Biological Control of Insect Pests
Using Pest Break Strips
A New Dimension to
Integrated Pest Management

Everett J. Dietrick
John M. Phillips
Joel Grossman

A Publication Of
The Naturfarm Conversion Project

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and the
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Foreword

The 1980 U.S. Department of Agriculture Report and Recommendations on Organic Farming indicated that there was a growing concern among farmers, consumers, environmentalists and society as a whole on the adverse effects of pesticides on human and animal health; environmental quality and biodiversity; and food safety and quality. Consequently, the Report urgently recommended that the U.S. agricultural research establishment seek to develop "new and improved techniques for control of weeds, insects and plant diseases using biological, non-chemical methods." The Report placed particular emphasis on "the development of pest control methods using parasites, predator insects, and other biological means to eradicate or control unwanted (i.e., harmful) species."

While this recommendation resulted in some renewed interest in biocontrol methods and Integrated Pest Management (IPM), there was little additional support for such research in the years which followed. That is, research continued to focus on ways of increasing the production of basic commodity crops in chemical-based, monoculture, conventional farming systems.

Nevertheless, by the late 1980's, consumer and environmental groups had become very prominent and vocal in expressing their concerns about the use of synthetic chemicals, i.e., fertilizers and pesticides, in our food production system. Subsequently, the impact of this movement led to two significant events with regard to U.S. agriculture. First, in June 1993, the National Academy of Sciences, National Research Council published a report entitled Pesticides in the Diets of Infants and Children which indicated that this particular age group could be at higher risk than adults from ingestion of fruits and vegetables containing pesticide residues. And second, also in June 1993, a joint statement was issued by the Secretary of Agriculture (USDA); the Administrator of the U.S. Environmental Protection Agency (USEPA); and the Commissioner of the U.S. Food and Drug Administration (USFDA) that officially committed these agencies to work together with U.S. farmers to reduce their use of, and dependence on, pesticides, and to promote the principles of sustainable agriculture.

The 1980 USDA Report also revealed that farmers who had converted abruptly from conventional, chemical-based agriculture to organic or nature farming systems without synthetic pesticides often experienced serious weed, insect and disease problems during the first three to four years after conversion had begun. Thus, in view of this and the two events cited in 1993, perhaps the most frequently asked question by U.S. farmers is "How can I accomplish such a conversion from conventional to organic or nature farming successfully and profitably, and with minimum risk?"
These historical and recent events are relevant because they underscore the goals and objectives of the California Energy Commission/Naturfarm Conversion Project, a five-year study which began in 1989. This report on the Biological Control of Insect Pests Using Pest Break Strips represents only one aspect of the overall project. The results of systems research and analysis of other components, including tillage, soil fertility, pest management and farm management, will be presented in other reports available from the Nature Farming Research and Development Foundation. Meanwhile, this report on pest break strip technology appears to offer a new and exciting approach to biological control, and an added dimension to Integrated Pest Management (IPM). The concept of pest break strips and their practical application should provide a more effective and reliable approach to the conversion from conventional agriculture to a nature/organic farming system. Moreover, when farmers realize that the Nature Farming Model can result in a substantial reduction in the energy needed for such production inputs as tillage, soil fertility, weed control, and insect pest management, their interest level will increase accordingly.

Certainly, additional research will help to refine the methods and techniques described in this report to a) enhance its adaptation over a wide range of agroecological and climatic conditions; and b) promote its acceptance and use by commercial farmers, both organic and conventional. Nevertheless, the results presented herein are scientifically-credible, convincing, and worthy of further on-farm testing and demonstration. The California Energy Commission/ Naturfarm Conversion Project is an excellent example and model of how resources can be integrated into more sustainable farming systems that are energy-efficient, environmentally-sound, and economically-viable. This report is both timely and innovative, and should be widely read by farmers, researchers and extension workers.

Dr. James F. Parr
President, Nature Farming Research and Development Foundation
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and

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U.S. Department of Agriculture,
Beltsville, Maryland
Preface: The Naturfarm Conversion Project

In 1989, the California Energy Commission (CEC) funded the Naturfarm Conversion Project to demonstrate the conversion process from an energy intensive farming system to a production system with less dependence on chemical and fuel energy use. The purpose of the CEC's Agricultural Energy Assistance Program (AEAP) is to promote the efficient use of energy resources in California's food and fiber industry. To achieve its purpose, the AEAP provides funding for applied research and demonstration projects to monitor and evaluate targeted technologies and farming practices that could help farmers reduce energy consumption.

The goal of the Energy Commission in funding the Naturfarm Conversion Project was to demonstrate energy conservation practices to reduce pesticide and fertilizer use, and achieve fuel use savings. Additional goals were set to achieve agricultural resource use efficiencies, reduce soil, air and water contamination, and limit worker exposure to harmful chemicals. The project was designed to document project results, assess benefits to the farmer, and develop educational materials.

The purpose of this technical report is to document the transition experience of converting a conventionally-farmed land area to a biologically-integrated farming system. In addition, it is hoped that the benefits of using the Naturfarm practices will become apparent and some of the successful methods described in this transition guide will be adopted by farmers. The results of this project should help to develop a greater appreciation of energy costs and how farming systems can become more energy efficient.

The Naturfarm has achieved a high level of energy efficiency by eliminating the use of chemical fertilizers and pesticides, and reducing diesel fuel consumption by eliminating pesticide applications and using conservation tillage practices. These results have been evaluated and summarized after four years of field research and test demonstrations. The project results reflect an overall improvement in the farm's effectiveness to control pest damage. Improvements also have been documented in crop quality and gross revenue, reduced pest problems, and better monitoring and management skills. Farm personnel have become more knowledgeable about insect ecology and biological control practices. Additional benefits have been measured in decreased fuel consumption, reduced soil compaction, and increased water infiltration and retention. Improved management skills have contributed to the development of a whole farm systems approach to decisions on production practices. We hope that reading this document will assist farmers as they strive to develop more energy efficient farming systems.

Ricardo Amon, Agricultural Energy Assistance Program
California Energy Commission
Acknowledgements

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The contributions and dedication of those who served at various times as members of the CEC Naturfarm Conversion Project Team are acknowledged with sincere thanks and appreciation. Project Team Members were Ricardo Amon, Warren Bendixon, Everett Dietrick, Paul Dilger, Bill Gillette, Ron Gilman, Stephen Gliessman, Bill Liebhardt, Harlyn Meyer, James Meyer, Philip Northcraft, John C. Phillips, John M. Phillips, Thomas Ruehr, Louie Valenzuela, and Victor Wegryn.

Dr. Teruo Higa provided technical counsel throughout this project on Kyusei Nature Farming and the use of EM technology, and his assistance is sincerely appreciated with many thanks.

Harlyn and James Meyer designed and initiated the CEC Naturfarm Conversion Project and served as initial NFRDF Project Manager and Cooperating Farmer, respectively. Their contributions and service over many years, both to Nature Farming and to the organic farming movement in California, are recognized and appreciated.

Izuo Miyashita, President of NFRDF(1990-1994) gave wholehearted support to the CEC Naturfarm Conversion Project, which contributed immeasurably to its success. Dr. James F. Parr, President of NFRDF since 1995, has continued this support for the Project, and has served as Executive Editor of this Report. Dr. Sharon B. Hornick, Executive Director of NFRDF, contributed valuable comments and insights to this Report, and has fully supported this Project. Ann Mayse (UC-SAREP) reviewed and assisted in editing the Report and Susan E. Randall (NFRDF) also provided valuable comments and editorial assistance.

Lastly, Ricardo Amon, Project Manager for the California Energy Commission and John M. Phillips, Project Manager for NFRDF and the Naturfarm, have been instrumental in leading the CEC Naturfarm Conversion Project to a successful conclusion, which includes this Report. Sincere thanks and appreciation are extended to all who have contributed to the success of this Project.
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Biological Control of Insect Pests Using Pest Break Strips
A New Dimension to Integrated Pest Management

I. Introduction

Pest break strips are an essential part of the Naturfarm's transition strategy for enhancing the biological control of insect pests. They are a specialized form of strip-intercropping and provide a new dimension to integrated pest management (IPM). At the Naturfarm, pest break strips of an alfalfa-clover mixture are strip-intercropped with organic vegetables. Pest break strips have a dual role: 1) as trap crops, they divert pests away from market crops; and 2) as insectary crops, they grow beneficial insects helping to provide biological control of pests in adjacent rows of vegetable crops (Grossman and Quarles, 1993).

At the Naturfarm, a cultural practice known as strip-cutting maximizes the number of pests and the populations of natural enemies found in pest break strips. Strip-cutting is simply the practice of cutting only half the pest break strip at any one time. This allows half the pest break strip to flower prior to cutting, while the other half is in mainly a vegetative state. The young, lush uncut strips make excellent trap crops, catching incoming pests from cut strips, harvested crops and migrations. Beneficial insects are several-fold more numerous when pest break strips are strip-cut compared with simply cutting to a uniform height (Schlinger and Dietrick, 1960).

The exclusive reliance on natural biological control organisms and cultural practices like strip-cutting for sustainable insect pest management is rarely, if ever, attempted anymore. Such methods are almost unprecedented for vegetable crops. However, there have been times and places in California's agricultural history where such methods have provided all of the pest control needed for the production of major commercial crops such as citrus, cotton and alfalfa.

