INFORMATION TO USERS

This reproduction was made from a copy of a manuscript sent to us for publication and microfilming. While the most advanced technology has been used to photograph and reproduce this manuscript, the quality of the reproduction is heavily dependent upon the quality of the material submitted. Pages in any manuscript may have indistinct print. In all cases the best available copy has been filmed.

The following explanation of techniques is provided to help clarify notations which may appear on this reproduction.

1. Manuscripts may not always be complete. When it is not possible to obtain missing pages, a note appears to indicate this.

2. When copyrighted materials are removed from the manuscript, a note appears to indicate this.

3. Oversize materials (maps, drawings, and charts) are photographed by sectioning the original, beginning at the upper left hand corner and continuing from left to right in equal sections with small overlaps. Each oversize page is also filmed as one exposure and is available, for an additional charge, as a standard 35mm slide or in black and white paper format.*

4. Most photographs reproduce acceptably on positive microfilm or microfiche but lack clarity on xerographic copies made from the microfilm. For an additional charge, all photographs are available in black and white standard 35mm slide format.*

*For more information about black and white slides or enlarged paper reproductions, please contact the Dissertations Customer Services Department.

UMI University Microfilms International

8612615

Rosset, Peter Michael

ECOLOGICAL AND ECONOMIC ASPECTS OF PEST MANAGEMENT AND POLYCULTURES OF TOMATOES IN CENTRAL AMERICA

The University of Michigan PH.D. 1986

University
Microfilms
International 300 N. Zeeb Road, Ann Arbor, MI 48106

Copyright 1986

by

Rosset, Peter Michael

All Rights Reserved

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark __✓__.

1. Glossy photographs or pages _____
2. Colored illustrations, paper or print _____
3. Photographs with dark background _____
4. Illustrations are poor copy _____
5. Pages with black marks, not original copy _____
6. Print shows through as there is text on both sides of page _____
7. Indistinct, broken or small print on several pages __✓__
8. Print exceeds margin requirements _____
9. Tightly bound copy with print lost in spine _____
10. Computer printout pages with indistinct print _____
11. Page(s) _____ lacking when material received, and not available from school or author.
12. Page(s) _____ seem to be missing in numbering only as text follows.
13. Two pages numbered _____. Text follows.
14. Curling and wrinkled pages _____
15. Dissertation contains pages with print at a slant, filmed as received _____
16. Other _____

_____

_____

University
Microfilms
International

ECOLOGICAL AND ECONOMIC ASPECTS OF PEST MANAGEMENT AND POLYCULTURES OF TOMATOES IN CENTRAL AMERICA

by

Peter Michael Rosset

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Biological Sciences)
in The University of Michigan
1986

Doctoral Committee:

Professor John Vandermeer, Co-Chairperson
Assistant Professor Beverly Rathcke, Co-Chairperson
Professor Brian Hazlett
Professor Warren Wagner, Jr.
Professor John Witter

RULES REGARDING THE USE OF

MICROFILMED DISSERTATIONS

Microfilmed or bound copies of doctoral dissertations submitted to The University of Michigan and made available through University Microfilms International or The University of Michigan are open for inspection, but they are to be used only with due regard for the rights of the author. Extensive copying of the dissertation or publication of material in excess of standard copyright limits, whether or not the dissertation has been copyrighted, must have been approved by the author as well as by the Dean of the Graduate School. Proper credit must be given to the author if any material from the dissertation is used in subsequent written or published work.

© Peter Michael Rosset 1986
All Rights Reserved

For my parents

and for the people of Nicaragua

ACKNOWLEDGEMENTS

Many people helped me in many ways, too numerous to list, over the last six years. It is your contributions that more than anything else have made this work possible. I wish to thank all of you from the bottom of my heart: Bob Ambrose, Pam Anderson, Dave Andow, Rodolfo Araya, Elia Arce, Rosa Argentina, Liana Babbar, Mario Baudoin, David Bay, Francisco Berrios, Doug Boucher, Judie Bronstein, Judy Butler, Alberto Camacho, Mayra Cano, Julio Castillo, Primo Luis Chavarría, Joe Collins, Bayardo Conrado, Tim Coone, Rainer Daxl, Lu Deakin, Ismael Diaz, Chip Downs, Laura Enriquez, Mary Ferguson, Gary Fowler, Ursula Freimarck, Jorge Góngora, Anselmo Gonzalez, Fred Gould, Galio Gurdian, Andy Gutierrez, Mike Hansen, Brian Hazlett, Carsten Hellpap, Jesús Hernández, Alan Hruska, Michael Jody, Benita Kaimowitz, David Kaimowitz, Peter Kareiva, Ligia Lacayo, Amanda Lara, Fiona MacIntosh, Hugh McGuinness, Alain Meyrat, Julio Monterrey, Shelley Moscowitz, Doug Murray, Mario López, Pascual López, José Miguel Obando, Rafael Obando, Roxanna Ortiz, Jeff Paige, Ivette Perfecto, Cruz Phillips, Ken Pohronezny, Sunny Power, Juan Ramirez, Beverly Rathcke, Steve Risch, Gene Rosenberg, Laurie Russman, Kathy Savoie, Brian Schultz, Bayardo Serrano, Ann Snook, John Steggall, Claude Steiner, Sean Swezey, Flor Torres, Enrique Tovar, Eliseo Ubeda, Peter Utting, John Vandermeer, Hans van Kuyck, Gregorio Varrela, Herb Wagner,

Lynn Walker, Mark Weisbrot, Tom Will, John Witter, Katherine Yih, Michael Zalkan and Larry Zwiebel.

I also wish to thank the workers at the Sébaco Valley Experiment Satation and at the Fabio Baudrit Experiment Station for their assistance in maintaining my experiments.

The Ministry of Agrarian Reform and Agricultural Development (MIDINRA) of Nicaragua, the members of the Luciano Vilchez Agricultural Cooperative, the University of Michigan and the Organization for Tropical Studies all supplied logistical support and the use of their facilities. Funding was provided by the National Science Foundation, the Organization of American States, the Jessie Smith Noyes Foundation and the University of Michigan.

TABLE OF CONTENTS

DEDICATION.....ii

ACKNOWLEDGEMENTS.....iii

LIST OF FIGURES.....vii

LIST OF TABLES.....x

CHAPTER

1. ECONOMIC DEVELOPMENT, AGRICULTURAL ECOLOGY, AND INTEGRATED PEST MANAGEMENT: TOMATOES IN NICARAGUA.....1

    Introduction
    Economic Development in Nicaragua
    Ecology and Development: the need for IPM
    The Economics and Ecology of Tomatoes in Nicaragua
    Literature Cited

2. SAMPLING METHODS, YIELD REDUCTION, AND ECONOMIC INJURY LEVELS FOR THE COTTON WHITEFLY, *Bemisia tabaci* Gennadius, ON TOMATOES IN NICARAGUA.....32

    Introduction
    Materials and Methods
    Results
    Discussion
    Literature Cited

3. YIELDING PROPERTIES OF POLYCULTURES OF TOMATO AND BEAN IN COSTA RICA 68

    Introduction
    Materials and Methods

Results
Discussion
Literature Cited

4. EVALUATION OF A TOMATO AND BEAN POLYCULTURAL CROPPING SYSTEM AS A COMPONENT OF THE INTEGRATED PEST MANAGEMENT OF TOMATOES IN NICARAGUA 84

Introduction
Materials and Methods
Results
Discussion
Literature Cited

5. LARGE SCALE VALIDATION OF PEST POPULATION SUPPRESSION IN A POLYCULTURE OF TOMATOES AND BEANS 117

Introduction
Materials and Methods
Results and Discussion
Literature Cited

6. BEANS AS A TRAP CROP TO PROTECT TOMATO SEEDLINGS FROM ATTACK BY *Spodoptera sunia* Guenée (Lepidoptera: Noctuidae) 128

Introduction
Materials and Methods
Results and Discussion
Literature Cited

7. GENERAL CONCLUSIONS 138

LIST OF FIGURES

CHAPTER 1

Figure

1. Schematic outline of the Nicaraguan economy 16

2. Prices of principal Nicaraguan export crops, 1974-84 17

3. Price of imported tractors averaged over three year periods 18

4. Volume, dollar value and price of insecticide imports, 1968-84 19

5. Dollar value of agricultural exports, and imported inputs for agriculture as a percentage of exports, 1969-1984 20

6. Relationship of terms of trade (goods), 1970=100 21

7. Annual food imports to Nicaragua, 1969-1978 22

8. Area planted to tomatoes by region as percent of total tomato area, and average yields, 1983-84, and map of the Regions of Nicaragua 23

9. Percent of total area planted to tomatoes by organization of production, 1982-83 24

10. Average tomato yields by organization of production, 1982-84 25

11. Area planted to tomatoes by month, 1982-84, with mean 26

12. Monthly production of tomatoes, 1982-84, with average 27

13. Monthly fluctuations in wholesale tomato price 1981-82 28

14. Phenology of tomatoes and tomato pests in Nicaragua 29

CHAPTER 2

Figure

1. Population dynamics of Bemisia tabaci adults on basal leaflets during the growing season in six treatments 59

2. *Bemisia tabaci* numbers in pooled treatments: with and without synthetic insecticides toxic to it 60

3. Regression of final yield in kg against whitefly density at 43 DAP as estimated by the apical sampling method 61

4. Regression of final tomato yield in kg against whitefly density at 43 days after planting as estimated by the basal sampling method 62

