranus*. In 1998, only three species, *Harpalus longicollis*, *Poecilus chalcite* and *Scarites subterranus,* were found in crop rows, and no-till plots had higher densities of all three species than black plastic mulch plots. Similarly, in 1999, only

four species, *Harpalus longicollis*, *Harpalus pennsylvanicus, Pterostichus tristis* and *Chalcite tricolor,* were found in crop rows, with higher densities in no-till than plastic treatments.

Key words: black plastic mulch, Carabidae, habitat, no-till, spiders, Staphylinidae

INTRODUCTION

Striped and spotted cucumber beetles lay eggs which hatch into larvae on or below ground (Houser and Balduf, 1925; Gould, 1944; Elsey, 1988). Since cucumber beetle larvae feed on cucumber roots and develop in the soil, they have a high exposure to ground predators before the completion of their life cycles (Brust, 1990; Brust, 1991). Carabidae, Staphylinidae, Cantharidae (*Chauliognathus* sp.), spiders, and larval predators can attack these life stages (Brust and House, 1990). Carabidae and spiders tend to prefer covered areas (Varchola and Dunn, 1999 – Carabidae; Reichert and Bishop, 1990 - spiders) and they overwinter in uncultivated field edges and move into the field in early spring (Lys and Nentwig, 1992; Snyder and Wise, 1999).

Habitat diversity in no-till and surrounding field edges has been found to increase densities of Carabidae in several other crops (Brust and House, 1990; Altieri, 1991; Riddick and Mills, 1994; Snyder and Wise, 1999). The abundance (population in a habitat) and diversity or species richness (number of species found in a given area) of Carabidae were higher in roadside habitat than in corn fields before canopy enclosure, while after corn canopy closure there was no difference (Varchola and Dunn, 1999). Some Carabidae are herbivorous while others are omnivorous, insectivorous, or scavengers. The first and second larval stage of several species in the genus *Lebia* are host specific to pupae of the beetles in Chrysomelidae family and die if a suitable host in the Chrysomelidae is not found (Allen, 1979). Carabidae species belonging to the genera *Harpalus, Pterostichus,* and *Scarites* feed on first and second instars (Brust, 1990) that emerge from spotted cucumber beetle eggs. In reduced tillage cornfields, Carabidae densities were higher in weedy vegetation than in conventional plots, possibly due to suitable prey availability and microclimate preferences. However, weeds led to reduction in corn yield (Pavuk et al., 1997). Higher densities of predatory Carabidae species such as *Harpalus* spp*., Scarites* spp., and *Pterostichus* spp. were found in no-till plots (Brust and House, 1990). The *Harpalus Pennsylvanicus* is an omnivorous carabid that feeds mainly on seeds but also on cutworm larvae, while *Scarites* spp. and *Pterostichus chalcites* are predaceous (Best and Beagle, 1977; Barney and Pass, 1986). In Virginia, higher densities of these species were reported in habitat plots in 1995-96 (Amirault and Caldwell, 1998). The effects of field manipulations through inclusion of habitats and use of no-till in comparison with conventional black plastic mulch on the abundance and diversity of Carabidae species in cucurbit agro-ecosystems designed to minimize yield reduction have not been explored.

Other potential ground predators are larval stages of various insects. Most of these larvae are polyphagous, hence they can feed on a variety of insect eggs and larva while others tend to feed on plants. Larvae of the Carabidae such as *Harpalus* spp. and *Pterostichus* spp. (Tomlin, 1975; Allen, 1979) and of the Pennsylvania leatherwing (Houser and Balduf, 1925; Gould, 1944) are predatory on cucumber beetle eggs and larvae. These larvae all have sharp strong mandibles for holding and tearing the prey (Tomlin, 1975). The presence of Pennsylvania leatherwing adults and adult Carabidae had been reported in the same area of Virginia in 1994-97 (Platt, 1997; Amirault and Caldwell, 1998; Platt et al., 1999).

Spiders are one of the generalist predators common in agro-ecosystems with a very high diversity; they range in size from small to giants (Young, 1989; Reichert and Bishop, 1990). Giant spiders have been shown to help control cucumber beetles. The spotted cucumber beetles tend to hide when they sense giant spiders around them; hence, beetle feeding on cucumbers and other cucurbits was reduced (Snyder and Wise, 2000). This can reduce damage due to beetle feeding and thereby increase yield. In this case it is clear that the presence of these spiders invoked a change in the behavior of the cucumber beetles without the spiders attacking and killing them. Cucumber beetles can detect the predators through chemical stimulus (Stanton, 1983; Wisenden et al., 1997), and in some cases vibration cues from the predators is used as a means of detection by the beetles (Brodsky and Barlow, 1986).

Staphylinidae are predatory in agro-ecosystems, and their species diversity compared to Carabidae may vary from one ecosystem to another. They are generalist predators, which feeds on eggs and larvae of Diptera as well as other insects (Hu and Frank, 1997). Bauer (1989) observed that Staphylinidae tend to move from one habitat to another due to their high flight activity compared to less activity for Carabidae, which tend to move mostly on the ground. However, higher Staphylinidae species diversity was observed in reduced tillage and areas with less pesticide usage. It was suggested that increased weed density provided a favorable microclimate for Staphylinidae and abundance of prey might have been the major cause (Krooss and Schaefer, 1998).

In order to realize the maximum benefits of these predators and others, it is important to establish overwintering strips at the edges of the field (Lys and Nentwig, 1992; Lys et al., 1993; Lys, 1994). Higher ground insect diversity and abundance have been reported in an organic farm in Switzerland on a sown wild flower strip, a hedge, a permanent meadow and a meadow under cherry trees, all of which are semi-natural habitats (Pfiffner and Luka, 2000). More similarity in Carabidae and spider densities has been reported between grassland and crop fields than between forest and grassland (Kajak and Lukasiewicz, 1994). Microclimate and prey availability created by cover crops may lead to higher density of Staphylinidae in no-till than conventional plots (Brust, 1990; Pavuk et al., 1997). Staphylinidae tend to prefer organic matter, which results from breakdown of organic residues (Davies et al., 1988).

In this study, the null hypothesis is that all treatments will attract the ground predators equally while the alternative is that rye/vetch habitat will attract more ground insect predators early in the spring when they are becoming active. They will form colonies in these patches where their populations will continue to increase up to rye/vetch rolling and flail mowing time. After rolling/flail mowing of rye/vetch and planting cucumbers, the ground insects in the habitat strips will move into the cucumber rows in search of prey. This can occur before and after drying up of the habitat strips. There is a high chance that they will stay in cucumber rows after the habitat is dead and the dry mulch has degraded, since this will leave the ground more open while the cucumbers have dense canopies, which will provide a suitable environment for these insects.

MATERIALS AND METHODS

Location and experimental design

The experiment was carried out at the Virginia Polytechnic Institute and State University's Kentland Farm near Blacksburg, Virginia, from 1 October 1997 to 10 September 1998 and 14 October 1998 to 13 September 1999. No-till potato had been planted on the sites prior to the experiments in 1997 and 1998. The soil type is classified as a Shottower silt loam (Virginia Polytechnic Institute and State University - Soil Survey, 1990) for both sites.

Four main plot treatments combining rye/vetch management and cucumber planting methods were compared with black plastic mulch covered strips for cucumber production with or without rye/vetch habitats for beneficial insects between the cucumber strips:

(1) Conventional – direct seeding of cucumber into black plastic mulch, with bare ground between plastic strips (plastic on soil, direct seeded, no habitat);

(2) Flail mowed rye/vetch residue rototilled into the soil, in strips, with rye/vetch habitats left between rototilled strips, and black plastic mulch laid on top and cucumber direct seeded (plastic on rototilled rye/vetch, direct seeded, with habitat; RTDS);

(3) Cucumber direct seeded into rolled rye/vetch strips using no-till equipment, with rye/vetch habitats left between no-till strips (rye/vetch no-till, direct seeded, with habitat; NTDS);

(4) Cucumber seedlings transplanted into rolled rye/vetch strips using no-till equipment with rye/vetch habitat between no-till strips (rye/vetch no-till, transplanted, with habitat; NTTP).

The treatments were replicated four times in a randomized complete block design with a split plot arrangement of herbicide application and manual weeding. Alley ways 4.5 m (15 ft) wide separated the plots.

Treatment establishment

On 1 October 1997 and 14 October 1998, grain rye, *Secale cereale* L. (Poaceae), unclassified variety, and hairy vetch, *Vicia villosa* Roth (Poaceae), unclassified variety (Source: Southern States Seed Company, Christiansburg, Virginia), were seeded using a mechanical seeder. Only grain rye was planted in conventional plots.

The plots were rolled (treatments 3-4) or flail mowed (treatment 2) in three planting strips alternating with habitat strips on 22 May 1998 and 22 May 1999. A habitat strip of 1.2 m (4 ft) wide was left on both sides of the center strip. The outer planting strips were bordered by a habitat strip on the outside edge of the plot 0.60 m (2 ft) wide from the edge of the planting strips on each side. After cucumber planting, 0.60 m (2 ft) of strip remained between each cucumber row and the adjacent habitat strip for tractor movement.

Hybrid cucumber cv Dasher II 194A (Stokes Seeds Inc., Buffalo, New York) for transplanting was seeded in the Virginia Tech greenhouse on 21 May 1998 and 25 May 1999. The same variety was direct seeded in plots for treatments 1, 2 and 3 on 8 June 1998 and 3 June 1999 and transplanted in treatments 4 on 16 June 1998 and 14 June 1999, respectively, one week after direct seeding, so that transplants were set in the field at the same time as the direct seeded plants emerged, and both types of plants were presented at the same time to cucumber beetles. Other details of treatment establishment methods and effects on stand establishment are given in Ogutu and Caldwell (1999).

Insect monitoring

Pitfall traps were installed in two periods before planting and after planting and removed every two weeks. There was no monitoring in the habitat area before planting in 1998, but in 1999, monitoring was done in the habitat area from 19 May to 2 July. After planting, monitoring of ground predator was done in the cucumber crop rows from 14 July to 14 September 1998 and 2 July to 10 September 1999. Pitfall traps have been used to study different types of ground insects and other predators (Greenslade, 1964; Loreau, 1989; Carmona and Landis, 1999). In the habitat area, one trap was placed in each plot, each trap 2.1 m (7 ft) from the edge and 3.75 m (12.5 ft) into the plot in the east-west direction on ends opposite dry matter sampling sites. After planting, pitfall traps were installed in the center of the middle pair of cucumber rows in each main plot treatment, making sixteen traps in total. The pitfall traps were made of plastic cups of top and bottom diameters of 7.5 cm and 4.5 cm, respectively, and heights of 9.45 cm. Pitfall traps were installed by removing soil cores of a diameter slightly more than that of the plastic cup. One plastic cup with three holes punched at the bottom was first inserted into the hole and inside it another cup filled half way with water and three to four drops of Chloroform was added to preserve the trapped insects. The traps were emptied every two weeks. The contents of the trap were sieved into an empty plastic cup and the insects left on the sieve were put into vials containing a preservative solution comprising of (1 glycerin: 21 100% ethanol: 49 distilled water). The vials were labeled according to the replicate, treatment and date the sample was removed. They were taken to the laboratory and sorted into Carabidae, Staphylinidae, larvae group (any larvae), and spiders, while densities of others insects caught in the traps, including ants, other coleopterans, wasps/ flies, and stinkbugs, are not reported here because their densities were consistently low, less than one total / sampling date in both years. Both the Carabidae (Allen, 1979) and spiders (Snyder and Wise, 2000) were known predators on eggs and larvae of cucumber beetles. The Carabidae were further identified to genus and species level with assistance of the scientific staff and reference collections of the Smithsonian Institute, Museum of Natural History, Washington DC.

Differences between treatments in densities of ground insects were analyzed by analysis of variance with single-degree-of-freedom contrasts (no habitat versus habitat, no-till versus plastic with habitats, and transplants versus direct seeded) and (plasticulture versus no-till, plasticulture with versus without habitats, no-till transplanted versus direct seeded) using PROC GLM of the Statistical Analysis Systems (SAS Institute, 1997). Insect and spider densities were transformed using the square root of (x +0.5) prior to analysis. Means of significant effects were reported using untransformed values (Gomez and Gomez, 1984).

RESULTS

In 1998, no monitoring was done before rolling and flail mowing of rye/vetch. Prior to planting, higher Carabidae, Staphylinidae, and spider densities were found in rye/vetch habitat plots than in rye only conventional plots in May 1999. The mean densities of Carabidae (5.9/plot), Staphylinidae (6.4/plot), and spiders (5.1/plot) were higher in the habitat plots than in the conventional plots before planting (Table 3-1).

Monitoring in the cucumber crop rows in 1998 after planting indicated that mean densities of Carabidae were higher than other predators. Carabidae and spider mean densities of 11.7/plot and 6.7/plot, respectively were not different from densities of Carabidae (7.7/plot) and spiders (4.9/plot) in conventional plots without habitats. The mean Staphylinidae densities were not different in all treatments. The mean larvae densities (5.7/plot) in habitat plots were higher than mean densities (3.7/plot) in the conventional plots without habitats (Tables 3-2). After planting, *Harpalus longicollis, Poecilus chalcitae,* and *Scarites subterranus* species were present in crop rows in higher numbers in no-till than in black plastic mulch plots (Figure 3-1).

After planting, monitoring in the habitat areas between crop rows (habitat in treatments RTDS, NTDS, and NTTP; bare soil in the conventional black plastic mulch treatment) between 2 June and 2 July 1999 showed that there were higher densities of Carabidae, Staphylinidae, and spiders in the habitat areas between crop rows than in the bare area between crop rows in conventional black plastic mulch. Mean Carabidae densities in habitat plots were more than double densities in the conventional plots. The Staphylinidae densities in habitat plots were 4-fold greater than the mean densities in conventional plots. The mean densities of spiders per habitat plot were 1.5 times greater than in conventional plots. The mean densities of larvae (5.1/plot) in habitat plots was not different from larvae densities (2.9/plot) in the conventional plots (Table 3-2).

The cumulative Carabidae mean densities from cucumber rows in 1999 showed no differences between plastic plots (conventional and RTDS) and no-till plots (NTDS and NTTP). The no-till direct seeded plot had a 1.3 beetles/plot higher than no-till transplants but there was no difference. Habitat plots had higher cumulative mean Staphylinidae densities than conventional plots. However, there were no differences in mean densities between plastic and no-till. The mean spider densities in conventional plots were 5.7 spiders/plot less than in habitat plots. The mean spider densities in plastic plots were 16 spiders/plot less than in no-till plots, but there was no difference. The mean spider densities in no-till direct seeded plots were 10.2 spiders/plot less than in the transplant plots. The cumulative mean larva density in conventional plots was 5.7 larvae/plot less than the mean densities in habitat plots. The mean larvae density in plastic plots was 5.7 larvae/plot less than in no-till plots (Table 3-2).

There was a higher diversity of Carabidae species in the habitat areas early in the season than in crop rows in 1999 (Figures 3-2 and 3-3). The habitat areas had twice as many Carabidae species as in crop rows in 1999. In the crop row areas, there was greater diversity in plots with habitats than in the plots with bare areas between the strips. There were only two species of Carabidae (*Harpalus longicollis, Scarites subterranus*) in the between-crop row bare areas of conventional treatments, while there were three to four times as many (six to eight) species of Carabidae in the habitat treatments than in conventional before rolling or flail mowing. The highest densities in habitat plots were observed for *Harpalus longicollis*, *Poecilus chalcite* and *Agonum angustata* (Figure 3-2).

TABLE 3-1. EFFECT OF TREATMENTS ON DENSITIES (MEAN ± SE) OF GROUND PREDATORS PER PLOT IN HABITAT AREA BEFORE PLANTING, 1999

Removal Date[x]	Treatments[z]	Carabidae	Staphylinidae	Spiders	Larvae group
02 June	Conventional	2.5 ± 0.3	1.0 ± 1.0	3.5 ± 0.7	2.3 ± 0.6
	RTDS	6.8 ± 1.1	6.8 ± 2.1	4.5 ± 1.0	3.8 ± 2.2
	NTDS	5.3 ± 0.3	7.5 ± 2.3	5.0 ± 1.1	2.3 ± 1.9
	NTTP	5.5 ± 1.4	5.0 ± 1.5	5.8 ± 1.3	2.0 ± 1.7
Significance of Comparisons[y]					
Conv. vs habitat		p= 0.008[**]	p= 0.008[**]	p= 0.005[**]	p= 0.86[ns]

[z] Conventional = plastic on soil, direct seeded, no habitat

RTDS = plastic on rototilled rye/vetch, direct seeded, with habitat

NTDS = rye/vetch no-till, direct seeded, with habitat

NTTP = rye/vetch no-till, transplanted, with habitat

[y] Conv. = Conventional; Habitat = RTDS, NTDS, NTTP

Probability of significant differences: [ns] - P>= 0.05; [*] - 0.01 < P < 0.05; [**] - P < 0.01

[x] Pitfall traps put up on 19 May and removed after two weeks on 2 June

TABLE 3-2. EFFECT OF TREATMENTS ON GROUND PREDATOR DENSITIES (MEAN ± SE) IN HABITAT AREAS AND CUCUMBER ROWS AFTER PLANTING, 1998 AND 1999

Treatments[z]	Carabidae	Staphylinidae	Spiders	Larvae group
In crop rows, 1998				
Conventional	7.7 ± 0.5	4.9 ± 0.5	4.9 ± 0.4	3.7 ± 0.3
RTDS	11.4 ± 0.3	4.1 ± 0.3	6.6 ± 0.8	4.8 ± 0.4
NTDS	11.8 ± 0.3	4.9 ± 0.2	6.1 ± 0.2	5.3 ± 0.2
NTTP	12.0 ± 1.1	4.0 ± 0.3	7.3 ± 0.5	6.9 ± 0.3
Significance of Comparisons[y]				
Conv. vs habitat	p= 0.12 ns	p= 0.54 ns	p= 0.18 ns	p= 0.01 *
Plastic vs No-till	p= 0.77 ns	p= 0.72 ns	p= 0.89 ns	p= 0.10 ns
NTDS vs NTTP	p= 0.92 ns	p= 0.44 ns	p= 0.48 ns	p= 0.09 ns
In habitat area, 1999				
Conventional	2.9 ± 0.2	1.8 ± 0.4	5.4 ± 0.6	2.9 ± 0.5
RTDS	7.7 ± 0.5	8.0 ± 0.7	7.2 ± 0.3	5.9 ± 0.2
NTDS	5.4 ± 0.6	7.2 ± 0.9	9.8 ± 0.5	3.9 ± 1.0
NTTP	5.6 ± 0.9	9.5 ± 1.3	9.8 ± 0.6	5.6 ± 1.0
Significance of Comparisons[y]				
Conv. vs habitat	p= 0.02 *	p= 0.03 *	p= 0.04 *	p= 0.26 ns
Plastic vs No-till	p= 0.18 ns	p= 0.96 ns	p= 0.15 ns	p= 0.65 ns
NTDS vs NTTP	p= 0.92ns	p= 0.56 ns	p= 0.94 ns	p= 0.50 ns
In crop rows, 1999				
Conventional	5.6 ± 0.2	3.5 ± 0.2	3.9 ± 0.2	3.3 ± 0.2
RTDS	6.4 ± 0.4	5.9 ± 0.4	8.9 ± 0.9	6.1 ± 0.2
NTDS	7.2 ± 0.6	7.2 ± 0.5	10.8 ± 0.8	10.4 ± 0.8
NTTP	5.9 ± 0.5	7.7 ± 0.5	21.0 ± 0.9	10.4 ± 0.3
Significance of Comparisons[y]				
Conv. vs habitat	p= 0.58 ns	p= 0.01 *	p= 0.004 **	p= 0.0009 **
Plastic vs No-till	p= 0.88 ns	p= 0.29 ns	p= 0.07 ns	p= 0.01 *
NTDS vs NTTP	p= 0.46 ns	p= 0.72 ns	p= 0.03 *	p= 0.99 ns

[z] Conventional = plastic on soil, direct seeded, no habitat

RTDS = plastic on rototilled rye/vetch, direct seeded, with habitat

NTDS = rye/vetch no-till, direct seeded, with habitat

NTTP = rye/vetch no-till, transplanted, with habitat

[y] Conv. = Conventional; Habitat = RTDS, NTDS, NTTP

Plastic = Conventional, RTDS; No-till = NTDS, NTTP

Probability of significant differences: ns - p>= 0.05; * - 0.01 < p < 0.05; ** - p < 0.01

FIGURE 3-1. CUMULATIVE MEAN CARABIDAE DENSITIES IN HABITAT AREA BEFORE CUCUMBER ESTABLISHMENT, 1999

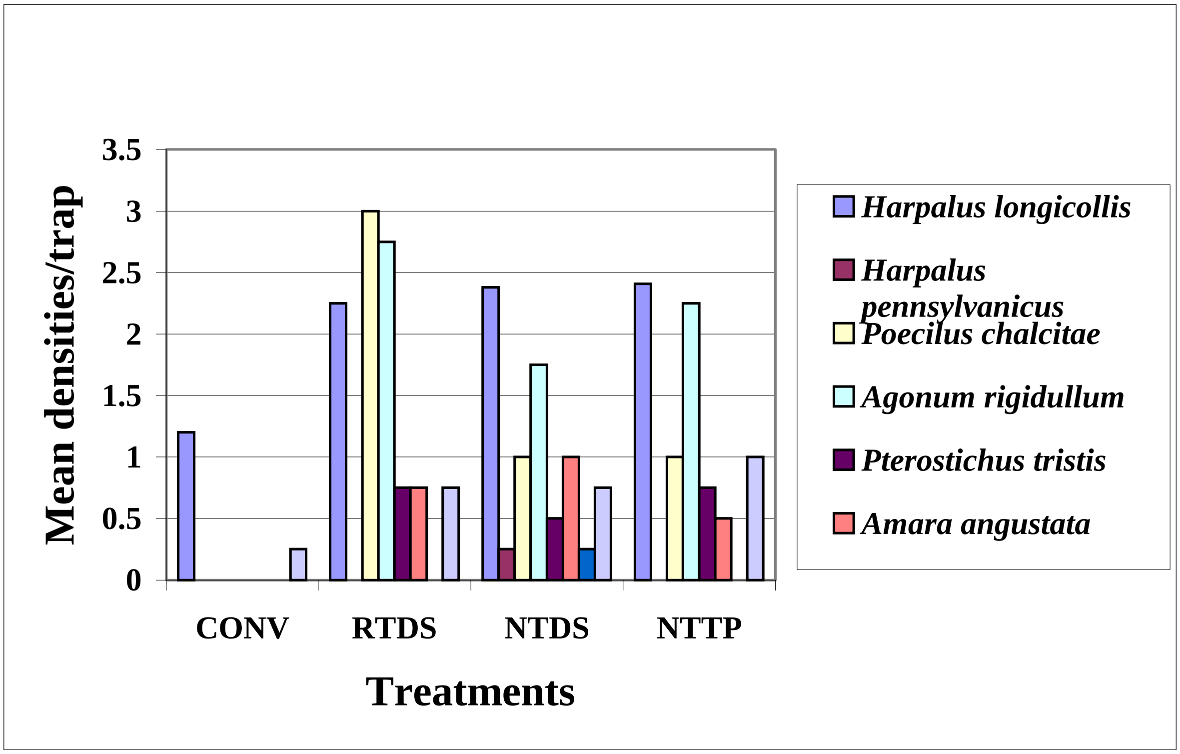


FIGURE 3-2. CUMULATIVE MEAN CARABIDAE DENSITIES IN CUCUMBER ROWS AFTER PLANTING, 1998

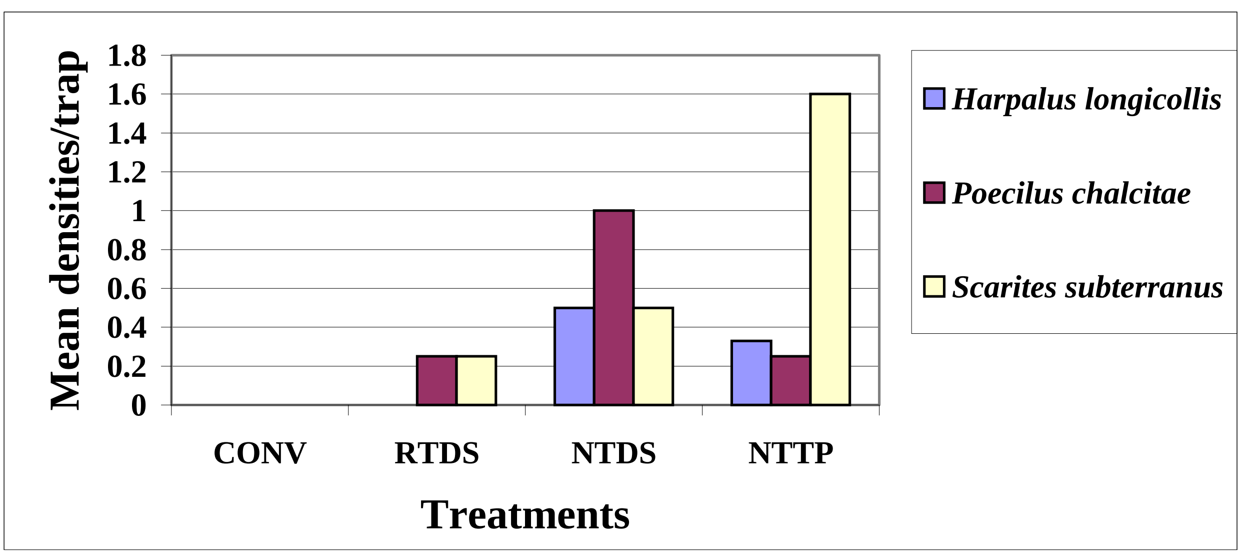
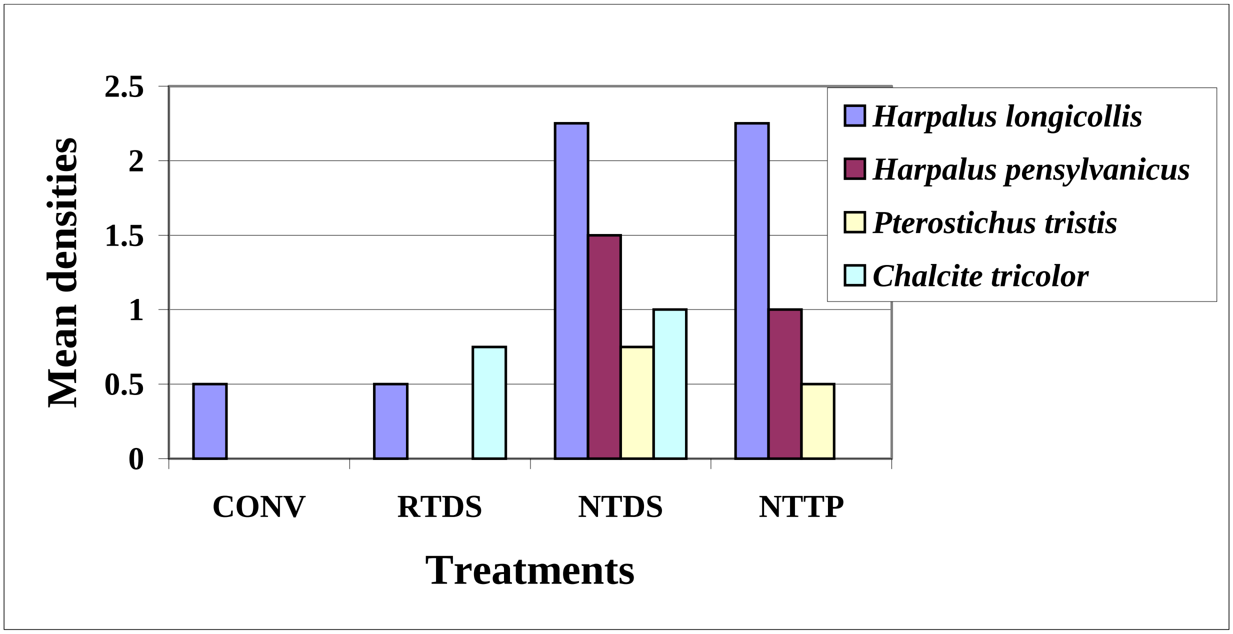


FIGURE 3-3. CUMULATIVE MEAN CARABIDAE DENSITIES IN CUCUMBER ROWS AFTER PLANTING, 1999



DISCUSSION

Ground predators have been found in several agro-ecosystems including cereal fields, pastures, and vegetable plots. The most common predatory ground predators found in agro-ecosystems are Carabidae, Staphylinidae and Spiders. Their abundances tend to be higher in plots with dead or live mulch than on bare ground (Brust, 1991). The results for this study showed higher densities of Carabidae, Staphylinidae, larvae and spiders in habitat than in conventional plots, which were bare ground (Table 4-2). It is possible that the cover crop created a microenvironment conducive for predators by attracting herbivorous insects feeding on vetch flowers and pollen. Some of these insects either in the adult or egg stage may have then served as prey for the predators, hence providing adequate food for the predators, leading to higher mean densities of predators than in the plots without the cover crop where such food resources were limiting. Pavuk et al. (1997) found that higher prey abundance and favorable microclimate in plots with high plant species diversity led to high ground predator density.