II. Historical Background

Everett J. "Deke" Dietrick, a registered entomologist and widely recognized authority on biological control of insect pests, served as the Naturfarm's Pest Control Advisor (PCA) on the CEC Naturfarm Conversion Project. Dietrick worked in southern California on cotton, citrus and alfalfa during a time when natural biological control techniques were the predominant methods used to control insect pests. Over the last 50 years, while a researcher at the University of California, Riverside, and later in private practice with Rincon-Vitova Insectaries, Inc., Dietrick helped develop, monitor and implement IPM techniques, such as strip-cutting and classical biological control releases, in unsprayed California cotton, citrus and alfalfa (Drik, 1995). Dietrick drew upon his personal knowledge, based on decades of experience on biological control successes in southern California, to develop the IPM program for the Naturfarm.
A system similar to that designed for the Naturfarm's pest break strips and used for the production of vegetable crops was described by Marcovitch (1935). In those early experiments, strips of turnips, a good cabbage aphid host, were planted a month ahead of market cole crops as insectary plants to attract aphid natural enemies. The turnips were partially destroyed by aphid infestations by late spring or early summer. However, predators like lady beetles and parasitic wasps like Lysiphlebus testaceipes (Cresson) provided biological control of aphids for most of the season in the nearby market crops.

Naturfarm's pest break strips were designed to make this type of biological control a more permanent feature of vegetable farms. Part of making this system more permanent and effective is the use of strip-cut alfalfa which was first adapted for biological pest control in 1956 by Evert I. Schlinger and Everett J. Dietrick as part of the University of California's statewide effort to control the spotted alfalfa aphid.

Strip-cutting of alfalfa was devised in the 1950's as a means of maintaining beneficial insects in the field as a "defensive army" preventing population explosions of aphids and other pests from occurring in new crop growth (Dietrick, 1989-94). Strip-harvesting half of the field following each irrigation (12-to 14-day intervals), compared with complete harvesting of the field after the usual two irrigations (25 to 30 days), traps and protects the vast numbers of beneficial arthropods that were previously lost. When adapted to use in pest break strips, a 12-to 14-day cutting interval is also important because pests like adult Lygus bugs begin moving out of maturing hay when alfalfa reaches three-fourths maturity.

During the 1960's, University of California researchers Stern, van den Bosch and Leigh (1964) documented this added value of uncut alfalfa as a trap crop for Lygus, which can severely damage strawberries, cotton and vegetable seed crops. Continuously cutting the pest break strip before seed set prevents alfalfa and other pest break strip crops from becoming too favorable for seed feeders such as Lygus bugs and certain leafhoppers. If the entire pest break strip is cut and there is no nearby uncut alfalfa then Lygus and other pests typically migrate into nearby market crops. Besides "trapping" pests like Lygus, strip-cutting also retains beneficial insects, mites and spiders, which increase in number by feeding on small soft-bodied insects thriving in the young, tender strip-cut regrowth.

In their historic report on numbers of beneficial insects in strip-cut alfalfa in southern California, Schlinger and Dietrick (1960) counted 400 percent more natural enemies per acre in strip-cut alfalfa, compared with cutting and harvesting the whole stand. Alfalfa plants also yield 15 percent more biomass when managed by strip-cutting, which gives an extra ton of hay per acre per season. When the cut alfalfa is sheet-composted rather than removed from the field, an expanded food chain of decomposing organisms feeds an even more diverse and abundant fauna of beneficial
arthropods. An estimated one thousand species of insects, mites and spiders interact in a strip-cut alfalfa field that is not sprayed with pesticides. The increased numbers of insect predators and parasites in strip-cut alfalfa reported by Schlinger and Dietrick in 1960 and shown in Table 1 convinced Naturfarm management that this approach was worth adapting for pest break strips in diversified vegetable farming.

Table 1. Comparison of Numbers of Beneficial Arthropods in Strip-Cut and Full-Cut Alfalfa.¹

<table>
<thead>
<tr>
<th>Beneficial Arthropod</th>
<th>Strip-Cut (No./Acre)</th>
<th>Full-Cut (No./Acre)</th>
<th>Increase From Strip-Cut (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predatory Spiders</td>
<td>1,000,000</td>
<td>100,000</td>
<td>1000</td>
</tr>
<tr>
<td>Parasitic Wasps</td>
<td>287,000</td>
<td>71,750</td>
<td>400</td>
</tr>
<tr>
<td>Big-Eyed Bugs</td>
<td>401,000</td>
<td>200,500</td>
<td>200</td>
</tr>
<tr>
<td>Lady Beetle (Adults)</td>
<td>200,000</td>
<td>50,000</td>
<td>400</td>
</tr>
<tr>
<td>Lady Beetle (Larvae)</td>
<td>232,000</td>
<td>11,000</td>
<td>2000</td>
</tr>
</tbody>
</table>

¹ Based on the Data of Schlinger and Dietrick, 1960.

If one were to purchase the numbers of beneficial arthropods that can be grown through the management of strip-cut alfalfa, it would be prohibitively expensive (Schlinger and Dietrick, 1960). At the Naturfarm, pest break strips of strip-cut alfalfa became on-farm insectaries, producing numerous beneficial arthropods close to cash crops which created a highly-effective biological control system for the management of insect pests in vegetable crops.

Historically, economics helped make unsprayed strip-cut alfalfa a regional reservoir of natural biological control agents for insect pests in southern California. The reason for this was that it was not cost-effective to spray alfalfa, and existing equipment could only harvest a limited area at one time. This changed when it became economically viable to spray alfalfa with pesticides and when the use of larger equipment and custom harvesting became the norm. When alfalfa and other crops producing beneficial biological controls are sprayed, there may be dramatic and costly consequences affecting an entire region. For example, in recent years in California's Imperial Valley, massive migrations of secondary pests like whitefly has affected the production of cotton and winter vegetables. Imperial Valley vegetables, like lettuce, broccoli, cantaloupe and cabbage, now suffer from devastating whitefly invasions that have replaced the migrations of insect predators and parasites from alfalfa fields.
Insect pest management at the Naturfarm uses pest break strips consisting of alfalfa and clovers to enhance plant and insect biodiversity. The staggered cutting schedule also enhances biodiversity by providing plants of different ages or maturities. The net result of this increased biodiversity is an IPM program of great ecological stability because it provides beneficial insects with permanent refuge to help prevent devastating pest population outbreaks.

III. Function, Design and Operation of Pest Break Strips

A Habitat for Insect Wildlife

The pest break strips at the Naturfarm are more than just a shift away from spraying pesticides of one form or another, they are really about creating a habitat for beneficial insect wildlife. Just as maintaining wetland habitats for migratory waterfowl is essential for a healthy ecology, it is necessary to create permanent or semi-permanent, on-farm habitats for beneficial insect, mite and spider populations. Providing habitats for beneficial organisms is as essential to achieving sustainable biological control on vegetable farms as wetlands are to maintaining the existence of ducks and other aquatic wildlife in agricultural areas. In essence, pest break strips are wildlife refuges for natural enemies of agricultural pests. This role as the protector of beneficial wildlife is one of the longest-held traditions of farming. Pest break strips are a tool that helps the farmer to maintain this tradition while protecting his crops from insect pests.

Design and Layout

The Naturfarm is using pest break strips in an attempt to create the biological control benefits of unsprayed and strip-cut alfalfa. Five to ten percent of the land base of farmable acres is planted to pest break strips. The initial Naturfarm pest break strips were five to seven beds wide (80-inch bed width) at 350 foot intervals across the farm. The layout of the strips on the farm is shown in Figure 1.

Figure 1. Layout of Pest Break Strips at the Naturfarm.
Five years of experience at the Naturfarm has provided valuable information about the design and operation of pest break strips. For example, it takes time for pest break strips to become fully effective. Alfalfa and other perennial species take time to become established due to their growth characteristics. It may take three to six months following planting for pest break strips to become established well-enough to begin strip-cutting. Initial strip-cutting for the first year may have to be staggered at greater intervals to allow plants to recover and continue their root and crown development. Thus, it is recommended that pest break strips be planted up to a year ahead of when they are needed to protect cash crops from damage.

When first setting up this system at the Naturfarm, pest break strips were newly planted right along with cash crops, and sometimes, well after cash crops were already started. As a result, insect damage on these first cash crops was often severe and typical of organic farming operations at startup. Releases of beneficial insects from a commercial insectary could not control insect damage to sub-economic levels. In the following six to nine months, there was a dramatic reduction of pest activity and crop damage. Predator and parasite species increased rapidly in pest break strips and throughout the farm. This development of effective biological control was documented by Dietrick at monthly intervals during this critical transition phase.

Some comments from Dietrick's reports after the first year are noteworthy:

- "The insect populations on the farm are at least 10 fold less this year than last, and the good bug / bad bug ratio has switched dramatically in favor of the beneficials. There are still flea beetles and cucumber beetles, but much fewer in number and they offer minimum threat to crop production at this time."

- "This biological control by natural enemies is dependable because there are so many backup systems of beneficials that help maintain this low level pest population. Take away this natural enemy complex and pest populations explode. This is what chemical addiction is all about. When the natural enemies are destroyed, there is no other recourse than to spray periodically, suppressing the pest populations with poisons until the crops are harvested."

- "Marketable crops of all kinds of vegetables are being grown without the use of any pesticides. The success of this farming system is undeniable, and it can be improved with time and management."