5. Regression of % final yield loss (weight) against whitefly density at 43 DAP as estimated by the basal sampling method 63

CHAPTER 4

Figure

1. Population dynamics of *Liriomyza sativae* on tomatoes as estimated by the number of active mines on the the fourth fully expanded compound leaf from the top of the plant 106

2. Population dynamics of *Heliothis spp.* on tomatoes as estimated by the number of damaged fruit per 20 plants 107

3. Population dynamics of *Spodoptera spp.* on tomatoes as estimated by the number of damaged fruit per 20 plants 108

4. Percent tomato fruit infected with bacterial spot, and number of fruits per tomato plant 109

5. Percent tomato plants with symptoms of *Fusarium* wilt 110

6. Percent survivorship of tomato plants 111

7. Relative Value Total (RVT) of the polyculture at different tomato prices 112

CHAPTER 5

Figure

1. Damage by *Heliothis spp.* on tomatoes in monoculture and polyculture 126

2. Damage by *Spodoptera spp.* on tomatoes in monoculture and polyculture 127

LIST OF TABLES

CHAPTER 1

Table

1. Indicators of external financial dependence in Nicaragua: 1975-84 30

2. Estimated crop budget for 1 manzana of tomatoes in Nicaragua: 1983-84 31

CHAPTER 2

Table

1. Correlation matrix of final tomato yields and *Bemisia tabaci* numbers over the season for apical sampling method 64

2. Correlation matrix of final tomato yields and *Bemisia tabaci* numbers over the season for basal sampling method 64

3. Final yields (kg and numbers) of tomatoes and *Bemisia tabaci* numbers (number per 4 leaves over twelve plants) from the basal sampling method at 43 DAP 65

4. Final yields (kg and numbers) and whitefly numbers (number per 4 leaves over twelve plants) from the basal sampling method at 43 DAP, for pooled treatments (with and without insecticides) 66

5. Economic Injury Level (EIL) for *Bemisia tabaci* on tomatoes in Nicaragua in 1983 67

CHAPTER 3

Table

1. Treatments used in the experiments 82

2. Relative yields obtained in the experiments 82

3. Tomato yields (kg/ha) obtained in the experiments 82

4. Bean yields (kg/ha, 15% moisture) obtained in the experiments 83

5. Virus levels on tomato found in the experiments 83

6. Percentage tomato plants with aphid colonies 83

CHAPTER 4

Table

1. Soil characteristics at the Sébaco Valley Regional Experiment Station, near San Isidro, Matagalpa, Nicaragua 113

2. Absolute and relative yields (kg/ha) of polycultures and monocultures, and land equivalent ratios (LERs) 114

3. Percent tomato fruits rejected at harvest by category of damage, in polyculture and monoculture 115

4. Mean number of root nodules per bean plant 116

CHAPTER 6

Table

1. Number of larvae of *Spodoptera sunia* per 100 seedlings in polyculture and monoculture 136

2. ANOVA table, 3 X 5 X 2 factorial, Crop (Tomato in monoculture, tomato in polyculture, beans in polyculture) X Person X Block, with orthogonal comparisons 137

CHAPTER 1

ECONOMIC DEVELOPMENT, AGRICULTURAL ECOLOGY, AND INTEGRATED PEST MANAGEMENT: TOMATOES IN NICARAGUA

Introduction

In this dissertation I describe a program that I have developed for the Integrated Pest Management (IPM) of tomatoes in Nicaragua and other Central American countries with similar agricultural ecosystems and economic problems. In this first chapter I present the rationale and need for such a program, based on an analysis of economic development and agricultural ecology, and on the interaction between the two.

The organization of the chapter is as follows: first is a brief overview of economic development in Nicaragua, with particular attention to the role of agriculture in that development. The question of agricultural technology is viewed as both an economic and an ecological issue, focussing on pesticides and IPM. Next, I survey the tomato industry in Nicaragua, the arena in which the subsequent research must be viewed. Finally, I give an overview of the ecology of tomatoes in Nicaragua, and the need for IPM for that crop.

Economic Development in Nicaragua

Structural Weakness of the Economy: The history of Nicaragua since the Spanish conquest has been a history of the development of a dependent, underdeveloped economy, oriented first toward the export of raw materials and primary agricultural commodities, and later also toward assembly-type, import substitution industry (Molina, 1977; Nuñez, 1978; Castillo, 1980; Wheelock, 1980, 1985; Biderman, 1982, 1983; Weeks, 1985). In this chapter I will not review that history, but rather confine myself to a presentation of the economy inherited by the new government from the Somoza dynasty in 1979, and the development model that the Sandinista-led government has followed since that time.

The concept of a disarticulated economy within the center-periphery structure of the world capitalist economy, as developed by de Janvry (1981), is an analytical tool particularly well suited to understanding the Nicaraguan economy, and how agricultural development and technology fit in. Three distinct sectors of the Nicaraguan economy can be distinguished through such an analysis (Figure 1). By 1979 the agroexport sector was dominated by *latifundio*-style production of cotton and coffee, followed by beef and sugar. (Figure 2). The traditional agricultural sector consisted of peasant production of corn, beans and sorghum, the staples (with rice) of the Nicaraguan diet. The industrial sector first became a significant part of the economy in the 1960s through investment stimulated by the Central American Common Market and the Alliance for Progress (Molina, 1977; Castillo, 1980; Wheelock, 1985). Production in this sector was dominated by assembly industries.

The "modern sector" of the economy, comprised of commercial agriculture and industry, has a major weakness: its external dependence at every point. Commercial agriculture depends on imported inputs, including farm machinery, irrigation equipment, fertilizer and pesticides. At the same time it is dependent on external markets for the commodities it produces, except for a small, urban internal market. This makes the economy vulnerable to fluctuations in the prices of the inputs and the exports, both of which are beyond national control.

The prices of agricultural inputs, such as tractors (Figure 3) and insecticides (Figure 4), have tended to rise during the past two decades. At the same time the prices of Nicaragua's principal agricultural exports have stagnated since the mid-seventies, creating a growing foreign exchange crisis. The total dollar value of agricultural exports has declined since 1977, while the value of inputs has risen since 1976 (Figure 5). The relationship between the price of exports and the price of imports is given by the terms of trade, which have declined precipitously since the late seventies (Figure 6). By 1984 a unit of Nicaraguan exports was worth only 62% of a unit of 1970 exports, in terms of the power to purchase imports (CEPAL, 1985; Figure 5).

The situation has been much the same in the industrial sector, which is also dependent on externally determined prices. This sector is specialized in light manufacture, particularly the final assembly of imported components (Castillo, 1980). Industries of this type in Nicaragua include textiles, beverages, leather goods, rubber, plastics and chemicals (CEPAL, 1985). The value of the exports of these products has always been less than the value

of the imported components[1], partially because some production has gone to the small internal market, but also because of the high cost of imported components and capital goods (Castillo, 1980).

Another key structural weakness in the economy is the lack of linkage, or articulation, between the agricultural and industrial sectors. The case of cotton and textiles is a good example of this. While cotton is one of Nicaragua's two major exports, and textiles one of the major industries, historically cotton was not processed into thread within the country (Collins, 1985). Rather ginned cotton was exported, thread and fabric were then imported, and clothing produced under sweatshop conditions was reexported. In the complete production process from agricultural inputs through clothing, only two low value-added steps occurred in Nicaragua: farming and sweatshop tailoring. The capital intensive, high value-added steps, production of petrochemical inputs and machinery, processing of cotton, and marketing of clothing, took place outside the country. The result has been a poor rate of capital accumulation on a national level (Wheelock, 1985).

A further problem arose from the expansion of commercial agriculture, which pushed peasant producers off fertile land and onto increasingly marginal soils, at first gradually and then rapidly during the cotton boom of the sixties and seventies (Paige, 1984; Biderman, 1982). The result was stagnation in national food production, which is based in the traditional sector, and thus an increasing dependence on imports (Figure 7). These imports were subsidized through concessionary aid from United States during the Somoza era, and have become a critical point of vulnerability for

[1]Banco Central de Nicaragua. Departamento de Estudios Económicos. Boletines Trimestrales.

the current Sandinista-led government since the Reagan Administration suspended aid in 1980 (Barry et al., 1983).

In the late seventies and early eighties crises in all sectors of the economy led to the present-day debt crisis. Agriculture and industry were both caught in the crunch of a downturn in the terms of trade, provoked by restricted demand in center countries due to the world stagflation crisis (Weeks, 1985). Repatriation of profits, payments of interest on debt, and food imports also contributed. Conroy (1984) has proposed a modified balance of payments statement to illustrate the dependence on foreign financial resources in this structural crisis. In Table 1 I extend a version of this analysis through 1984, summarizing the extreme external financial dependence of the Nicaraguan economy. Clearly, if the ambitious plans for social programs and equitable economic development put forth by the Sandinista government are to be implemented, a structural change in the economy is essential.

Sandinista Development Model: The development policies proposed by the current Nicaraguan government address the three structural weaknesses of the economy: dependence on imported inputs, disarticulation and stagnant food production.