After rolling and flail mowing of rye/vetch, live habitat remained between cucumber twin rows in all treatments except the conventional. When the life cycle of the habitat (cover crop) was over approximately a month after cucumber planting, the cover crop plants died and formed dry mulch. This mulch, together with the no-till mulch in the crop rows, covered the whole plot in the no-till treatments. Dried cover crop mulch also remained in the area between the cucumber twin rows in the intermediate treatment with plastic mulch in the crop rows between habitat strips (RTDS). There were higher densities of ground predators in no-till than plastic plots even after planting of cucumbers. The intermediate treatment recorded slightly higher densities than the conventional. It may be inferred that the habitat strip kept the ground predators closer to the crop rows in habitat plots. In the conventional plots uncultivated field edges were further away from the cucumber rows, hence there were lower densities of ground predators in the cucumber rows compared to habitat plots.

The habitat plots had higher larvae densities than the conventional plot, which indicates that the habitat attracted more insects that laid eggs and subsequently hatched into larvae (Table 3-2). The larvae of Carabidae and Pennsylvania leatherwings are known to be predatory on the eggs, larvae and adults cucumber beetles (Houser and Balduf, 1925; Allen, 1979; Brust and House, 1990). If the majority of these larvae are predatory on eggs and larvae of cucumber beetles in habitat plots, they could contribute to a reduction in the cucumber beetle densities in habitat plots.

Spider densities were very high in both habitat and crop rows in no-till treatments (Table 3-2). However, the high number of spiders does not necessarily mean that they actually feed on cucumber beetles. Some of the spiders found in agro-ecosystems are small while others are large (Young, 1989; Reichert and Bishop, 1990). Cucumber beetles have been observed to hide and stop feeding when they sense giant spiders around them in diversified agro-ecosystems (Snyder and Wise, 2000). This could be a contributing factor to the yield increase observed in no-till plots (Ogutu and Caldwell, 1999; Unpublished data).

Staphylinidae densities were not different in all comparisons in 1998. In 1999, higher Staphylinidae densities were observed in habitat and in cucumber rows in habitat plots than in conventional plots. In addition to Carabidae and spiders, the habitats and no-till plots attracted and conserved Staphylinidae.

Leaving uncultivated strips close to crop fields can be used as a means of ensuring abundance and activity of ground predators in agro-ecosystems (Brust and House, 1990; Lys and Nentwig, 1992; Riddick and Mills, 1994; Snyder and Wise, 1999; Pfiffner and Luka, 2000; Snyder and Wise, 2000). Carabidae is one of the major groups of ground predators found in agro-ecosystems. Since the rye/vetch (cover crop) habitat is established earlier in the season before planting of other crops, it provides an environment with thicker canopy cover than the surrounding grasses and shrubs, and thereby attracts more Carabidae. A similar mechanism has been reported as the major cause of Carabidae migration between field edges and cornfields (Kajak and Lukasiewicz, 1994; Varchola and Dunn, 1999). When the field was rolled, the canopy cover was reduced in the crop row areas, so attractiveness to Carabidae was restricted mainly to the habitat strips between the cucumber twin rows. Cucumber growth led to increased canopy cover within the twin rows, so that by the time the habitat lost its canopy due to senescence, the movement of the Carabidae was towards the cucumber twin rows, leading to higher densities in the rows than in the habitats.

Since the no-till plots were covered with mulch which acted as refuge for the Carabidae, movements to crop rows from the habitats was greater than from the intermediate (RTDS) treatment in which the crop area had no plant residue mulch (Table 3-2). Lys and Nentwig (1992) reported similar observations of increased Carabidae in crop fields when uncultivated habitat strips were left closer. Since cucumber beetles lay their eggs on ground and at the same time spend most of the time closer to the ground under plant canopies, this may expose them to the Carabidae and other ground predators. This may have contributed to the lower cucumber beetle populations observed in the no-till plots compared to conventional and intermediate treatments (Unpublished data).

The Carabidae from the pitfall traps were further identified into genus and species. Higher diversity of Carabidae species was observed in habitat than conventional plots. The species observed in conventional plots were *Harpalus longicollis* and *Scarites subterranus,* both of which can feed on spotted cucumber beetle larvae. These Carabidae species could be important in controlling cucumber beetles but their mean densities were extremely low. The following six species were present in the habitat plots in addition to the above two species: *Harpalus pennsylvanicus* – feeds on spotted cucumber beetle larva and other insects. *Poecilus chlacitae* – may feed on seeds of nursery crops, as well as on insects. *Agonum rigidullum* – feeds on plants, insect eggs and larvae. *Pterostichus tristis* – feeds on Chrysomelidae family larvae; *Amara angustata* – feeds on mites and grass fragments. *Galeritia tricolor* – feeds on insects (Allen, 1979). This indicates that habitat plots attract both predaceous and non- predaceous Carabidae species (Figure 3-2). Since the species are present in these habitats, their activity might have contributed to the observed reduction in cucumber beetle densities. The number of species observed in cucumber twin rows after planting was lower than in habitat areas before planting. However, this suggests that there was movement of some of these species into the crop area, hence they would feed on the cucumber beetle and other insects larvae and eggs in the crop rows (Figures 4-1 and 4-3). Voucher specimens of the above carabid species have been placed in the Virginia Museum of Natural History, Blacksburg, Virginia.

In summary, this study has shown increased Carabidae beetles and spider densities in no-till plots compared to black plastic mulch plots with and without habitats. Cucumber beetle densities were lower and yields higher in no-till plots compared to black plastic mulch treatments (Table 4-3).

These results suggest that the combination of no-till and habitats can contribute to effective cucumber beetle management by ground predators.

LITERATURE CITED

Allen, R. T. 1979. The occurrence and importance of ground beetles in agricultural and surrounding habitats. In: Erwin, T. L., G. E. Ball, and D. R. Whitehead (eds). Carabid beetles: Their evolution, natural history and classification. Dr. W. Junk Publishers, The Hague-Boston-London.

Altieri, M. A. 1991. How best can we use biodiversity in agroecosystems? Outlook on Agriculture. 20(1): 15 – 23.

Amirault, J. P. and J. S. Caldwell. 1998. Living mulch strips as habitats for beneficial insects in the production of cucurbits. HortScience. 33(3): 524.

Barney, R. J. and B. C. Pass. 1986. Ground beetle (Coleoptera: Carabidae) populations in Kentucky alfalfa and influence of tillage. Journal of Economic Entomology. 79: 511-517.

Bauer, L. J. (1989). Moorland beetle communities on limestone 'habitat islands'. Isolation, nvasion and local species diversity in Carabidae and staphylinids. Journal of Animal Ecology. 58: 1077-1098.

Best, R. L. and C. C. Beegle. 1977. Food preferences of five species of carabids commonly found in Iowa cornfields. Environmental Entomology. 6: 9-12.

Brodsky, L. M., and C. A. Barlow. 1986. Escape responses of pea aphid, *Acyrthosiphon pisum* (Homoptera: Aphididae): influence of predator type and temperature. Canadian Journal of Zoology. 64: 937-939.

Brust, G. E. 1990. Effects of below ground predator-weed interactions on damage to peanut by southern corn rootworm (Coleoptera: Chrysomelidae). Environmental Entomology 19(6):1837-1844.

Brust, G. E. 1991. Soil moisture, no-tillage and predator effects on southern corn rootworm survival in peanut agroecosystems. Entomologia Experimentalis Applicata. 58: 109-121.

Brust, G. E. and G. J. House. 1990. Effects of soil moisture, no-tillage and predators on Southern Corn Rootworm (*Diabrotica undecimpunctata howardii*) survival in corn agroecosystems. Agriculture, Ecosystems and Environment. 31:199-216.

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.

Davis, A. L. V., B. M. Doube and P. D. McLennan.1988. Habitat associations and seasonal abundance of coprophilous Coleoptera (Staphylinidae, Hydrophilidae, and Histeridae) in the Hluhluwe region of South Africa. Bulletin of Entomological Research. 78: 425-434.

Elsey, K D. 1988. Cucumber beetle seasonality in coastal South Carolina. Environmental Entomology. 19: 1503-1511.

Gomez, K. A. and A. A. Gomez. 1984. Statistical procedures for agricultural research. International Rice Research Institute, Los Banos, Phillipines.

Gould, G.E. 1944. The biology and control of the striped cucumber beetle. Bulletin 490. Purdue University Agricultural Experiment Station, Lafayette, Indiana.

Greenslade, P. J. M. 1964. Pitfall trapping as a method for studying populations of Carabidae (Coleoptera). Journal of Animal Ecology. 33(2): 301-310.

Houser, J.S., and W.V. Balduf. 1925. The striped cucumber beetle. Bulletin 368. The Ohio Agricultural Experiment Station, Columbus, Ohio.

Hu, G. Y. and J. H. Frank. 1997. Predation on the horn fly (Diptera: Muscidae) by five species of *Philonthus* (Coleoptera; Staphylinidae). Environmental Entomology. 26(6): 1240-1246.

Kajak, A. and J. Lukasiewicz. 1994. Do semi-natural patches enrich crop fields with predatory epigean arthropods? Agriculture, Ecosystems and Environment. 49: 149-161.

Krooss, S. and M. Schaefer. 1998. The effect of different farming systems on epigeic arthropods: a five-year study on the rove beetle fauna (Coleoptera: Staphylinidae) of winter wheat. Agriculture, Ecosystems and Environment. 69(2): 121-133.

Loreau, M. 1989. On testing temporal niche differentiation in carabid beetles. Oecologia. 81: 89- 96.

Lys, J-A, and W. Nentwig. 1992. Augmentation of beneficial arthropods by strip-management. 4. Surface activity, movements and activity density of abundant carabid beetles in cereal field. Oecologia. 92: 373-382.

Lys, J.A., M. Zimmermann, and W. Nentwig. 1993. Increase in activity density and species numbers of carabid beetles in cereals as a result of strip-management. Entomologia Experimentalis et Applicata 73:1-9.

Lys, J.A. 1994. The positive influence of strip-management on ground beetles in a cereal field: increase, migration, and overwintering. pp.451-455. In K. Desender et al. (eds.), Carabid beetles: ecology and evolution. Kluwer Academic Publishers, Netherlands.

Ogutu, M. O. and J. S. Caldwell. 1999. Stand differences in no-till and plasticulture direct seeded and transplanted cucumbers (*Cucumis sativus* L.). Acta Horticulturae. 504: 129-134.

Pfiffner, L. and H. Luka. 2000. Overwintering of arthropods in soils of arable fields and adjacent semi-natural habitats. Agriculture, Ecosystems and Environment. 78(3): 215-222.

Pavuk, D. M., F. F. Purrington and C. E. Williams. 1997. Ground beetle (Coleoptera: Carabidae) activity density and community composition in vegetationally diverse corn agroecosystems. The American Midland Naturalist. 138: 14-28.

Platt, J.O. 1997. The use of buckwheat border habitats to attract natural enemies of cucumber beetles in a cucurbit agroecosystem. M.S. Thesis. Virginia Tech, Blacksburg, Virginia.

Platt, J. O., J.S. Caldwell, J.S., and L.T. Kok. 1999. Effect of buckwheat as a flowering border on populations of cucumber beetles and their natural enemies in cucumber and squash. Crop Protection 18:305-313.

Reichert, S. E. and L. Bishop. 1990. Prey control by an assemblage of generalist predators: Spiders in garden test systems. Ecology. 71(4): 1441-1450.

Riddick, E.W. and N. J. Mills. 1994. Potential of adult carabids (Coleoptera: Carabidae) as predators of fifth-instar codling moth (Lepidoptera: Tortricidae) in apple orchards in California. Environ. Entomol. 25(5): 1338-1345.

SAS Institute. 1997. SAS/STAT user's guide 4th Edition Volume. Version 6.12. SAS Institute, Cary, North Carolina.

Snyder, W. E. and D. H. Wise. 1999. Predator interference and the establishment of generalist predator populations for biological control. Biol. Control. 15: 283-292.

Snyder, W. E. and D. H. Wise. 2000. Antipredator behavior of spotted cucumber beetles (Coleoptera: Chrysomelidae) in response to predators that pose varying risks. Environ. Entomol. 29(1): 35-42.

Stanton, M.L. 1983. Spatial patterns in the plant community and their effects upon insect search. In: S. Ahmad (ed.), Herbivorous insects. Academic Press, New York.

Tomlin, A. D. 1975. Notes on the biology and rearing of two species of ground beetles, *Pterostichus melanarius*, and *harpalus pennsylvanicus* (Coleoptera: Carabidae). Canadian Entomologist. 107: 67-74.

Varchola, J. M. and J. P. Dunn. 1999. Changes in ground beetle (Coleoptera: Carabidae) assemblages in farming systems bordered by complex or simple roadside vegetation. Agriculture, Ecosystems and Environment. 73: 41-49.

Virginia Polytechnic Institute and State University (VPI&SU), Soil Survey. 1990 Soil map for Kentland Research Farm, Blacksburg, Virginia.

Wisenden, B. D., D. P. Chivers, and R. J. F. Smith. 1996. Damselfly larvae learn to recognize predators from chemical cues in the predator's diet. Animal Behaviour. 52: 15-320.

Young, O. P. 1989. Field observations of predation by *Phiddipus audax* (Araneae:Salticidae) on arthropods associated with cotton. Journal of the Entomological Sciences. 24: 266-273.

CHAPTER 4

EFFECTS OF NO-TILL AND BLACK PLASTIC MULCH PRODUCTION SYSTEMS ON CUCUMBER PETIOLE SAP NITROGEN AND SOIL MOISTURE TENSION

ABSTRACT

Petiole sap nitrogen and soil moisture status were monitored in cucumbers grown in no-till and black plastic mulch systems. Plots with cucumbers planted into black plastic mulch laid over incorporated flail mowed rye/vetch (incorporated rye/vetch) and plots with cucumbers direct seeded into no-till rolled rye/vetch (no-till direct seeded) had higher sap nitrogen readings than plots with cucumbers directed seeded into black plastic mulch laid on tilled bare soil (conventional) or plots with cucumbers transplanted into no-till rolled rye/vetch (no-till transplants). In 1999, petiole sap nitrate readings declined by 50% in samples taken two weeks after the first sampling (six weeks after emergence), with the highest decline observed in conventional and no-till transplant plots.

Soil moisture was monitored in plots with black plastic mulch and in no-till plots using tensiometers to schedule irrigation. Moisture tension was higher in plots with black plastic mulch than in no-till plots four weeks after the first monitoring. After rains, no-till plots had higher moisture content than plots with black plastic mulch on five out of ten sampling dates.

Key words: nitrate, fertigation, tensiometers.

INTRODUCTION

Black plastic is the most commonly used mulch in cucurbit production, mainly to control weeds and reduce evaporative moisture loss. It is used in both pickle and fresh cucumber production. Its use ensures that water supplied through the trickle line is available to the plants with less percolation into the area between black plastic strips.

An alternative to black plastic mulch is no-till mulch made *in situ* by rolling or flail mowing a cover crop mixture. Cover crops during their establishment stages before rolling or flail mowing utilize water just like the main crop, and this can lead to moisture depletion in the no-till plots at planting time. However, cover crops have the advantages of covering the ground, thereby minimizing soil loss, and increasing soil nitrogen content when nitrogen fixing legumes are used. After rolling, cover crop residues form mulch, which covers the ground and reduces evaporative soil moisture losses. The residue can also enable growers to go into the field much sooner after rainfall or irrigation with farm equipment and start field operations with less soil compaction (Morse, 1999; Rutledge, 1999). Decomposition of no-till mulch (cover crop residues) improves soil structure, thereby facilitating water percolation and retention in the upper horizons of the soil profile when moisture is applied through irrigation or rainfall (Tyler et al., 1994; Christensen et al., 1994a).

Nitrogen is one of the major nutrients utilized by plants in large quantities. Plant available nitrogen forms are nitrate and ammonium. Plant uptake occurs when they are in the soil solution, and uptake is dependent on soil moisture status. In soils with very high moisture deficits less nitrogen will be available in soil solution, with consequently reduced N-uptake by plants. Quick mineralization of incorporated vetch residues may lead to nitrogen losses through leaching and denitrification. In very wet soils nitrogen loss through denitrification when vetch residue is decomposing has been shown to be 24% as compared to 1% in soils with moisture tension at field capacity (Shelton et al., 2000). Denitrification can occur much more rapidly in no-till plots when saturated with moisture than conventional black plastic mulch plots due to faster percolation of water in no-till (Christensen et al., 1994b; Bonfil et al., 1999). Under both situations, plants will show nitrogen deficiency symptoms. In early spring, when low nitrogen mineralization occurs in no-till (Smith et al., 1987), uniform application of nitrogen to all treatments early in the season is recommended (Follett and Schimel, 1989).

Percolation of rainfall in no-till is similar to percolation of rainfall on bare soil (Fortin, 1993). Soil under black plastic mulch is sealed so water from rainfall runs into the middles between crop rows, resulting in less becoming available to the crop. Plant residues in no-till retard direct soil moisture loss through evaporation from the soil surface compared to bare soil, hence crop water requirements in short term drought periods can easily be met in no-till (Blevins et al., 1971; Christensen et al., 1994b). No-till has been shown to increase water holding capacity and water use efficiency in wheat production in arid climates (Bonfil et al., 1999).

Sap nitrogen readings are an easy method of assessing the nitrogen needs of a crop during the season. Its validity has been shown for cole crops and greenhouse tomatoes. There is strong correlation between dried sap and fresh sap measurements in cauliflower and broccoli, and this is not affected by irrigation rate (Kubota et al., 1996; Kubota et al., 1997). Petiole sap nitrogen readings have been successfully used for monitoring nitrogen status, improving nitrogen use efficiency, and increasing yield in greenhouse tomatoes (Coltman, 1988). Research results from University of California-Davis (Spectrum technologies Inc., 1997 **http://www.specmeters.com**), for cantaloupes and melons were similar to levels established for muskmelon by the University of Florida team. The sap nitrate-nitrogen requirements established by the University of Florida for cucumbers at first bloom, fruits 3-inches long, and first harvest are 800-1000, 600-800, and 400-600 ppm, respectively (Spectrum Technologies Inc. Manual, 1997).

Several vegetable and small fruit growers in Virginia use this method to determine when to fertigate their fields. In some cases they use both potassium and sap nitrate meters, particularly in soils prone to potassium deficiency. However, the majority of farmers supply their plants with adequate amounts of potassium at planting time; hence, only monitoring of nitrogen is done continuously to make fertigation decisions (C.R. O'Dell, personal communication, 2000).

Water management is one of the most critical factors in successful and profitable vegetable production. Cucumber growth is affected by inadequate soil moisture, which results in decreased plant dry weight and reduced yield (Janoudi et al., 1993). Low soil moisture also reduces the ability of the plant to transport calcium to fruits, resulting in pillowy fruit disorder, which lowers fruit quality (Navazio and Staub, 1994). Adequate soil moisture is essential for microbial activity under no-till conditions for faster degradation of no-till mulch into organic matter, thereby releasing plant nutrients (Shelton et al., 2000).

Trickle irrigation is an efficient method of applying water to crops, but monitoring of soil moisture status is essential for accurate timing of water application (Shock et al., 2000). Eldredge et al. (1992) found that that trickle irrigation maintained stable soil moisture in silt loam soils at 0.2 m depth with moisture tension of 20 kPa, but serious oscillations of soil moisture levels occurred between 30 kPa and 70 kPa. They also found that maintaining soil moisture tension at 20 kPa provided adequate water for evapotranspiration in onions and maintained bulb quality and yield, with less leaching than when irrigation was increased to maintain soil moisture tension at 10 kPa. The Virginia Commercial Vegetable Production Recommendations (O'Dell et al., 2000) recommends that irrigation be started at 25 kPa for vegetable production.

Tensiometers have been used to monitor soil water status and determine effective scheduling of drip irrigation in sugarcane (Hodnett et al., 1990) and citrus orchards (Paramasivam et al., 2000). In vegetables they have been used to schedule irrigation in cabbages (Imtiyaz et al., 1999) and lettuce (Aggelides et al., 1999), and to control pillowy disease disorder in cucumbers (Serce et al., 1999). Their use is also recommended by Virginia Commercial Vegetable Production Recommendations (O'Dell et al., 2000).

This study examined no-till mulch as part of a sustainable production system using a cover crop mixture as a habitat in strips between cucumber rows and as no-till mulch for both weed control and as a ground insect habitat in crop rows. The details of treatment establishment and effects on stand establishment, yield, pests and beneficial insects of this system are discussed in Ogutu and Caldwell (1999) and other chapters of this dissertation (Unpublished data).

The objectives of this part of the study were: (1) to determine the effects on petiole sap nitrate-nitrogen status in cucumbers of rototilled (incorporated) rye/vetch versus leaving it on the ground as a no-till mulch in crop rows, as compared to conventional tillage of black plastic mulch laid over tilled bare soil; (2) to determine when to apply nitrogen through drip irrigation lines (fertigation) in relation to cucumber growth stages in no-till compared with black plastic mulch; (3) to determine irrigation requirements in no-till compared with black plastic mulch. The null hypothesis is that both petiole sap nitrate-nitrogen and soil moisture status are unaffected by rototilling (incorporating) or using rye/vetch as no-till mulch, compared to use of black plastic mulch on tilled soil. The alternative hypothesis is that incorporation of rye/vetch or use as no-till mulch both increase petiole sap nitrate-nitrogen and soil moisture.

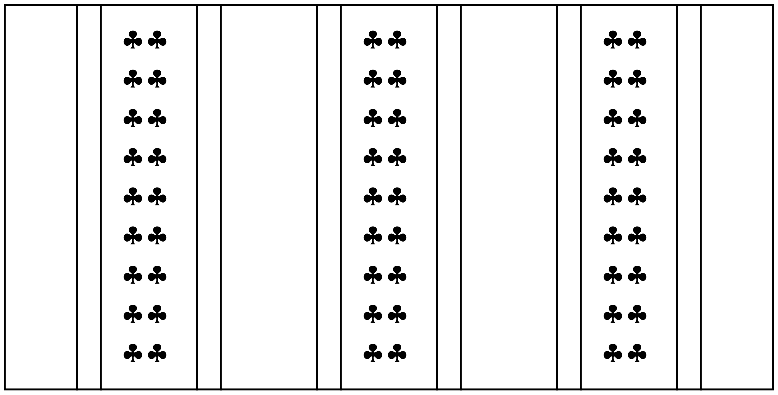
MATERIALS AND METHODS

Experimental design

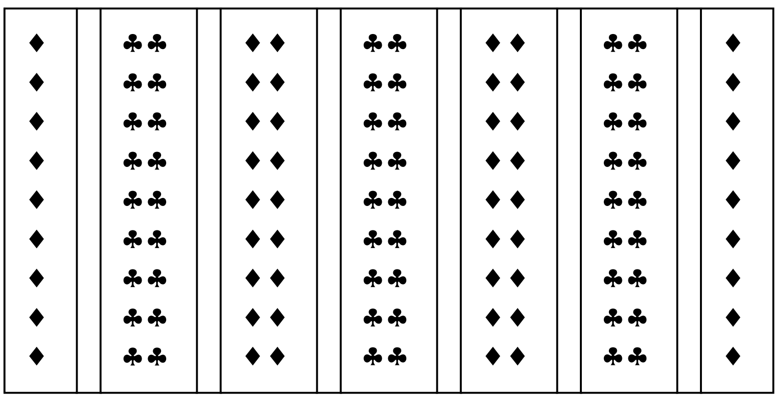
This experiment was part of a larger strip cropping cucumber production systems experiment carried out at Virginia Polytechnic Institute and State University, Kentland Farm, near Blacksburg, Virginia, from 1 October 1997 to 10 September 1998 and 14 October 1998 to 13 September 1999. The soil type is a fertile Shottower silty loam where potatoes were previously planted. Four main plot treatments compared rye/vetch no-till and black plastic mulch covered strips for cucumber production with or without rye/vetch habitats for beneficial insects between cucumber strips: (1) Conventional – direct seeding of cucumber into black plastic mulch, with bare ground between plastic strips (plastic on soil, direct seeded); (2) Flail mowed rye/vetch residue rototilled into the soil, black plastic mulch laid on top and cucumber direct seeded (plastic on rototilled rye/vetch, direct seeded; RTDS); (3) Cucumber direct seeded into rolled rye/vetch using no-till equipment, with rye/vetch habitats left between no-till strips (rye/vetch no-till, direct seeded; NTDS); (4) Cucumber seedlings transplanted into rolled rye/vetch using no-till equipment with rye/vetch habitat between no-till strips (rye/vetch no-till, transplanted; NTTP). Each main plot (9 m x 9 m) consisted of three strips (1.2 m x 9 m each) of cucumbers planted in twin rows at an inter-row spacing of 0.3 m and an intra-row spacing of 0.225 m, with habitats or bare soil (1.5 m x 9 m) between the crop strips (Figure 4-1). The treatments were replicated four times in a randomized complete block design. Details of treatment establishment methods and effects on stand establishment, beneficial insects, pest insects, and weed management are reported in Ogutu and Caldwell (1999; Unpublished data).