To be effective, pest break strips need to be located at regular intervals within the production area, not just as border strips at the field boundaries. With proper management and care, pest break strips become on-farm insectaries producing crops of beneficial species to control pests. When located directly in the production area, a pest break strip helps distribute beneficial species throughout the cash crop. When
located at the border of production fields, valuable biological control agents may be tempted to migrate out of the field and away from target pests.

In areas with a prevailing wind factor, it helps to layout out pest break strips perpendicular to the prevailing wind if possible. This orientation maximizes the pest trapping effects and facilitates distribution of beneficial arthropods to the pest crop. Intervals between strips should be between 350 and 700 feet. For the Naturfarm, with a strong prevailing westerly wind, 350 feet has proven to be an effective interval for locating pest break strips as intercrops to organic vegetable crops. As little as 5 percent of the production area may need be dedicated to pest break strips. At the Naturfarm, it was found that the economic value of the pest control agents produced in the pest break strips exceeds the lost value of potential cash crops that could have been raised in the same area. Also, the cost of growing and managing pest break strips is much less than the cost of conventional control of pests with chemical sprays. Further information on this point is reported in Section V. Results.

Pest break strips provide another function at the Naturfarm by serving as reference point beds for our permanent bed tillage system. During tillage operations, bed row marks and wheel tracks are temporarily erased in the field. Beds are then remarked by going over the last bed in the adjacent pest break strip and making a clear line for marking the field. In this way, wheel tracks and bed row marks can be reestablished very close to the original settings.

Pest break strips should be designed with strip-cutting and irrigation management in mind from the very beginning. Bed number, layout and irrigation can be coordinated for efficient management. Using odd numbers of beds, for example, means inefficient mowing operations because an extra pass to the far end of the field is inevitable with this layout. This can be overcome if pest break strips are managed in pairs and if there are even numbers of strips in fields. A better choice is to configure pest break strips in pairs of beds at the start. Four beds at 80-inch centers is a recommended minimum area for an effective pest break strip that is easy and efficient to manage. Obviously, an important design consideration is the width of the equipment that will be used to manage the bed preparation, planting, strip-cutting, insect vacuuming and irrigation operations. At the Naturfarm, all equipment is designed to work with a permanent bed system that uses 80-inch centers as a uniform standard throughout the farm. Other farms may wish to use separate equipment to manage pest break strips like forage crops and manage vegetables as row crops.

As a forage crop, alfalfa is usually flood irrigated. Irrigation schedules aim to apply water at 12-to 14-day intervals. Alfalfa can use considerable water when grown for forage, as much as 10 acre-feet per season in warm climates. At the Naturfarm, pest break strips were planted on our standard 80-inch raised beds and sprinkler irrigated.
Sprinkler irrigation was convenient, as this was the standard practice for the farm. However, growing alfalfa on raised beds and using sprinkler irrigation can cause some problems that can be eliminated by using flood irrigation. Gophers are often a problem in raised bed, sprinkler-irrigated alfalfa. Flood irrigation helps control gophers by submerging their nests and burrows. Also, sprinkler pipe dedicated to irrigating pest break strips is in demand for use on cash crops. Sometimes, the need to irrigate cash crops conflicts with the need to irrigate the pest break strips. At the Naturfarm, pest break strips are so essential to insect pest management that sprinkler pipe, valves and main line are dedicated exclusively for this purpose. Also, pest break strips are deliberately located near the risers that connect the above ground mainline with the underground 12-inch main feeder line from the pumps. This makes it convenient to water the pest break strips. For farms not using a permanent bed system, setting up pest break strips for flood irrigation is a recommended practice whenever possible. Pest break strips should always be located near a source of irrigation water where irrigation is required for crop production.

Plant Selection and Blends

The first pest break strip, planted in 1990, was a mixture of alfalfa, strawberry clover and orchard grass. In 1992, the Naturfarm switched to a commercially available insectary blend designed to attract beneficial insects. In 1994, the Naturfarm changed to a blend of alfalfa and four clovers.

The choice of plant species used in the pest break strips is arbitrary, so long as alfalfa is included as a dominant component of the mixture. Alfalfa seems to attract the most insect pests and their predators and parasites, and is the most amenable plant species for strip-cutting. It is important to select mostly perennial species for use in pest break strips. Perennials persist year round and begin growing early in spring when most needed. Annual and biennial species do not adapt well to the practice of regular mowing. Also, the ability of many annual and biennial species to attract beneficial insects is usually short-lived and may not last year-round or for the whole growing season.

The Naturfarm learned by experience that insectary blends based on annual and biennial plant species are designed for other uses and are not suitable for pest break strips. Annual and biennial plants are most attractive to beneficial species as nectar and pollen sources when they are in flower. In pest break strips, annual and biennial species usually do not complete their life cycle or produce flowers due to the strip-cutting management technique. Insectary blends may be more useful as border strips and trap crops. As border strips, they can serve as refuges and nectar sources for insect predators and parasites. As trap crops, they can be timed to draw pests away from cash crops. Trap crops can also catch and hold pests where they can be controlled by other means, such as by insect vacuums or by sprays.
Unfortunately, trap crops can also have negative impacts. At the Naturfarm, use of an insectary blend that included annual weed species such as black mustard and wild radish attracted large numbers of flea beetles. At first, the result was beneficial to nearby broccoli crops with the insectary plants serving as a trap crop for the flea beetles, thereby averting damage to the cash crops. However, as the radish and mustard completed their life cycle and went to flower, flea beetles migrated in great numbers to the broccoli crop causing considerable damage and economic loss. See Table 2 for the plant species composition of the three blends tested at the Naturfarm from 1990 to 1995.

Table 2. Plant Species Composition of Three Blends Tested for Use in Pest Break Strips at the Naturfarm (1990-1995).¹

<table>
<thead>
<tr>
<th>Blend</th>
<th>Species</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Naturfarm Blend No. 1 (1990-1992)</td>
<td>Alfalfa</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Pasture Grass</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Strawberry Clover</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Barley</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Karridale Subclover</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Common Vetch</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Yellow Sweet Clover</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Crimson Clover</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Alfalfa</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Mustard</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Wildflowers</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Herbs, Various</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Vegetables, Various</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Dutch White Clover</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Strawberry Clover</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Berseem Clover</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Crimson Clover</td>
<td>10</td>
</tr>
</tbody>
</table>

¹ All Blends Mixed at Lohse Mills, P.O. Box 168, Atrois, CA 95913.
It is useful to keep in mind that the pest break strips are similar to a livestock rearing operation because their function is to grow beneficial insect predators and parasites. Insects, like most livestock, benefit from a diet of high protein plants like alfalfa. In fact, insects grow in greater number and diversity on alfalfa than on most any other domesticated plant (University of California Statewide IPM Project, 1981). The results of two samples taken one week apart in March 1994 record the comparative abundance of insect life in a cover crop of Naturfarm Blend No. 2 (Alfalfa/Clover Mix) and in two pest break strips planted to the Beneficial Blend Mix (Annuals/Biennials Mix) as shown in Table 3.

Table 3. Comparison of Insect Counts in Beneficial Blend and Naturfarm Blend No. 2.¹ (Average of two samples, one week apart, in March 1994. Each sample consists of 50 sweeps with a standard insect sweep net.)

<table>
<thead>
<tr>
<th>Species or Group</th>
<th>Beneficial Blend Pest Break Strip 4</th>
<th>Beneficial Blend Pest Break Strip 5</th>
<th>Naturfarm Blend No. 2 Field 9/10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ants</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Aphid</td>
<td>9</td>
<td>4</td>
<td>144</td>
</tr>
<tr>
<td>Cucumber Beetle</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Flies (1/2 Benef.)</td>
<td>12</td>
<td>8</td>
<td>43</td>
</tr>
<tr>
<td>Wasps</td>
<td>6</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Lady Beetle</td>
<td>1</td>
<td>0</td>
<td>56</td>
</tr>
<tr>
<td>Leafhopper</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Caterpillars</td>
<td>2</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Lygus</td>
<td>1</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Spiders</td>
<td>3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Weevil, Alfalfa</td>
<td>1</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>Total:</td>
<td>39</td>
<td>27</td>
<td>295</td>
</tr>
<tr>
<td>Pests:</td>
<td>23</td>
<td>14</td>
<td>209</td>
</tr>
<tr>
<td>Beneficial:</td>
<td>13</td>
<td>13</td>
<td>86</td>
</tr>
<tr>
<td>Ratio: (P/B):</td>
<td>1.8</td>
<td>1.1</td>
<td>2.4</td>
</tr>
</tbody>
</table>


The data shown in Table 3 demonstrate the ability of the alfalfa/clover mixture to produce abundant crops of beneficial predators and parasites. Pests are also produced in greater numbers on the alfalfa-based mix. This is one of the paradoxes of using the pest break strip system. A primary function of the pest break strips is to produce pests in sufficient abundance to attract and feed large numbers of beneficial predators and
parasites. In this sense, larger numbers of pests in the pest break strips are desirable. Because pests as well as beneficial species are produced in the pest break strips, proper management and care are very important. Neglect of the strips can result in their becoming a liability by producing pests rather than an asset that produces beneficial natural biological control organisms.