The substitution for imported inputs has been one of these policies. In industry an "innovators movement" has been promoted, in which workers are encouraged to produce replacement parts locally that would otherwise need to be imported (Downs, 1983). In cotton a major success has been achieved using Integrated Pest Management (IPM) to reduce the need for, or "substitute for," imported insecticides. This well documented program has used trap crops of cotton stubble during the dry season to reduce boll weevil

populations (Swezey and Daxl, 1983; Swezey et al., 1984; Swezey et al., 1986). In 1983 and 1984 the program resulted in a net savings of $5.04 million (Swezey et al., 1986). This savings came despite a general increase in the price of pesticides, and was a major factor contributing to an overall decline in the volume of insecticide imports (Figure 4).

The second key policy is to focus investment on developing agroindustry (Wheelock, 1985; MIDINRA, 1984a, 1985). Agroindustry is the potential link between commodity production in commercial agriculture and assembly in industry. For example construction has started on a textile mill to produce thread locally from Nicaraguan cotton (Collins, 1985). According to Minister of Agriculture Jaime Wheelock, agroindustry will change Nicaragua's insertion in the international division of labor from that of a seller of cheap commodities and buyer of expensive inputs, to that of a producer of downstream processed agricultural products, produced by its own industry from its own agricultural raw materials (Wheelock, 1985). In that way a greater proportion of the value-added of final products like clothing will accrue in Nicaragua, and the structural dependence on external capital will be lessened.

Finally, there are two parallel strategies to achieve food self-sufficiency, reducing the expenditure of scarce foreign exchange for imports of food. The agrarian reform functions, in the economic sphere, as a stimulus to the traditional sector, through the provision of credit, land, inputs and technical assistance (Collins, 1985; Deere et al., 1985). Because of military attacks by the U.S.-backed *contras*, however, which have driven the civilian population out of many grain producing areas in the North, a second strategy has been developed. Originally called the "contingency plan" for basic grain production, it was based on irrigated production of basic grains

on cotton fields during the dry season (Anonymous, 1984; Collins, 1985). More recently, however, the extrapolation of demand through the year 2000 has led to the conclusion that the peasant sector alone could never produce enough to meet the projected demand. The large-scale irrigation of the cotton-producing Pacific lowlands is now seen as a necessary complement to increased peasant production (Wheelock, 1985; MIDINRA, 1984b).

Ecology and Development: the need for IPM

The ecology of agricultural production interacts in significant ways with plans for economic development. In the case of cotton in Nicaragua, the widespread use and abuse of insecticides led to severe economic problems. These problems were felt at the macroeconomic level, where rising petrochemical imports accentuated the foreign exchange crisis. They were also felt at the level of the farm, where net losses were taken on every manzana (1 mz = 0.7 ha) between 1977 and 1979 (Swezey et al., 1986). There were also heavy external social costs, including a malaria outbreak due to resistant mosquitoes, acute pesticide poisonings, and reduced beef exports due to contamination. A 1977 United Nations report estimated the total annual social and environmental cost at $200 million (cited in Swezey et al., 1986; compare to Figure 5).

Questions have been raised about potential ecological-economic interactions in the irrigated basic grain production plan. Rosset (1983) predicted, for example, that the plan would make host plants available year-round to generalist insect pests, that before had suffered heavy mortality during the dry season. This has apparently been born out by the observation

that armyworm (*Spodoptera spp.*) populations are now reaching devastating proportions in irrigated grains (Savoie, 1985).

It seems reasonable, therefore, to propose a series of criteria by which different technologies for agricultural production may be evaluated. These are in addition to the standard criteria based on compatibility with existing technology, acceptability to users, labor requirements, etc. In the context of the current Nicaraguan development model, the critical new features from an economic viewpoint are clearly that the technology either reduce dependence on imported inputs and/or be compatible with the development of agroindustry. At the same time the experience of cotton demonstrates the need to evaluate the potential environmental impact, particularly as it may frustrate economic plans.

Integrated Pest Management clearly meets these criteria. As a pesticide minimization strategy it replaces imported capital inputs with management tactics that at worst carry their cost in local currency. In the cotton example, in 1983 an investment of roughly 3,200 c$ (córdobas) per manzana, resulted in a net profit in foreign exchange saved of U.S. $2.14 million (Swezey et al., 1986). Furthermore it in no way interfered with the industrialization of cotton. IPM can also dramatically reduce the environmental and social costs of pesticide use.

The Economics and Ecology of Tomatoes in Nicaragua

Tomatoes are grown in a wide variety of habitats on the Pacific half of Nicaragua. All Pacific regions produce some tomatoes, although the greatest area planted is in Regions I, III, IV and VI (Figure 8). The mountainous Region I, Nueva Segovia, Madriz and Estelí, has the highest average yields,

probably because it has the coolest temperatures. Production in this area is primarily peasant cultivation of fresh market varieties. Region VI (Matagalpa and Jinotega) is also mountainous and cool, and has a mixture of peasant production of fresh market varieties and some large-scale commercial production of processing varieties in the lower and warmer Sébaco Valley. Region IV (Carazo, Masaya, Granada, Rivas) is considerably lower, and has both peasant and commercial production. Region III, Managua, is almost at sea level, is very hot, and has low average yields.

Individual producers with small to medium size holdings dominate tomato production, sometimes organized into credit and service cooperatives (Figure 9). There is some large-scale commercial production, by the state and by private producers. Much of this is destined for the IFRUGALSA processing facility in Grenada. There are also peasant production cooperatives that produce for fresh market and sometimes for processing. The state production units tend to be highly capitalized farms on high quality land confiscated from the Somoza family, and have the highest average yields (Figure 10). All tomatoes in Nicaragua are harvested by hand, although cultivation and seeding are often mechanized.

As part of the program of agroindustrial development, the IFRUGALSA plant is being expanded, and a newer and larger one is being contructed in the Sébaco Valley (MIDINRA, 1984a, 1985; Wheelock, 1985). Processed tomato products are currently exported within Central America, and the goal is to increase the volume and value of those exports.

Tomatoes are planted during all months except July and October, with peak planting in May-June, August-September and November-January (Figure 11). The first peak in planting corresponds to the *primera,* or first wet season, the second to the *postrera*, or second wet season, and the third to

irrigated production in the dry season. Indeterminate, fresh market varieties predominate in the rainy season, while determinate processing varieties are more common under irrigation. Variation in development time leads to production in all months, with peaks in August-October, December, and March-April (Figure 12).

Price fluctuations are perhaps the most serious problem faced by tomato producers, as prices fluctuate more than 300% in an unpredictable fashion (Figure 13). Beyond these fluctuations, however, the need for investment capital is a major obstacle. A manzana of tomatoes requires an investment of c$3,150 for purchased inputs (Table 2), compared to about c$600 for the same area planted to beans (BND, 1983b). This high initial investment, combined with variation in both tomato prices and yields, makes tomatoes a high risk, albeit potentially high return, crop.

A significant factor in the variation of yields is insect pest and disease attack, which is reflected in the large 56.5% contribution that insecticide (33.5%) and fungicide (23%) make to the fixed costs of production (Table 2). 60% of the cost of inputs for tomatoes is ultimately in foreign exchange (PAN, 1982), 35.6% of which is for insecticide (unpublished figures, Direción General de Planificación, MIDINRA, 1982-83). This makes tomatoes and tomato products very import-intensive commodities, making IPM a potentially very important technology, as in the case of cotton.

According to the estimated crop budget used by the National Development Bank to determine credit authorizations, the average producer applies insecticide 9 times on tomatoes each season (BND, 1983a). Interviews by this author with many producers did not reveal any who sprayed so few times, so that figure is probably an underestimate.

There is a complex of pests on tomatoes, the components of which are unpredictable in time and space, making control strategies difficult to develop (Figure 15). A number of these insect species are also pests in cotton, where they have acquired high levels of insecticide resistance. These are the cotton whitefly, *Bemisa tabaci* Genn. (Chapter 2), the armyworm complex, *Spodoptera spp.* (Chapter 4), and the tomato fruitworm complex, *Heliothis spp.* (Chapter 4). Furthermore two other pests, the vegetable leafminer, *Liriomyza sativae* Blanchard, and the tomato pinworm, *Keiferia lycopersicella* Walsingham, are known as secondary pests provoked by excessive pesticide use (Chapter 4). *K. lycopersicella*, the cutworms, and *Diabrotica spp.* beetles are very sporadic pests, and are not dealt with further in this study.

The research presented in the remainder of this dissertation represents the first attempt to develop a pest management program for tomato pests in Central America. Although the work was conducted in Nicaragua and Costa Rica, it probably best applies to those countries that share the cotton agroecosystem and its acompanying pest complex and resistance problems. These are Nicaragua, El Salvador, and Guatemala.

There are two basic strategies incorporated in this pest management program. Chapter 2 develops Economic Injury Levels for the cotton whitefly, which are the basis for a strategy of spraying insecticide only in response to pest density, eliminating unnecessary applications. Chapters 3 through 6 then develop a prophylactic strategy designed to reduce colonization of tomatoes by the fruitworm and armyworm complexes and by the vegetable leafminer. This strategy is based on the use of a tomato and bean polyculture as a cultural control tactic. A secondary benefit of this cropping system is the production of a basic grain in fields devoted to

commercial cropping, which is important within the context of the move toward food self-sufficiency. The yielding and economic properties of the polycultural cropping system are developed in some detail. Chapter 7 summarizes the overall IPM program.

Literature Cited

Anonymous. 1984. Plan contingente de granos básicos. Revolución y Desarrollo 2:28

Barry, T., B. Wood and D. Preusch. 1983. *Dollars and Dictators: A Guide to Central America*. New York, Grove Press, 282 pp.