FIGURE 4-1. LAYOUT OF TREATMENTS

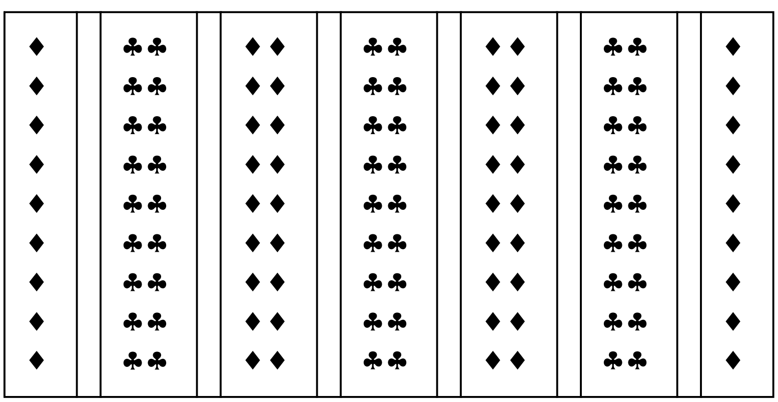
a. Plastic laid on soil without habitat



b. Plastic laid on rototilled rye/vetch with habitat strips



c. No-till rye/vetch with habitat strips



♦ - habitat – 0.6 m wide; ♦ ♦ - habitat – 1.2 m wide; ♣♣ - cucumber twin row – 0.6 m wide;

- tractor lane – 0.6 m wide

Plant sap nitrate-nitrogen status

Plant sap nitrogen status was assessed based on petiole sap nitrate-nitrogen content. Three leaf petioles were taken from each main plot, in each twin-row crop strip. Each sample was taken from a healthy plant 4.5 m (15 feet) into each strip (in the middle of the strip), and three petioles were taken from each of the three strips. Samples were taken between 10:00 AM and 2:00 PM from recently matured non-expanding leaves at the third node from the growing tip. The lower 2.5 cm (1 in) of the leaf petiole was trimmed off and put into a labeled (treatment and replicate) plastic bag. The rest of the leaf was discarded. The petioles were taken to a shade house and sap readings taken within 1½ hours. The three petioles were chopped up and mixed, the fresh plant tissue was squeezed, and the extruded sap analyzed for nitrogen (nitrate) using a Cardy NO_3^- Nitrate Meter (Spectrum Technologies Inc., Plainfield, Illinois). The procedure for the bulk sample was repeated three times and the average meter reading was used as the overall representative for the sample. One sample was taken in 1998, on 9 July (26 days after planting); three samples were taken in 1999, on 9 July, 20 July and 6 August (36, 47, and 64 days after planting). Fertigation was done two days after each reading when N status was less than the level recommended by the Cardy meter users' manual (Spectrum Technologies Inc., 1997) using a 20N-8.6P-16.7K soluble fertilizer incorporated into the trickle line. Trickle lines were set up separately for plastic and no-till treatments, and rates were varied depending on plant growth stage. In 1998, prior to beginning petiole sap nitrate-nitrogen assessment, an initial fertigation was done in all plots on 25 June (12 days after planting) by incorporating 11.8 $kg.ha^{-1}$ (10.5 $lb.ac^{-1}$) and 2.8 $kg.ha^{-1}$ (2.5 $lb.ac^{-1}$) of soluble fertilizer 20N-8.6P-16.7K into trickle lines serving plastic and no-till plots respectively. In 1999, fertigation was done one day later on 10 July by incorporating 37 $kg.ha^{-1}$ (33 $lb.ac^{-1}$) and 0.70 $kg.ha^{-1}$ (0.60 $lb.ac^{-1}$) of a 20N-8.6P-16.7K soluble fertilizer into the trickle lines for plastic and no-till plots, respectively. Lower N application rates were used for no-till than for plastic because of the expected availability of nitrogen fixed by vetch. Overall, N rates were set low due to high native soil fertility of the experimental field, to assess differences between plasticulture and no-till under low-input conditions.

Soil moisture status

Tensiometers (Irrometer model, Irrometer Company, Riverside, California) were prepared before installation following the six steps in the manufacturers' manual. A slender soil augur of diameter slightly larger than that of the tensiometer stem was used to bore a hole in the center of the plot at 0.45 m (18 in) depth and 0.15 m (6 in) away from the trickle line (O'Dell et al., 2000). The tensiometers were installed in one no-till and one plastic plot in each replicate. Readings were taken weekly between 9:00 AM and 12:00 noon from 23 June 1999 to 8 September 1999. Irrigation was done when tensiometers showed a reading between 20-30 kPa, which is above the field capacity for silt loam soil (30-50 kPa) (O'Dell et al., 2000). The tensiometer gauge indicator range was 0-40 kPa, where 0 is very wet while 40 or more indicates dry conditions. Tensiometers were also used in 1998 to schedule irrigation, but the number installed in 1998 (only 2 replications) was inadequate for statistical analysis, and results are not reported here. Daily rainfall was recorded from April through August 1999 and cumulated over 10 day periods.

Statistical analysis

The petiole sap nitrate-nitrogen data were analyzed using SAS PROC GLM (SAS Institute, 1997) with treatments and replicates as independent variables and the petiole sap readings as dependent variables with single-degree-of-freedom contrasts [plastic (conventional, RTDS) versus no-till (NTDS, NTTP); plastic with habitat (RTDS) versus plastic without habitat (conventional) and no-till transplanted (NTTP) versus no-till direct seeded (NTDS)].

RESULTS

Plant sap nitrate-nitrogen status

From leaves sampled on 9 July 1998 (26 days after planting), rye/vetch residue rototilled plots had higher petiole sap nitrate-nitrogen than plastic laid on bare ground ($p= 0.01$). There was no difference between plastic and no-till ($p= 0.14$) or between no-till direct seeded and no-till transplants ($p= 0.21$) (Figure 4-2). The average readings for the two plastic (534 ppm) and two no-till (785 ppm) treatments were below the petiole sap NO_3^- -nitrogen sufficiency limit of 800 ppm for cucumbers at the first bloom stage.

In 1999, there was a progressive decline in petiole sap NO_3^--nitrogen as the plants matured. Petiole sap NO_3^--nitrogen from the samples taken on 9 July (36 days after planting) and 20 July (47 days after planting) 1999 showed no differences between all treatment comparisons, but petiole sap concentrations were lower than the first sample by half. The conventional treatment recorded the lowest reading of 57% of RTDS while NTDS was highest (98% of RTDS). The mean sap readings for plastic and no-till treatments were above the minimum sufficiency level at pre-bloom stage (800 ppm) in 9 July samples (Table 4-1). However, the plastic (479 ppm) and no-till (518 ppm) readings taken on 20 July when cucumber fruits were 8 cm (3 in) long were below sufficiency limit of 600 ppm, hence fertigation was done on 21 July using 16.8 $kg.ha^{-1}$ (15 $lb.ac^{-1}$) and 11.2 $kg.ha^{-1}$ (10 $lb.ac^{-1}$) of a 20N-8.6P-16.7K soluble fertilizer injected into the plastic and no-till trickle lines, respectively.

No-till direct seeded plots had higher sap nitrate-nitrogen than black plastic mulch with habitat plots on 6 August (64 days after planting) ($p= 0.04$). The sap concentration in no-till direct seeded was the highest (143% of RTDS) but it was not different from no-till transplants (105% of RTDS) ($p= 0.76$). Conventional continued to record the lowest concentration (89% of RTDS) (Figure 4-3).

Soil moisture status

There was no difference between the moisture tension in plastic and no-till plots in June 1999 readings ($p= 0.20$) even though plastic tended to have higher soil moisture tension than no-till plots. Although soil moisture tension was higher in plastic than in no-till plots on five of ten readings in July and August 1999, there were no differences in early July ($p= 0.50$), late July ($p= 0.09$), early August ($p= 0.15$), late August ($p= 0.09$) and September ($p= 0.33$) (Table 4-2). Analysis of the moisture tension data on a weekly basis indicated no difference between plastic and no-till plots. However, there was a sharp rise in soil water tension of 30 kPa on the 27 July (54 days after planting - DAP) sampling in plastic plots and drop of 25 kPa on 26 August (84 DAP) in both plastic and no-till plots (Figure 4-4).

The biomass of cucumber plants on 27 July was not different between plastic and no-till plots, although the conventional plots had slightly higher biomass than the other treatments (Figure 4-5). The season was characterized by two peak periods of high rainfall, mid- May and late July. From late May to mid-July, the period of crop establishment and growth, rainfall was low (Figure 4-6). The no-till system had higher yields than the plastic system in both years ranging from 26.8 to 51.6 $t.ha^{-1}$ (30 to 57.8 $t.ac^{-1}$) (Table 4-3).

Table 4-1. Effects of rototilled rye/vetch on cucumber petiole sap nitrate-nitrogen in comparison to black plastic mulchdirect seeded, no-till rye/vetch direct seeded, and no-till rye/vetch transplanted cucumbers, 1998 and 1999

Treatments	1998		1999					
	Means	% RTDS[z]	Means			%RTDS		
Dates[y]	7/9 (26)	7/9 (26)	7/9 (36)	7/20 (47)	8/6 (64)	7/9 (36)	7/20 (47)	8/6 (64)
Conventional	200	23%	854	348	146	65%	57%	89%
RTDS	869	100%	1309	609	165	100%	100%	100%
NTDS	929	107%	995	597	237	76%	98%	144%
NTTP	641	74%	748	440	174	57%	72%	105%
Sufficiency level	800	92%	800	600	400	61%	99%	242%
Significance								
RTDS vs. Conv	p= 0.02		0.09	0.14	0.54			
RTDS vs. NTDS	p= 0.78		0.22	0.94	0.04			
RTDS vs. NTTP	p= 0.30		0.05	0.32	0.76			

[z] Conventional, Conv= Cucumber direct seeded in black plastic mulch laid on tilled bare ground, no habitat; RTDS = Cucumber direct seeded in black plastic mulch laid on rototilled rye/vetch residues, rye/vetch habitat; NTDS= Cucumber direct seeded into furrows in no-till rolled rye/vetch, rye/vetch habitat; NTTP= Cucumber transplanted into furrows in no-till rolled rye/vetch, rye/vetch habitat.

[y] Values in parenthesis after dates indicate the number of days after planting.

TABLE 4-2. EFFECTS OF PLASTICULTURE AND NO-TILL RYE/VETCH ON BI-WEEKLY MEAN ±SE SOIL MOISTURE TENSION IN CUCUMBER PLOTS, 1999

Period	Days After Planting	Mean soil moisture tension (kPa) Plastic	No-till	F	P	Significance
23 & 29 June	20-26	9.8 ± 3.4	18.5±2.4	2.76	0.19	NS
06 & 13 July	33-40	19.8 ± 5.7	14.5±2.8	0.57	0.50	NS
19 & 27 July	47-54	37.5 ± 8.0	14.8±2.3	6.06	0.09	NS
02,09 & 16 Aug.	60-74	75.8 ± 15.0	49.3±2.0	3.62	0.15	NS
23, 26 & 30 Aug.	81-88	68.8 ± 11.8	43.5±2.2	5.89	0.09	NS
08 September	96	4.0 ± 1.4	5.8±0.6	1.37	0.33	NS

NS - Not significant – P> 0.05

kPa – Kilopascal

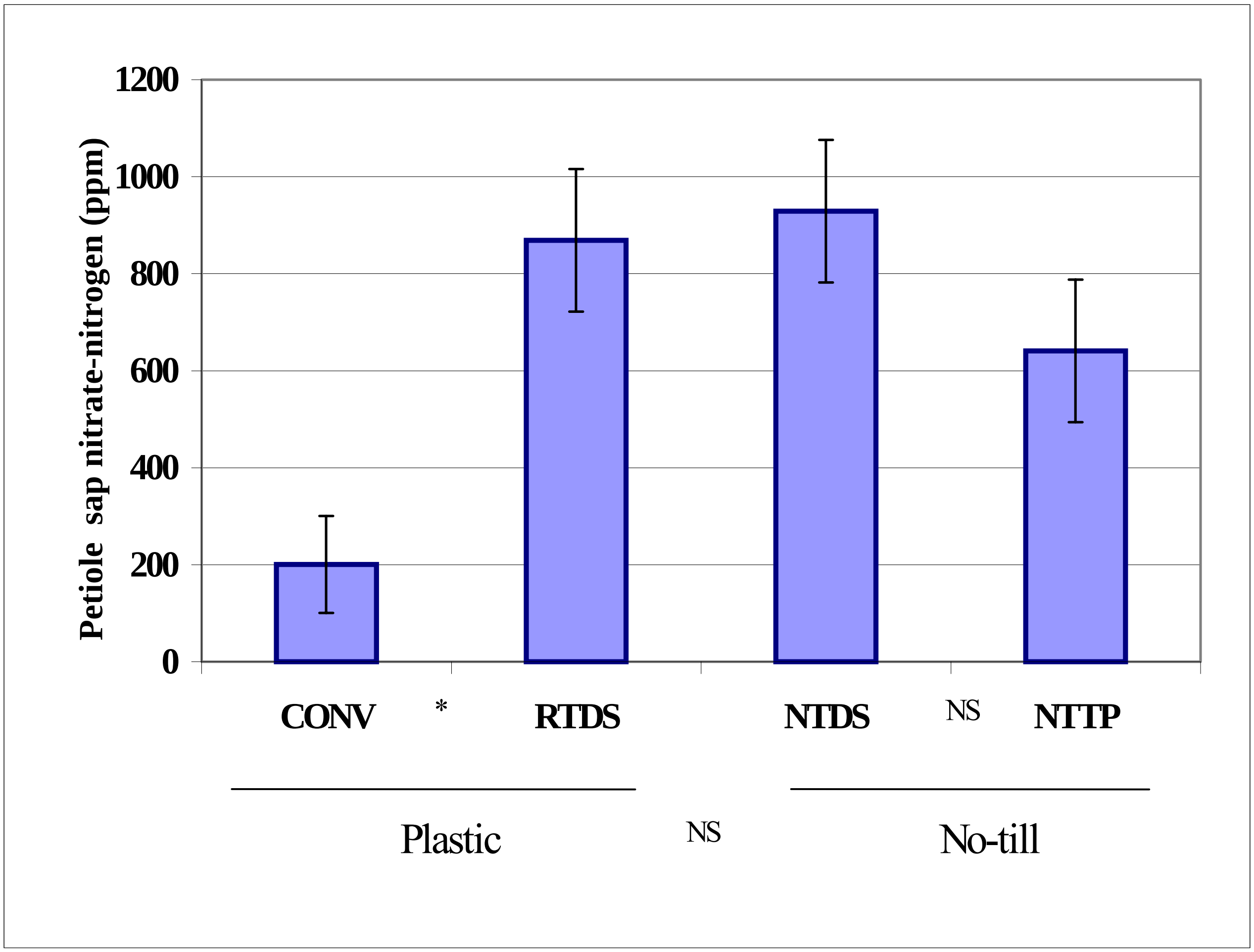
TABLE 4-3. CUMULATIVE MEAN MARKETABLE YIELDS FOR FRESH MARKET CUCUMBER IN 1998 AND 1999

Treatments[z]	Cumulative marketable yields ($t.ha^{-1}$)	
	1998	1999
Conventional	26.8 ± 4.3	38.6 ± 4.7
RTDS	26.8 ± 6.7	37.9 ± 2.6
NTDS	40.3 ± 5.7	43.3 ± 4.0
NTTP	41.9 ± 3.9	51.6 ± 1.8
Significance of Comparisons[y]		
No-till vs. Plastic	**	**
Conv. vs. RTDS	NS	NS
NTDS vs NTTP	NS	*

[z] – Conventional, Conv = Cucumber direct seeded in black plastic mulch laid on tilled bare ground, no habitat; RTDS = Cucumber direct seeded in black plastic mulch laid on rototilled rye/vetch residues, rye/vetch habitat; NTDS = Cucumber direct seeded into furrows in no-till rolled rye/vetch, rye/vetch habitat; and NTTP = Cucumber transplanted into furrows in no-till rolled rye/vetch, rye/vetch habitat.

[y] - Probability of significant differences: NS – $p >= 0.05$; * - $0.01 < p < 0.05$; ** - $p < 0.01$.

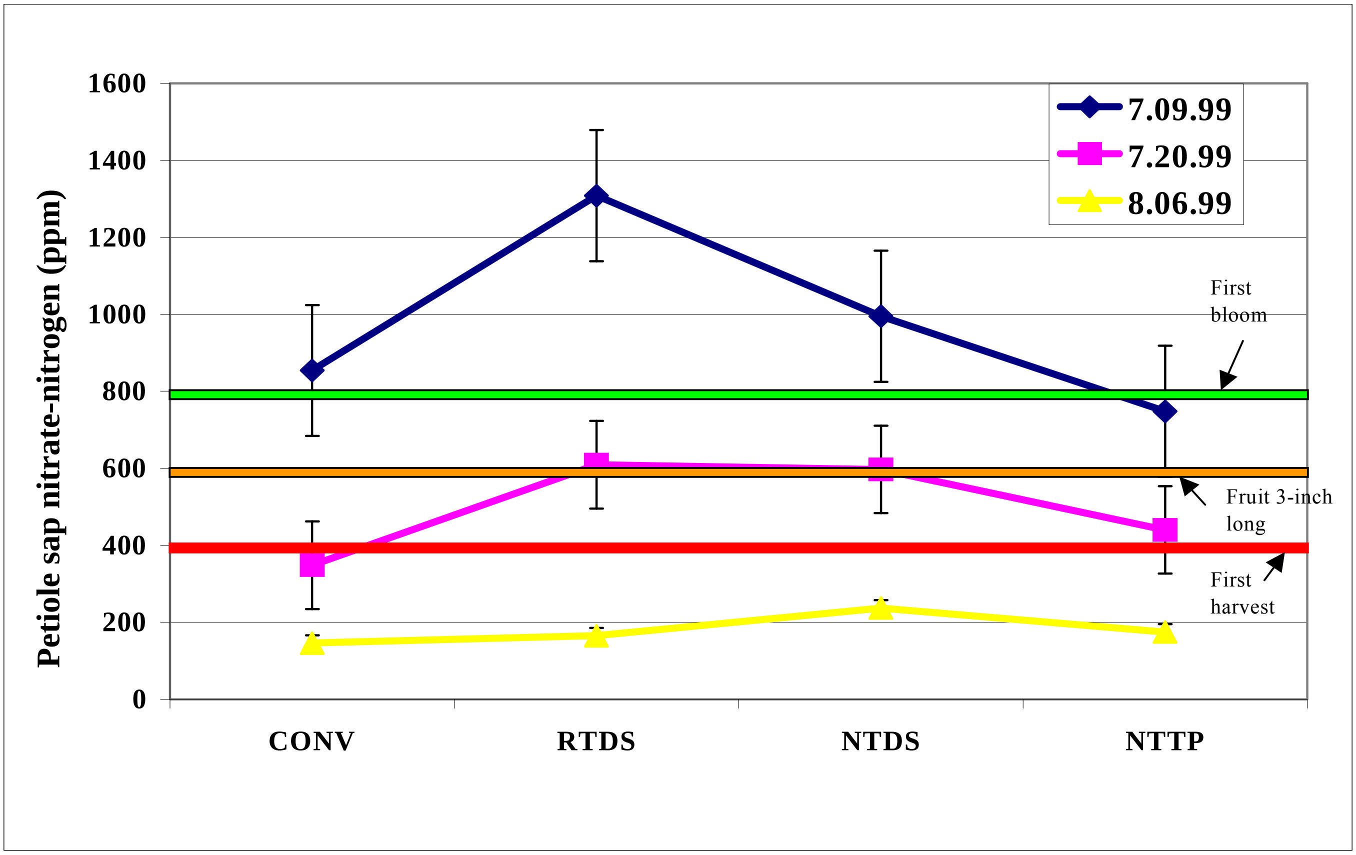
FIGURE 4-2. EFFECTS OF NO-TILL RYE/VETCH, ROTOTILLED RYE/VETCH AND BLACK PLASTIC MULCH ON PETIOLE SAP NITRATE-NITROGEN OF CUCUMBERS ON 9 JULY 1998 (26 DAYS AFTER PLANTING)[Z, Y]



[z] Conventional, Conv= Cucumber direct seeded in black plastic mulch laid on tilled bare ground, no habitat; RTDS = Cucumber direct seeded in black plastic mulch laid on rototilled rye/vetch residues, rye/vetch habitat; NTDS= Cucumber direct seeded into furrows in no-till rolled rye/vetch, rye/vetch habitat; NTTP= Cucumber transplanted into furrows in no-till rolled rye/vetch, rye/vetch habitat.

[y] - Probability of significant differences: NS – $p >= 0.05$; * - $0.01 < p < 0.05$; ** - $p < 0.01$.

FIGURE 4-3. EFFECTS OF RYE/VETCH NO-TILL AND ROTOTILLED, AND BLACK PLASTIC MULCH ON PETIOLE SAP NITRATE-NITROGEN SUFFICIENCY LIMITS FOR CUCUMBERS AT 36, 47 AND 64 DAYS AFTER PLANTING, 1999[Z, X]



[z] Conventional, Conv= Cucumber direct seeded in black plastic mulch laid on tilled bare ground, no habitat; RTDS = Cucumber direct seeded in black plastic mulch laid on rototilled rye/vetch residues, rye/vetch habitat; NTDS= Cucumber direct seeded into furrows in no-till rolled rye/vetch, rye/vetch habitat; NTTP= Cucumber transplanted into furrows in no-till rolled rye/vetch, rye/vetch habitat.

[x] - Sampling dates: 7.09.99 (9 July 1999), 7.20.99 (20 July 1999) and 8.06.99 (6 August 1999).

FIGURE 4-4. SOIL MOISTURE TENSION (MEAN ± SE) MONITORING IN PLASTIC AND RYE/VETCH NO-TILL PLOTS FROM 23 JUNE TO 8 SEPTEMBER 1999 (20 – 96 DAYS AFTER PLANTING)

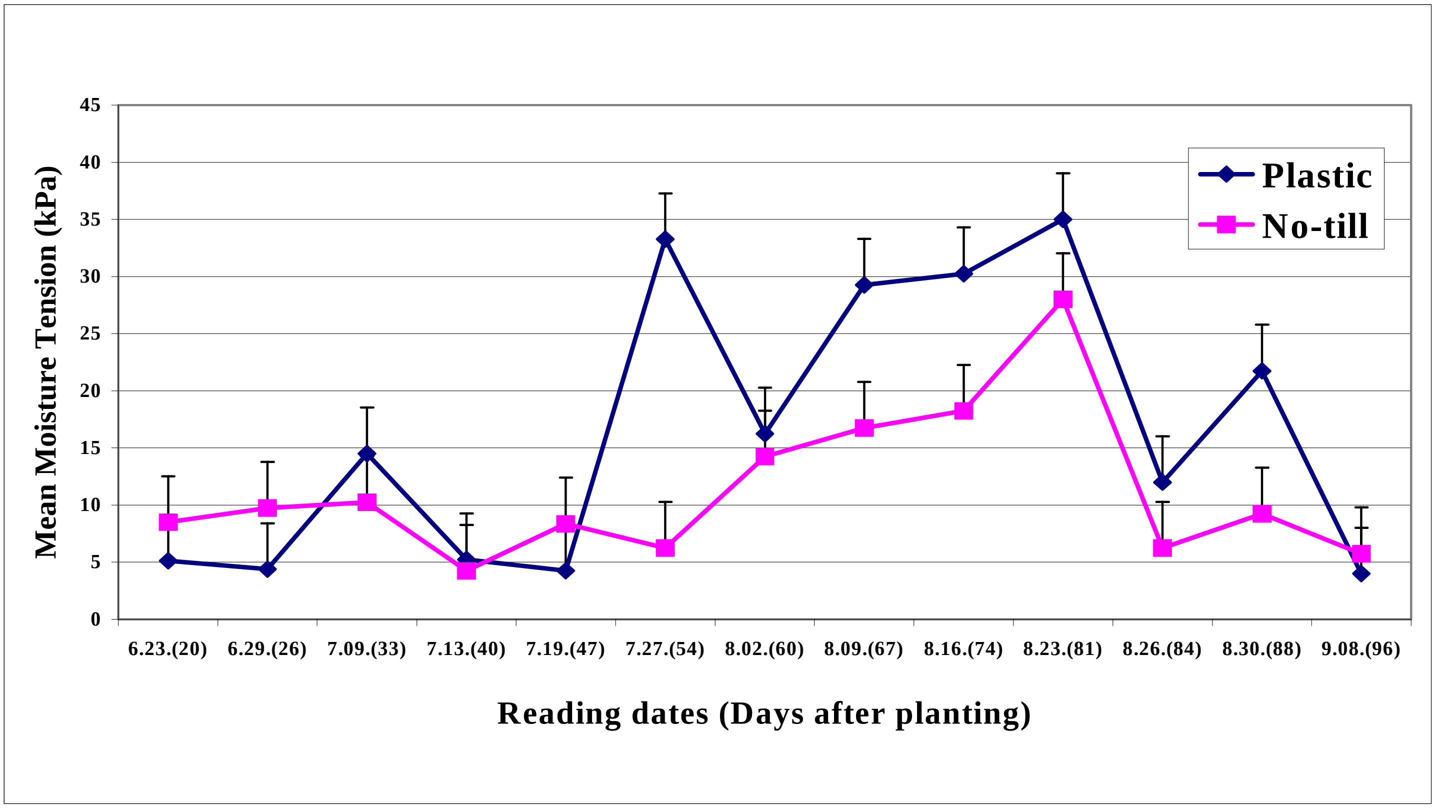
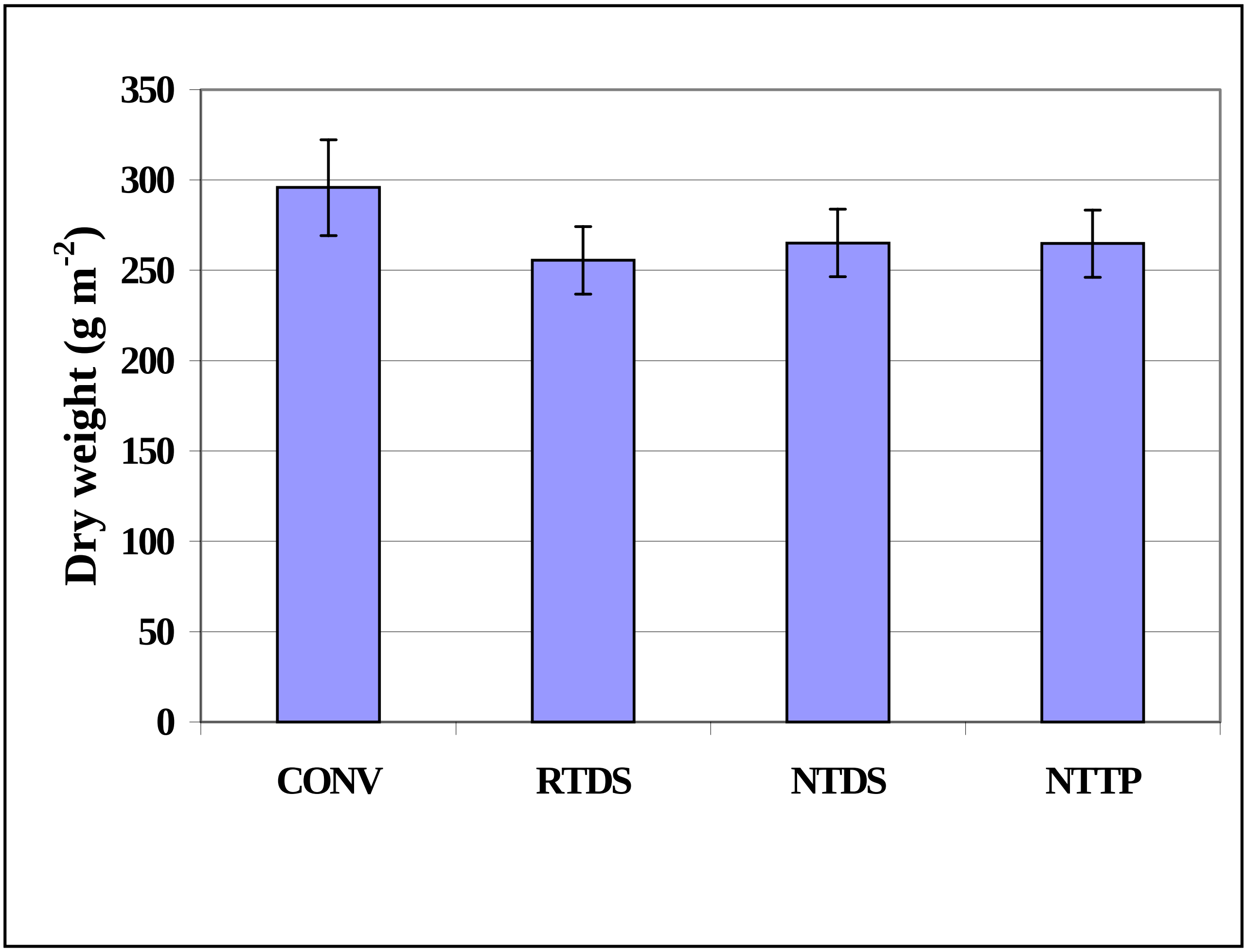
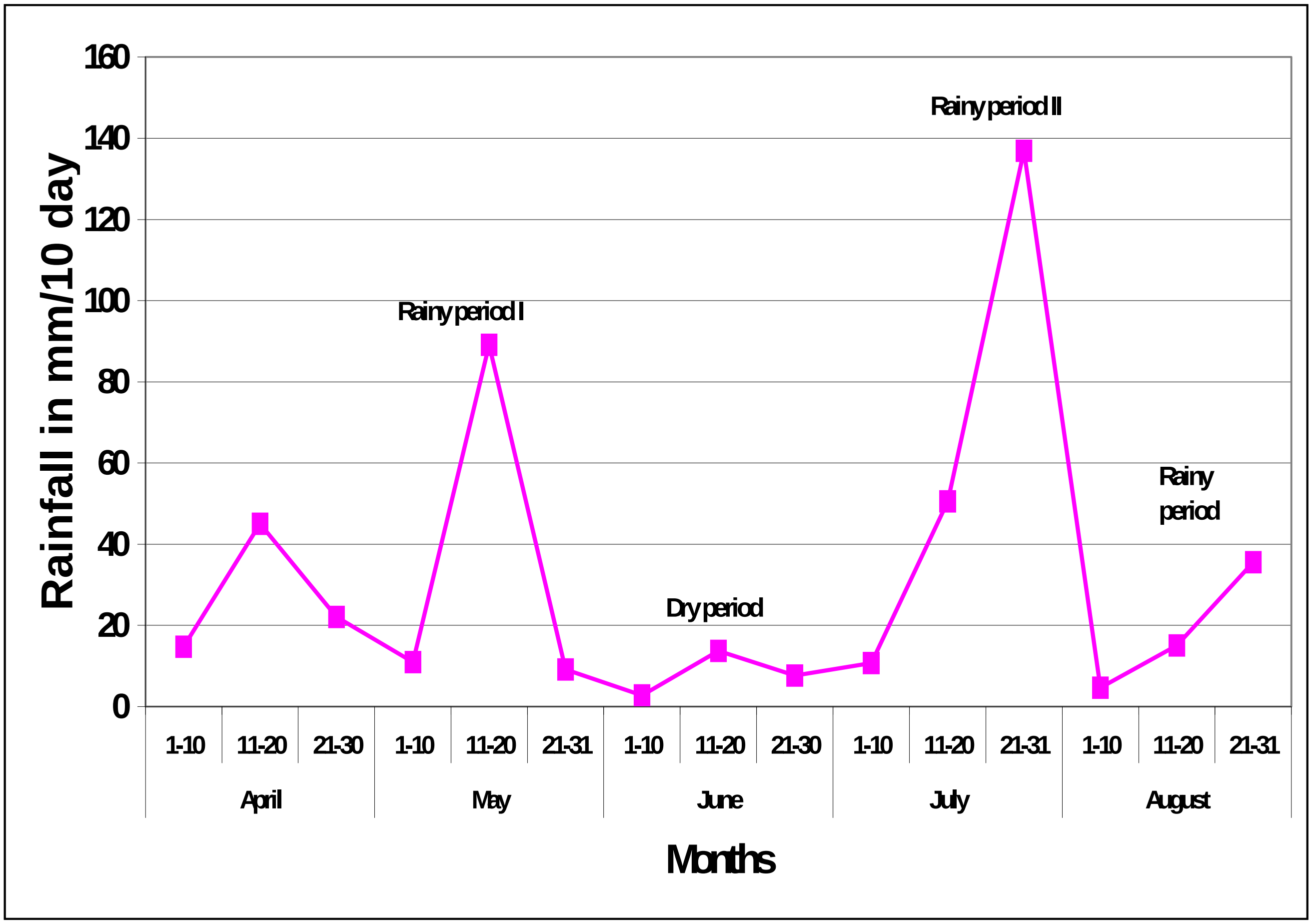