**Economic Value and Benefit**

The economic value and benefit of pest break strips need to be recognized. Table 4 provides some indication of the dollar value of some of the beneficial arthropods produced per acre of pest break strip. It is important to note that this is only a partial list of the many important biological control agents produced in a properly managed and well-functioning pest break strip. This list is based on the data of Schlinger and Dietrick (1960) for strip-cut alfalfa and recent prices (where available) from commercial insectaries. The dollar value of the full complement of the biological control agents produced in the pest break strips is many times more than the total listed in Table 4. Many of these biological control species simply cannot be produced in commercial insectaries and are only available from natural sources. Additional dollar value must be assigned to the savings in pest control costs and the value of the cash crops that can be successfully produced using pest break strips as the principal insect pest management strategy.

**Table 4. Value in Dollars Per Acre of Some of the Beneficial Arthropods Produced in Pest Break Strips on the Naturfarm.**

<table>
<thead>
<tr>
<th>Group or Species</th>
<th>Population/Acre of Pest Break Strip (No.)</th>
<th>Individual Cost ($ U.S.)</th>
<th>Value Per Acre ($ U.S.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lady Beetle (Adults)</td>
<td>200,000</td>
<td>0.0006</td>
<td>125</td>
</tr>
<tr>
<td>Lady Beetle (Larvae)</td>
<td>232,000</td>
<td>0.025</td>
<td>5,820</td>
</tr>
<tr>
<td>Lacewing Larvae</td>
<td>206,000</td>
<td>0.003</td>
<td>5,071</td>
</tr>
<tr>
<td>Spiders</td>
<td>1,000,000</td>
<td>0.003</td>
<td>3,000</td>
</tr>
<tr>
<td>Big-Eyed Bugs</td>
<td>401,000</td>
<td>0.003</td>
<td>1,203</td>
</tr>
<tr>
<td>Parasitic Wasps</td>
<td>287,000</td>
<td>0.007</td>
<td>2,009</td>
</tr>
<tr>
<td><strong>Total Numbers and Value/ Acre</strong></td>
<td><strong>2,326,000</strong></td>
<td><strong>Aver. 0.007</strong></td>
<td><strong>17,208</strong></td>
</tr>
</tbody>
</table>
IV. Management of Pest Break Strips

In 1990, Dietrick confirmed that the vast complexes of beneficial predators and parasites of insect pests known to inhabit strip-cut alfalfa were present in the pest break strips at the Naturfarm. The principal management techniques that produced this result were simply regular irrigation and strip-cutting. Additional management techniques that were evaluated included: 1) seeding pest break strips with commercial insectary reared beneficial insects; 2) selective insect vacuuming to remove pest species and re-release beneficial species; 3) release of new species of classical biological control agents; 4) various methods of gopher control; and 5) varying plant species composition in pest break strips. These and other details of the techniques involved in managing pest break strips are discussed below.

Establishment

Refer to the guidelines given in Section III (Design and Layout). Whenever possible, pest break strips should be planted well ahead of when they are needed for pest control. Alfalfa is usually planted either in the early spring or early fall. For Naturfarm Blend No. 2, it has been our experience that early fall is the best time for planting. Spring would be next best for planting, and summer the least best. Winter plantings do not work at all. Strips can be planted with a modified grain drill, a brillion, or a specialty planter, depending on the mix and the equipment that are available. At the Naturfarm, the first plantings of pest break strips were broadcast seeded using a rotary spreader. Later plantings were drilled with a 6-foot wide Schmeizer Vineyard Drill (Great Plains, Mfg.) which provided more even-spacing than broadcast seedings.

Mowing and Strip-Cutting

Strip-cutting is best started in the spring. In a historic and definitive University of California how-to publication on strip-cutting of alfalfa for biological control of Lygus, alfalfa weevil and other pests, Stern et al. (1967) concluded that:

"Strip-cutting works best and is started most easily on the first cutting. In the spring when days are short, alfalfa is slow to go into bloom. At this season, the correct time for cutting can be determined from the new buds at the base of the plant. The first set of strips should be cut when 25 percent of the new shoots are 1/2 to 3/4 inches high. About 10 days later, the second or alternate set of strips should be cut. This will set up a harvesting differential for the second cutting . . . If the alfalfa in the adjoining strips is 6 to 8 inches tall, these females [Lygus] will drift into these plots and remain there. Shorter hay is not as attractive to these drifting Lygus. At cutting time, when the alternate strips have about 10 inches or more regrowth, all of the Lygus are driven from the cut strips to this young succulent hay."
At the Naturfarm, the alfalfa-based pest break strips are mowed at regular intervals. One of the key indicators that a stand is ready for mowing is the onset of flowering of plants in the strip. Some flowering is desirable, as this helps attract certain beneficial species. However, once seed is set and reaches the milky stage of development, pest species such as Lygus and squash bugs and others are attracted in great numbers. Furthermore, there are substances in the milky stage of seed development that induce these pests to reproduce. So, this condition is to be avoided in managing the mowing schedule of pest break strips. Usually, if half the strip is cut when flowers in alfalfa first start to appear, the second half can be cut in 10 to 14 days before too many flowers reach the milky stage of seed production. In the spring, the clovers in the mixture can be managed according to the same guidelines. These criteria will also apply to a newly planted pest break strip.

Scheduling the mowing operations in pest break strips by monitoring flowering activity in the strips is more reliable than using regular calendar intervals. Flowering activity is controlled by plant physiology and the plant's intricate response to the environment. Comparable to using temperature degree-days to predict crop maturity, using flowering activity to schedule mowing operations is linked to phenology, the study of the timing of phenomena occurring in nature as related to environmental conditions. Phenology is becoming increasingly important in IPM programs for biological control of insect pests. Today, local weather station information on degree day accumulations can be interpreted by computer software to help predict pest activities (University of California Statewide IPM Project, 1993). This information can be used to time pest control measures such as setting out monitoring traps, releasing beneficial arthropods, or other measures, such as spraying pesticides.

The first mowing of a new pest break strip will be determined by several factors including the amount of competition with weeds and the degree of maturity of the alfalfa and other desirable plants. Mowing may be necessary on occasion to allow the alfalfa to dominate the weeds. Certainly, it is recommended to mow the strips before the weeds set seed.

Once pest break strips are well-established, regular mowing of half the strip every two weeks, starting with the onset of flowering, will work well. Some farmers may be tempted to harvest the alfalfa as forage for livestock. In a mature strip, this practice is fine. However, the chopped plant material that falls and remains in the strip when it is simply mowed and not harvested for forage is an important habitat for many larvae of predatory beetles and bugs. So, again, it is useful to regard the production of beneficial predator and parasites as a livestock operation. In cases where pest break strips are strip-cut and harvested for forage, one or two cuts per season might be mowed and left in the field as a duff to increase production of beneficial insects.
Equipment that the Naturfarm has used for mowing pest break strips includes a forage chopper and a flail mower. A rotary mower would probably also work well. A sickle-bar mower would be used where the alfalfa was going to be harvested for hay; however, use of this tool for routine cutting of pest break strips has not been tried yet. One concern would be the accumulation of excessive amounts of plant material on the surface, which may act like a mulch and smother the growth of beneficial plants. This practice may be worth evaluating as it would produce a surface layer of plant material which might increase production of ground beetles and other beneficial predators.

Irrigation Methods and Practices

The Naturfarm enjoys a Mediterranean climate with a coastal influence that provides a winter rainy season which is generally frost-free, and a summer that is cool and dry. During the winter, irrigation of the pest break strips usually is not necessary if rains are normal. In dry periods during the winter, an irrigation rate of one or two inches per month is sufficient. Once the rainy season is over, regular irrigation of pest break strips becomes necessary. The goal is to maintain the plants in the pest break strip in a vegetative green and attractive condition. This is different from irrigating alfalfa for maximum production of forage. At the Naturfarm, one to two inches every two weeks is sufficient for irrigating the pest break strips. Annual water requirements are about 3 acre-feet per year per acre of pest break strips. If the strips are also being managed for forage production, irrigation requirements may more than double. The farmer must learn the amount of irrigation needed to meet the climatic requirements and production goals of the pest break strips for a particular farm and location.

Since irrigation is basic to the health and welfare of the pest break strips, all other activities need to be coordinated with the irrigation schedule. Mowing the pest break strip can alternate with the irrigation schedule, so that mowing occurs about a week after irrigation. Other activities, like insect vacuuming, releasing beneficial insects, and sampling and monitoring the pest break strips can be scheduled anytime between irrigations. It should be emphasized that irrigation and mowing are vital practices to maintaining healthy, productive pest break strips. If these two operations are attended to, most of the benefit of using pest break strips for biological control of insect pests will be realized. If they are neglected, pest break strips may not perform their desired function, and may even be a source of problems for the farmer.
Other Management Practices for Pest Break Strips

Pest break strips are designed to bring IPM strategies to a new level of effectiveness. Pest break strips are really on-farm insectaries and a new, important tool for farmers and pest control advisors. This new technique needs to be integrated with the other, older, traditional methods of biological control and IPM.

Release of Commercial Insectary-Reared Beneficial Arthropods

Today, many species of beneficial insects and mites and other organisms are reared in commercial insectaries and sold for pest control. In the first year of operation, while pest break strips were being planted and growing, release of beneficial insects provided by a commercial insectary was the mainstay of the biological pest control program at the Naturfarm. These releases were energy and cost-effective, although they did not always save the cash crop. As the pest break strips developed, some releases of beneficial insects were made directly into the strips, in addition to the target cash crops. This practice became increasingly effective as the alfalfa began to dominate in the pest break strips. Later sampling often showed the presence of not only the released beneficial species, but also related wild species that could not be insectary reared. A neighboring field with a four-year-old stand of unsprayed alfalfa was the probable local source of the wild beneficial complex that quickly developed in the new pest break strips at the Naturfarm. A rapid buildup of aphid predators and parasites was especially noted. By the summer of 1990, it was difficult to find any aphids in the insect samples at the Naturfarm. When the first crops were planted in the fall of 1989, aphids were a major pest.