Biderman, J.M. 1982. *Class Structure, the State and Capitalist Development in Nicaraguan Agriculture*. Berkeley: University of California, unpublished Ph.D. dissertation, 256 pp.

Biderman, J.M. 1983. The development of capitalism in Nicaragua: a political economic history. Latin American Perspectives 10(1):7-32.

BND. 1983a. *Presupuestos de Financiamientos para Hortalizas y Farinaceas. Crédito Rural. Ciclo 1983/1984*. Managua, Nicaragua: Banco Nacional de Desarrollo.

BND. 1983b. *Presupuestos de Financiamientos Agrícolas. Crédito Rural. Ciclo 1983/1984*. Managua, Nicaragua: Banco Nacional de Desarrollo.

Castillo R., D. 1980. *Acumulación de Capital y Empresas Transnacionales en Centroamerica*. Mexico: Siglo Veintiuno, 277 pp.

CEPAL. 1985. *Notas para el Estudio Económico de America Latina y el Caribe, 1984. Nicaragua*. Mexico: Comisión Económica para America Latina y el Caribe (CEPAL), 73 pp.

Collins, J. 1985. *Nicaragua: What Difference Could a Revolution Make? Food and Farming in the New Nicaragua*. San Francisco: Institute for Food and Development Policy, 292 pp.

Conroy, M.E. 1984. External dependence, external assistance, and 'economic aggression' against Nicaragua. Kellog Institute (University of Notre Dame) Working Paper 27:1-27.

Deere, C.D., P. Marchetti, S.J., and N. Reinhardt. 1985. The peasantry and the development of Sandinista agrarian policy, 1979-1984. Latin American Research Review 20(3):75-109.

Downs, P. 1983. Towards a people's science: the innovators movement in Nicaragua. Science for the People 15(6):20-24.

de Janvry, A. 1981. *The Agrarian Question and Reformism in Latin America.* Baltimore: Johns Hopkins, 311 pp.

MIDINRA. 1984a. *Sector Agropecuario: Resultados 1983, Plan de Trabajo 1984.* Managua, Nicaragua: Ministerio de Desarrollo Agropecuario y Reforma Agararia (MIDINRA), 115 pp.

MIDINRA. 1984b. *A Strategy of Irrigation of the Pacific Plain of Nicaragua.* Managua, Nicaragua: Ministerio de Desarrollo Agropecuario y Reforma Agararia (MIDINRA), 94 pp + appendix.

MIDINRA. 1985. *Plan de Trabajo, Balance y Perspectivas 1985.* Managua, Nicaragua: Ministerio de Desarrollo Agropecuario y Reforma Agararia (MIDINRA), 105 pp.

Molina C., G. 1977. *Integración Centroamericana y Dominación Internacional.* San José, Costa Rica: EDUCA, 95 pp.

Nuñez S., O. 1978. *El Somocismo y el Modelo Capitalista Agroexportador.* Managua, Nicaragua: UNAN, 147 pp.

PAN. 1982. *Propuesta de Metas de Producción Hortícola para el Año 1982/1983.* Managua: MIDINRA, Programa Alimentario Nicaraguense (PAN), Dirección de Horticultura, unnumbered.

PAN. 1983. *Programa Operativo de la Producción Hortícola - Ciclo 83/84* . Managua: MIDINRA, Programa Alimentario Nicaraguense (PAN), Dirección de Horticultura, unnumbered.

Paige, J.M. 1984. Cotton and revolution in Nicaragua. Center for Research on Social Organizations (University of Michigan) Working Paper 319:1-34.

Rosset, P. 1983. Plagas comunes entre maíz y algodón en el sistema de maíz bajo riego. Memorandum de la Sección de Control Integrado, MIDINRA, Managua, Nicaragua.

Savoie, K. 1985. Nicaragua's program for basic grain production. New World Agriculture Group Newsletter 3:4-5.

Swezey, S.L., and R. Daxl. 1983. Breaking the circle of poison: the integrated pest management revolution in Nicaragua. Food First Research Report (San Francisco: Institute for Food and Development Policy), 23 pp.

Swezey, S.L., R.G. Daxl and D.L. Murray. 1984. Getting off the pesticide treadmill in the developing world: Nicaragua's revolution in pesticide policy. Manuscript.

Swezey, S.L., D.L. Murray and R.G. Daxl. 1986. Nicaragua's revolution in pesticide policy. Environment 28(1):6-9,29-36.

Wheelock R., J. 1980. *Nicaragua: Imperialismo y Dictadura.* Habana, Cuba: Editorial de Ciencias Sociales, 213 pp.

Wheelock R., J. 1985. *Entre la Crisis y la Agresión: la Reforma Agaria Sandinista.* Managua, Nicaragua: Editorial Nueva Nicaragua, 148 pp.

Weeks, J. 1985.*The Economies of Central America.* New York: Holmes & Meier, 209 pp.

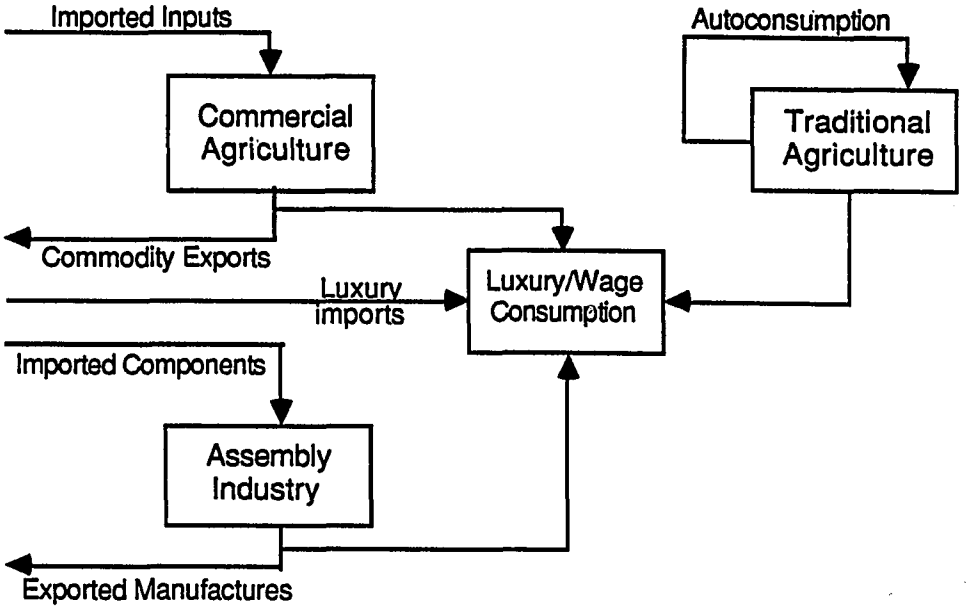


Figure 1. Schematic outline of the Nicaraguan economy.

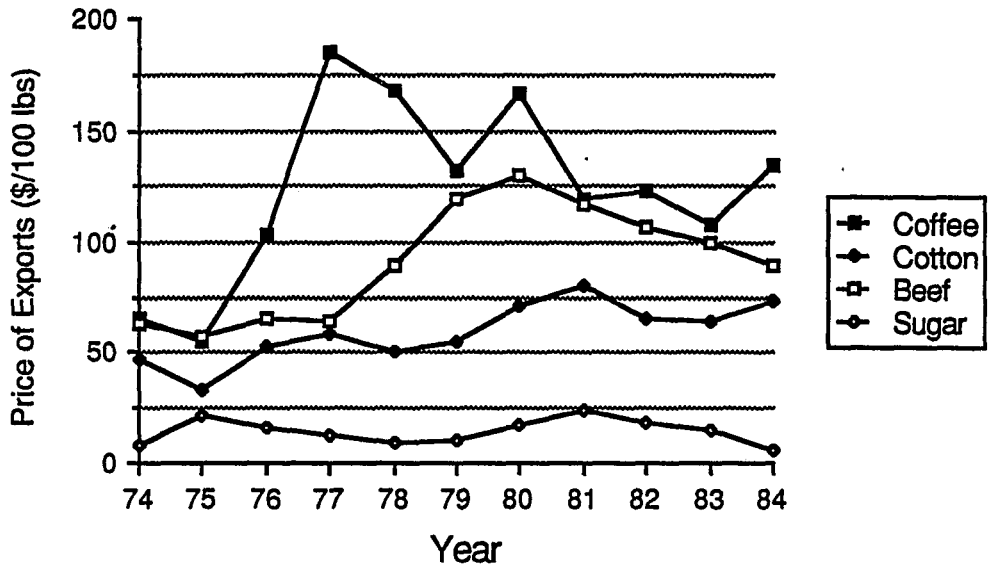


Figure 2. Prices of principal Nicaraguan export crops, 1974-84. SOURCES: Banco Central de Nicaragua (BCN), Dept. de Estudios Económicos, Boletines Trimestrales.; Collins, 1985.