FIGURE 4-5. EFFECTS OF TREATMENTS ON CUCUMBER DRY WEIGHTS AT 54 DAYS (ON 27 JULY 1999) AFTER PLANTING[z]



[z] Conventional, Conv= Cucumber direct seeded in black plastic mulch laid on tilled bare ground, no habitat; RTDS = Cucumber direct seeded in black plastic mulch laid on rototilled rye/vetch residues, rye/vetch habitat; NTDS= Cucumber direct seeded into furrows in no-till rolled rye/vetch, rye/vetch habitat; NTTP= Cucumber transplanted into furrows in no-till rolled rye/vetch, rye/vetch habitat.

FIGURE 4-6. MEAN RAINFALL (MM/10 DAY PERIOD) BEFORE AND AFTER PLANTING CUCUMBERS, APRIL – AUGUST 1999



DISCUSSION

Rototilled rye/vetch had higher petiole sap nitrate-nitrogen concentration than conventional black plastic mulch at 26 days after planting. Some of the incorporated rye/vetch residues had decomposed at this time, which would release available nitrogen into the soil solution, resulting in higher uptake rates, and hence would explain the higher petiole sap nitrate concentration. Since the conventional treatment did not have incorporated vetch, petiole sap nitrate-nitrogen concentration in conventional plots was much lower than in rototilled rye/vetch plastic plots (Table 4-1, Figure 4-2). There was no difference between plastic and no-till treatments or between no-till direct seeded and transplants in 1998 during the same growth stage. The no-till plots at this stage also benefited from nutrients released from decomposing vetch mulch on the ground. Although the mineralized nitrogen quantities may be low (Smith et al., 1987), the plant uptake from the no-till system appeared to be similar to that from rye/vetch residues incorporated into the soil, as indicated by the absence of differences in petiole sap nitrate-nitrogen at this growth stage. These results contrast with results obtained by Schimel and Folpett (1989) who reported that due to low nitrogen mineralization in no-till plots, plants showed lower concentration of nitrogen in the leaves, particularly in early spring. Although an initial fertigation was done at 12 days after emergence for all treatments, no-till received only a quarter of the rate of plastic because of the nitrogen fixed by vetch, hence plastic benefited from greater mineral fertilization, but the effect of this one-time application was less than the effect of the slow release of nitrogen by decomposing vetch. Transplants came into the field initially at a more mature stage than direct seeded seedlings, but the effects on petiole sap nitrogen were influenced more by the presence of vetch in no-till plots than by plant age, as indicated by the absence of differences between these two treatments at this stage (Table 4-1 and Figure 4-2).

In 1999, at 36 and 47 days after planting there were no differences among treatments, although the sap concentration at 47 days after planting was only half that at 36 days after planting. At 36 days after planting, the plants were 10 days older than the ones sampled during the same date in 1998; hence, the roots were more established and able to tap adequate nitrogen from a larger area in the soil profile. This may explain the absence of a difference in petiole sap nitrate-nitrogen between treatments. At 47 days after planting, the petiole sap nitrate-nitrogen had declined by half again in all treatments, with no differences among treatments.

At 64 days after planting, the petiole sap nitrate-nitrogen concentrations had declined further, but no-till had higher petiole sap nitrate-nitrogen than plastic plots. At this stage, most of the rye/vetch mulch had been degraded, which released additional nutrients into the soil, leading to higher concentration of petiole sap nitrate-nitrogen than in plastic where the mature plants had exhausted the available soil nitrogen in the soil solution, with no other source for replenishment. This level was below the nitrogen sufficiency level at first harvest (Table 4-1, Figure 4-3; Spectrum Technologies Inc., 1997).

There were no differences in soil moisture tension between no-till and plastic plots from late June to first week of September 1999 on either a weekly or bi-weekly basis (Table 4-2, Figure 4-4). Irrigation was done when the soil moisture tension was above 25 kPa. In early June just before and at planting, there were low amounts of rainfall. At 54 days after planting, immediately following rainfall, soil moisture tension was low in no-till, through which water from rainfall could percolate, whereas it rose in the plastic plots, which were sealed, and did not benefit from the rainfall, and continued to be subject to transpiration. In contrast, at 84 days after planting (26 August) following irrigation, soil moisture tension in the plastic plots did drop to a level similar to that in no-till plots after rainfall. This indicates that most of the moisture needs of plants in no-till plots can be met by rainfall, whereas under plastic mulch monitoring is necessary even when rainfall occurs, because no water percolates into the soil in plastic plots (Figures 4-5 and 4-6; Table 4-2).

Both petiole sap nitrate-nitrogen and soil moisture tension monitoring are important in cucumber production systems. These results indicate that rye/vetch when incorporated into the soil leads to higher petiole sap nitrate-nitrogen than in conventional plasticulture on bare soil, and that the flush of available nitrogen occurs primarily between 26 and 36 days after planting, so that later on, the petiole sap nitrate-nitrogen concentration in no-till and plastic plots are almost the same. For these effects to be realized, in terms of plant growth and yield, adequate moisture must be available in the soil or else cucumbers may show pillowy disease symptom (Navazio and Staub, 1994); hence, soil moisture monitoring by tensiometer is very important. Sap nitrate-nitrogen becomes more limiting in both plastic and no-till plots later in the season as plants become larger and their demand for nitrogen increases, but these results suggest that decomposition of rye/vetch residues may supplement these requirements, hence the need for nitrogen fertilizer application through trickle irrigation will be less for no-till than for plasticulture. More of the water needs of no-till plots can be met through rainfall while plastic plots will be dependent on irrigation, hence no-till can save on irrigation, and monitoring after rainfall is less critical. In contrast, regular monitoring of soil moisture tension is essential at all times in plasticulture.

The no-till system had higher cumulative fresh market cucumber yields than black plastic mulch plots in both 1998 (Ogutu and Caldwell, 1999; Table 4-3) and 1999 (Table 4-3). The average cumulative yield of 26 $t.ha^{-1}$ (29 $t.ac^{-1}$) in the black plastic mulch system was 37% lower than 41 $t.ha^{-1}$ (46 $t.ac^{-1}$) in no-till plots in 1998. In 1999, the average cumulative yield of 38 $t.ha^{-1}$ (43 $t.ac^{-1}$) in black plastic system was 19% lower than 47 $t.ha^{-1}$ (53 $t.ac^{-1}$) in rye/vetch no-till systems. The average yields in both years 26 – 47 $t.ha^{-1}$ (29 - 53 $t.ac^{-1}$) in all systems were within the national range for fresh market cucumbers of 21 – 36 $t.ha^{-1}$ (Table 4-3; Maynard and Hochmuth, 1997).

In conclusion, black plastic mulch laid over rototilled (incorporated) rye/vetch residue led to increased early petiole sap nitrate-nitrogen readings, due to faster decomposition of residues and more nitrate released into the soil solution earlier than in no-till plots where the vetch was not incorporated into the soil. The faster earlier growth rate led to early flowering and yield (Ogutu and Caldwell, 1999; Unpublished data); hence, this system would have an advantage for early spring cucumber production. The no-till direct seeded system is good for later production, since decomposition of rye/vetch early in the season is slow. The no-till transplant system had low petiole sap nitrate-nitrogen readings earlier in the season. This stabilized later as the rye/vetch decomposed. No-till transplants are good for the early market also, since the plants mature earlier, but early supplemental nitrogen application is needed. The subsequent slow release of nitrogen from the mulch enable harvesting to be extended more than in plasticulture treatments, unless the latter is supplemented by additional fertigation. The measurement of petiole sap nitrate-nitrogen and soil moisture tension in cucumbers is critical in optimizing cucumber yields using different combinations of plastic, no-till and planting methods.

LITERATURE CITED

Aggelides, S., I. Assimakopoulus, P. Kerkides and A. Skondras. 1999. The effects of soil water potential on the nitrate content and the yield of lettuce. Communication in soil science and plant analysis. Monticello, N. Y. Marcel Dekker Inc. 30 (1/2): 235-243.

Blevins, R. L., D. Cook, S. H. Phillips and R. E. Phillips. 1971. Influence of no-tillage on soil moisture. Agronomy Journal. 63: 593-596.

Bonfil, D. J., I. Mufradi, S. Klitman and S. Asido. 1999. Wheat grain yield and soil profile water distribution in a no-till arid environment. Agronomy Journal. 91:368-373.

Christensen, N. B., W. C. Lindeman, E. Salazar-Sosa and L. R. Gill. 1994a. Nitrogen and carbon dynamics in no-till and stubble mulch tillage systems. Agronomy Journal. 86:298-303.

Christensen, N. B., T. L. Jones and G. J. Kauta. 1994b. Infiltration characteristics under no-till and clean till furrow irrigation. Soil Science Society of America Journal. 58:1495-1500.

Coltman, R. R. 1988. Yields of greenhouse tomatoes managed to maintain specific petiole sap nitrate levels. HortScience. 23: 148-151.

Eldredge, E.P., Z.A. Holmes, A.R. Mosley, C.C. Shock, and T.D. Stieber. 1996. Effects of transitory water stress on potato tuber stem-end reducing sugar and fry color. American Potato Journal. 73: 517-530.

Follett, R. F. and D. S. Schimel. 1989. Effect of tillage practices on microbial biomass dynamics. Soil Science Society of America Journal. 53:1091-1096.

Fortin, M. C. 1993. Soil temperature, soil water, and no-till corn development following in-row residue removal. Agronomy Journal. 85:571-576.

Hodnett, M. G., J. P. Bell, P. D. Ah Koon, G. C. Soopramanien, and C. H. Batchelor. 1990. The control of drip irrigation of sugarcane using 'index' tensiometers: Some comparisons with the control by the water budget method. Agricultural Water Management. 17:189-207.

Imtiyaz, M., N. P. Mgadla and S. K. Manase. 1999. Drip irrigation scheduling for cabbage under a semi-arid climate. Tropical Agriculture. 76(2): 99-103.

Janoudi, A. K., I. E. Widers, and J. A. Flore. Water deficits and environmental factors affect photosynthesis in leaves of cucumber (*Cucumis sativus*). Journal of the American Society for Horticultural Sciences. 118:366-370.

Kubota, A., T. L. Thompson, and T. A. Doerge. 1996. A petiole sap nitrate test for cauliflower. HortScience. 31: 934-937.

Kubota, A., T. L. Thompson, and T. A. Doerge. 1997. A petiole sap nitrate test for broccoli. Journal of Plant Nutrition. 20(6): 669-682.

Maynard, D. N. and G. J. Hochmuth. 1997. Knott's handbook for vegetable growers. Fourth edition. John Wiley and sons, New York.

Morse, R. D. 1999. No-till vegetable production – Its time is now. HortTechnology. 9(3): 373-379.

Navazio, J., P. and J. E. Staub. 1994. Effects of soil moisture, cultivar, and post harvest handling on pillowy fruit disorder in cucumber. Journal of the American Society of Horticultural Sciences. 119(6): 1234-1242.

O'Dell, C. R., S. A. Alexander, J. S. Caldwell, H. E. Holt, B. A. Nault and S. B. Sterrett. 2000. Commercial Vegetable Production Recommendations. Virginia Cooperative Extension. Publication No. 456-420.

Ogutu, M. O. and J. S. Caldwell. 1999. Stand differences in no-till and plasticulture direct seeded and transplanted cucumbers (*Cucumis sativus* L.). Acta Horticulturae. 504: 129-134.

Ogutu, M. O. and J.S. Caldwell. a. Densities of cucumber beetles their potential natural enemies and relationships with cucumber yield in conventional and rye/vetch strip cropped cucumber production systems. I. Above ground insects. Unpublished.

Ogutu, M. O. and J. S. Caldwell. b. Densities of cucumber beetles and their potential natural enemies in conventional and rye/vetch strip cropped cucumber production systems. II. Ground insects. Unpublished.

Paramasivam, S., A. K. Alva and A. Fares. 2000. An evaluation of soil water status using tensiometers in a sandy soil profile under citrus production. Soil Science. 165(4): 343-353.

Rutledge, A. D. 1999. Experience with conservation tillage vegetables in Tennessee. HortTechnology. 9(3): 366-372.

Serce, S., J. P. Navazio, A. F. Gocke, and J. E. Staub. 1999. Nearly isogenic cucumber genotypes differing in leaf size and plant habit exhibit differential response to water stress. Journal of the American Society for Horticultural Sciences. 124(4):358-365.

SAS Institute. 1997. SAS/STAT user's guide 4th Edition. Version 6.12. SAS Institute, Cary, North Carolina.

Shelton, D. R., A. M. Sadeghi, and G. W. McCarty. 2000. Effect of soil water content on denitrification during cover crop decomposition. Soil science. 165(4): 365-371.

Shock, C. C., E. B. G. Feibert, and L. D. Saunders. 2000. Irrigation criteria for drip-irrigated onions. HortScience. 35:63-66.

Smith, M. S., W. W. Frye, and J. J. Varco. 1987. Legume winter cover crops. Advances in Soil Science. 7:95-139.

Spectrum Technologies Inc. 1997. Cardy Sap Nitrate-nitrogen Meter User Manual. Spectrum Technologies Inc., Plainfield, Illinois. Website: http://www.specmeters.com

Tyler, D. D., M. D. Mullen, and B. N. Duck. 1994. Soil management research in Tennessee. Tennessee Farm Home Science. 172:10-13.

CHAPTER 5

ECONOMIC ANALYSIS OF PLASTICULTURE AND RYE/VETCH NO-TILL DIRECT SEEDED AND TRANSPLANTED FRESH MARKET CUCUMBER PRODUCTION SYSTEMS

ABSTRACT

Economic analysis of four cucumber production systems was conducted based on physical yield data, production costs and five-year average market prices for five terminal markets on the Eastern seaboard. The production systems were conventional plasticulture with cucumbers direct seeded, rye/vetch cover crop flail mowed and incorporated into the soil with cucumbers direct seeded, rye/vetch cover crop rolled with cucumbers no-till direct seeded, and rye/vetch cover crop rolled and cucumbers no-till transplanted. All the systems had rye/vetch habitat for beneficial insects except the conventional.

Results indicate that production costs were highest for the conventional system and least for the no-till direct seeded system. Transplants and plastic systems can generate higher net revenues than the other two systems during the July market period while no-till direct seeded and no-till transplants generate higher net revenues from August to the end of the season. For the whole season, no-till direct seeded system generated higher net revenues than the other systems. The Atlanta market generated the highest revenue, followed by the Baltimore market in the 1-15 August marketing period in both years.

Key words: Terminal markets, net revenue

INTRODUCTION

Black plastic mulch is the most commonly used fresh market cucumber production system in Virginia (O'Dell et al., 2000a) and other states such as North Carolina, South Carolina, Florida and Texas (Swiader et al., 1996). The ground is first tilled in early spring, harrowed into a fine seedbed, pre-planting weed and insect pest control chemicals applied, and then a tractor used to laid black plastic mulch in strips with drip irrigation tubes underneath. In addition to land preparation, recommended pesticide (for control of insect pests, diseases and weeds) and fertilizer (for adequate plant nutrition) application programs are routinely followed (O'Dell et al., 2000a). Black plastic mulch is used for weed control and warming of the soil in early spring when temperatures are still low (Teasdale and Abdul-Baki, 1995). This production system is popular among farmers due to its large reduction in labor requirements (Robert and Swinton, 1996).

In recent years, however, increasing consumer awareness about the side effects of pesticide residues on human health and the environment has led to searches for alternative production systems. Alternative systems are desirable because of their potential to reduce contamination of surface or ground water, decrease pesticide residue on marketed products, and contribute to maintaining soil tilth. However, these systems may require more knowledgeable managers and more labor. Sometimes they are developed specifically to solve a particular problem, for example reduction of soil erosion in medium textured soils (Fleming et al., 1997). Other times they are developed for crop specific situations such as potato production where higher net revenues were realized with alternative systems than with conventional systems (Gallandt et al., 1998).

Exploiting niche markets is an important factor leading to the development of alternative systems (Munn, 1998). However, several studies summarized by Govindasamy and Italia (1999) have shown that most consumers are not aware of alternative production systems using Integrated Pest Management (IPM) practices in crop production. The public needs to be educated about the benefits of IPM by state and marketing agencies. This information dissemination could help in expanding the market and also enabling consumers to understand why it can be necessary under some circumstances to pay premium prices for such products (Govindasamy and Italia, 1999).

Premium prices and returns vary with products. For example, for organically produced apples, farm gate prices are 33-38% higher than prices for conventionally produced apples and are adequate for profitable economic returns. However, if prices offered are the same as for conventional products, then returns are low (Swezey, et al., 1998). The additional cost associated with production of commodities using alternative practice can make them more expensive for consumers than conventionally grown produce; hence, it is important to explore what premium consumers attach to organically produced crops. In an attempt to answer such questions, Kuchler et al. (2000) reported that health (cancer) risk is one of the major factors driving consumers away from conventionally grown produce. If environmental benefits are explained to consumers in addition to benefits for human health, then this group of concerned consumers could form a market niche strong enough to sustain organic producers.

In the absence of niche markets and premium prices, alternative production systems must compete on the basis of higher productivity and/or lower production costs. Assessment of their economic viability is critical to determine if and when they can be competitive even without premium prices. Even in non-differentiated wholesale markets, prices vary over time and location. Because of effects on crop growth of differing practices, alternative systems may be more productive in different time periods than conventional systems. Combination of these three factors, market period, market location, and period of greater productivity, may affect the relative competitiveness of conventional and alternative systems.

Several alternative production systems have been tested in vegetable production (vetch residue- tomatoes – Kelley et al., 1995; Abdul-Baki and Teasdale, 1997 and no-till rye/vetch – cucumbers- Amirault and Caldwell, 1998; Ogutu and Caldwell, 1999), but even when comparable or higher physical yields relative to conventional systems were achieved, the economic viability of the alternative systems was not evaluated.

The objectives of this study are to identify: which period of the harvest season would be most profitable for cucumbers production using alternative practices in five terminal markets based on wholesale prices without a premium for organic practices; whether alternative production systems should target specific terminal markets; and which system is more economically viable overall. For this purpose, net revenues from four cucumber production systems are compared based on their yields and variable production costs (O'Dell et al., 1994; Sterret et al., 1996) from fresh cucumber crop budgets for Virginia and terminal market information.

MATERIALS AND METHODS

Experimental design and treatment establishment

Rye/vetch was planted in plots located at the Kentland research farm, Blacksburg, Virginia, in all treatments on 1 October 1997 and 14 October 1998 except the conventional, in which only rye was planted. The soil type is a Shottower silty loam where potatoes were planted the previous year. Cucumber cultivar Dasher II was direct seeded on 13 June 1998 and 3 June 1999. Transplants were seeded in the greenhouse on 21 May 1998 and 1999 and transplanted into the field one week after direct seeding in both years. Spacing was 0.3 m (1 foot) by 0.225 m (9 inches). The experiment was designed as a Randomized Complete Block Design with four main plot treatments and two subplot treatments comparing weed control methods for plots with rye/vetch, and replicated four times (Ogutu and Caldwell, 1999). The four main plot treatments were:

1. Conventional - Rye only in the entire plot, flail mowed in early May 1998 and 1999, residues removed from the plots, and the ground tilled. Black plastic mulch laid over the tilled areas with bare ground between plastic strips. Cucumber direct seeded in twin rows. Virginia recommended pesticide applications four times in each year in 1998 and 1999 to control insect pests, diseases, and weeds between plastic strips (O'Dell et al., 2000a).
2. RTDS – Rye/vetch flail-mowed in strips in late May 1998 and 1999, and residues incorporated into the soil. Black plastic mulch laid over the tilled areas with rye/vetch habitat left between the plastic strips (Ogutu and Caldwell, 2000). Cucumber direct seeded in twin rows by hand into holes in the plastic mulch. No insecticide or fungicide applied; pre-emergence herbicides applied three days after seeding in the area between the black plastic strips and the habitat in one half of each plot. Critical manual weeding done in the area between black plastic strips in the other half at twenty-one days after planting.
3. NTDS – Rye/vetch rolled in strips in late May 1998 and 1999, twin rows made by no-till planter. Rye/vetch mulch in rolled strips and undisturbed rye/vetch habitat between strips. Cucumber direct seeded in twin rows using precision planter. No insecticide or fungicide applied; pre-emergence herbicides applied three days after direct seeding in the rolled area between the cucumber rows and the habitat in one half of each plot. Critical manual weeding done in the area between the cucumber rows and the habitat in the other half at twenty-one days after direct seeding.

4. NTTP – Rye/vetch rolled in strips in late May 1998 and 1999, twin rows made by no-till planter. Rye/vetch mulch in rolled strips and undisturbed rye/vetch habitat between strips. Cucumber seedlings seeded in the greenhouse four weeks earlier manually transplanted one week after direct seeding (just as cucumbers were emerging in direct seeded plots, so all the treatments would be exposed to pest insects at the same time, to assess the effects of habitats on beneficial and pest insects). Pre-emergence herbicide applied four days before transplanting in the area between cucumber rows and the habitat in one half of each plot. Critical manual weeding was done in the area between the cucumber rows and the habitat in the other half fourteen days after transplanting.

Cucumber fruits were harvested twice a week from 22 July to 10 September 1998 and 22 July to 13 September 1999, respectively, in the middle strip of each half plot 0.90 m (3 feet) from the edges and 3.15 m (10.5 feet) into the strip. Cucumber fruits were graded according to USDA standards as Fancy, US No.1, US No. 2, and Culls (USDA, 1958) and then weighed. The first three grades were combined and categorized as medium grade marketable yield. This is the grade for fresh market cucumbers sold in terminal markets. The analysis of physical yield data for both years indicated no difference between herbicide and critical manual weed control methods, hence the conversion of yield data into revenue is reported for the four main plot treatments only.

Economic analysis

Net revenue was calculated based on fresh market cucumber production budgets for Virginia (O' Dell et al., 1994; O'Dell et al., 2000b) for 1998 and 1999, with adjustments for labor and pesticide inputs that varied among the different treatments. Production costs for each treatment were calculated based on variable costs (O'Dell et al., 1994; O'Dell et al., 2000b). Terminal market prices for the previous five years (Market Information Systems, University of Florida website, 2000) for five markets where Virginia medium grade fresh cucumbers were sold during the harvesting period of the experimental data were selected. These markets were: Atlanta, GA; Baltimore, MD; Columbia, SC; New York City, NY; and Philadelphia, PA. These markets are within a radius of 500 miles from the nearest regional wholesale farmers' market (Hillsville, Virginia). The distances between Hillsville and these markets were calculated using the National

Geographic Trip Planner Deluxe software (TLC, Multimedia Inc., One Athenaeum street, Cambridge, MA 02142). The daily average prices for 11/9 cartons (50 lbs) fresh market cucumbers from 22 July to 15 September (1994-1999) for each of the five markets were used to calculate weekly average prices. The average yield per hectare for each harvest was converted to 11/9 cartons and multiplied by the average price over five years for that week of harvest to get total revenue for each treatment at each harvest. These values were summed over each bi-weekly period based on the results of analysis of the physical yield data (Ogutu and Caldwell, 1999; Ogutu and Caldwell, 2000). The price at the regional wholesale farmers' market was calculated by deducting from the terminal market average price a 20% brokerage fee and average transportation costs to the terminal market at $ 1.30 per mile for an 850-carton loaded truck. The net revenue per carton was calculated by deducting the production cost per carton from the price at the regional wholesale farmers' market.

Statistical analysis

The projected net revenue from each of the five terminal markets was analyzed using analysis of variance in PROC GLM (SAS Institute, 1997). The total net revenues for the terminal markets were used as response variables, while replicate, treatment, harvest time (month and date), replicate*treatment (error for split plot in time), and treatment*harvest time were used as independent variables. Three single-degree-of-freedom contrasts were made to determine the effects of treatments (systems) on net revenue in the five terminal markets as follows: black plastic vs. no-till systems; black plastic with rye/vetch habitats vs. black plastic without habitats; and no-till direct seeded vs. no-till transplants.

RESULTS

The average production cost per carton was highest in the conventional system, followed by RTDS and NTTP, and lowest in NTDS (Tables 5-1). Transport costs were lower to nearer terminal markets, and brokers' fees were higher when terminal market prices were higher (Table 5-2). Hence, transport costs and brokerage fees, in addition to production costs determined the net revenue from each system.