The relationship between the on-farm insectaries, in the form of pest break strips, and the off-farm commercial insectary became clear as the project matured. During the critical start-up phase, the off-farm insectary was a source of crucial advice and monitoring services as well as beneficial insects. The role of the Pest Control Advisor (PCA) was as important to the success of the pest break strips as was the role of the insectary as a source of biocontrol insects. Most commercial insectaries have in-house PCA’s that can make recommendations to the farmer. Monitoring progress and problems is vital to the success of IPM. The commercial insectary is an important link in the use of pest break strips for biological control of insect pests. It is a source of beneficial species that can help to make the pest break strip system a producer of insect predators and parasites. Commercial insectaries can be a source of new species with biocontrol potential for pests, including newly-introduced or emerging pests. Commercial insectaries can augment the pest break strips, especially in the spring or in dealing with unusual outbreaks of pests.
Pest break strips, however, may also provide a new, important source of beneficial predators and parasites that can be reared or collected from the strips instead of in commercial, climate-controlled insectaries. This is very energy and cost-effective compared to the labor and energy costs of commercial facilities. Pest break strips may become a commercial source of beneficial arthropods, or even of pests themselves as a food stock for commercial insectaries. At the Naturfarm, we experimented with collecting and sorting insects from the pest break strips using the D-vac and Cycle-vac devices developed by Deke Dietrick with reasonable success.

Selective Insect Vacuuming and Re-Releasing

Deke Dietrick, Pest Control Advisor to the Naturfarm Conversion Project, introduced the idea of selective insect vacuuming into our pest management strategies at the Naturfarm. He had invented two insect sampling devices using vacuum principles to provide better representation of insect populations. One, was hand-held and known as the D-vac which could be dropped by the operator over a sample area, wherein the insects would be collected by suction into mesh bags. A series of screened bags could separate insects of various sizes by varying the mesh from large to small.

To collect larger samples of insects, Dietrick had invented the Cycle-vac. Driven by a small motorcycle, the Cycle-vac also had a separate gasoline engine that powered a squirrel-cage fan which provided suction. Insects were collected in mesh bags as the Cycle-vac was driven over the sampling area. This was a convenient method to sample a large area quickly and comprehensively. The wheel base of the Cycle-vac was 80 inches, the same width as the permanent beds used at the Naturfarm, including the pest break strips. The Cycle-vac was used to get an overview of the development of the whole complex of insects that was present in the pest break strips at any one time.

During the summer of 1990, several samples were collected from the pest break strips using the Cycle-vac. These were examined in several ways. Some samples were put in glass cages to get an overview of the whole complex of insects: predators, parasites and pests. Other samples were sorted by the D-vac and separated into various fractions based on size. It was found that the large-sized insects could be separated further by varying the vacuum in the D-vac.
The samples of small-sized insects were subsampled at random to check the ratio of beneficial insects to pests. Samples were placed in alcohol and examined under a dissecting microscope. The samples showed a good ratio of small parasites to various pests. The bulk of the small fraction was released back into the pest break strip. It was found that these methods allowed us to selectively eliminate numerous reproductive adult Diabrotica while releasing most of the beneficial predators and parasites back into the pest break strips. Thus, we developed the practice of selective insect vacuuming.

Selective insect vacuuming has great potential for future work and development. Currently, all other techniques of insect vacuuming are non-selective and destructive to both pest and beneficial insects. In this sense, insect vacuuming can be as ineffective as non-selective pesticides, indiscriminately destroying both beneficial and pest species alike. Selective insect vacuuming at the Naturfarm demonstrated that numbers of pest species could be reduced effectively without harming the beneficial complex. Considerable further research into use of selective insect vacuuming as a management tool for pest break strips would enhance the effectiveness of the pest break strip system in IPM. In addition, selective insect vacuuming can be used to harvest beneficial arthropods that can be sorted and sold to other farmers at considerable savings compared to supplies purchased from commercial insectaries.

Classical Biological Control Agents

Pest break strips make ideal habitats for rearing and releasing new introductions of classical biological control agents. When pest species are exported to a new area outside their normal range, the technique of classical biological control aims to seek out predator and parasite species from the homeland of the pests to introduce them into the new range of the pest species. Most insect pests in the U.S. are foreign introductions that came to this country hidden in crops and seed. Classical biological control has demonstrated great effectiveness in past years. Unfortunately, this method of insect pest management has been neglected since the practice of using chemical pesticides became widespread. These chemicals often affect beneficial species as well as pests and disrupt the establishment of effective biological control.
In March 1991, *Peristenus digoneutis*, a European Braconid parasite of the nymphs of the Western tarnished plant bug, *Lytus hesperus*, was made available to Deke Dietrick by the USDA for trial release. Dietrick chose a site in one of the pest break strips at the Naturfarm where alfalfa and other plants were allowed to reach the milky stage of seed development to attract large numbers of *Lytus*. This site was then covered by a screened tent, and a small number of the parasites were introduced and allowed several weeks to reproduce. After the tent was removed, the site was sampled using the D-vac. Sampling showed that the parasite survived and reproduced inside the tent in the pest break strip. Within a year, samples taken from various pest break strips all over the farm recovered specimens of the new parasite. This experience points to another role for pest break strips in IPM, i.e., as on-farm insectary strips to help establish new species for classical biological control.

**Ant Interference**

A tomato crop in the greenhouse at the Naturfarm became infested with aphids due to the action of Argentine ants that herded and protected them from predators and parasites. Ant interference can selectively remove predators and parasites when the ant species, such as the Argentine ant, is carnivorous on other insects. Predators and parasites are not only prevented from preying on the aphids, they are killed and eaten by the ants. This has a devastating effect on the beneficial insect complex, especially under greenhouse conditions. Ant interference can be prevented by disrupting ant trails and disturbing ant nests. Sticky barriers can keep them off seedling benches and can be used to protect trellised plants and pots on benches. Ant bait traps are available, with either organic or synthetic chemical poisons, which can help destroy the queens. Ant interference is one of the chief causes of failure in biological control programs. Thus, early detection and effective control are very important. In the fields, ant nests and trails are usually disrupted due to tillage operations and irrigations.

**Gopher Control**

Western pocket gophers were major pests in the pest break strips at the Naturfarm. Various control strategies were attempted. Poison baits were never used out of a concern for the safety of workers and non-target wildlife. We encouraged the activity of predators, both domestic and wild. Owl boxes were erected. Bobcats, foxes and coyotes, and many hawks and owls competed with domesticated cats and dogs in preying on gophers. In the end, simple spring-loaded traps proved to be the most
effective measure. Setting traps immediately following a close mowing would target active burrows. In addition, flood irrigation may help control gophers by drowning, or making them easier targets for predators.

Replacement and Renovation

Pest break strips, using alfalfa as the dominant plant, should last four to ten years or more before replacement or renovation is needed. Loss of stand due to gophers, insects, or disease may force an early replacement or renovation of a pest break strip. Usually, alfalfa does not follow itself in rotations due to an inhibitory effect preventing germination of alfalfa seed. This may force the farmer to move the pest break strips to new locations. At the Naturfarm, the pest break strips were renovated in their original locations rather than moving them. Between plantings, the seed mix was varied, starting with an alfalfa-based blend, followed by a cereal-based blend, followed by an alfalfa/clover mix in a rotation with about 12 to 18 months between plantings.

At the Naturfarm, pest break strips also function as internal borders for production fields. It would be inconvenient to adjust the official farm maps and field locations to accommodate moving or shifting the pest break strips. Each field contains a set number of beds that are numbered and measured. This allows very accurate tracking and planning for each bed in each field. Pest break strip beds are also the locator beds for marking the fields. However, on other farms, there may be reason to rotate areas devoted to pest break strips. Alfalfa is a soil improvement crop, and many field crops benefit from following it in rotation. Farms already using alfalfa in rotation with other crops may get the benefit of having pest break strips simply by strip-cutting and leaving part of their alfalfa unsprayed.

Management of Pest Break Strips to Enhance IPM

Pest break strips can form a vital link between the harmony and balance of nature and the need to prevent economic losses in crop production due to the activities of insect pests. IPM recognizes the inherent balance of nature and the role of natural controls in preventing damage from insect pests. One fundamental idea in Integrated Pest Management (IPM) is to use natural controls whenever possible, and to use non-selective chemical sprays only if necessary to avoid economic damage to the crop.