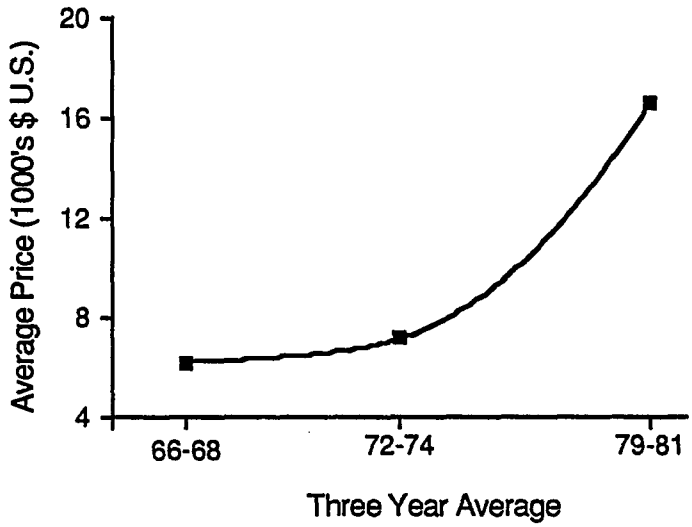


Figure 3. Price of imported tractors averaged over three year periods.
SOURCE: FAO Trade Yearbook, 1972, 1976, 1982.

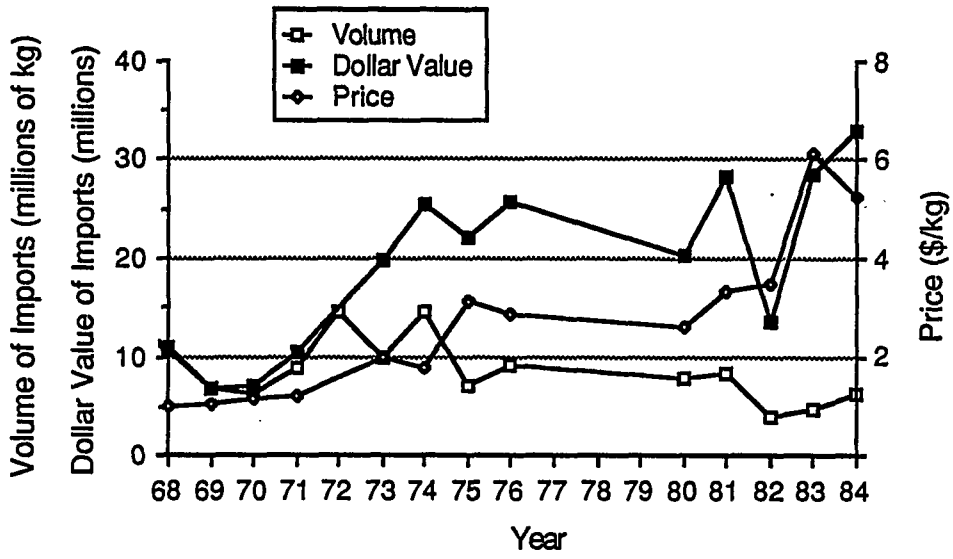


Figure 4. Volume, dollar value and price of insecticide imports, 1968-84. SOURCES: Swezey et al., 1984; unpublished data, Sección Regístro de Plaguicidas, DGA-MIDINRA, 1985.

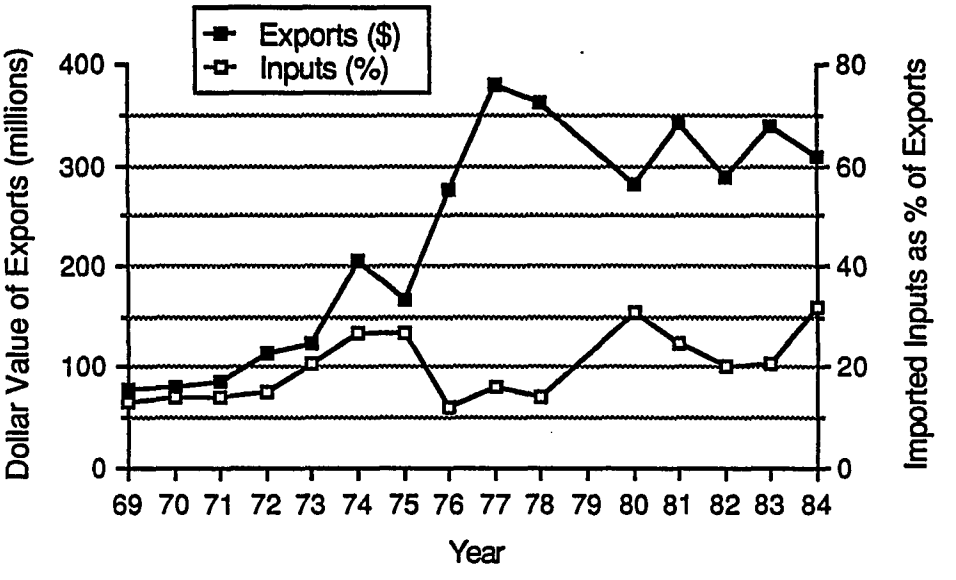


Figure 5. Dollar value of agricultural exports, and imported inputs for agriculture as a percentage of exports, 1969-1984.
SOURCES: Banco Central De Nicaragua. Dept. de Estudios Económicos. Boletines Trimestrales.; Wheelock, 1985; CEPAL, 1985.

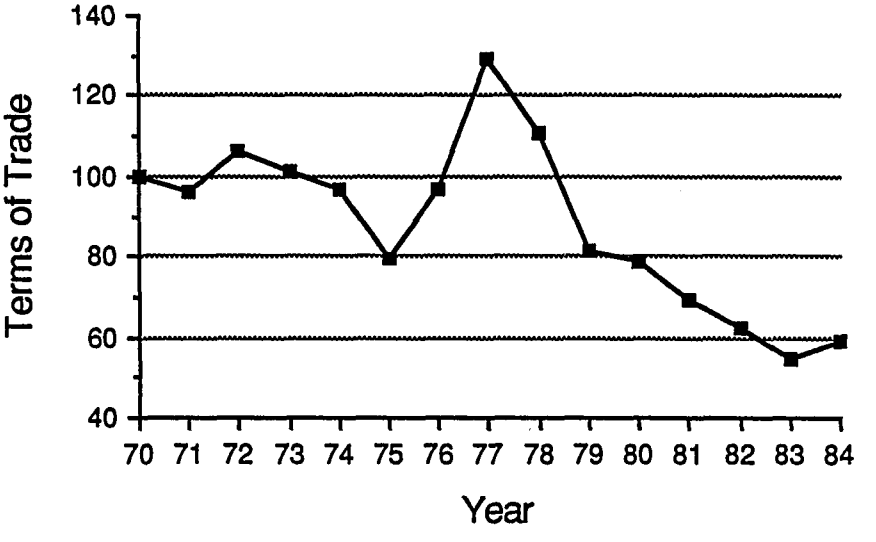


Figure 6. Relationship of terms of trade (goods), 1970=100.
SOURCES: ECLA Economic Survey of Latin America, 1976, 1980; CEPAL, 1985.

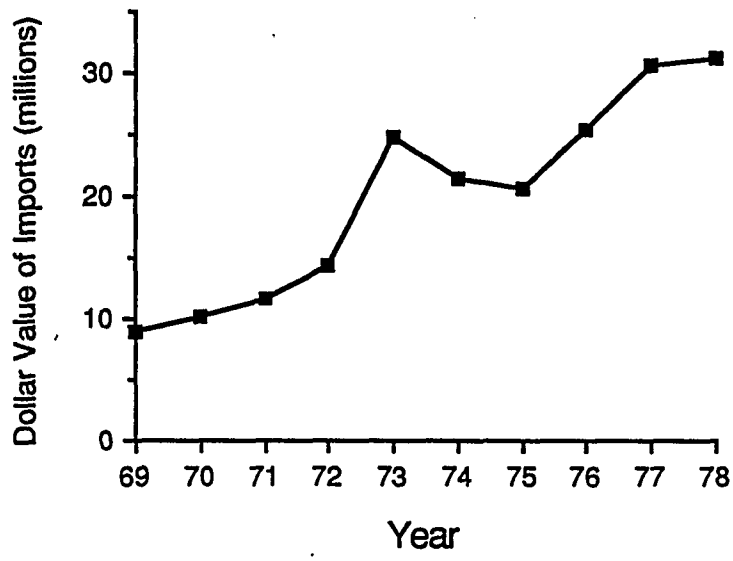
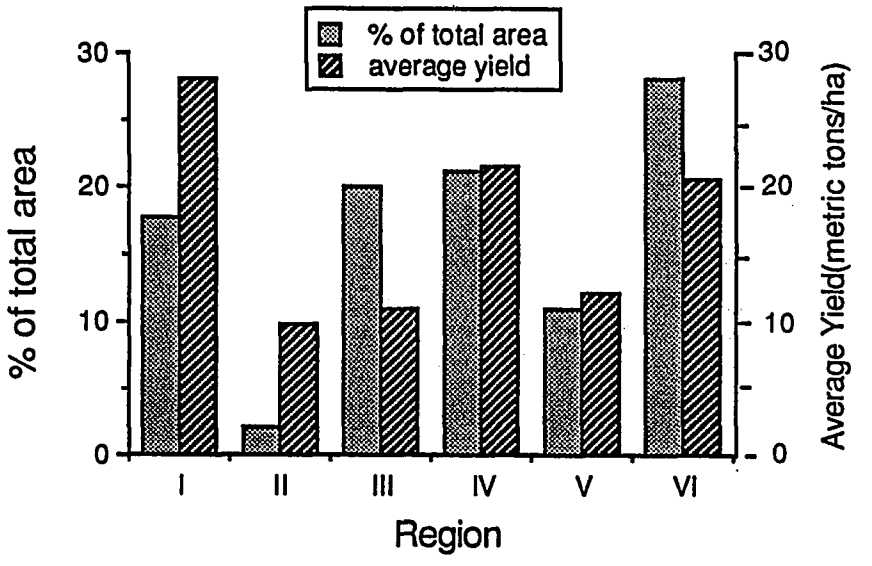
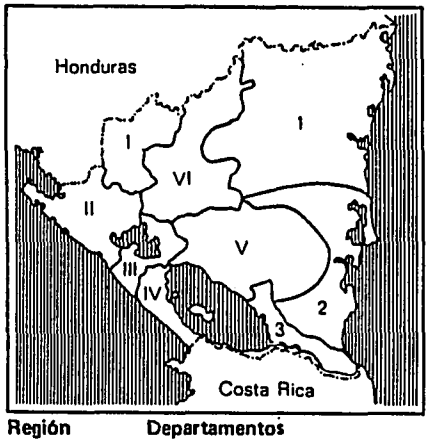


Figure 7. Annual food imports to Nicaragua, 1969-1978.
SOURCE: BCN. Dept. de Estudios Económicos. Boletines Trimestrales.