The weekly average terminal market prices per carton for medium grade fresh cucumbers from 1994 to 1999 varied during the harvest periods of the experiments, 15 July - 15 September. The weekly market prices in each market rose and fell independently of one another. The weekly prices in Atlanta terminal market were always higher regardless of period. Weekly market price trends in the four other terminal markets were generally similar. Baltimore had higher prices in the 16-23 August marketing period (in the middle), and the 1-15 September period (at the end) than the other three markets, while New York had the advantage in the 16-23 July period (at the beginning). Prices at the Columbia market were the lowest (in six out of eight weeks) among the five the terminal markets (Figure 5-1).

Cumulative net revenue was higher in no-till than black plastic systems in all terminal markets, with the highest net revenue in Atlanta and the lowest in Columbia in both years. There were no differences in net revenue between black plastic mulch with habitats and black plastic mulch without habitats in 1998. In contrast, in 1999, higher cumulative net revenue in black plastic mulch with habitats was found in four of the five markets (Baltimore, Columbia, New York, and Philadelphia). The no-till direct seeded system had higher net revenue than no-till transplants in the Columbia and Baltimore terminal markets in 1998, but similar trends in these two markets in 1999. There were no differences between the two no-till systems in the New York and Philadelphia terminal markets in either year (Figures 5-2 and 5-3; Table 5-3).

In both years, net revenue was higher in no-till than in black plastic systems during the first three marketing periods, 16-31 July, 1-15 August, and 16-31 August in all terminal markets, and it was also higher in the 1-15 September period in Atlanta. In 1998, net revenue in the no-till system was highest in Atlanta during the 16-31 August period and lowest in Columbia during the 1-15 September period. The highest net revenue for the black plastic mulch system was during 1-15 August period, while the lowest net revenue for this system was in New York during the 1-15 September period [Figures 5-4(a-e) and Table 5-4]. In 1999, net revenue in the no-till system was highest in Atlanta during the 16-31 August period, the same market and period as in 1998, while the lowest net revenue for this system was in Baltimore in the 16-31 July period, which was different from 1998 results. Net revenue in the black plastic mulch system was highest in

Atlanta during 16-31 August period and the lowest in Philadelphia during the 1-15 September period [Figures 5-5(a-e) and Table 5-5].

Net revenue was higher in black plastic with habitats than in black plastic without habitats earlier in the season in both years, but there were variations in the specific markets and periods between the two years. In 1998, black plastic with habitats had higher net revenue in all terminal markets during the 16-31 July and 1-15 August periods. During the 16-31 August period, the black plastic system with habitats had higher net revenue than black plastic without habitats in the Columbia terminal market, while in the Atlanta terminal market, during the same period black plastic without habitats had higher net revenues than black plastic mulch with habitats. The highest net revenue in black plastic mulch with habitats was in the 16-31 July period in the Atlanta market, while the lowest was in the 1-15 September period in New York. The highest net revenue in black plastic mulch without habitats was in the 16-31 August period in Atlanta and the lowest was in the 1-15 September period in Philadelphia [Figures 5-4(a-e) and Table 5-4]. In 1999, black plastic mulch with habitats had higher net revenue than black plastic mulch without habitats in all markets during the 1-15 August period. It also had higher net revenues in the Columbia and Baltimore terminal markets in the 16-31 July period, and in Atlanta and Columbia in the 16-31 August period. The highest net revenue in the black plastic mulch system with habitats was in Atlanta in the 1-15 August period and the lowest in Philadelphia in the 1-15 September period. The highest net revenue in the black plastic mulch without habitats was in Atlanta in the 1-15 August period, and the lowest was in Baltimore in the 16-31 July period [Figures 5-5(a-e) and Table 5-5].

The no-till planting system with higher net revenue was reversed in the two August market periods in 1998 and 1999. In both years, net revenue for no-till transplanted was higher than no-till direct seeded during the 16-31 July period. However, in 1998, no-till direct seeded was higher than no-till transplanted during the 1-15 August period (except in Philadelphia) and the 16-31 August period in all markets. The highest net revenue for no-till transplanted was in Atlanta during the 16-31 July period and lowest in Columbia during the 1-15 September period, while no-till direct seeded net revenue was highest in Atlanta during the 16-31 August period and lowest in Columbia during the 16-31 July period [Figures 5-4(a-e), and Table 5-4]. In 1999, in contrast with 1998, no-till transplanted continued to have higher net revenue than no-till direct seeded during the periods 1-15 August (except in Atlanta and Philadelphia), and 16-31 August in all terminal markets. The highest net revenue in no-till transplanted was in Atlanta during the 1-15 August period and the lowest was in Philadelphia during the 1-15 September period, while the highest net revenue in no-till direct seeded was in Atlanta during the 16-31 August period and the lowest in Columbia during the 1-15 July period [Figures 5-5(a-e) and Table 5-5].

Overall, across all treatments, average net revenue was highest in the Atlanta terminal market during all four marketing periods, followed by Baltimore in all marketing periods except the first, from 1-15 August through 1-15 September, in both years (Figures 5-4f and 5-5f).

TABLE 5-1. AVERAGE PRODUCTION COSTS PER CARTON FOR MEDIUM GRADE FRESH MARKET CUCUMBERS, 1998 AND 1999 ASSUMING A 300 CARTON PER ACRE YIELD

Variable Costs		Costs per acre ($ ac^{-1}) in each production system[a]							
			Conventional		RTDS		NTDS		NTTP
Items	Units	Quant.	Cost ($)	Quant.	Cost ($)	Quant.	Cost ($)	Quant.	Cost ($)
Seeds - Rye	BUSHEL	2	$ 18.00	1	$ 9.00	1	$ 9.00	1	$ 9.00
- Vetch	BUSHEL	0	$ -	1	$ 28.80	1	$ 28.80	1	$ 28.80
- Cucumber Dasher II F1	LB	2	$ 116.00	2	$ 116.00	2	$ 116.00	1.5	$ 87.00
Plastic Trays	PIECES	0	$ -	0	$ -	0	$ -	17	$ 55.93
Black plastic mulch	ROLLS	4	$ 200.00	4	$ 200.00	0	$ -	0	$ -
Tractor time - Laying plastic	HOURS	4	$ 15.24	4	$ 15.24	0	$ -	0	$ -
Plow	HOURS	1	$ 4.47	0	$ -	0	$ -	0	$ -
Disc	HOURS	0.5	$ 2.34	0	$ -	0	$ -	0	$ -
Harrow	HOURS	0.3	$ 0.99	0	$ -	0	$ -	0	$ -
Sprayer	HOURS	1	$ 4.01	0	$ -	0	$ -	0	$ -
Mist Blower	HOURS	8	$ 6.00	0	$ -	0	$ -	0	$ -
Rolling	HOURS	0	$ -	0	$ -	1	$ 5.00	1	$ 5.00
Rototilling	HOURS	0	$ -	1	$ 4.47	0	$ -	0	$ -
Flail mowing	HOURS	0	$ -	0.3	$ 3.06	0	$ -	0	$ -
Slitting mulch	HOURS	0	$ -	0	$ -	2	$ 12.62	2	$ 12.62
Pick-up Truck	HOURS	18	$ 69.30	18	$ 69.30	18	$ 69.30	18	$ 69.30
Irrigation @ 16%	$$	$2,294.00	$ 367.00	$2,294.00	$ 367.00	$2,294.00	$ 367.00	$2,294.00	$ 367.00
Marketing: Boxes (1 1/9 BU)	CARTONS	300	$ 405.00	300	$ 405.00	300	$ 405.00	300	$ 405.00
Hauling, Grading, Cooling	BOX	300	$ 450.00	300	$ 450.00	300	$ 450.00	300	$ 450.00
Labor - Greenhouse work	HOURS	0	$ -	0	$ -	0	$ -	10	$ 70.00
Punching holes	HOURS	15	$ 105.00	15	$ 105.00	0	$ -	0	$ -
Seeding in field	HOURS	20	$ 140.00	20	$ 140.00	12.5	$ 87.50	0	$ -
Transplanting	HOURS	0	$ -	0	$ -	0	$ -	22	$ 154.00
Tillage	HOURS	15	$ 105.00	2	$ 14.00	0	$ -	0	$ -
Critical weeding	HOURS	0	$ -	10	$ 70.00	35	$ 245.00	21.5	$ 150.50
Pesticides - Asana XL	GAL	1	$ 118.00	0	$ -		$ -	0	$ -
Fungicides - Bravo 720	GAL	0.38	$ 21.27	0	$ -	0	$ -	0	$ -
Herbicides - Curbit 4E	GAL	0.3	$ 18.00	0	$ -	0	$ -	0	$ -
- Command	GAL	0.3	$ 21.83	0	$ -	0	$ -	0	$ -
Operating interest @ 7.5%		$749.00	$ 56.18	$749.00	$ 56.18	$749.00	$ 56.18	$749.00	$ 56.18
Total Operating Cost			**$ 2,243.63**		**$ 2,053.05**		**$ 1,851.40**		**$ 1,920.33**
Production Cost per carton			$ 7.48		$ 6.84		$ 6.17		$ 6.40

[a] - 1 hectare = 2.47 acres; Adapted from O'Dell et al., 1994.

Table 5-2. Average marketing costs per carton to five terminal markets from the Hillsville, Virginia regional wholesale farmers' market, [z] 1999

Terminal Markets	Avg. Price ($/ carton)	Brokerage Fee ($/carton[y])	Distance (mi) from Hillsville	Transport cost ($/carton[x])	Total cost[w] $/carton
Atlanta	13.00	2.60	353	0.54	3.14
Baltimore	10.40	2.10	353	0.54	2.64
Columbia	9.30	1.90	205	0.31	2.21
New York	10.80	2.20	535	0.82	3.02
Philadelphia	10.50	2.10	452	0.69	2.79

[z] based on 850 cartons per truckload
[y] calculated at 20% of average price / carton
[x] calculated at $ 1.30 / mile
[w] brokerage fee + transport cost

TABLE 5-3. SUMMARY OF THE EFFECTS OF PLASTIC, NO-TILL RYE/VETCH AND HABITAT ON THE CUMULATIVE NET REVENUE FROM FOUR PRODUCTION SYSTEMS FOR MEDIUM GRADE FRESH MARKET CUCUMBERS IN 1998 AND 1999 BY TERMINAL MARKET

Terminal markets	Effect of production systems on cumulative net revenue per hectare					
	Black plastic mulch vs. no-till[z,y]		Black plastic mulch with vs. without habitat [z,x]		No-till direct seeded vs. transplanted [z]	
	1998	1999	1998	1999	1998	1999
Atlanta	**	**	NS	NS	NS	NS
Baltimore	**	**	NS	*	**	NS
Columbia	**	**	NS	**	*	NS
New York	**	**	NS	*	NS	NS
Philadelphia	**	**	NS	**	NS	NS

[z] Differences between systems highly significant at p< 0.01 (**); significant at 0.05 <p< 0.01 (*); or not significant at p >= 0.05 ([NS]);

[y] Black plastic mulch = Conventional and RTDS; No-till = NTDS and NTTP; Conventional, RTDS, NTDS and NTTP as described in Table 1 above .

[x] Plastic with habitat = RTDS; Plastic without habitat = Conventional.

TABLE 5-4. MEAN NET REVENUES EXPECTED FROM FOUR PRODUCTION SYSTEMS BY SELLING AT THE TERMINAL MARKETS FOR FOUR HARVEST PERIODS FROM 22 JULY – 10 SEPTEMBER 1998.

		Expected net revenue per hectare in each production system[z,y]					
Harvest Period	Terminal Markets	Plastic	No-till	Conv.	RTDS	NTDS	NTTP
July	Atlanta	674	1152**	120	1107**	485	1819**
	Baltimore	111	254**	-4	218**	175	333**
	Columbia	86	322**	-13	185**	160	483**
	New York	192	574**	10	373**	224	923**
	Philadelphia	159	411**	6	311**	206	616**
1-15 Aug	Atlanta	887	1753**	748	1026**	1944**	1561
	Baltimore	273	754**	140	405**	950**	557
	Columbia	62	585**	-72	195**	699**	471
	New York	132	606**	-35	228**	715**	497
	Philadelphia	48	522**	-81	177**	621	422
16-31 Aug	Atlanta	868	1912**	1005**	730	2560**	1264
	Baltimore	471	1488**	472	469	1846**	1129
	Columbia	77	880**	-43	197**	1122**	638
	New York	123	832**	43	202	1116**	547
	Philadelphia	111	886**	25	197	1124**	648
1-15 Sept	Atlanta	399	734**	446	352	845	622
	Baltimore	225	473	235	214	545	401
	Columbia	23	217	-17	62	268	166
	New York	9	244	-1	19	301	186
	Philadelphia	40	226	6	73	180	272

[z] - Conv. = Conventional system; Plastic systems = Conventional and RTDS; No-till systems = NTDS and NTTP; Plastic with habitat = RTDS; Plastic without habitat = Conventional; Conventional, RTDS, NTDS and NTTP as described in Table 1 above.

[y] ** - Significant at p< 0.01; * - Significant at 0.05 <p< 0.01; NS – Not significant at p >= 0.05, for each pair of single-degree-of-freedom contrast comparisons (plastic vs. no-till, conv. vs. RTDS, NTDS vs. NTTP) for a given harvest period and terminal market.

TABLE 5-5. MEAN NET REVENUE EXPECTED FROM EACH PRODUCTION SYSTEM BY SELLING AT THE TERMINAL MARKETS FOR THE FOUR HARVEST PERIODS FROM 22 JULY – 13 SEPTEMBER 1999

Harvest Period	Terminal Markets	Expected net revenue per hectare for each production system [z,y] Plastic	No-till	Conv.	RTDS	NTDS	NTTP
July	Atlanta	843	963	996	689	172	1754**
	Baltimore	113	241**	-45	180**	69	413**
	Columbia	73	301**	1	144**	62	540**
	New York	258	506**	274	242	81	931**
	Philadelphia	170	371**	116	223	78	663**
1-15 Aug	Atlanta	1685	2302**	1486	1883**	2281	2322
	Baltimore	601	1204**	413	789**	1230	1177**
	Columbia	242	821**	45	439**	857	785**
	New York	292	889**	105	479**	928	849**
	Philadelphia	202	805**	21	383**	850	759
16-31 Aug	.Atlanta	544	2445**	716	1083**	2806	2083**
	Baltimore	544	1758**	384	704	2040	1476**
	Columbia	231	1039**	107	355**	1230	848**
	New York	233	1083**	112	354	1290	875**
	Philadelphia	198	1077**	72	323	1290	864**
1-15 Sept	Atlanta	239	1285**	175	303	1559	1011
	Baltimore	137	791	99	175	959	623
	Columbia	39	428	9	68	542	314
	New York	49	495	15	83	626	363
	Philadelphia	41	400	17	65	499	300

[z] - Conv. = Conventional system; Plastic systems = Conventional and RTDS; No-till systems = NTDS and NTTP; Plastic with habitat = RTDS; Plastic without habitat = Conventional; Conventional, RTDS, NTDS and NTTP as described in Table 1 above.

[y] ** - Significant at $p < 0.01$; * - Significant at $0.05 < p < 0.01$; [NS] – Not significant at $p >= 0.05$, for each pair of single-degree-of-freedom contrast comparisons (plastic vs. no-till, conv. vs. RTDS, NTDS vs. NTTP) for a given harvest period and terminal market.

FIGURE 5-1. FIVE YEAR (1994-1999) AVERAGE WEEKLY TERMINAL MARKET PRICES FOR 1 1/9 CARTONS OF MEDIUM GRADE FRESH MARKET CUCUMBERS