However, farmers face stringent grading standards that classify insect damaged products as unsalable culls. This often results in the excessive use of chemical sprays as a preventive measure. IPM is difficult to carry out because use of broad-spectrum pesticides disrupts the inherent balance of nature and natural biological controls. Thus, farmers must deal with a pesticide dilemma. The use of pesticides kills most insects, harmful and beneficial alike. More sprays are needed to control secondary pests that erupt into major pest problems due to the loss of natural biological controls.
Intensive cash-crop production practices have frequently resulted in farming "fence row to fence row." Border strips and other potential habitats that might produce effective populations of beneficial insects have been virtually eliminated with this type of farming. Monoculture production of cash grain and other basic commodity crops supported by USDA has effectively replaced the diversified plantings of rotated crops. Pest break strips can provide a stabilizing factor in today's farming systems and enhance the effectiveness of IPM. By providing crop diversity and suitable habitats, and by serving as on-farm insectaries, pest break strips can help in the control of secondary pests, and most primary pests, through natural biological control. By combining pest break strip management techniques with standard IPM practices, the farmer gains an added measure of pest control without resorting to chemical sprays. This creates a hierarchy of response measures that reflects the strength of basing pest management strategies on the inherent harmony and balance of nature.

Figure 5 shows a diagram of the hierarchy of responses to insect pest management when pest control is based on natural controls. Pest break strips, as on-farm insectaries and insect habitats, are the next step up from the natural controls available from nature at large. Pest break strips provide the on-farm site where natural control agents can live and increase, and where management techniques such as releasing beneficial predators and parasites and selective insect vacuuming can be practiced. Combined with the simple technique of strip-cutting, the pest break strip becomes the on-farm source of biological controls of insect pests. The farmer then has additional options to manage insect pests in the cash crops. Bt sprays can selectively eliminate caterpillar pests. Predatory nematodes attack many insect pests in the soil. Soap sprays kill aphids and mites. Botanicals are effective against many target pests. Biorational pesticides are becoming available where a pheromone bait may lure a target pest to its destruction. All these measures can be used before the farmer or PCA has to resort to toxic chemical sprays to save a crop or preserve its quality.
IPM based on using pest break strips, supplemented by organic pest management practices successfully produces many kinds of vegetables without using insecticides of any kind, organic or synthetic. Biological controls produced in the pest break strips and supplemented with the occasional release of beneficial insect predators and parasites, and the rare use of predatory nematodes and Bt sprays, have been the basis of insect pest management at the Naturfarm during the Naturfarm Conversion Project. The lessons learned and the results of this five-year study are now presented.

V. Results of the CEC Naturfarm Conversion Project

The CEC Naturfarm Conversion Project was conceived as a study of the transition process that would develop strategies for helping farmers in converting from conventional agricultural practices using chemical fertilizers and pesticides to organic or nature farming systems. The study focused on energy and cost savings in three components of farm management: fertility, tillage and pest control. After five years, the results of the Project show a clear energy and cost savings in the insect pest management component.

Biological Control of Insect Pests in Vegetable Crops

At the Naturfarm, seventy-five acres of diverse vegetable crops are managed without using non-selective sprays of any kind, whether organic, such as soaps and botanicals, or synthetic chemicals. The results are often acceptable to excellent. Many kinds of vegetable crops are produced without significant pest problems and attain the highest quality grading standards. Some crops are pest-free in certain seasons of the year, but come under increased pressure in the summer from Diabrotica and flea beetles. Crops in the mustard family are especially vulnerable to these two pests. The crop plan usually reduces the acreage in these susceptible crops during the period of vulnerability. This plan capitalizes on the strengths and avoids the weaknesses in certain crops at those times when pest pressures are high. The farm manager uses cultural controls, including crop variety selection, timing of operations, and crop planning, to gain the best advantage.

Table 5a lists those crops and pests that are responsive to Integrated Pest Management using pest break strips as the primary pest management technique. These crops are produced regularly at the Naturfarm without significant problems from insect pests. In 1994, for example, 8,500 boxes of lettuce were produced and sold for $97,000 without sprays of any kind applied to the crops. Lettuce, carrot, summer and winter squash, pumpkin, tomato, pepper and potato were all produced without significant pest problems in the field.
<table>
<thead>
<tr>
<th>Crops</th>
<th>Pest Species Controlled</th>
<th>Pest Break Strip Effectiveness</th>
<th>IPM Management Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lettuce</td>
<td>Aphid, Flea Beetle, Leafhopper, Leaf Miner, Looper</td>
<td>Good to excellent.</td>
<td>Good control of Aphid if strips kept in good condition; occasional release of Lady Beetle and Lacewing.</td>
</tr>
<tr>
<td>Tomato, Pepper, Potato</td>
<td>Aphid, Flea Beetle, Leaf Miner, Cutworm, Corn Earworm, Hornworm, Whitefly, Mite</td>
<td>Insect predators and parasites keep Aphid and caterpillars under control; Leafhopper and Leaf Miner prefer alfalfa in pest break strips to other hosts.</td>
<td>Aphid can erupt if ant interference is uncontrolled, other pests under good control as for lettuce.</td>
</tr>
<tr>
<td>Summer Squash, Zucchini, Yellow Scallop</td>
<td>Aphid, Cucumber Beetle (Diabrotica sp.)</td>
<td>Minor feeding damage of Diabrotica sp. does not affect yields. Other pests under good control.</td>
<td></td>
</tr>
<tr>
<td>Winter Squash, Kabocha, Butternut, Acorn, Spaghetti</td>
<td>Leafflower, Leaf Miner, Mite, Squash Bug</td>
<td>No damage.</td>
<td></td>
</tr>
</tbody>
</table>
Crops and pests with moderate to good response to Integrated Pest Management using pest break strips are listed in Table 5b. These crops may require additional pest management beyond simply maintaining the pest break strips. Releases of insect predators and parasites may be helpful at critical stages of crop growth or at various seasonal transition points. For example, aphid populations can literally "explode" in the early spring, and the local population of predators and parasites may need to be increased by releases from commercial insectaries. Caterpillar pests are usually controlled effectively with pest break strips. However, migrations from the surrounding foothills and other natural areas may increase pest pressure.

A key transition time in much of California is when the dry season comes in the late spring/early summer. This is when many pests migrate to crop fields in search of food and water. Therefore, it is important to have the pest break strips in lush condition at this critical period so pests will be attracted to the strips instead of to the cash crops. Bt, predatory nematodes and other measures may be needed to supplement pest break strips and releases of beneficial insects for the crops and pests listed in Table 5b.

In southern and central California, year-round vegetable crop production is possible. The fall-winter-spring shipping market is a major marketing window of opportunity for California vegetable producers. The coastal zone is also a primary producer of summer, cool-season vegetables, such as lettuce, broccoli and carrots. The Naturfarm is located in the southern California coastal zone near Lompoc and Santa Maria. Broccoli, cabbages, spinach, chard and beets produce well with few insect problems during the fall to spring production/marketing window at the Naturfarm. As the warm, dry summer approaches, there are more problems with insect pests for these crops. Tables 5b and 5c list the problem crops and insects for the difficult mid-summer/dry-season production period. Supplemental IPM techniques are required for these crops and pests at this time of the year. Attention to details of individual crop production and pest-control requirements can still produce maximum economic crop yields. Phenology modeling of pests may help refine IPM techniques such as releases of beneficial insects and sprays of Bt and other controls.

For commercial farmers, the decision to adopt alternative methods of pest control is closely linked with economics. New techniques, methods and substances must prove to be cost-effective, easy to set up and manage, and equally as effective at maintaining crop productivity and quality as existing chemical controls. Many producers are reluctant to change and feel they are doing a responsible job of producing food with existing methods. While this is understandable, it is also true that society and government are moving resolutely toward increasing the restrictions on the use of chemical pesticides. Eventually, the farmer must find ways of reducing his dependence on pesticides. Pest break strips can help build a foundation for IPM based on natural biological control instead of pesticides.
<table>
<thead>
<tr>
<th>Crops</th>
<th>Pest Species Controlled</th>
<th>Pest Break Strip Effectiveness</th>
<th>IPM Management Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cucumber</td>
<td>Spotted Cucumber Beetle (Diabrotica sp.)</td>
<td>Moderate to good.</td>
<td>Aphid may need releases of Lady Beetle and Lacewing.</td>
</tr>
<tr>
<td>Greens</td>
<td>Swiss Chard - Diabrotica sp.</td>
<td>Additional management needed, such as timing plantings to escape pest pressure, especially to avoid mid-summer Flea Beetle infestations.</td>
<td>Caterpillars under good control usually; may need a spray of Bt if out of control.</td>
</tr>
<tr>
<td></td>
<td>Red Chard - Flea Beetle</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spinach - Flea Beetle</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cole Crops</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Broccoli - Aphid, Flea Beetle</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cabbage - Looper</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kale - Cabbage Worm</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kohlrabi - Diamondback Moth</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Green Bean</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aphid, Diabrotica sp., Mite</td>
<td>Diabrotica sp. and Flea Beetle cause most of the problems and damage; may be controlled by botanical pesticides.</td>
<td>Predatory nematodes may be sprayed to control Diabrotica and Flea Beetle larvae in soil.</td>
</tr>
<tr>
<td></td>
<td>Red Beet</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aphid, Flea Beetle, Leaf Miner</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Snow pea</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5c. Crops and Pests with Limited Response to Integrated Pest Management Using Pest Break Strips. Additional IPM Measures Required.¹