Región	Departamentos
Región I	Nueva Segovia, Madriz, Estelí
Región II	Chinandega, León,
Región III	Managua,
Región IV	Carazo, Masaya, Granada, Rivas,
Región V	Chontales, Boaco, (Rama y Nueva Guinea),
Región VI	Jinotega, Matagalpa,
Zona Especial I	Zelaya Norte, (Puerto Cabezas),
Zona Especial II	Zelaya Sur (Bluefields),
Zona Especial III	Río San Juan.

Figure 8. Area planted to tomatoes by Region as percent of total tomato area, and average yields, 1983-84, and map of the Regions of Nicaragua. SOURCE: PAN, 1983.

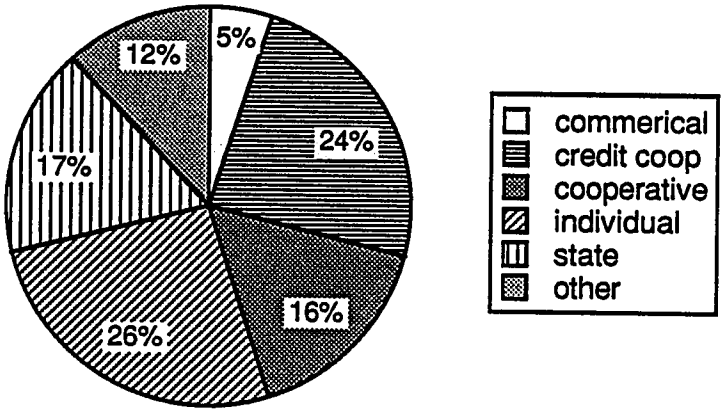


Figure 9. Percent of total area planted to tomatoes by organization of production, 1982-83.
SOURCE: Banco Nacional de Desarrollo, Informe Estadístico 1982-83.

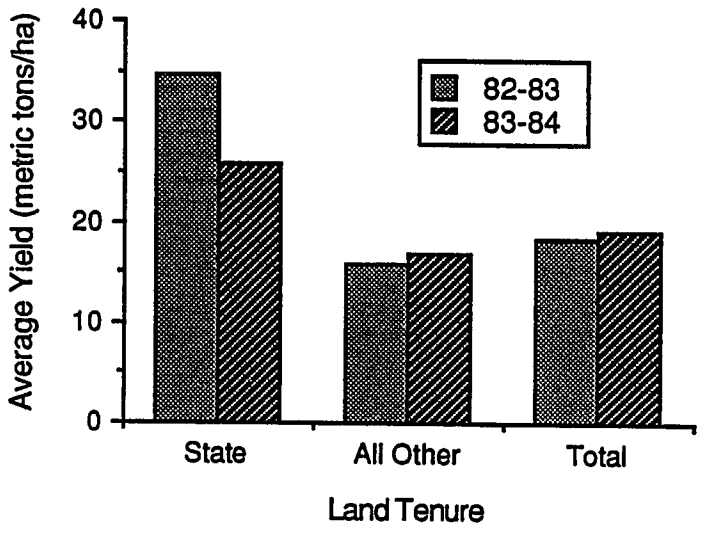


Figure 10. Average tomato yields by organization of production, 1982-84.
SOURCE: Pan, 1982, 1983.

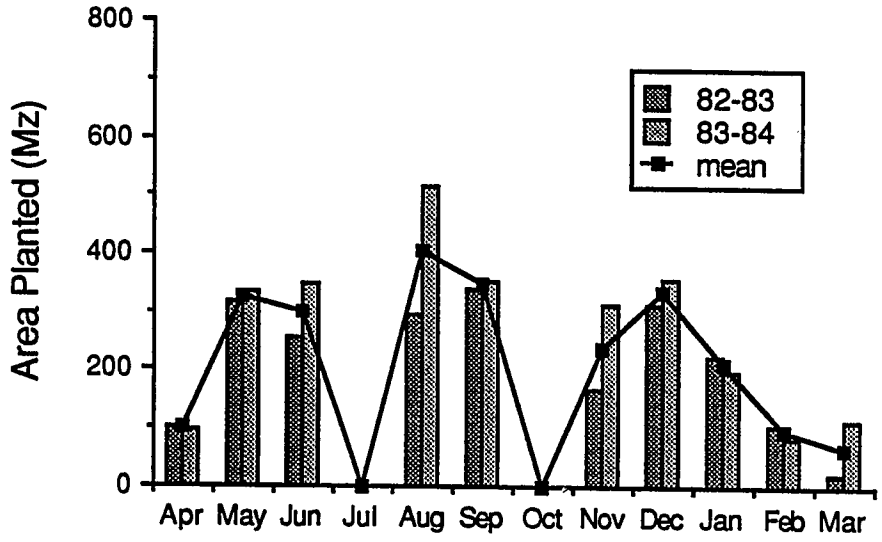


Figure 11. Area planted to tomatoes by month, 1982-84, with mean.
SOURCE: PAN, 1983, 1984.

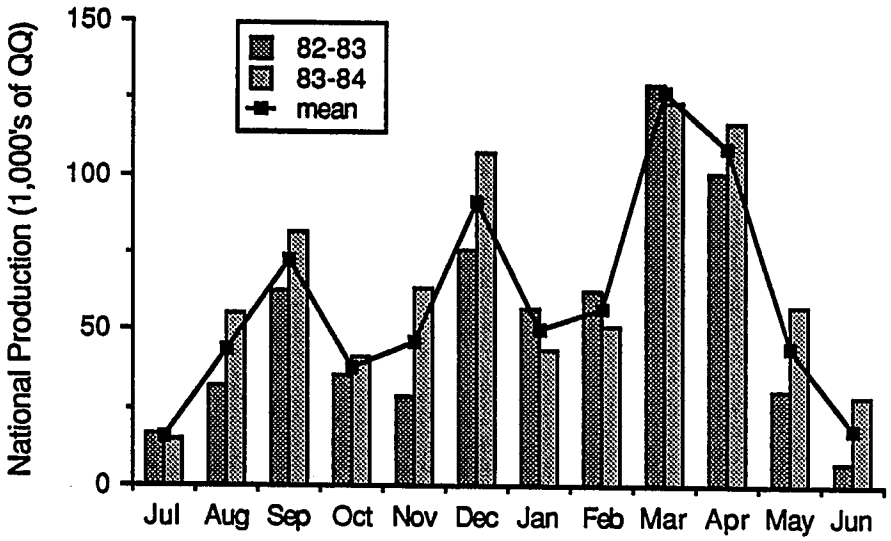


Figure 12. Monthly production of tomatoes, 1982-84, with average.
SOURCE: PAN, 1983, 1984.

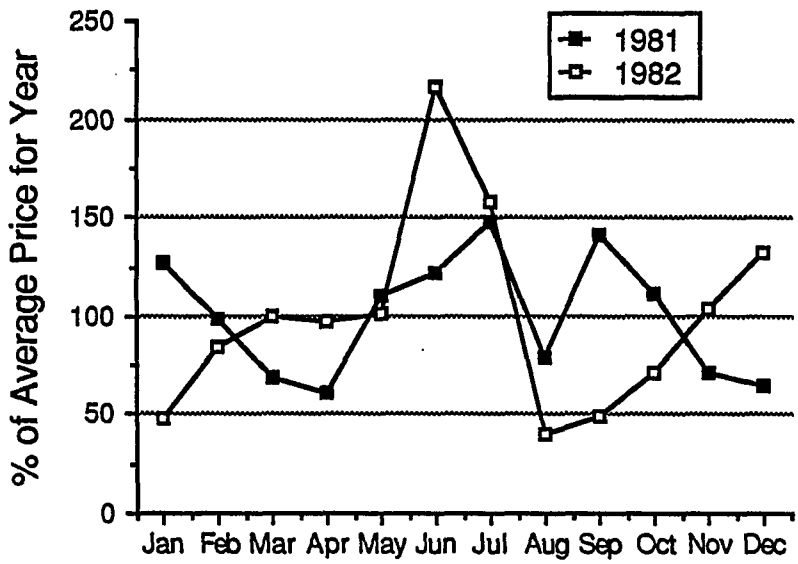


Figure 13. Monthly fluctuations in wholesale tomato price 1981-82.
SOURCE: INEC, unpublished statistics.