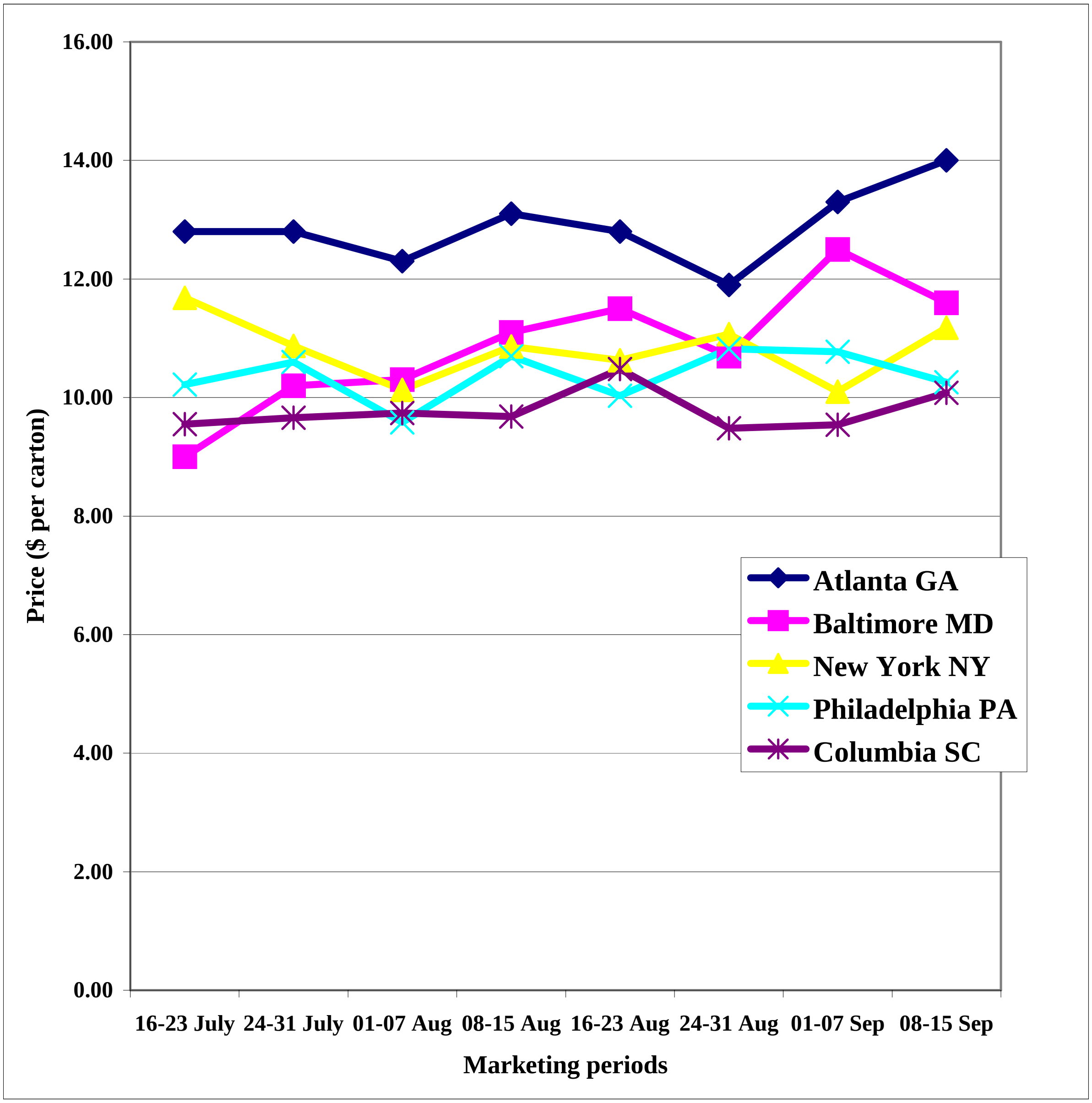


FIGURE 5-2. EFFECTS OF FOUR PRODUCTION SYSTEMS ON CUMULATIVE NET REVENUES PER HECTARE FROM FIVE TERMINAL MARKETS, 1998

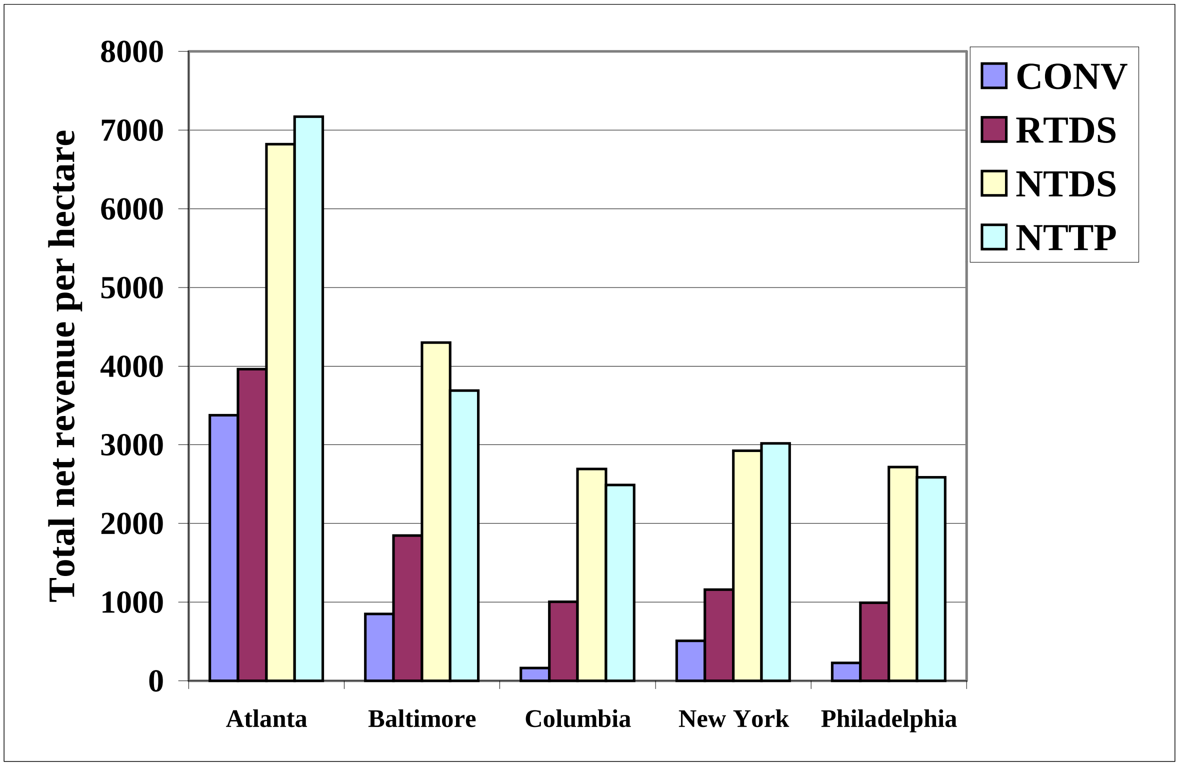


FIGURE 5-3. EFFECTS OF FOUR PRODUCTION SYSTEMS ON CUMULATIVE NET REVENUES PER HECTARE FROM FIVE TERMINAL MARKETS, 1999

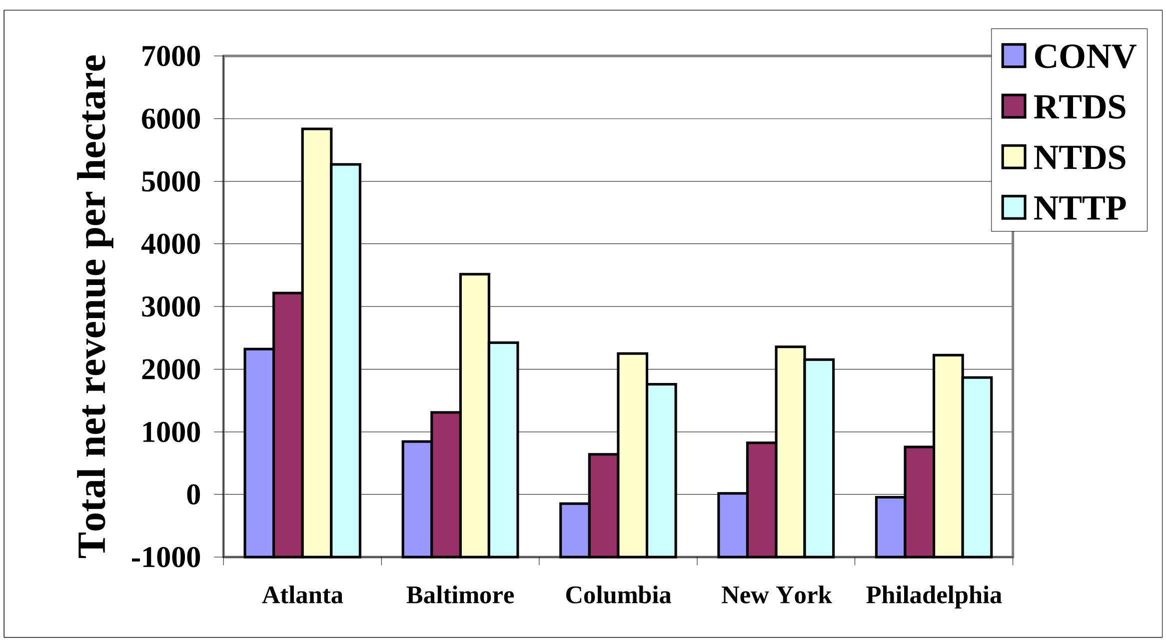


FIGURE 5-4. EFFECTS OF FOUR PRODUCTION SYSTEMS ON NET REVENUES PER HECTARE FROM FIVE TERMINAL MARKETS, 1998

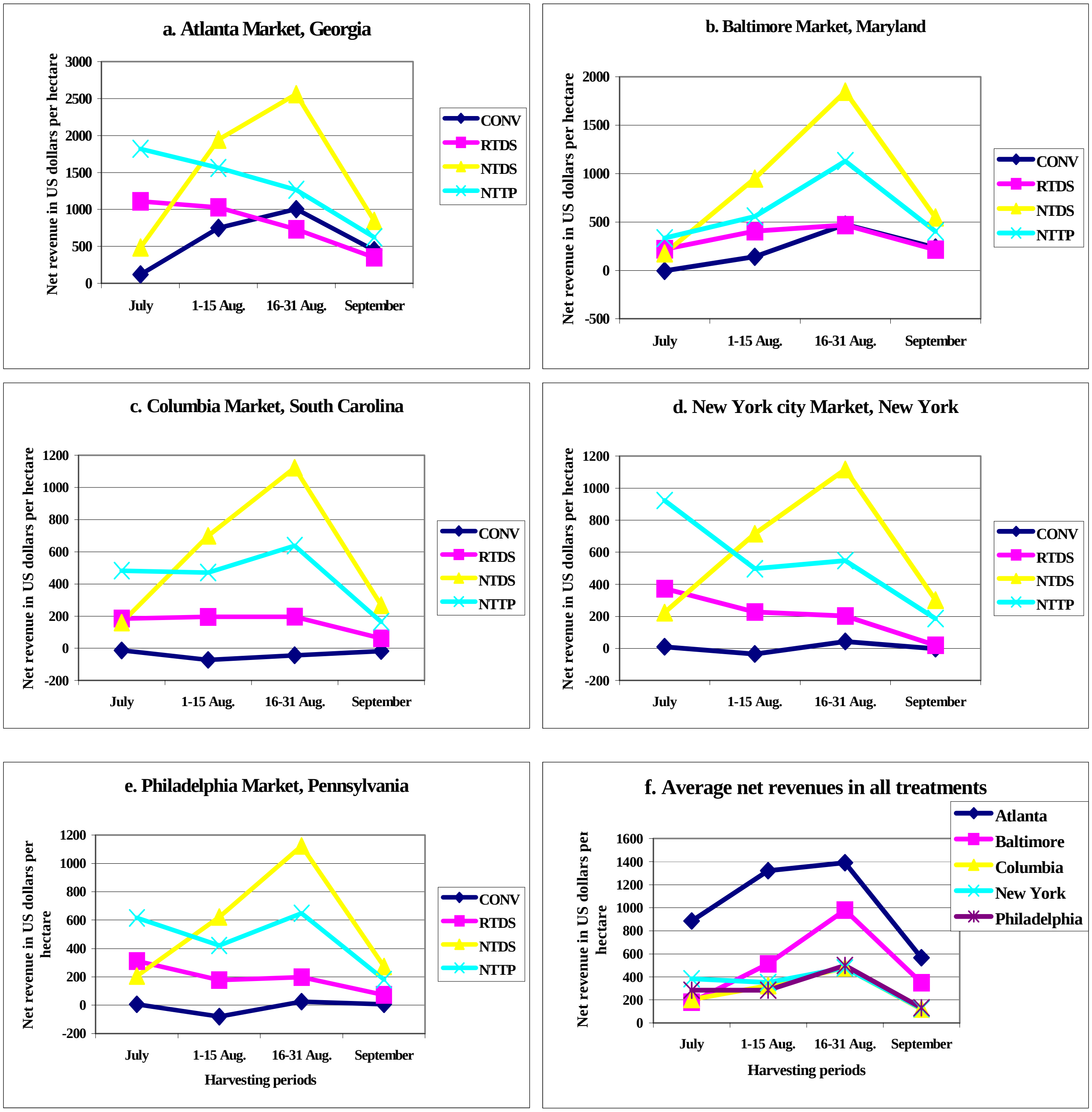
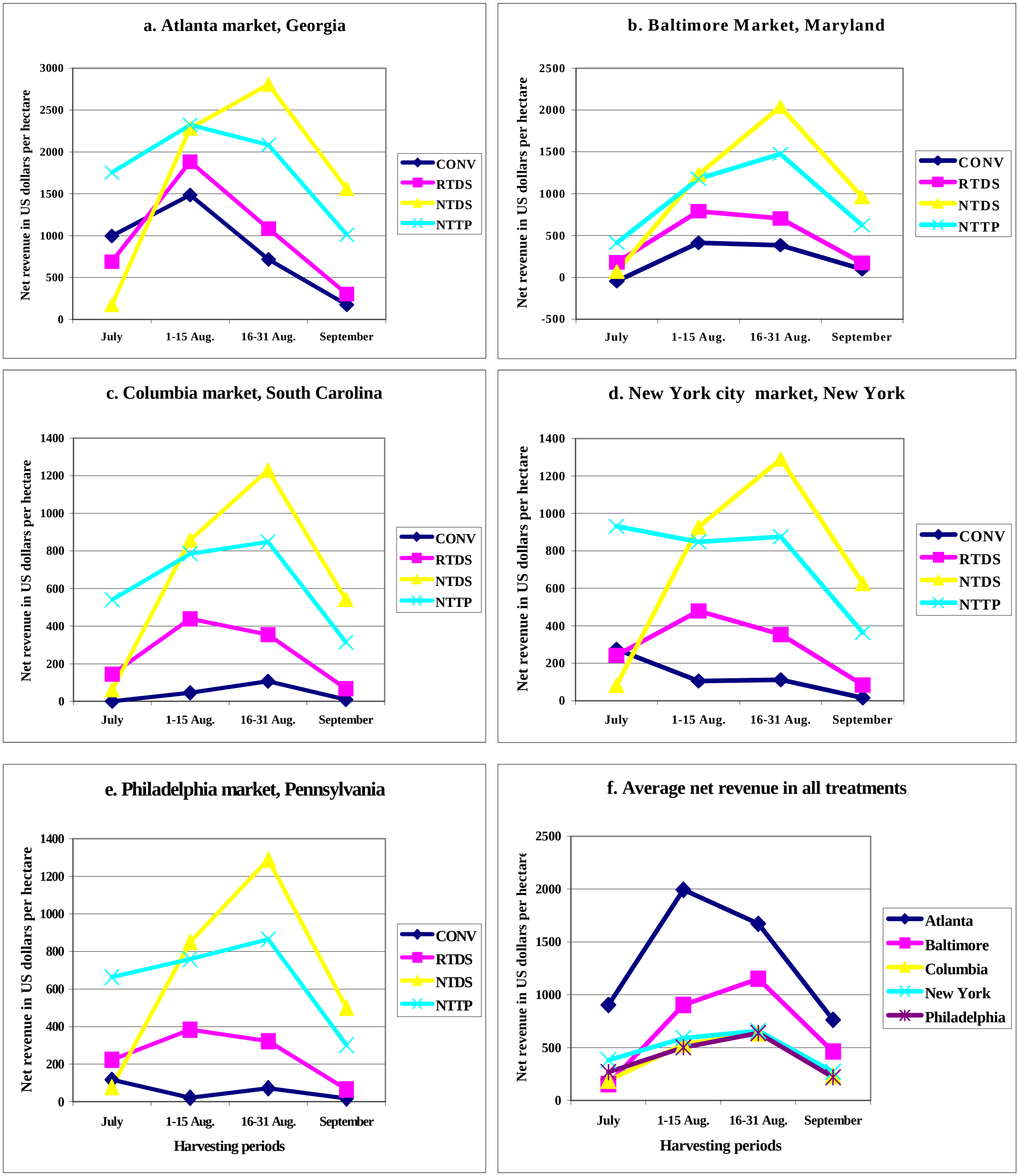


FIGURE 5-5. EFFECTS OF FOUR PRODUCTION SYSTEMS ON NET REVENUES PER HECTARE FROM FIVE TERMINAL MARKETS, 1999



DISCUSSION

Variable production costs for the conventional system using black plastic mulch without habitats were higher than in the no-till systems because of the cost of purchased inputs including black plastic mulch, insecticides and herbicides. The intermediate system using black plastic mulch with habitats was also more expensive than the no-till systems, because of the cost of purchased black plastic mulch. In the no-till systems, no-till transplanted was more expensive than no-till direct seeded because of the costs of plastic flats for seeding and labor for watering cucumber seedlings in the greenhouse (Table 5-1).

The above system comparisons are based on variable costs (O' Dell, 1994). The average cost of labor over the two years in the no-till system is \$ 873 ha^{-1} (\$ 353 ac^{-1}). This labor cost was more than the labor cost in the conventional system using black plastic mulch without habitats of \$ 865 ha^{-1} (\$ 350 ac^{-1}). The average cost of tractor and pick-up truck hours in the plastic system was \$ 240 ha^{-1} (\$ 97 ac^{-1}), which was higher than \$ 215 ha^{-1} (\$ 87 ac^{-1}) in no-till systems. Despite the closeness in total costs of labor in black plastic and no-till systems, the cost of black plastic mulch of \$ 510 ha^{-1} (\$ 200 ac^{-1}), in addition to labor and tractor costs made the black plastic mulch system more expensive than no-till systems. The input cost in black plastic mulch without habitat system is highest due to the cost of pesticides of \$ 456 ha^{-1} (\$ 179 ac^{-1}). The labor cost of \$ 873 ha^{-1} (\$ 353 ac^{-1}) in the no-till system was far much less than the total cost of black plastic mulch, pesticides and labor of \$ 1,800 ha^{-1} (\$ 729 ac^{-1}) in the black plastic mulch system without habitats (Table 5-1).

There were lower variations in the five-year weekly average price per carton than the 1998 and 1999 prices within most of the terminal markets. The minimum and maximum five-year weekly average prices per carton in the five markets were Atlanta: \$ 11.90 – 14.00, Baltimore: \$ 9.00-12.50, New York: \$10.10-11.87, Philadelphia: \$ 9.58-10.82, and Columbia: \$ 9.54-10.48, resulting in average weekly variations of \$ 2.10, \$ 3.50, \$ 1.77, \$ 1.24 and \$ 0.94, respectively. The average weekly variation in all terminal market prices over the entire period was \$ 1.91 per carton. The maximum price variation of \$ 3.50 between early and late season prices was recorded in the Baltimore market, while variations in other markets ranged between \$ 0.94- 2.10, with the lowest value in Columbia and the highest in Atlanta, respectively. Variations in price per carton between markets were greater in markets with higher prices. The highest average price in each market was Atlanta, $12.88; Baltimore, $10.86; New York, $10.82; Philadelphia, $10.37; and Columbia, $9.78. This resulted in a maximum average price variation across markets of $ 3.10 between Atlanta and Columbia, and a minimum average price variation across markets of $ 0.06 between Baltimore and New York. The average price variation between Baltimore, New York and Philadelphia was $ 0.30. These figures show that there was less price variation within these three markets in the Northeast region, whereas the two markets in the Southeast region had higher variation ($ 3.10). Hence price variation between markets was greater than price variation between periods in the Southeast region (Figures 5-1 and 5-4f).

Gross revenues (five year average price for the week of the harvest X yield of the harvest of that week = gross revenue per harvest) were calculated using the prices and marketable yields from each production system for 1998 (Ogutu and Caldwell, 1999) and 1999 (Ogutu and Caldwell, 2000), and the production system that achieved maximum yield in a particular period also generated maximum net revenue. The cumulative gross revenue from the Atlanta market in 1998 (which followed a similar trend in 1999) is used to explain this point by comparing the yields, gross revenues, and net revenues between black plastic mulch with habitats and no-till systems. In this market with an average price per carton of $ 12.73, the average cumulative yield of 1,172 cartons in black plastic mulch generated $ 14,900 average gross revenue ha^{-1}, while the average cumulative yield for the no-till systems of 1,798 cartons generated $ 22, 858 average gross revenue ha^{-1}. The difference in gross revenue was thus $ 7,958 ha^{-1}, or 53%, greater in no-till than in black plastic mulch system, reflecting the greater yield in no-till. The average production cost for black plastic mulch system was $ 6.83/carton versus $ 6.29/carton for no-till, but because of lower yield, total production costs for black plastic mulch with habitats was only $ 8,005 ha^{-1}, 29% less than the total production cost for the no-till system of $ 11,309 ha^{-1}. These figures result in net revenues of $ 6,895 ($ 14,900-$ 8,005) ha^{-1} for black plastic mulch with habitats and $ 11,549 ($ 22,858-$ 11,309) ha^{-1} for no-till. This shows how the difference in net revenues between production systems was due more to increased gross revenues than reduced production costs (Tables 5-1 and 5-3; Figure 5-2). The system generating higher gross revenue is the best option for the farmer.

The production system yields varied with the four harvest periods of July, early August, late August and September. Following the same relationships as demonstrated in the above example for cumulative yields, systems with higher yields during a given period generated higher net revenues. These trends were observed in both years. Comparing no-till transplanted and no-till direct seeded systems using 1998 data for one terminal market provides an example. During the July 16-31 period, based on the average price per carton of \$ 9.60 at the Columbia terminal market, no-till transplanted system yielded highest, at 577 cartons per hectare, which generated gross revenue of \$ 5,521 ha^{-1}. The no-till direct seeded system yield of 141 cartons per hectare generated gross revenue of \$ 1,354 ha^{-1} in the same market. The difference in gross revenue of \$ 4,426 ha^{-1} between the two systems mean revenue was 307% greater in the no-till transplanted system than in the no-till direct seeded system. The production cost per carton was \$ 6.17 and \$ 6.40 for no-till direct seeded and no-till transplanted systems respectively; hence, the production cost for 141 cartons in the no-till direct seeded system was \$ 870 while the cost for 577 cartons in the no-till transplanted system was \$ 3,693 ha^{-1}. The difference of \$ 2,823 ha^{-1} represents a 324% higher production cost in no-till transplanted than no-till direct seeded. The net revenue from the no-till transplanted system of \$ 1,828 (\$ 5,521 - \$ 3,693) ha^{-1} was three times greater than the net revenue from the no-till direct seeded system of \$ 484 (\$ 1,354 - \$ 870) ha^{-1}. The higher net revenue from the no-till transplanted system during this period makes it a better option for the farmer than the no-till direct seeded system.

During the early August (1-15) period, based on the average price per carton of \$ 9.70 in Columbia terminal market, the no-till transplanted system yielded 512 cartons and generated gross revenue of \$ 4,968 ha^{-1}, while the no-till direct seeded system yielded 592 cartons and generated gross revenue of \$ 5,744 ha^{-1}. The difference between the two systems in gross revenue was \$ 776 ha^{-1}, 16% greater in the no-till direct seeded system than in the no-till transplanted system due to higher yield. Using the same production costs per carton for the July period, the costs of producing 512 cartons were \$ 3,277 ha^{-1} and \$ 3,653 ha^{-1} in no-till transplanted and no-till direct seeded systems respectively. The difference in production costs of \$ 376 ha^{-1} was only 11% higher in the no-till direct seeded system than in the no-till transplanted system. The net revenue from no-till transplanted system of \$ 1,691 (\$ 4,968 - \$ 3,277) ha^{-1} was lower than the net revenue of \$ 2,091 (\$ 5,744 - \$ 3,653) ha^{-1} from the no-till direct seeded system by \$ 400 ha^{-1}, this net revenue was 24% greater in no-till direct seeded system than in the no-till transplanted system. The higher net revenue in the no-till direct seeded system compared to the no-till transplanted system was due to higher yield but not to reduced production costs, which made no-till direct seeded system a better option for the farmer than no-till transplanted during this period.

Similar system comparisons can be done between markets within periods or between periods in the same market, and the trends are the same, in which the system that dominates with higher net revenue in a particular period is the one with the highest yield in that period. The system with the highest yield is more desirable for the farmer, and this depends on the harvest period when cucumbers yield was highest.

There was a consistent pattern in net revenue dominance for treatments from July to September in both years. During the July period, the no-till transplanted system generated the highest net revenue (\$ 1,754 -1,819 ha^{-1}) in all markets, followed by black plastic mulch with incorporated rye/vetch with habitats (\$ 689 – 1,107 ha^{-1}) in all 1998 and most of 1999 markets. During early August, the no-till direct seeded (\$ 1,944 - 2,281 ha^{-1}) and no-till transplanted (\$ 1,561 - 2,322 ha^{-1}) systems dominated, with the order reversed between these two in 1998 and 1999, but both having higher net revenue than plastic systems. This pattern continued in late August, with the no-till direct seeded (\$ 2,560 - 2,806 ha^{-1}) and no-till transplanted systems (\$ 1,264 - 2,083 ha^{-1}) dominating, but their relative order reversed between 1998 and 1999. In September, net revenues declined in all systems (Tables 5-4 and 5-5).

Farmers aiming to maximize profits in early July can choose no-till transplanted and black plastic mulch systems with incorporated rye/vetch, while farmers targeting the early August, late August and September market periods should consider the no-till direct seeded system. For both the conventional grower using the black plastic mulch system, July 16-31 is the best period for this system, and for organic and sustainable vegetable growers using, no-till systems, the highest net revenues are possible during the August market periods.

In conclusion, production costs for black plastic mulch systems were higher than no-till systems due to the costs of purchased black plastic, pesticides and tractor use. The labor requirement in no-till was comparable to plastic systems. There were smaller variations in five-year weekly average prices within weeks than between markets, with three markets in Northeast having smaller variation and the two markets in the Southeast having higher variations. Gross revenues, which are derived directly from marketable yields, influenced net revenues more than production costs. The system with the highest yield tends to dominate in a harvesting period. No-till transplanted and plastic systems with incorporated rye/vetch generated higher net revenues in the late July harvest period, while the no-till direct seeded and no-till transplanted systems dominated in the remaining three harvest periods. This study indicates that yields, terminal market prices and production costs can be an important tool in decision making by farmers considering introduction of no-till systems of production.

LITERATURE CITED

Abdul-Baki, A. and J. R. Teasdale. 1997. Sustainable production of fresh-market tomatoes and other summer vegetables with organic mulches. USDA, ARS. Farmers' Bulletin No. 2279.

Amirault, J-P., and Caldwell, J. S. 1998. Living mulch strips as habitats for beneficial insects in the production of cucurbits. Hortscience. 33(3): 524.

Gallandt, E.R., E.B. Mallory, A. R. Alford, F. A. Drummond, E. Groden, M. Liebman, M. C. Mara, J. C. McBurnie and G. A. Porter. 1998. Comparison of alternative pest and soil management strategies for Maine potato production systems. American Journal of Alternative Agriculture. 13(4): 146-161.

Fleming, K. L., W. L. Powers, A. J. Jones, and G. A. Helmers. 1997. Alternative production systems' effects on the K-factor of the revised universal soil loss equation. American journal of Alternative Agriculture. 12(2): 55-58.

Govindasamy, R. and J. Italia. 1999. Evaluating consumer knowledge of alternative agricultural commodities: the case of IPM produce. American Journal of Alternative Agriculture. 14(4): 180-187.

Kelly, T. C., Y. C. Lu, A. Abdul-Baki and J. R. Teasdale. 1995. Economics of a hairy vetch mulch system in fresh-market tomato production in the Mid-Atlantic region. Journal of the American Society for Horticultural Sciences. 120: 854-860.

Kuchler, F., K. Ralston, and R. Tomerlin. 2000. Do health benefits explain the price premiums for organic foods?. American Journal of Alternative Agriculture. 15(1): 9-17.

Market Information Systems (MIS). 2000. University of Florida website: http://www.ifas.ufl.edu/~MARKETING/MARKET.html

Munn, D. A., G. Coffing and G. Sautter. 1998. Response of corn, soybean and wheat crops to fertilizer and herbicides in Ohio compared with low-input production practices. American Journal of Alternative Agriculture. 13(4): 181-189.

O'Dell, C. R., H. Snodgrass and G. Groover. 1994. 45 Selected costs and returns budgets for horticultural food crops production/marketing. Virginia Cooperative Extension. Publication No. 438-898. Pages 20-21.

O' Dell, C.R., S.A. Alexander, J. S. Caldwell, H. E. Holt, B. A. Nault, and S. B. Sterret. 2000a. Commercial vegetable production recommendations - Virginia. Publication Number 456-420.176 pages.

O'Dell, C. R., H. Snodgrass and G. Groover. 2000b 45 Selected costs and returns budgets for horticultural food crops production/marketing. Virginia Cooperative Extension. Publication No. 438-898. Pages 20-21.

Ogutu, M. O. and J. S. Caldwell. 1999. Stand differences in no-till direct seeded and plasticulture direct seeded and transplanted cucumbers (*Cucumis sativus* L.). Acta Horticulturae. 505: 129-134.

Ogutu, M. O. and J. S. Caldwell. 2000. Effects of rye/vetch no-till, habitat strips and black plastic mulch on insect densities, weed control, and fresh market cucumber growth and yields. Hortscience. 35(3); 478-479.

Robert, W. S. and S. M. Swinton. 1996. Economic methods for comparing alternative crop production systems: A review of the literature. American Journal of Alternative Agriculture.11(1): 10-17.

SAS Institute. 1997. SAS/STAT System. Version 6.12. SAS Institute, Cary, North Carolina.

Sterrett, S. B., S. D. Thornsbury, C. W. Coale Jr, D. B. Taylor, S. G. Sturt, and J. W. Mapp. 1996. The process for evaluating agricultural alternatives: An eastern shore Virginia example. REAP Report No. 22. Department of agricultural and applied economics, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

Swezey, S. L., M. R. Werner, M. Buchanan and J. Allison. 1998. Comparison of conventional and organic apple production systems during three years of conversion to organic management in coastal California. American Journal of Alternative Agriculture. 13(4): 162-179.

Teasdale, J. R. and A. Abdul-Baki. 1995. Soil temperature and tomato growth associated with black polyethylene and hairy vetch. J. Amer. Hort. Sci. 120: 848-853.

Swiader, J.M., G.W. Ware, and J.P. MacCollum. Danville. 1996. Illinois: Commercial

Cucumber Production. Producing Vegetable Crops. Interstate Publishers Inc. Chapter 17, cucumbers.
http://www.lpl.arizona.edu/~bcohen/cucumbers/commercial.html#prod

United States Department Agriculture (USDA), Agricultural Marketing Service. 1958. United States standards for grades of cucumbers. USDA Source 23 FR 1166.

CHAPTER 6

MAINTAINING AN INSECTARY THROUGH THREE WEEK STAGGERED PLANTINGS OF BUCKWHEAT

ABSTRACT

Buckwheat was planted on three successive dates separated by three week intervals from early May to mid June in 1998 and 1999. On all three dates, germination occurred after one week and plants reached 50% flowering three weeks after germination. Dry matter samples of buckwheat and weeds were taken on three dates separated by approximately two weeks, starting at 54-55 days after planting for the first seeding, 33-34 days after planting for the second seeding, and 25-28 days after planting for the third seeding. Above ground insects were monitored at weekly intervals using yellow sticky cards. Buckwheat and weed competition was assessed by dividing weed dry weight by buckwheat dry weight multiplied by 100% and reported as weeds/buckwheat (%). Buckwheat had higher dry weight than broad-leaved and grass weeds, with no differences in buckwheat dry weights at the same number of weeks after planting among planting date treatments. Weed competition was minimal in all treatments, with weeds/buckwheat (%) ranging between 0.5 and 4.5%. Densities of adult Diptera and other Coleoptera were maintained throughout the season, with 15 or more insects / card in one of the seedings in every sampling date in both years. Densities of Coccinellidae were maintained at 10 or more insects per card in one of the seedings on 9 of 12 sampling dates in 1998 and 11 of 12 sampling dates in 1999. Cumulative densities were higher in the second seeding than the first or third. Pennsylvania leatherwing densities were low, <10 insects / card for all seedings on all but one sampling date in each year. Striped cucumber and spotted cucumber beetle densities were also low in all seedings, <4 insects / card on all sampling dates in 1998 and <8 insects / card on all one sampling date in 1999.

Key words: beneficial insects, Coccinellidae, Coleoptera, Diptera, Pennsylvania leatherwing

INTRODUCTION

Buckwheat (*Fragoporum esculentum* Moench) is a plant grown both as a cover and an economic crop. In Canada buckwheat is grown mainly for export to Japan for making noodle (*soba*) (Wall and Smith, 1999). It can be grown as a cover crop to attract beneficial insects (Platt et al., 1999). Buckwheat takes a shorter time to reach flowering and seed formation stages compared with vetch, and this may lead to inadequate supply of nectar and pollen for adult beneficial insects. The supply of nectar and pollen can only be achieved if the floral stage is maintained for an adequate period of time to enable life cycle changes to occur. Growing fall and summer ecotypes (Michiyama et al., 1998) and removal of flower buds (Michiyama et al., 1999) are two methods for prolonging flowering in buckwheat. Another option, which needs to be considered if you have only one ecotype, is staggered planting to maintain buckwheat throughout the summer. Delaying seeding from early to late June in Canada led to major declines in seed yields (Gubbell et al., 1990), but this is not important when maintenance of the floral stage is the ultimate goal. When buckwheat is grown as a cover crop, weed competition tends to be minimal possibly due to allelopathic effects (Eskelsen and Crabtree, 1995).

In strip cropping production systems (Ogutu and Caldwell, 1999; Ogutu and Caldwell, 2000), rye/vetch habitats for *in situ* conservation of beneficial insects are alternated with cucumber planted on plastic or in no-till strips. Since vetch flowering capacity diminishes by the end of June, buckwheat seeded to flower after the time vetch flowering capacity begins to drop could continue to provide food for adult beneficial insects and thereby maintain populations of beneficial insects. Where black plastic mulch strips alternate with the rye/vetch habitat strips, buckwheat could be seeded on the bare ground between the habitat and black plastic mulch strip. In no-till strip cropping, a buckwheat strip could be established after rolling of rye/vetch and planting of cucumbers.

If rainfall is inadequate, buckwheat establishment can be poor and may require irrigation (such as through a separate trickle line when trickle irrigation is used), which would add more expense to production. However, shading effects should not be a problem, as buckwheat growth was reduced only minimally when planted between corn plants, which are much taller than cucurbits (Gubbels, 1985). In a no-till strip cropping system, over-seeding of buckwheat into the no-till area between the cucumber twin rows and the habitat would be also be another possibility. Although over-seeding can result in shorter plants, flowering capacity is not affected (Gubbels et al., 1986). Establishment may be affected by moisture stress in hot summers, but the presence of the no-till mulch may be adequate to conserve moisture and ensure survival of the seedlings without a supplemental trickle line. These possibilities need to be explored in future research.

The objective of this experiment was to study the effect of staggered planting of buckwheat on attraction of adult beneficial insects. The hypothesis is that plants in staggered plantings of buckwheat will attract and maintain beneficial insects throughout the growing season, and that their densities will remain high over the entire season. The alternative hypothesis is that plants in staggered plantings of buckwheat will fail to attract and maintain beneficial insects throughout the season despite the continued presence of buckwheat flowers. Other studies have shown that buckwheat can attract beneficial insects (Bugg and Ellis, 1990; Altieri, 1991; Pickett et al, 1997; Platt et al., 1999) but the maintenance of such insectaries throughout the season was not investigated.

MATERIALS AND METHODS

Tilled plots 3 m (10 feet) by 9 m (30 feet), were seeded at the Virginia Tech Kentland Farm on three dates separated by three week intervals in a randomized complete block design with dates as treatments replicated four times. Buckwheat (*Fragoporum esculentum* Moench) unclassified variety (Southern States, Christiansburg, Virginia), mixed with 560 $kg.ha^{-1}$ (500 $lb.ac^{-1}$) soybean meal to ensure uniform distribution was broadcast by hand at the rate of 123 $kg.ha^{-1}$ (110 $lb.ac^{-1}$). One half of the weighed amount per plot was broadcast in one direction, and the other half in a perpendicular direction to ensure uniform coverage. Seed was raked into the soil the same or following day. Dates of seeding were 8 May, 29 May, and 19 June 1998 and 6 May, 27 May, and 17 June 1999.

Weed competition was assessed through dry matter samples taken in a 1 m by 1 m Sampling Square in one corner of each plot, 0.9 m (3 ft) from the edge; a different corner was used on each sampling date. In 1998, samples were taken on 2 July 1998 for the first and second plantings, on 14 July 1998 for all three plantings, and on 28 July 1998 for the second and third plantings. In 1999, the first dry matter samples were taken on 29 June (first and second plantings) followed by the second sampling on 15 July (all three plantings) and the third sampling on 4 August (second and third plantings only). The first sampling dates corresponded to 54-55 days after planting for the first seeding, 33-34 days after planting for the second seeding, and 25-28 days after planting for the third seeding, with subsequent sampling dates approximately two weeks apart (Table 6-1). Buckwheat and weeds were cut at the soil line with shears and separated into buckwheat, broad-leaved weeds, and grass weeds. Each plant type was put in a separate paper bag, dried at 70^0 C for 24 hours in the Virginia Tech Agronomy Lab, and weighed.

Due to low overall weed weights, broad-leaved and grass weed dry matter weights were combined to form weed dry weight. Weed dry weight was divided by buckwheat dry weight and multiplied by 100 to obtain weed dry weight as a percentage of buckwheat dry weight, as an indicator of competition between weeds and buckwheat. This ratio was transformed by arcsine- ($\theta = \arcsin\sqrt{p}$) where p is the proportion (Gomez and Gomez, 1984) and analyzed using SAS Proc GLM, with orthogonal comparisons made among treatments (SAS Institute, 1997). The results were reported as untransformed percentages.

Yellow sticky-card traps 15 cm by 15 cm (6 in by 6 in) (Olsen Products, Medina, Ohio) attached to 1.2 m (4 ft) stakes using 6 mm (1/4 in) staples above the plant canopy in the center of each plot were used to monitor attractiveness to insects. The first set of traps was put up on 25 June 1998 and 18 June 1999, and removed after one week (on 2 July 1998 and 25 June 1999, respectively). By this time buckwheat in the first planting date had reached 100% flowering, while on the other two planting dates, insect monitoring started at 50% flowering. Monitoring continued weekly until 1 September 1998 and 14 September 1999, when buckwheat in the third planting had lost 80% of the flowers in all treatments. The number of striped cucumber beetles (*Acalymma vittata* Fabricus), spotted cucumber beetles (*Diabrotica undecimpunctata howardii* Barber), ladybird beetles, Pennsylvania leatherwings (*Chauliognathus pennsylvanicus* DeG.), other Coleoptera, and adult Diptera were counted on both sides of the traps.

Insect densities were cumulated over sampling date, to provide a measure of the total attractiveness of the planting date. The weekly insect densities were grouped into three major periods as follows: the early June-July period when both first and second seeded plots were in flower (P1); the mid-season August period when both second and third seeded plots were in flower (P2); and the late season September period, also when second and third seeded plots were in flower (P3). In 1998, the periods cover the sampling dates P1 (6/29, 7/06, 7/13, 7/20), P2 (7/27, 8/03, 8/11) and P3 (8/17, 8/24, 9/01) and in 1999 as P1 (6/25, 7/02, 7/09, 7/16, 7/22), P2 (8/03, 8/09, 8/18, 8/25) and P3 (9/01, 9/08, 9/14).