<table>
<thead>
<tr>
<th>Crops</th>
<th>Problem Pest Species</th>
<th>Pest Break Strip Effectiveness</th>
<th>IPM Management Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summer Cole Crops and Crucifers</td>
<td>Flea Beetle</td>
<td>Massive migrations from off-farm sites during summer dry season limits effectiveness of pest break strips.</td>
<td>Predatory Nematodes may help control larval stage of flea beetle and Diabrotica sp.</td>
</tr>
<tr>
<td>Broccoli</td>
<td>Diabrotica sp.</td>
<td>Supplemental IPM measures needed to maintain pest damage at sub-economic levels.</td>
<td>Sprays of botanical pesticides may help control adult Flea Beetle and Diabrotica sp.</td>
</tr>
<tr>
<td>Cabbage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Collards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kohlrabi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mustard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turnips</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daikon</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer Red Beet</td>
<td>Flea Beetle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer Greens Spinach</td>
<td>Diabrotica sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Swiss Chard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweet Corn</td>
<td>Corn Earworm</td>
<td>Few predators and parasites available to control adult reproductive stage of these pests.</td>
<td>Trichogramma sp. releases and Bt sprays may help to control Earworm and Borer.</td>
</tr>
<tr>
<td></td>
<td>Corn Borer</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Diabrotica sp.</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flea Beetle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Energy and Cost Analysis

a. Projections at Start-up

The CEC Naturfarm Conversion Project provided a unique opportunity to study the transition process during an abrupt conversion from a conventional, chemical-based agriculture to an organic or nature farming system. A projection of energy and cost savings for the organic or nature farming system compared with conventional agricultural practices was based on the experiences of an earlier study known as the Camarillo Naturfarm Project as outlined in the project proposal to the California Energy Commission (NFRDF, 1988). Two models were constructed, one for nature farming and one for conventional agriculture, which compared these two systems of farming with respect to energy and costs for tillage, fertility and pest control. The data for the Nature Farming Model was based on the farm records of the Camarillo Naturfarm. The data for the Conventional Farming Model was based on published information from the University of California Cooperative Extension Service (Brendler, 1983), the University of Arizona Cooperative Extension Service (Olson and Horel, 1981), and the Handbook of Energy Utilization in Agriculture (Pimentel, 1980).

The results of this analysis are summarized in Table 6 for the Conventional Farming Model and the Naturfarm Model. In Table 6, labor hours, equipment hours and input supplies are converted to gallons of diesel equivalents for the purpose of comparing energy use in the two farming systems. The costs are the dollar costs of labor and equipment hour charges plus the cost of materials. The two farming systems are compared for three components of farm operations: tillage, soil fertility, and pest control.

The system of farming practices is very different for the two models. For example, the Naturfarm system used a "permanent bed" minimum tillage system, while the Conventional Model assumed standard tillage practices including diskin, plowing and planing, bed-marking and shaping for each crop. Soil fertility for the Naturfarm Model was based on growing cover crops and using compost. For the Conventional Model, soil fertility was provided by chemical fertilizers. In the analysis presented in Table 6, pest management energy and costs were the total for weed control, disease control and insect pest management. Insect control in the Naturfarm Model assumed use of typical organic methods, including releases of beneficial insects reared in commercial insectaries combined with application of "soft pesticides" like Bt, soap, and botanicals. The Conventional Model assumed the use of chemical sprays for weeds, diseases and insect pests. Table 6 shows the projected energy and cost savings in all three components of tillage, fertility and pest control for the Naturfarm Model compared with the Conventional Model. Based on a model farm of 60 crop-acres, the new Naturfarm in Lompoc, California projected a sizable dollar savings by using nature farming methods compared with conventional methods as shown in Table 7.

<table>
<thead>
<tr>
<th>Model/Component</th>
<th>Labor (Hrs.)</th>
<th>Equipment (Hrs.)</th>
<th>Supplies (Lbs.)</th>
<th>Fuel (Gal.)</th>
<th>Cost ($ U.S.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tillage</td>
<td>2.00</td>
<td>2.00</td>
<td></td>
<td>17.00</td>
<td>53.15</td>
</tr>
<tr>
<td>Fertility</td>
<td>0.44</td>
<td>0.44</td>
<td>356.00</td>
<td>35.69</td>
<td>193.30</td>
</tr>
<tr>
<td>Pests</td>
<td>22.18</td>
<td>1.18</td>
<td>10.32</td>
<td>13.88</td>
<td>408.11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>24.62</strong></td>
<td><strong>3.62</strong></td>
<td><strong>366.32</strong></td>
<td><strong>66.57</strong></td>
<td><strong>654.56</strong></td>
</tr>
</tbody>
</table>

| Natufarm       |              |                  |                 |             |               |
| Tillage        | 2.19         | 2.06             |                 | 7.28        | 40.72         |
| Fertility      | 2.51         | 1.26             | 6,000           | 19.41       | 156.10        |
| Pests          | 34.06        | 1.67             | 10              | 6.40        | 317.37        |
| **Total**      | **38.76**    | **4.99**         | **6,010**       | **33.09**   | **514.19**    |

Table 7. Model of a 60-Acre Natufarm: Cost Savings ($) per Year.

<table>
<thead>
<tr>
<th></th>
<th>Tillage</th>
<th>Fertility</th>
<th>Pest</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>53.15</td>
<td>193.30</td>
<td>408.11</td>
<td>654.56</td>
</tr>
<tr>
<td>Natufarm</td>
<td>40.72</td>
<td>156.10</td>
<td>317.37</td>
<td>514.19</td>
</tr>
</tbody>
</table>

Savings/Crop-Acre

|                | 12.43   | 37.20    | 90.74   | 140.37 |

Summary: $140.37 (Savings/Crop-Acre) x 2 (Crops/Year) = $280.74 (Savings/Crop-Acre/Year) x 60 Acres = $16,844.40 per Year.
b. Interim Results

In 1992, the interim results of the CEC Naturfarm Conversion Project at the Naturfarm in Lompoc, California were calculated. Actual energy use at the Naturfarm for various farm operations was measured using Fluidyne fuel flow meters on one of the tractors. Fuel use for each farm operation for each crop enterprise was also calculated from farm records. These values were compared with an updated model of conventional agriculture which was derived from information supplied by County Extension personnel, farm advisors, custom farm services and other sources (Brendler, 1990; UCCES, 1990; Daugherty and Wade, 1990; Pimentel, 1980). The values obtained using the fuel flow meters are presented in Table 8.


<table>
<thead>
<tr>
<th>Field Operation</th>
<th>Fuel Use (Gallons/Hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layout Beds</td>
<td>0.78</td>
</tr>
<tr>
<td>Mow Residue</td>
<td>1.33</td>
</tr>
<tr>
<td>Sub-Soil</td>
<td>1.35</td>
</tr>
<tr>
<td>Chisel Plow</td>
<td>1.49</td>
</tr>
<tr>
<td>Disk</td>
<td>1.19</td>
</tr>
<tr>
<td>Rototill</td>
<td>1.48</td>
</tr>
<tr>
<td>Flat Harrow</td>
<td>0.97</td>
</tr>
<tr>
<td>Spike Harrow</td>
<td>1.23</td>
</tr>
<tr>
<td>Shape Beds</td>
<td>1.05</td>
</tr>
<tr>
<td>Plant</td>
<td>0.61</td>
</tr>
<tr>
<td>Spread Compost</td>
<td>0.72</td>
</tr>
<tr>
<td>Spray Foliar and Microbials</td>
<td>0.91</td>
</tr>
<tr>
<td>Cultivate</td>
<td>0.40</td>
</tr>
</tbody>
</table>

Using the values in Table 8, and the energy, cost and yield data for four different crops, the Naturfarm Model was compared with the Conventional Agriculture Model based on 1991-92 crop performance data at the Lompoc Naturfarm and the updated conventional model. The four crops chosen for this comparison were carrot, leaf lettuce, summer squash and sweet corn. This data is presented in Figures 6-9.

Figure 6 shows that for carrots, the cost of tillage, fertility and pest control was lower for the Naturfarm method, while cost of weed control was significantly higher. Yields were much lower for Naturfarm due to a combination of low fertility, high weed pressure and reduced plant density per acre as the result of planting only four rows per eighty-inch bed. Income was much closer than the low yields would predict due to the premium price for organic carrots.

Fertility and weed control costs were higher for leaf lettuce produced at the Naturfarm in 1991-92 compared to norms for conventional farming practices, as shown in Figure 7. However, tillage costs and insect pest control costs were significantly less for the Naturfarm method. The lower cost for insect pest management, due to pest break strips, helped to offset the fertility and weed control costs and resulted in nearly identical total costs. Reduced yields are typical of the early transition stage of conversion from conventional to organic farming practices, and this fact is reflected in the comparative yields for Naturfarm and conventional leaf lettuce. Again, the organic premium price helped offset the lower yields so that the gross income per acre was only slightly lower for Naturfarm lettuce compared to conventionally-grown lettuce.

In 1991, tillage, fertility and weed control costs were all significantly higher for Naturfarm summer squash than for conventional farming practices as shown in Figure 8. Pest control was significantly less for the Naturfarm system using pest break strips. Although yields were less and total costs were more, gross income per acre was nearly identical for the two systems due to the organic premium price. It is likely that gross income will increase for the Naturfarm over time as fertility, tilth and weed control are improved.

Again as with summer squash, the tillage, fertility and weed control costs were significantly higher for the Naturfarm sweet corn than for conventional farming as seen in Figure 9. However, yields of sweet corn were greater for the Naturfarm. Total costs were nearly double for organically-grown sweet corn, but gross income was nearly the same as conventionally-grown corn due to the unusual fact that organic sweet corn does not command a premium price.