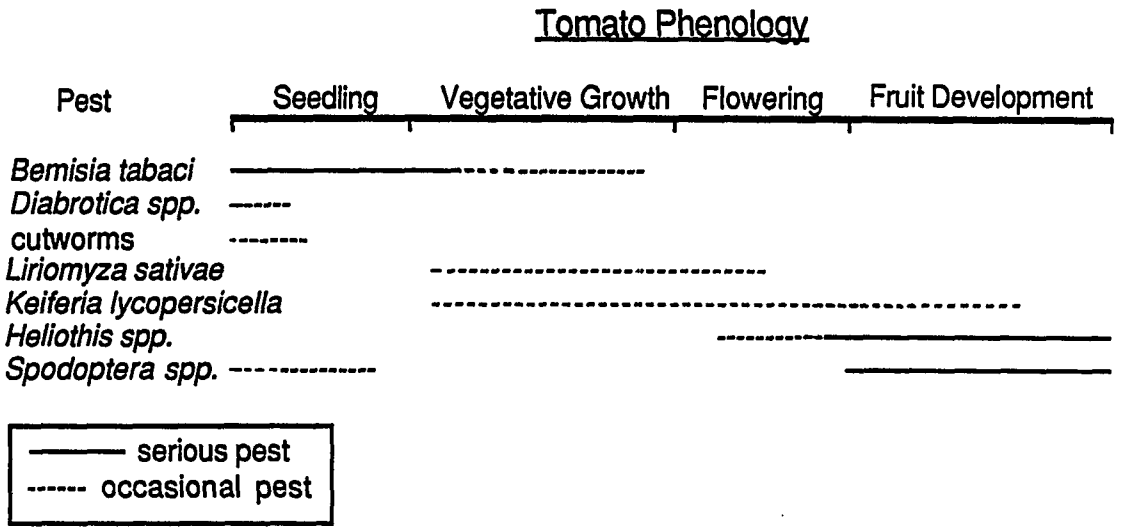


Figure 14. Phenology of tomatoes and tomato pests in Nicaragua.

Table 1. Indicators of external financial dependence in Nicaragua (Millions of $ U.S.): 1975-84.

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Total Exports of Goods and Services	448	630	733	720	672	495	553	447	463	428
Total Imports of Goods and Services	720	678	926	658	511	909	1037	829	933	902
Outflow of Profits, Interest and Debt Service	104	143	178	175	106	111	163	213	127	105
External Balance: Total Exports less Total Structural Foreign Exchange Requirements	-376	-191	-371	-113	55	-525	-647	-595	-597	-579

SOURCES: 1975-77: Conroy, 1984.
1977-84: CEPAL, 1985.

Table 2: Estimated crop budget for 1 manzana of tomatoes in Nicaragua (c$): 1983-84.

Pre-Harvest Costs	
Variable	
Land Preparation	580
Labor (84 person/days)	3,268
Services	40
Sub-Total	3,888
Fixed	
Seeds	400
Fertilizer	914
Insecticide (9 applications)	1,055
Fungicide (12 applications)	725
Sticker	55
Sub-Total	3,149
Harvest Costs	856
Total Costs	7,893
Expected Yield	800 Baskets (@25 lbs)
Expected Price	20/basket
Expected Value	16,000
Expected Profit	8,107
Other Costs (when necessary)	
Irrigation (dry season)	1,873
Stakes and wire (wet season)	3,500

Source: BNDa, 1983.

CHAPTER 2

SAMPLING METHODS, YIELD REDUCTION, AND ECONOMIC INJURY LEVELS FOR THE COTTON WHITEFLY, *Bemisia tabaci* Gennadius, ON TOMATOES IN NICARAGUA

Introduction

The purpose of this study is first, to establish the relationship between the yield of tomatoes, *Lycopersicum esculentum* L. (Solanaceae), and the population density of the cotton whitefly, *Bemisia tabaci* Gennadius (Homoptera: Aleyrodidae), a vector of viral pathogens. In addition, two sampling methods for the whitefly are compared in terms of their ability to predict yield reduction. The information thus gained is employed in conjunction with economic data to calculate Economic Injury Levels (EIL) for use in tomato Integrated Pest Management (IPM) in Nicaragua.

Biology of the Whitefly: *Bemisia tabaci* is a ubiquitous pest of cotton, tobacco, and irrigated beans and irrigated tomatoes in Nicaragua, where it vectors viral diseases of all of these crops (Comité de Control Integrado, 1979; Gamez, 1971; interviews with agricultural technicians). It is primarily a dry season pest, having a small population peak during the *veranillo* or "small dry season" between mid-July and mid-August, and a large build-up

beginning at the start of the regular dry season in mid-October and peaking in late February. It has numerous generations per year, with a life cycle of about 21 days from oviposition through eclosion (5 days), three nymphal instars (3-6, 3 and 2 days, respectively), pupation (2-4 days) and adult emergence. The adults may live from days to weeks (Comité de Control Integrado, 1979).

Prior to 1961 *B. tabaci* was not known as a pest in Central America. Its first appearance was on cotton in El Salvador during the 1961-62 growing season (Kramer, 1966). It appeared in 1964 in Honduras, and in 1965 in Guatemala and Nicaragua. Simultaneously with the subsequent increase in *B. tabaci* populations, Cotton Leaf Curl Virus problems also increased, suggesting a vector relationship. Kramer attributes the outbreak of *B. tabaci* to the long cycle of cotton in Central America, which extends well into the dry season, to the abundance of an alternative malvaceous host, *Sida* sp., and to the growing resistance of the whitefly to the mixture of DDT, toxaphene, and methyl parathion. This mixture was the most common control measure employed in Central America at that time, sprayed up to 38 times per season. Thus *B. tabaci* in Central America has been judged a secondary outbreak pest induced by excessive insecticide use (Vaughn and Leon, 1977; Flint and van den Bosch, 1981; Swezey and Daxl, 1983). Similarly, Pollard (1955) reported earlier that DDT applications in the Sudan were generally followed by an outbreak of *B. tabaci*, while Melamed-Madjar et al. (1970, cited in Cohen et al., 1974) attributed *B. tabaci* outbreaks in Israel to endrin resistance.

Whiteflies and Tomatoes: There is some confusion in the literature as to whether *B. tabaci* can complete its life cycle , or if adults just feed, on

tomatoes. Eggs and larvae have been reported on tomatoes in the Middle East (Al-Musa, 1982; Cohen et al., 1974; El-Helaly et al., 1971), while Flores and Silberschmidt (1958) in Brazil, and Anzola and Lastra (1985) in Venezuela report that only adults are found on tomatoes. During two years working on tomatoes in Nicaragua I only encountered *B. tabaci* adults, indicating that other hosts are necessary. This difference in apparent host ranges suggests that there are different host races of *B. tabaci*, as has been speculated by various authors (Costa, 1969; Flores and Silberschmidt, 1958; Yassin, 1984; among others).

Whitefly-Vectored Diseases of Tomatoes: In a recent review Hein (1984) listed several viral diseases of tomatoes in tropical and subtropical countries that are transmitted by *B. tabaci* adults. Only whitefly adults are involved in virus transmission, the presumed mechanism by which *B. tabaci* affects crop yield (Costa 1969, 1976). The viruses are Tomato Yellow Leaf Curl Virus (TYLCV), Tomato Yellow Mosaic (TYM), Tomato Golden Mosaic (TGM), and enation leaf curl. The viral particles involved have been characterized from only three countries, TGM in Brazil (Matyis et al., 1975, cited in de Uzcátegui and Lastra, 1978), TYM in Venezuela (Anzola and Lastra, 1985), and TYLCV in Israel (Russo et al., 1980). In all three cases they were described as being 15-18 nm, occurring predominantly in pairs, and belonging to the Gemini-virus group. Mechanical transmission was possible but extremely difficult (de Uzcátegui and Lastra, 1978). Few, if any, whitefly transmitted viruses are also seed transmitted (Costa, 1976).

The symptoms of TYLCV, common in the Old World, are severe stunting of growth, erect shoots, and small, misshapen leaflets. The first leaflets to appear after infection are cupped down- and inwards, while those

that develop subsequently are chlorotic and curl upward at the margins (Cohen and Harpaz, 1964). The description of TYM in Venezuela (de Uzcátegui and Lastra, 1978), is similar: yellow mosaic, stunting of plants, and curling of leaves. The symptoms of TGM in Brazil are also similar, although unlike TLM it could not be transmitted from tomato to tomato, only from *Datura* sp. to tomato (Matyis et al., 1975, cited in de Uzcátegui and Lastra, 1978). Tomatoes in Brazil infected by *B. tabaci* with Infectious Chlorosis of Malvaceae have curled leaves with yellow spots (Flores et al., 1960). Although virus levels were not quantified in the present study conducted in Nicaragua, many plants showed symptoms of stunting, leaf curling, and yellowing.

All of these viruses have large, similar but not identical, host ranges (de Uzcátegui and Lastra, 1978; Flores and Silberschmidt, 1958; Cohen and Nitzany, 1966). In Venezuela a major source of whiteflies and TLM is is the weed *Pseudoconiza lyrata* H.B.K. (Compositae) (Anzola and Lastra, 1985). *Datura stramonium* L. (Solanaceae) is listed as a host of TLM in Venezuela (de Uzcátegui and Lastra, 1978) and TYLCV in Israel (Cohen and Nitzany, 1966), and of *B. tabaci* in Nicaragua (Comité de Control Integrado, 1979). de Uzcátegui and Lastra (1978) could not infect cotton, *Gossypium hirsutum* L. (Malvaceae), with TLM.