Both cumulated densities and densities on individual sampling dates were transformed using the square root (x + 0.5) for homogeneity of variance before analysis. The transformed cumulative and individual sampling date densities were compared by analysis of variance using orthogonal contrasts (SAS Institute, 1997). Second seeded buckwheat was compared to first and third seeded buckwheat (monitoring done in first and third seeded buckwheat was shorter than in second seeded buckwheat hence cumulative number of beneficial insects were higher in second than in either first or third seeded), and then first and third seeded were compared. Results are reported as means of untransformed densities by back transforming the means (Gomez and Gomez, 1984).

RESULTS

Buckwheat germination and growth

Most of the seeds emerged after 7-10 days for all the three seeding dates. Buckwheat seeded in early May (8 May 1998 and 6 May 1999) was at the 50% flowering stage 40 days after planting in mid June (17 June 1998 and 11 June 1999), which was 2 and 6 days earlier respectively than seeding done in mid June in both years. Buckwheat seeded in late May reached 50% flowering stage in early July, which was three weeks (21 days) after the first seeding in early May reached 50% flowering and 17-20 days earlier than buckwheat seeded in mid June (19 June 1998 and 17 June 1999) (Table 6-2). Field observations showed that by the time the mid June seeded buckwheat had reached 50% flowering, the buckwheat seeded in early May had mature seeds occupying over 80% of the canopy, hence insect monitoring was stopped in first seeded plots but continued in the late May and mid June seeded plots.

Competition between weeds and buckwheat

Dry weight sampling was done three times in second planted and twice in first and third planted buckwheat in both years (Table 6-1). Buckwheat dry weight was much higher than the combined dry weight of broad-leaved and grass weeds for all three planting dates in both 1998 and 1999, with weed dry weight as a percentage of buckwheat dry weight not exceeding 4% in either year. In 1998, there were no differences in weed dry weights as a percentage of buckwheat weight among planting dates in any of the individual sampling dates (Figure 6-1). Weed dry weight as a percentage of buckwheat dry weight was higher in first seeded buckwheat than in second seeded buckwheat on the first sampling date in 1999, but was still less than 4%. No differences were observed on the other two sampling dates in 1999 (Figure 6-2).

Insect densities

Cumulative insect densities varied more in 1999 than in 1998 (Table 6-3). In 1998, cumulative densities of Pennsylvania leatherwings (PLW) and other Coleoptera (OC) in second seeded buckwheat were not different from the mean cumulative densities for the first and third seeding dates, but cumulative densities in the first seeding were greater than in the third seeding. Adult Diptera (AD) cumulative densities were higher in the second seeding than in the first and third seedings. However, there was no difference in AD cumulative densities between the first and third seeding dates. Coccinellidae (COC) cumulative densities were different in all planting date comparisons. During the second seeding COC cumulative densities were double the densities in the first and third seeding (Figure 6-3).

In 1999, cumulative densities of OC and AD were more than five times higher than the cumulative densities of the other insects and twice as high as in 1998. Their cumulative densities were higher in the second than in the mean of the first and third seeding (Figure 6-4). There were more Pennsylvania leatherwings in the first seeding than in the third, and the first and third seedings were higher than the cumulative density of the second seeding, but overall cumulative densities were very low in all three seedings. In 1999, cumulative densities of OC and AD were higher in the second seeding than the first and third seedings, but there were no differences between the first and third seeding. COC cumulative densities were higher in the second seeding than the first and third seedings, and cumulative densities were higher in the third seeding than in the first. As in 1998, CUK cumulative densities were low in all treatments. However, comparisons among treatments indicated that they were higher in the second seeding than in the mean of the first and third seedings (Table 6-3).

The weekly mean density of adult Diptera was higher in second seeding than in the first seeding of buckwheat on 6 July ($p= 0.04$) and 20 July ($p= 0.02$) in 1998. In 1999, the first seeding of buckwheat had higher densities of adult Diptera than the second seeding of buckwheat on 25 June ($p= 0.001$), 2 July ($p= 0.001$), and 9 July ($p= 0.002$). There were higher densities of adult Diptera in the second seeding of buckwheat than the third seeding of buckwheat on 18 August ($p= 0.05$), but the third seeding of buckwheat had higher densities than the second seeding of buckwheat on 14 September ($p= 0.005$).

The weekly mean densities of Pennsylvania leatherwings in the first seeding of buckwheat were not different from the second seeding nor were there differences between the second compared to the third seeding on any sampling date in 1998. However, in 1999, the first seeding of buckwheat had higher densities than the second seeding on 25 June ($p= 0.02$), 2 July ($p= 0.004$), and 9 July ($p= 0.004$).

There was no difference in weekly Coccinellidae densities between seeding dates in 1998. In 1999, the first seeding of buckwheat had higher densities than the second seeding on 2 July ($p= 0.02$), 9 July ($p< 0.0001$), and the second seeding had higher densities than the third seeding on 3 August ($p= 0.04$), while the third seeding had higher mean density on 14 September ($p=0.01$).

The weekly mean density of OC was higher in the first seeding than in the second seeding of buckwheat on 20 July ($p= 0.04$) in 1998. There were no differences in weekly mean density for striped and spotted cucumber beetles in all planting date comparisons in both years.

The weekly monitoring curves depict three major periods in both years when insect densities follow a particular trend (Figures 6-5 and 6-6). The three major periods were: the early June-July period when both first and second seeded plots were in flower (P1); the mid-season August period when both second and third seeded plots were in flower (P2); and the late season September period, also when second and third seeded plots were in flower (P3). In 1998, there were no differences between seeding dates in densities of all insects monitored during periods P1 (6/29, 7/06, 7/13, 7/20), P2 (7/27, 8/03, 8/11) and P3 (8/17, 8/24, 9/01). In 1999, there were higher densities in the first than in the second seeding of buckwheat for PLW ($p = 0.04$), OC ($p = 0.04$) and AD ($p = 0.004$) during period P1 (6/25, 7/02, 7/09, 7/16, 7/22). There were no differences between seeding dates in densities of all insects in period P2 (8/03, 8/09, 8/18, 8/25), but there were higher densities of OC ($p = 0.02$) in the second than in the third seeding of buckwheat in period P3 (9/01, 9/08, 9/14) (Tables 6-4 and 6-5).

The weekly monitoring curves in Figures 6-5 and 6-6 show that densities of AD, OC and COC were maintained throughout the season. Densities of both AD and OC exceeded 15 insects / card in one of the seedings in every sampling date in both years. Densities of COC exceeded 10 or more insects / card in one of the seedings on 9 of 12 sampling dates in 1998 and 11 of 12 sampling dates in 1999. Cumulative densities were higher in the second seeding than the first or third. Pennsylvania leatherwing densities were low, <10 insects / card for all seedings on all but one sampling date in each year. Striped cucumber and spotted cucumber beetle densities were also low in all seedings, <4 insects / card on all sampling dates in 1998 and <8 insects / card on all but one sampling date in 1999.

TABLE 6-1. BUCKWHEAT DRY MATTER SAMPLING DATES, 1998 AND 1999

Sampling date	Number of days after planting date		
	1st seeded	2nd seeded	3rd seeded
	1998 dates		
	8 May	29 May	19 June
02 July	55	34	---
14 July	67	46	25
28 July	---	60	39
	1999 dates		
	6 May	27 May	17 June
29 June	54	33	---
15 July	70	49	28
04 August	---	69	48

TABLE 6-2. GERMINATION DATES AND 50% FLOWERING STAGES OF BUCKWHEAT SEEDED AT THREE-WEEK INTERVALS, 1998 AND 1999

Seeding Dates	Germination Dates	Days after Planting	50% Flowering	Days after Emergence
5/08/98	5/18/98	10	6/17/98	30
5/29/98	6/06/98	8	7/08/98	32
6/19/98	6/26/98	7	7/23/98	27
5/06/99	5/15/99	9	6/11/99	27
5/27/99	6/03/99	7	7/02/99	29
6/17/99	6/25/99	8	7/22/99	27

TABLE 6-3. ANALYSIS OF VARIANCE OF CUMULATIVE INSECT DENSITIES ON THREE SUCCESSIVE BUCKWHEAT SEEDING DATES IN 1998 AND 1999[z]

Comparisons	Cumulative Mean Insect Densities					
1998	SCB	SPB	COC	PLW	OC	AD
Second Vs						
First + Third	NS	NS	**	NS	NS	*
First Vs						
Third	NS	NS	**	**	**	NS
1999						
Second Vs						
First + Third	**	**	**	*	**	**
First Vs						
Third	*	*	*	**	NS	NS

[z] Pennsylvania leatherwings (PLW), adult Diptera (AD), Coccinellidae (COC), Other coleoptera (OC), striped cucumber beetles (SCB), Spotted cucumber beetles (SPB); CUK = SCB + SPB; ** - Significant at $P<0.01$; * - Significant at $0.01<P<0.05$, NS – Not significant

TABLE 6-4. EFFECT OF THREE-WEEK INTERVAL PLANTING DATES IN 1998 ON INSECT DENSITIES IN BUCKWHEAT CUMULATED OVER THREE PERIODS

		Mean insect densities			Comparisons[x]	
Periods[y]	Insects[z]	First Planting	Second Planting	Third Planting	1st vs 2nd	2nd vs 3rd
P1	PLW	22.3± 0.6	18.4± 1.0	-	NS	-
P1	OC	31.2± 0.6	35.1± 0.1	-	NS	-
P1	AD	52.4± 0.4	45.2± 0.8	-	NS	-
P1	COC	14.7± 0.3	21.7± 0.5	-	NS	-
P1	CUK	1.5± 0.0	2.6± 0.1	-	NS	-
P2	PLW	-	19.8± 0.1	18.6± 0.1	-	NS
P2	OC	-	311.7± 0.5	307.5± 1.3	-	NS
P2	AD	-	282.1± 0.9	317.8± 1.2	-	NS
P2	COC	-	111.2± 0.1	93.0± 0.6	-	NS
P2	CUK	-	54.4± 0.5	43.3± 0.4	-	NS
P3	PLW	-	23.0± 0.1	20.6± 0.2	-	NS
P3	OC	-	260.0± 1.2	218.5± 1.0	-	NS
P3	AD	-	370.8± 3.1	359.0± 2.5	-	NS
P3	COC	-	73.3± 0.8	82.4± 1.0	-	NS
P3	CUK	-	67.6± 0.8	39.8± 0.3	-	NS

[x] ** - Significant at P<0.01 * - Significant at 0.01<P<0.05, NS – Not significant.

[y] (**P1**- 6/29,7/06, 7/13, 7/20; **P2**-7/27, 8/03, 8/11; and **P3**- 8/17, 8/24, 9/01);

[z] Pennsylvania leatherwings (PLW), adult Diptera (AD), other coleoptera (OC), Coccinellidae (COC), CUK = striped cucumber beetles (SCB) + Spotted cucumber beetles (SPB)

TABLE 6-5. EFFECT OF THREE-WEEK INTERVAL PLANTING DATES IN 1999 ON INSECT DENSITIES IN BUCKWHEAT CUMULATED OVER THREE PERIODS

		Mean insect densities			Comparisons[x]	
Periods[y]	Insects[z]	First Planting	Second Planting	Third Planting	1st Vs. 2nd	2nd Vs. 3rd
P1	PLW	5.6 ± 0.2	1.5 ± 0	-	*	-
P1	OC	15.4 ± 2.1	1.5 ± 0	-	*	-
P1	AD	32.7 ± 0.4	1.5 ± 0	-	*	-
P1	COC	2.9 ± 0.2	1.5 ± 0	-	*	-
P1	CUK	1.5 ± 0	1.5 ± 0	-	NS	-
P2	PLW	-	31.5 ± 2.1	31.5 ± 2.1	-	NS
P2	OC	-	577.9 ± 1.9	550.8 ± 0.6	-	NS
P2	AD	-	258.7 ± 1.6	287.1 ± 1.5	-	NS
P2	COC	-	280.1 ± 0.6	215.9 ± 0.9	-	NS
P2	CUK	-	46.7 ± 0.6	43.7 ± 0.5	-	NS
P3	PLW	-	22.5 ± 0.2	26.5 ± 0.5	-	NS
P3	OC	-	100.7 ± 0.6	137.3 ± 0.6	-	*
P3	AD	-	146.4 ± 0.9	231.1 ± 0.5	-	NS
P3	COC	-	109.1 ± 0.5	182.3 ± 0.9	-	NS
P3	CUK	-	25.2 ± 0.4	25.6± 0.4	-	NS

x ** - Significant at P<0.01 * - Significant at 0.01<P<0.05, NS – Not significant

y (**P1**- 6/25,7/02, 7/09, 7/16, 7/22; **P2**-8/03, 8/09, 8/18, 8/25; and **P3**- 9/01, 9/08, 9/14);

z Pennsylvania leatherwings (PLW), adult Diptera (AD), other coleoptera (OC), Coccinellidae (COC), CUK = striped cucumber beetles (SCB) + Spotted cucumber beetles (SPB)

FIGURE 6-1. WEEDS AS PERCENTAGE OF BUCKWHEAT DRY WEIGHTS ON THREE PLANTING DATES, 1998

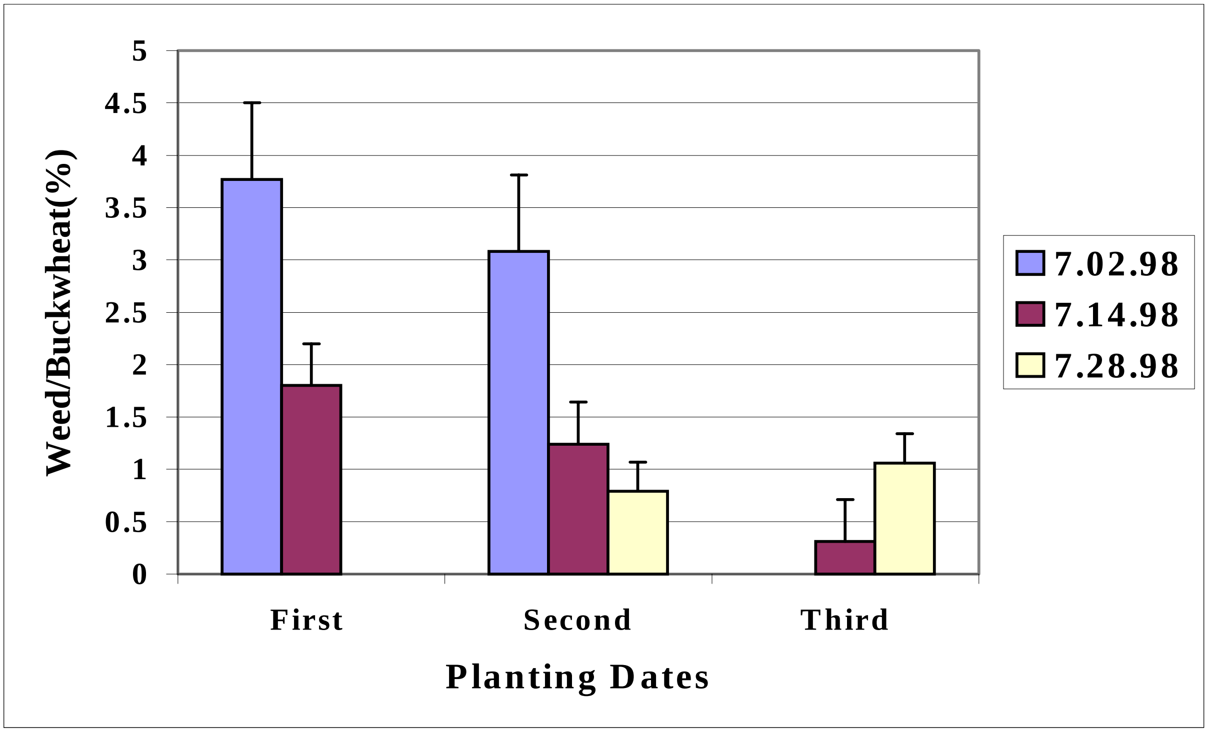


FIGURE 6-2. WEEDS AS PERCENTAGE OF BUCKWHEAT DRY WEIGHT ON THREE PLANTING DATES, 1999

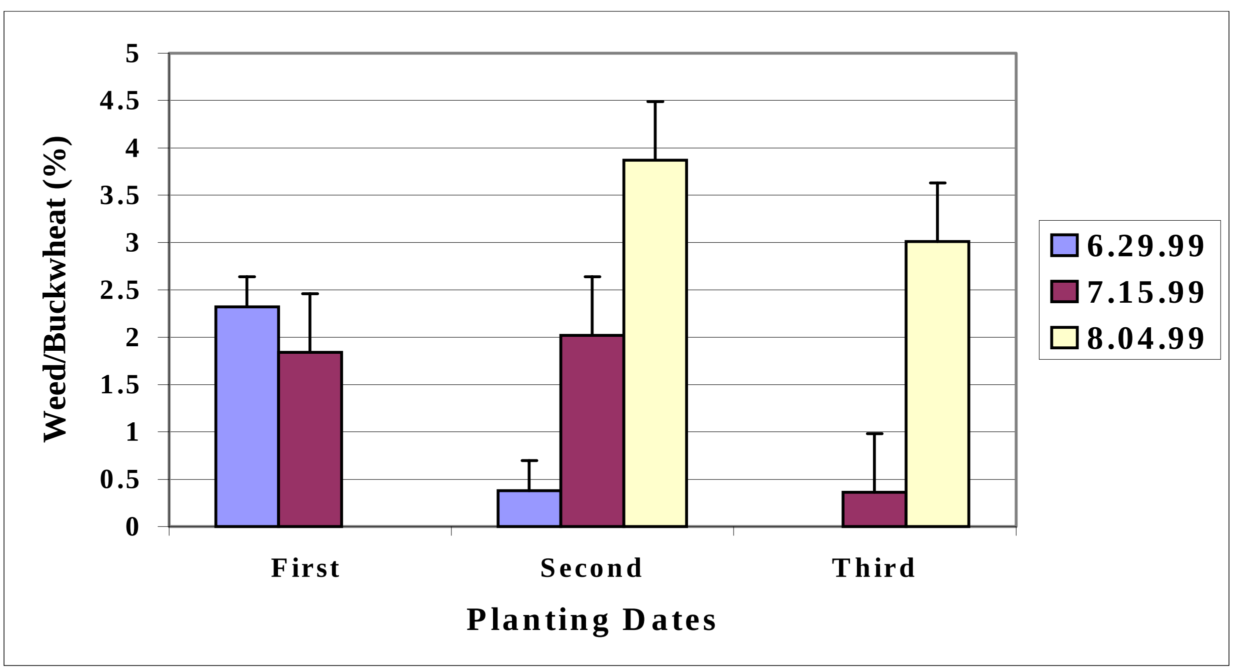


FIGURE 6-3. CUMULATIVE MEAN INSECT DENSITIES IN BUCKWHEAT PLANTED AT THREE-WEEK INTERVALS, 1998

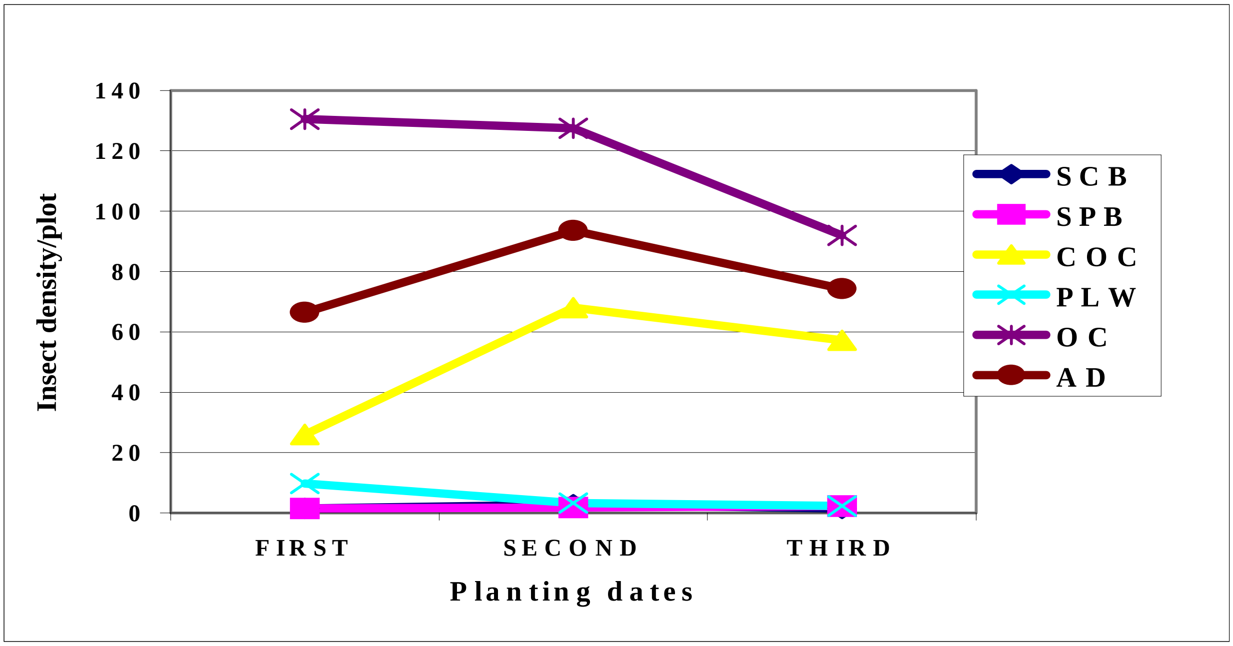


FIGURE 6-4. CUMULATIVE MEAN INSECT DENSITIES IN BUCKWHEAT PLANTED AT THREE-WEEK INTERVALS, 1999

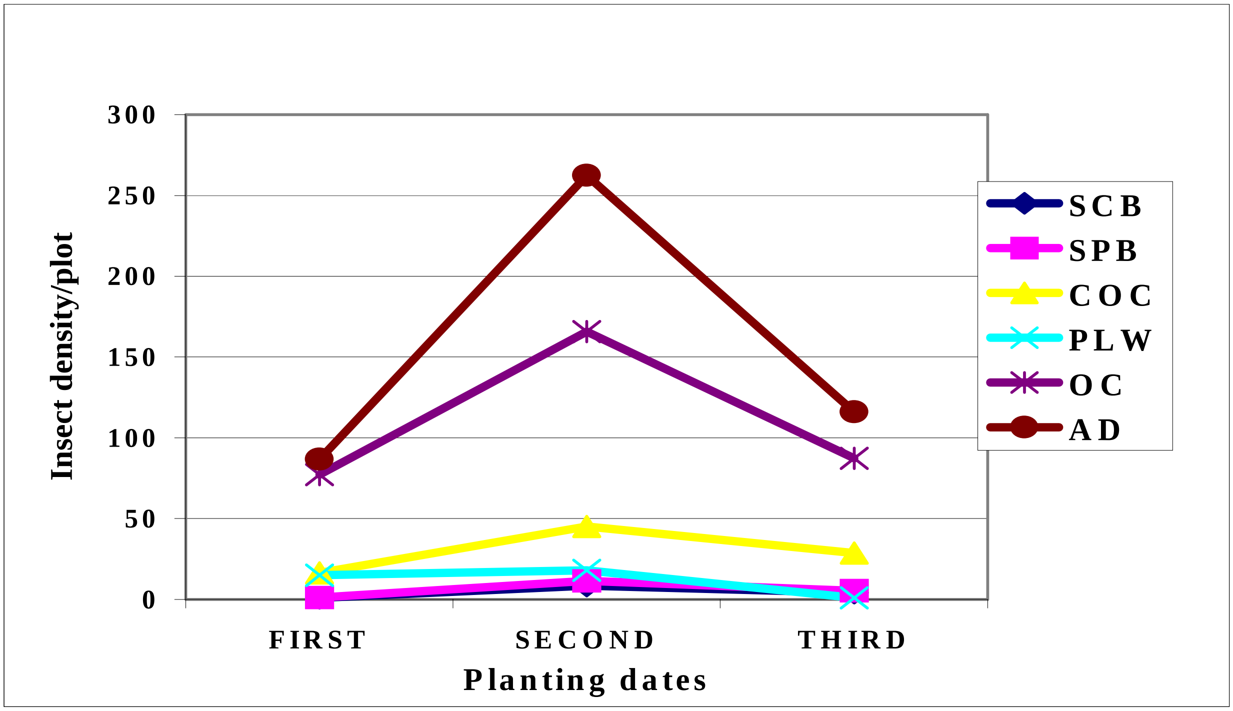


FIGURE 6-5. EFFECTS OF THREE-WEEK BUCKWHEAT PLANTING INTERVALS ON WEEKLY MEAN DENSITIES OF PENNSYLVANIA LEATHERWINGS, ADULT DIPTERANS, OTHER COLEOPTERANS, COCCINELLIDAE AND CUCUMBER BEETLES, 1998