The interim results show the basic differences between the Nature Farming System in the early stages of the transition process compared with the Conventional Farming System Model. In this stage of transition, as new practices and different kinds of inputs are introduced, yields are usually lower for organic agriculture than for conventional agriculture and costs are higher, especially for weed control. Income is usually compensated by a higher average price per unit for organic compared with conventional produce. As the system improves and matures, yields will likely increase and costs will decrease for the Nature Farming System. Also, it is noteworthy that, even at this early stage of transition, the Nature Farming System consistently exhibited considerable cost savings compared with the Conventional Model with respect to insect pest control. In addition, the Nature Farming System was invariably more energy efficient compared to the Conventional Farming Model for the production of carrots, lettuce, summer squash and sweet corn as shown in Figures 10-13.
Figure 10. Carrot: Energy Use for Various Operations in Gallons of Diesel Equivalents per Acre for Carrot Production in 1991 at the Naturfarm Compared with Conventional Farming Practices.

Figure 12. Summer Squash: Energy Use for Various Operations in Gallons of Diesel Equivalents per Acre for Summer Squash Production in 1991 at the Naturfarm Compared with Conventional Farming Practices.

Figure 13. Sweet Corn: Energy Use for Various Operations in Gallons of Diesel Equivalents per Acre for Sweet Corn Production in 1991 at the Naturfarm Compared with Conventional Farming Practices.
The actual energy expenditures for farm operations in terms of the diesel fuel equivalents (i.e., conversion of input costs per acre to the equivalent gallons of diesel fuel per acre) needed to produce the same four crops (Figures 6-9) at the Naturfarm compared with the Conventional Farming Model have been shown in Figures 10-13. In general, the energy required to provide fertility and pest control, tillage and weed control was considerably higher for the Conventional Farming Model compared with the Naturfarm System.

As shown in Figures 10-13, the total energy required in the production of carrot, leaf lettuce, summer squash and sweet corn for the Conventional Model was the equivalent of 150, 15, 60 and 79 gallons of diesel fuel per acre, respectively. In the Naturfarm System, these same crops were produced with the equivalent of only 19, 36, 25 and 29 gallons of diesel fuel per acre, respectively. Thus, the production of carrot, leaf lettuce, summer squash and sweet corn by the Naturfarm System resulted in a savings of 87, 66, 58 and 63 percent, respectively, when compared to the energy expended in producing these crops in a chemical-based farming system. Such a dramatic conservation of energy can be attributed mainly to:

- Savings in nitrogen fertilizer costs as a result of biological nitrogen fixation by the green manure/legume cover crops in the fertility component.
- Savings in energy use for pest control as a result of biological control of insects by the pest break strips.
- Reductions in energy use for tillage as a result of using a controlled-traffic, "permanent bed," minimum-tillage system.
- Energy savings resulting from the elimination of herbicides for weed control.

c. Final Project Results

The final project results also indicate that the use of pest break strips are a very cost-effective and energy efficient alternative to conventional insect pest management using chemical sprays. In an updated model comparing energy and costs for three annual vegetable crop rotations that might be used by local area farmers, the Naturfarm System, using pest break strips, again proved to be cost-effective and energy efficient. As before, conventional data provided by farm advisors and other recognized authorities was used to construct a model of conventional pest control to compare with the Naturfarm System (UCCES, 1994; Pimentel, 1980). In our final model, we included cost and energy requirements for establishing and maintaining the pest break strips. We also included cost and energy requirements for providing beneficial insects from a commercial insectary. These costs were compared with the conventional practice of using recommended chemical pesticide sprays.
The three crop rotations were:

1. Continuous leaf lettuce - four crops per year.
2. Broccoli, carrot, carrot.
3. Broccoli, sweet corn, fall leaf lettuce.

The results of this energy and cost analysis are presented in Table 9. This analysis of the data shows that the energy costs are reduced, and dollar costs per acre per year for insect pest management are very significantly reduced for the IPM system using pest break strips compared with conventional controls using chemical sprays. Based on five years of experience using pest break strips at the Natufarm, we conclude that this technique is worth trying by farmers who are interested in reducing operating costs and energy consumption for insect pest management. Commercial farmers who give this method a fair and objective evaluation will probably be rewarded with positive results.

<table>
<thead>
<tr>
<th>Rotation:</th>
<th>Energy Cost ($10^6$ BTU)</th>
<th>Cost ($\ $ U.S./Acre/Year)</th>
<th>Savings for Natufarm System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1: Leaf Lettuce 4x</td>
<td>20.75</td>
<td>875</td>
<td></td>
</tr>
<tr>
<td>Naturfarm</td>
<td>17.27</td>
<td>122</td>
<td>17</td>
</tr>
<tr>
<td>2: Broccoli, Carrot 2x</td>
<td>13.74</td>
<td>190</td>
<td></td>
</tr>
<tr>
<td>Naturfarm</td>
<td>12.34</td>
<td>87</td>
<td>10</td>
</tr>
<tr>
<td>3: Broccoli, Corn, Lettuce</td>
<td>13.92</td>
<td>510</td>
<td></td>
</tr>
<tr>
<td>Naturfarm</td>
<td>11.72</td>
<td>83</td>
<td>16</td>
</tr>
</tbody>
</table>

Table 9. Energy and Cost Comparison for Insect Pest Management for Three Annual Vegetable Crop Rotations Using Conventional Pesticides Compared with the Natufarm System with Pest Break Strips.\(^1\)

VI. Recommendations

Based on more than five years of successful testing of the pest break strip system as an Integrated Pest Management strategy for a seventy-five-acre organic vegetable farm that converted from a former conventional agriculture operation, we are confident in recommending this method to other farmers. Pest break strips can be a useful tool, not only for organic producers, but also for conventional farmers wishing to reduce their use of pesticide chemicals while adapting IPM methods to their operations. The advantages of this method include increased biological stability leading to more effective IPM and reduced energy consumption and operating costs.

The following recommendations may be helpful to those farmers who are interested in using pest break strips for insect pest management:

1. Pest break strips should be managed as on-farm insectaries producing cash crops of beneficial insects to control insect pests. As with any other farming enterprise, a businesslike approach, with proper management and attention to detail, is essential for success. Cost savings for insect pest management can be realized by using pest break strips with other IPM methods. A positive attitude may be the most important factor contributing to the farmer’s success.

2. If possible, anticipate the use of pest break strips in advance and phase them into the operation gradually. Plant strips and have them established and on-schedule with regular strip-cutting before they are actually needed for insect pest management. Use supplemental methods in the first year of operation such as soft pesticides. During the transition period, avoid chemical treatments in pest break strips unless monitoring clearly shows a dire need to spray. Use alternatives to chemical sprays when possible and phase-out non-selective pesticides as early as feasible.

3. Set pest break strips up for flood irrigation if possible. This will help control gophers. If flood irrigation is not possible, use traps and other measures to control gophers.

4. Use alfalfa as the dominant plant species in the mix planted in the pest break strip. Manage pest break strips as for strip-cut alfalfa.

5. Once established, pest break strips need regular irrigations and mowing. Pay attention to these needs and do not neglect the strips. However, the pest break strip is a resilient and flexible system. Irrigation and mowing schedules can be adjusted to fit operations in adjacent cash crops.
6. Integrate pest break strips with other IPM practices. Emphasize options and methods that favor beneficial insects. During critical outbreak periods, use releases from commercial insectaries to supplement the insect predators and parasites raised in the pest break strips. Use soft pesticides with selective activity on cash crops. Spray only when monitoring shows that it is really necessary.

7. Farm management decisions greatly influence pest pressure and the need for controls. Whenever possible, use resistant plant varieties. Target production windows for times with reduced pest activity. Use cultural controls wisely, such as timely incorporation of crop residues as soon as the crop is harvested. Monitor and treat hot spots, especially ends of rows and rows next to field borders, including rows next to pest break strips.

8. Crop and pest response to pest break strips varies because some crops and their pests are easier to manage than others. Try working with an easy crop first, like lettuce. Move on to more difficult crops after gaining experience. Work with a qualified Pest Control Advisor who supports your program and goals.

**VII. Summary**

Pest break strips represent a new IPM strategy for farmers who want to introduce biological stability into their pest management programs. Pest break strips may represent the missing piece of the puzzle of how a farmer can take advantage of the enormous potential of the biological controls that exist in nature. Beneficial insects, spiders, mites, and other natural enemies of insect pests can be used to considerable advantage by the farmer with this simple technique. Experience, research and study at the Naturfarm in Lompoc, California shows that pest break strips are energy-efficient, cost-effective, and field-proven alternatives to pesticides for many vegetable crops. This tool can be recommended to farmers genuinely interested in exploring alternatives to pesticide-based insect pest management. There is still much work that should be done to refine this technique to adapt it to commercial production for various crops, climates and soils. Nevertheless, the authors are confident that the proper application of pest break strip system technology will introduce a new dimension to Integrated Pest Management of harmful insects for a wide variety of crops in many different agroecosystems.
References


University of California Cooperative Extension Service, 1990. Projected Production Costs for Vegetable Crop Production in Imperial County, California. Sweet Corn, Broccoli and Lettuce. Imperial County Cooperative Extension Service, El Centro, California.


University of California Statewide IPM Project, 1993. MS-DOS and Macintosh Computer Software for Integrated Pest Management. 3.5 and 5.25 Media Available. U.C. ANR Publications. Available from Statewide IPM Project, University of California, Davis, California.