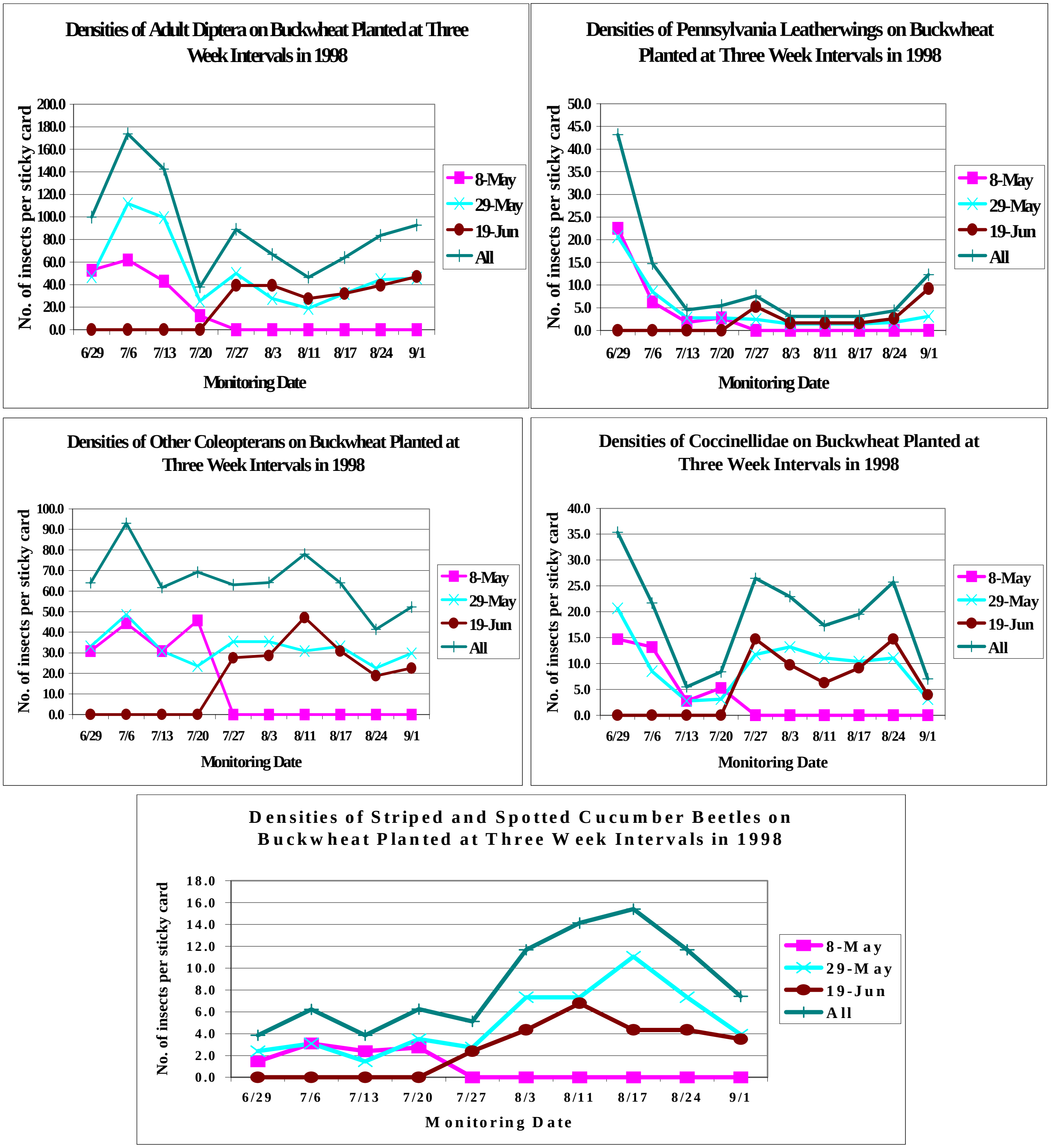
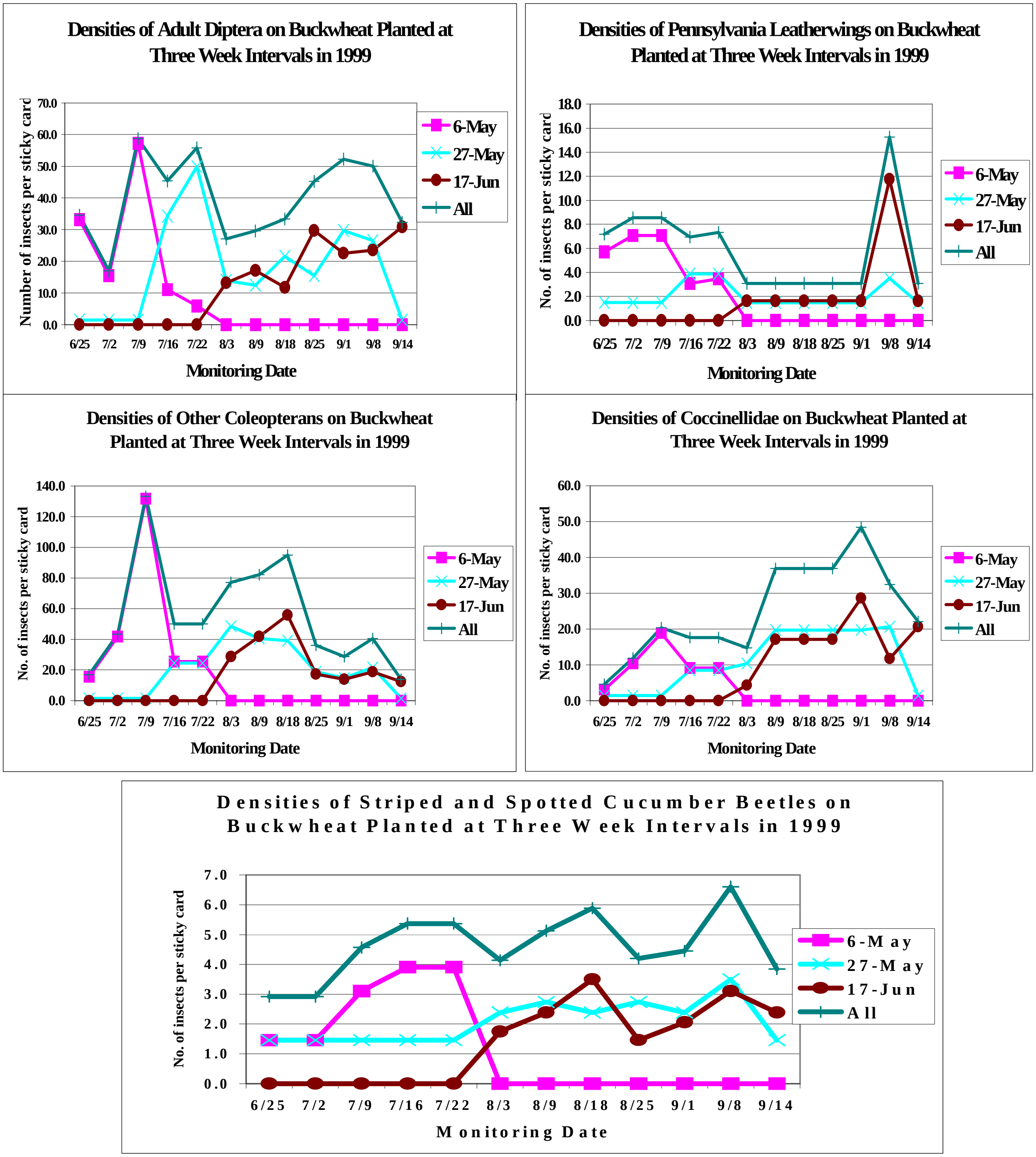


FIGURE 6-6. EFFECTS OF THREE-WEEK BUCKWHEAT PLANTING INTERVALS ON WEEKLY MEAN DENSITIES OF PENNSYLVANIA LEATHERWINGS, ADULT DIPTERANS, OTHER COLEOPTERANS, COCCINELLIDAE AND CUCUMBER BEETLES, 1999



DISCUSSION

This study showed that a buckwheat insectary is most attractive to OC and AD, and moderately attractive to COC (Figures 6-3, 6-4, 6-5 and 6-6; Table 6-4). It also showed that the densities of the above beneficial insects can be maintained over the entire crop season through staggered planting. The second seeding of buckwheat produced flowers for a much longer period than first and third seeding which explains why the cumulative densities of the insects at this seeding date was higher than in other dates.

The adult Diptera densities were maintained throughout the season in 1998. In 1999, the densities in individual seedings decreased with the first seeding predominating on 25 June and 2 July while the second seeding predominating on 16 and 22 July, and the third seeded predominated on 14 September (Figures 6-5 and 6-6). This shows that the densities of adult Diptera can be conserved as the seedlings progressively flowered and senesced. This result supports the benefits of staggered plantings as a means of creating an insectary. The weekly mean density of other Coleoptera was also maintained throughout the season in both years (Table 6-3; Figures 6-5 and 6-6). This indicates that three-week planting intervals can maintain the densities of other Coleoptera over the season.

Parallel results were obtained by Platt et al. (1999) and Amirault and Caldwell (1998). Buckwheat attracted Pennsylvania leatherwings, but their densities were low (Figures 6-5 and 6-6; Tables 6-4 and 6-5). Pennsylvania leatherwing densities were high only during the beginning of the season and towards the end of the season, but this may reflect their life cycle (Houser and Balduf, 1925). The presumed presence of their larvae between the two peaks of adults needs to be confirmed.

Coccinellidae densities were maintained throughout the season in 1998. In 1999, as densities in the individual seedings changed, the first seeding had the highest densities on 2 July and 9 July, the second seeding predominated on 3 August, and third seeding predominating on 14 September (Figures 6-5 and 6-6). This indicates that the density is conserved as the seedlings progressively flower and senesce, supporting the benefits of staggered plantings to create a full season insectary.

Buckwheat was much more attractive to beneficial insects than cucumber beetles, whose densities were low in both years (Figures 6-5 and 6-6). Densities of spotted and striped cucumber beetles were lower than densities of beneficial insects in buckwheat in both years. These results indicate that a buckwheat insectary does not attract pest insects in great numbers, paralleling results obtained by Bugg and Ellis (1990).

The attractiveness of buckwheat to beneficial insects was assessed by grouping the weekly sampling results into three periods. This analysis showed that the flowering time of the first seeded buckwheat coincided with the time when vetch had lost the flowers; hence was necessary for attracting beneficial insects in 1999, and the flowering time of the second seeded buckwheat was equivalent to the first seeded in 1998. In 1999, densities of three out of five beneficial insects were higher in the third seeding than in the second seeded buckwheat, but there was difference only for OC. This suggests that the third seeding may be useful in some years.

In this study, a buckwheat insectary was maintained over the summer through staggered planting using a variety adapted to the area. Buckwheat planted at three-week intervals attracted and conserved adult beneficial insects throughout the season (Figures 6-3, 6-4, 6-5, and 6-6; Tables 6-2, 6-3 and 6-4). Flowering of summer and fall ecotypes was compared in Japan and the fall ecotype was found to have higher number of flowers with a flowering period of about four months compared to one month for the summer ecotype. However, the seed yield of the former was low (Michiyama et al., 1998). This implies that varieties suitable for insectaries may not be necessarily used for economical grain production. Removal of flower buds to extend the vegetative growth phase has also been suggested as another option for prolonging flowering stage of buckwheat, but the procedure is tedious, and considering the high cost of labor, it would be very expensive to implement under field conditions (Michiyama et al., 1999).

Buckwheat accumulated dry weight much faster than weeds (Figures 6-1 and 6-2). Broad-leaved weeds had been reported to be a problem in buckwheat (Wall and Smith, 1999). However, weed/buckwheat (%) was very low in all the seeding dates (Figures 6-1 and 6-2), with minimal competition by weeds with buckwheat. This may be due to allelopathic effects

(Eskelsen and Crabtree, 1995) particularly on broad-leaved weeds. This property may be utilized as weed control measure in establishing insectaries.

When the field is to be used for production of succeeding crops for which a buckwheat insectary is not necessary, control of volunteer buckwheat can be a problem, particularly in cereal production (Remy et al., 1985; Remy and O'Sullivan, 1986). The competition can be minimized by increased seeding rates of the succeeding crop (O'Donovan, 1994). This increases the competitive ability of the crop, thereby leading to less reduction in yield. This would be a preferred option for organic growers. The other option for conventional growers is to spray with herbicide before planting the succeeding crop.

For the buckwheat insectary to be effective it must be within about 10 m from the crop (Platt et al., 1999). However, establishing buckwheat too close to the crop could also be detrimental, since buckwheat is very competitive and may cause a decline in crop yields. The presence of buckwheat close to the crop may also hinder mechanized field operations.

Spatial arrangement of buckwheat strips in the field needs to be investigated to determine the best arrangement to minimize competition with the main crop. Buckwheat might be inserted into the cucurbit strip cropping systems (Ogutu and Caldwell, 1999; Ogutu and Caldwell, 2000) at the time vetch had lost all flowers.

In summary, seeding buckwheat at three-week intervals maintained a uniform density of other Coleoptera, adult Diptera and Coccinellidae over entire cropping season. Pennsylvania leatherwing adult densities were high only during the beginning of the season and towards the end of the season, reflecting their life cycle. The insectary is not attractive to cucumber beetles. The second seeding of buckwheat reached 50% flowering stage 40 days after planting, like the other buckwheat seedings, but its flowering period was much longer than in other seeding dates; hence, its contribution to the maintenance of the insectary was greatest. However, the first and third seedings may be needed in some years to assure constant densities in the early and late parts of the season.

LITERATURE CITED

Altieri, M. A. 1991. How best can we use biodiversity in agroecosystems? Outlook on Agriculture. 20(1): 15 – 23.

Amirault, J. P. and J. S. Caldwell. 1998. Living mulch strips as habitats for beneficial insects in the production of cucurbits.

Bugg, R. L. and R. T. Ellis. 1990. Insects associated with cover crops in Massachusetts. Biological Agriculture and Horticulture. 7: 47-68.

Eskelsen, S. R. and G. D. Crabtree. 1995. The role of allelopathy in buckwheat (*Fagopyrum sagittatum*) inhibition of Canada thistle (*Cirsium arvense*). Weed Science. 43: 70-74.

Gomez, K. A. and A. A. Gomez. 1984. Statistical procedures for agricultural research. International Rice Research Institute, Los Banos, Phillipines.

Gubbels, G. H. 1985. The response of buckwheat to protection by two-row corn windbreaks. Canadian Journal of Plant Science. 65: 441-444.

Gubbels, G. H.; Campbell, C. G. 1986. Effect of seeding rate on height, yield and quality of large-seeded and semi-dwarf buckwheat genotypes. Canadian Journal of Plant Science. 66: 61-66.

Gubbels, G. H., C. G. Campbell, and R. C. Zimmer. 1990. Interaction of cultivar, seeding date and downy mildew infection on various agronomic characteristics of buckwheat. Canadian Journal of Plant Science. 70: 949-954.

Houser, J. S. and W. V. Balduf. 1925. The striped cucumber beetle. Bulletin 368. The Ohio Agricultural Experiment Station, Columbus, Ohio.

Michiyama, H., A. Tachimoto, and H. Hayashi. 1999. Effect of defloration and restriction of the number of flower clusters on the progression of successive flowering and seed-setting in common buckwheat (*Fagopyrum esculentum* Moench). Japanese Journal of Crop Science. 68 (1): 91-94.

Michiyama, H., A. Fukui, and H. Hayashi. 1998. Differences in the progression of successive flowering between summer and autumn ecotype cultivars in common buckwheat (*Fagopyrum esculentum* Moench). Japanese Journal of Crop Science. 67 (4): 498-504.

O'Donovan, J. T. 1994. Canola (Brassica rapa) plant density influences tartary buckwheat (*Fagopyrum tataricum*) interference, biomass, and seed yield. Weed Science. 42: 385-389.

Ogutu, M. O. and J. S. Caldwell. 1999. Stand differences in no-till direct seeded and plasticulture direct seeded and transplanted cucumbers (*Cucumis sativus* L.). Acta Horticulturae. 505: 129-134.

Ogutu, M. O. and J. S. Caldwell. 2000. Effects of rye/vetch no-till, habitat strips and black plastic mulch on insect densities, weed control, and fresh market cucumber growth and yields. Hortscience. 35(3): 478 – 479.

Pickett, J. A., L. J. Wadhams and C. M. Woodcock. 1997. Developing sustainable pest control from chemical ecology. Agriculture, Ecosystems & Environment. 64: 149-156.

Platt, J. O., J. S. Caldwell, and L. T. Kok. 1999. Effect of buckwheat as a flowering border on populations of cucumber beetles and their natural enemies in cucumber and squash. Crop Protection 18: 305-315.

Remy S. E. A. and P. A. O'Sullivan. 1986. Duration of tartary buckwheat (*Fagopyrum tataricum*) interference in several crops. Weed Science. 34: 281-286.

Remy S. E. A., J. T. O'Donovan and K. W. Alan. 1985. Influence of tartary buckwheat (*Fagopyrum tataricum*) density on yield loss of barley (*Hordeum vulgare*) and wheat

(*Triticum aestivum*). Weed Science. 33: 521-523.

SAS Institute. 1997. SAS System Release Version 6.12. SAS Institute, Cary, North Carolina.

Wall, D.A. and M.A.H. Smith. 1999. Weed management in common buckwheat (*Fagopyrum esculentum*). Canadian Journal of Plant Science. 79 (3): 455-461.

CHAPTER 7

SUMMARY AND OVERALL CONCLUSIONS

SUMMARY

Mean weed dry weight, as a percentage of cucumber dry weight for the two years in no-till plots was 65% for direct seeded and 30% for transplants at 3 weeks after planting (WAP) while at 6 WAP it declined to 5% in both no-till direct seeded and in no-till transplants. Cucumber dry weight in no-till direct seeded plots at 3 WAP was lower than broad leaved and grass dry weights in no-till transplanted plots but, at 6 WAP, no-till direct seeded plants had compensated for the slower early establishment and their dry weights were not different from the other treatments. This improved their competition against weeds. At both stages in all years, there was no difference between chemical and manual weed control in no-till direct seeded and no-till transplant plots (Ogutu and Caldwell, 1999; Unpublished data).

Rye/vetch habitat plots attracted more beneficial insects (adult Diptera and Pennsylvania leatherwings) and were unattractive to cucumber beetles before rolling and flail mowing in both years. Since the habitat plots have vetch flowers, which attract beneficial insects, higher densities were encountered than in plots with rye only. The pests (cucumber beetles) were not attracted to rye or vetch since these are not host plants like the cucurbits, which release chemical cues that attract cucumber beetles. After rolling or flail mowing of rye/vetch and planting of cucumbers, habitat strips were left between the cucumber strips. There were higher cucumber beetle densities in plastic than in no-till plots in four out of ten sampling dates in both years. The effect of the habitat was more pronounced in no-till than black plastic mulch plots, even in the rye/vetch residue rototilled plots where black plastic mulch strips were surrounded by habitats. This supports the associational resistance hypothesis, which states that it is difficult for pests to locate host plants in the presence of non- host plants (Root, 1973; Altieri, 1982; Altieri, 1991; Bach, 1981). After the vetch habitat was lost, and cucumber plants cover most of the ground, cucumber beetles landing in any of the treatments would not differentiate between no-till and plastic plots; hence, later in the season there was no difference in cucumber beetle densities. This change is also congruent with the associational resistance hypothesis. However, in 1999 bacterial wilt incidence was higher in the plastic compared to no-till plots, reflecting the higher density of cucumber beetles in plastic plots earlier in the season (Tables 2-3 and 2-4).

There were positive correlations between densities of adult Diptera and cucumber yield during two sampling periods in 1998 and seven sampling periods in 1999 (Figures 2-6c and 2-6d). There were five and six negative correlations between cucumber beetle densities and cucumber yields in 1998 and 1999 respectively (Figures 2-6a and 2-6b), but there were no correlations between Coccinellidae densities and cucumber yield in either year (Figures 2-6e and 2-6f). Most of the correlations were stronger in no-till than in plastic plots. These are indirect associations between pests and adult beneficial insects with yield. Cucumber beetles which are the pest feed on cucumber plants and if their density is high this can lead to reduction in yield, while adult Diptera are indicators for beneficial insects which have the potential of feeding on cucumber beetles (Houser and Balduf, 1925). Coccinellidae do not have a role in the control of the population of cucumber beetles, although they can control other pests (aphids) in the agroecosystem, which affect cucumber productivity; hence, we did not expect any correlation with yield.

There were higher ground predator (Carabidae, Staphylinidae, and spiders) densities in habitat plots with rye and vetch than conventional plots with rye only before rolling and flail mowing (Table 3-1). Further classification of the Carabidae into species revealed that six out of eight species recorded were found in the habitat plots and only two in the conventional plots (Figure 3-1). Higher densities in more diversified agroecosystems have been reported for Carabidae (Pavuk et al., 1997), Staphylinidae (Krooss and Schaefer, 1998) and spiders (Reichert and Bishop, 1990; Snyder and Wise, 2000).

After rolling/flail mowing there were higher densities of Staphylinidae, larvae and spiders in the habitat plots than in conventional plots in 1999, whereas in 1998 there was no difference in all comparisons except for larvae where habitat plots had higher densities than conventional plots. In 1999, there was a higher density of larvae in no-till than in plastic plots and higher densities of spiders in no-till transplanted plots than in no-till direct seeded plots (Table 3-2). It appears that more Staphylinidae, larvae and spiders in the habitat areas in habitat plots had moved into the cucumber rows. The movement of Carabidae appeared to be uniform as indicated by the treatments and the presence of similar patterns in treatment comparisons in both years.

Only three species of Carabidae were found in the crop rows in 1998, and four in 1999. No-till plots recorded three species, rototilled two species and in conventional plots none in 1998, and in 1999, no-till plots recorded 3-4 species, and conventional plots one species (Figures 3-1 and 3-3). This indicates that there was more Carabidae and other ground predator movement into the crop rows in no-till plots. The Carabidae species (*Harpalus longicollis, Poecilus chalcite, and Scarites subterranus*) that were found in the crop rows of no-till plots in 1998, as well as *Pterostichus tristis,* and *Chalcite tricolor,* are predaceous species and can feed on the larvae of cucumber beetles and other insects, while *Harpalus Pennsylvanicus* is an omnivorous species (Allen, 1979).

There was a higher petiole sap nitrate-nitrogen concentration in rototilled rye/vetch than in conventional black plastic plots in 1998, but there was no difference for the samples taken in 1999. Later in the season, after the nitrogen flush from the incorporated flail mowed rye/vetch residue in the rototilled plots had been exhausted, the effect of this supplemental nitrogen was lost, leading to no difference in petiole sap nitrate-nitrogen readings compared with the conventional plastic plots. In contrast, slower decomposition of rye/vetch in no-till was indicated by higher petiole sap readings in no-till than in plastic plots later on in the season (47 and 64 days after planting). These results indicate that no-till can serve as a source for slow release of nitrogen. They also show the value of monitoring of petiole sap nitrate-nitrogen status for making fertigation decisions in no-till and in black-plastic mulch cucumber production systems.

Monitoring of soil moisture status using tensiometers in 1999 indicated that trickle irrigation supplied water uniformly to the plastic and no-till plots with no difference between these treatments throughout the season. However, soil moisture tension in no-till plots tended to fall after rainfall due to percolation of rainwater into the soil faster than in plastic plots which were covered with black plastic mulch. Cucumber plant dry weights were not different between the treatments at this stage; hence, the amount of water lost through transpiration by plants in all treatments may be assumed to be the same. Soil moisture tension decreased in both treatments when it rained on no-till plots or plastic plots were irrigated as shown on 26 August (Figures 4-3, 4-4, and 4-5; Table 4-2). Petiole sap nitrate-nitrogen and soil moisture tension are important in cucumber production systems because plants subjected to water stress will not get adequate nutrients and photosynthetic activities will decline, leading to less biomass accumulation and reduction in yield.

No-till plots had higher cumulative cucumber yield than plastic plots in both years. There was no difference between no-till direct seeded and transplanted in 1998, while in 1999, no-till transplants had higher cumulative cucumber yield than no-till direct seeded (Table 4-3). Yield determined the profitability of each system more than market prices and transport costs. Plots with plastic over incorporated rye/vetch and no-till transplant plots had higher net revenues in the 16-31 July period while no-till direct seeded and no-till transplants had higher net revenues thereafter (Tables 5-1, 5-2; and Figures 5-1, 5-2, 5-3).

The establishment of a buckwheat insectary was evaluated in this study by planting of buckwheat at three-week intervals starting from the first week of May in both years. Buckwheat was a much stronger competitor than weeds (Figures 6-1, and 6-2). Buckwheat reached 50% flowering in 27 to 30 days after emergence (Table 6-2). The weekly monitoring of beneficial insects (adult Diptera, other Coleoptera, Pennsylvania leatherwings and Coccinellidae) indicated that there was no difference between the first and second seeded or between the second and third seeded buckwheat in 1998. In 1999, the first seeded buckwheat had higher densities of adult beneficial insects than the second seeded during the first group period (P1) and other Coleoptera in the third seeded than second seeded during third group period (P3) (Figures 6-3, 6-4, 6-5 and 6-6). The second and third seeding buckwheat can be incorporated into cucumber strip cropping to serve as an insectary when vetch has lost all flowers.

Rye/vetch cover crop habitat strips are useful for conservation of beneficial insects, and the *in situ* no-till mulch for moisture conservation and weed control can be substitutes for pesticide and black plastic mulch input in vegetable production. The no-till mulch provided effective weed control when rolled and critical manual weeding was done. Monitoring of plant nitrogen status by use of sap nitrate-nitrogen meter and soil moisture tension by tensiometers in no-till and plastic plots are important decision making tools for when to fertigate or irrigate respectively. There were higher cumulative yields in no-till plots than in plastic plots in both years. No-till direct seeded and transplants can generate higher net revenues in most of the late season markets but for earlier markets, black plastic mulch and no-till transplants systems were more profitable.

CONCLUSIONS AND FUTURE RESEARCH NEEDS

The insect pest (striped and spotted cucumber beetles) management was based on the natural enemies and associational resistance hypotheses. The natural enemies hypothesis states that there are more adult beneficial insects and other predators in a diversified habitat due to availability of food resources than in conventional system dominated by a pure stand of host plant. The cumulative densities of the natural enemies (Pennsylvania leatherwings and adult Diptera) in cucumber rows were not different between black plastic mulch and no-till plots in 1998. In 1999, the density of Pennsylvania leatherwing was higher in no-till than in black plastic mulch plots, but the cumulative density was very low (less than 5 insects/ plot). This indicates that no-till systems with habitats did not have a marked advantage in conserving above ground beneficial insects after planting. There were mixed results between no-till direct seeded and no-till transplanted systems as indicated by the absence of differences in 1998, whereas in 1999, the no-till direct seeded system had higher adult Diptera densities than the no-till transplanted system. There were mixed results for ground predators also. Diversity of Carabidae species was greater in plots with habitats, but densities of Carabidae, Staphylinidae and spiders in cucumber rows were not different between no-till and black plastic mulch plots in either year, and plots with habitats had higher densities of Staphylinidae and spiders in 1999 but not in 1998. In conclusion, these results did not clearly support the natural enemies hypothesis.

The associational resistance hypothesis predicts higher densities of cucumber beetles in pure stands due to higher concentration of desired host plants than in mixed stands. If a pest lands on a pure stand, it stays longer than if it lands on non-host plant. In the case of cucumber beetles, the longer they stay in a plot, the more feeding damage and bacterial wilt transmission incidence occur. There were consistently higher cumulative densities of cucumber beetles in black plastic mulch than in no-till plots in both years and the incidence of bacterial wilt was higher in black plastic mulch than in no-till plots in 1999. These results strongly support associational resistance hypothesis.

The no-till and black plastic mulch systems conserved soil moisture equally. The petiole sap nitrate-nitrogen was high in black plastic mulch plots with incorporated rye/vetch than in other treatments earlier in the season, but later on no-till plots had higher petiole sap nitrate-nitrogen than black plastic mulch plots. The no-till plots had higher cumulative cucumber yields than black plastic mulch plots in both years.

The cost of labor in no-till plots was higher than in plastic but considering the cost of plastic, tractor use and pesticides in conventional system, the no-till systems generated higher net revenues per hectare than black plastic systems. The black plastic mulch with incorporated rye/vetch and no-till transplanted systems were more profitable during the 16-31 July period, but the no-till systems dominated from 1-15 August to 1-15 September periods.

This study has demonstrated the value of strip cropping, but several topics remain for further research to increase its potential:

- Spatial arrangement and seeding methods for incorporating buckwheat into rye/vetch strip cropping need to be developed and tested.
- The life cycle of the Pennsylvania leatherwing, and particularly the extent of predation on cucumber beetles by larval stage, needs to be investigated in the laboratory and field in order to assess to what extent they can effectively control cucumber beetle populations, and determine if augmentation and release might be an option.
- More complete models combining petiole sap nitrate-nitrogen, soil moisture tension, weed dry weights, and cucumber dry weights in addition to insect densities as parameters need to be tested to develop a yield-predicting model for sustainable cucumber production systems.

Even in the absence of the above additional research, these results obtained here provide important information on new alternative production systems for organic and sustainable cucurbit growers, as well as for conventional growers interested in reducing chemical inputs.

Rye/vetch cover crop can be seeded in early October the previous year, and rolling and flail mowing of rye/vetch using disengaged flail mower done in May. These planting times compatible with current production systems. Cucumbers can be planted by either direct seeding or transplanting seedlings, depending on the market prices early in the season and labor availability, with similar cumulative yields. Incorporation of rye/vetch residues and laying black plastic mulch can enhance earlier stand establishment than in rolled rye/vetch, but final yields in rolled rye/vetch are greater than in rototilled plots. The rolling of rye/vetch mulch in combination with critical weeding can provide equally good weed control measure as application of pre-emergence herbicides. No-till plots conserve moisture equal to black plastic mulch and had lower densities of cucumber beetles than in black plastic mulch plots, resulting in fewer incidence of bacterial wilt. The no-till plots had higher cumulative yield and net revenue than black plastic mulch plots in both years. While no-till strip cropping has higher management demands relative to conventional practices, it provides growers with an economically feasible alternative for reducing pesticides.

CHAPTER 8

VITA

Maurice Okendo Ogutu was born on 20 October 1962 in Siaya district, Nyanza province, Kenya. During his early education, he attended Ndigwa Primary School (1971-1977) and Maranda High School (1978-1983). He then proceeded on to University of Nairobi for his B.S. (Agriculture) degree in 1985-1988 and M. S. (Agronomy) degree in 1988-1990. He then worked as Agricultural research officer, high school teacher, agro-based Industrial development/extension officer and lecturer in Kenya before coming to the United States of America in 1996. He is married with two children.