It seems that these diseases form a series of related, rapidly evolving complexes of persistently transmitted, circulative viruses (Costa, 1969, 1976; Hein, 1984; de Uzcátegui and Lastra, 1978). Cohen and Nitzany (1966) report that TYLCV has a minimum acquisition time of 15-30 minutes, a latent period of about 21 hours before transmission can occur, and a persistence in the vector of up to 20 days (usually less than 10 days, however). One hour of feeding was required to achieve 47% transmission.

TYLCV exhibits a peculiar phenomenon called periodic acquisition, in which the vector cannot be recharged until it has completely ceased to transmit the virus after about 10-12 days (Cohen and Harpaz, 1964). TYM has a minimum acquisition period of about 2 hours, a latent period of about 20 hours, and persists in the vector for up to 7 days (de Uzcátegui and Lastra, 1978). For all whitefly transmitted viruses several times more than the minimum acquisition time is required for a "full charge" (Costa, 1969). For both TYLCV and TLM, younger plants are far more susceptible than older ones (Yassin, 1984; Shaheen, 1983; Al-Musa, 1982; Anzola and Lastra, 1978). High temperatures lead to more spread of the virus (Costa, 1976; Anzola and Lastra, 1985). Yassin (1984), speaking of TYLCV, finds no evidence of primary foci and secondary spread within tomato fields, suggesting that elimination or "roguing" of diseased plants would be of little value as a control measure.

Sampling Methods Used and Estimates of Yield Reduction: A knowledge of the relationship between tomato yield and *B. tabaci* population density, as estimated by various sampling methods, is essential to the design of an IPM program for this pest. A variety of sampling methods have been used in the literature, and a number of estimates of yield reduction have been reported.

Al-Musa (1982) reported that tomato yields were reduced by 63% when the plants were innoculated with TYLCV 70 days after planting (DAP), whereas yields from plants innoculated 105 DAP did not differ significantly from the controls. He sampled *B. tabaci* weekly by counting individuals of all stages on four randomly chosen, fully expanded compound leaves per plant. Cohen et al. (1974) sampled whitefly larvae on whole young plants

(up to 15 cm in height) and on the third and fourth compound leaves from the top of older plants. 5 plants per replicate were sampled, and no yields were reported. Shaheen (1983) sampled adults on the entire plant, and presents data for yield loss attributed to TYLCV. Plants infested with *B. tabaci* at the seedling stage generally demonstrated 100% yield loss, while those infested during flowering and fruit formation had about 40% yield loss. When there were fewer than 2 adults per plant little virus infection and no yield loss was observed. In a recent review Yassin (1984) states that *B. tabaci* transmitted TYLCV, in Africa and the Middle and Far East, often results in up to 75% yield loss, and points out that over 200 tomato cultivars are susceptible.

In the New World, where *B. tabaci* transmits TYM and related diseases, Anzola and Lastra (1978) cite a calculated yield loss of 30-40% reported by Debrot et al. (1963). In their own studies they describe their sampling method only as "weekly counts." They compare final yields of tomatoes protected by screening prior to transplanting with those of unprotected plants, and report a yield reduction of 31% for those plants exposed to *B. tabaci* during the seedling stage. The same authors later monitored adult populations in tomato fields with sticky traps, but did not examine yield (Anzola and Lastra, 1985).

Lindquist et al. (1972) studied the greenhouse whitefly, *Trialeurodes vaporariorum* Westwood (Homoptera: Aleyrodidae), on greenhouse tomatoes in Ohio, U.S.A. The greenhouse whitefly is not known as a disease vector; rather it affects yield through the production of large quantities of honeydew which is the substrate for sooty mold. They sampled the number of adults on 2 apical leaflets per plant at 5-day intervals. Greenhouse whitefly densities seem generally to be at least an order of magnitude higher than *B. tabaci* in the field; for example Lindquist et al.'s numbers on just 2

apical leaflets were of approximately the same order as those observed by Shaheen (1983) for whole plants. Yet Lindquist et al. (1972) report a reduction in weight of fruit clusters of about 21%, while Shaheen shows yield reductions of 30-100%. It seems that *B. tabaci* does not reach densities sufficient to affect yield through honeydew production, but that virus transmission is a far more potent mechanism of yield reduction.

It is generally not practical to use whole plant sampling methods for monitoring in IPM programs, because the time and effort involved often preclude on-farm use. Therefore, it is necessary to develop partial plant methods that save time yet still correlate with yield reduction (e.g. Zalom et al., 1983; Wellik et al., 1979; Sears et al., 1985). As indicated above, two partial plant sampling units have been reported for *B. tabaci* : the third and fourth fully expanded compound leaves from the top of the plant (Cohen et al., 1974), and 4 compound leaves chosen at random from the entire plant (Al-Musa, 1982). Similar methods have been used to monitor other foliar pests of tomatoes. Pohronezny et al. (1980) recommend sampling the top three compound leaves for the tomato pinworm, *Keiferia lycopersicella* Walsingham (Lepidoptera: Gelechiidae), and the terminal trifoliate of the third leaf for the vegetable leafminer, *Liriomyza sativae* Blanchard (Diptera: Agromyzidae). Wellik et al. (1979) compared two sampling methods for *K. lycopersicella,* semirandomly selecting either 25 upper leaves or 25 lower leaves per plant, and examining the largest leaflet on each leaf. They found that neither method gave satisfactory results, because of extremely high variances.

There is ome evidence that the effect of*B. tabaci* attack depends on the age of the leaves attacked. For example Costa (1976) cites unpublished data indicating that TGM in Brazil is more effectively transmitted when the

whiteflies feed on young leaves. The present investigation compares the effectiveness of sampling young leaves (top of the plant) versus older leaves (bottom half of the plant) for predicting yield loss. A modification of the methods reviewed above was employed: 4 compound leaves from either the top or the bottom half of the plant were sampled. 2 m of row was chosen as the area sampled because it has been established in the literature as the best size for tomato pest monitoring (Pohroneznzy and Waddill, 1978; Pohroneznzy et al., 1980).

Economic Injury Level: The relationship between estimated pest density and predicted yield is the basis for the Economic Injury Level (EIL), the basic tool of pest management decision making (for recent reviews of this concept see Poston et al., 1983; Andow and Kiritani, 1983; Pedigo et al., 1986). A knowlege of the EIL for a given pest is the first step toward deciding when it is justified to employ a control measure.

In practice many insecticide applications made by farmers are unnecessary; insect pests present in the field are too sparse to cause sufficient economic losses to warrant the use of an expensive chemical for control purposes. Furthermore, excessive pesticide use accelerates the rate of evolution of resistance on the part of the pest population. Thus it is particularly important to eliminate unnecessary applications directed at pests with a proven capacity for developing resistance, and/or secondary outbreak pests, both of which characterize *B. tabaci* in Central America (Flint and van den Bosch, 1981).

The EIL is the pest population density or "break even point" at which the cost of control equals the expected benefit of control. Assuming that the pest population in a field is growing, it will usually be profitable to initiate

control measures *before* the EIL is reached. The "economic," "control," or "action" threshold is thus the lowest pest population density at which it is profitable to initiate control (Andow and Kiritani, 1983). This is far more difficult to calculate than the EIL, requiring knowledge beyond the relationship between density and yield loss, such as population growth rates, survivorship, etc.

For the purpose of this paper the EIL will be defined as that pest density at which,

$$C = E(y)\,E(p)\,E(s), \tag{1}$$

where C is the cost of the control measure, E(y) is the expected yield per unit area in the absence of attack by the indicated pest, E(p) is the expected price paid to the farmer per unit of yield, and E(s) is the expected proportionate yield loss saved by the control measure (yield loss saved over yield with control measure) (modified from Andow and Kiritani, 1983, and Pedigo et al., 1986). Assuming that we have an equation for percent yield loss regressed on pest density (% Yield Loss = mD), E(s) can be further broken down into,

$$E(s) = (mD - mD[1- E(r)])/100, \tag{2}$$

where m is the regression coefficient (% yield loss per unit of pest density), D is the pest density, and E(r) is the expected proportionate reduction in pest density resulting from the control measure (reduction in pest density over density without control measure). Equation (2) can be rewritten as,

$$E(s) = kD \tag{3}$$

where k represents the proportionate loss in yield saved by spraying, per unit of density, or,

$$k = m\,E(r)/100. \tag{4}$$

Equation (1) can then be rewritten as,

$$C = E(y)\, E(p)\, kD, \quad (5)$$

and we can obtain the EIL by solving for D,

$$EIL = C/kE(y)E(p). \quad (6)$$

In practice k is calculated from experimental data comparing pest density and yield loss, together with data on the percent pest density reduction resulting from the control measure. This is then taken as given, and combined with costs, expected yields, and prices, to be determined, guessed at, or otherwise obtained by the farmer or extension agent.

This model is based on a number of assumptions, among which are that a unit of control (such as one insecticide application) always reduces the pest population by a fixed proportion, regardless of density, and that a given pest density always reduces the yield by a fixed proportion, regardless of the yield expected in the absence of attack. Despite these and other possibly questionable assumptions, the EIL has remained the best available "first step" toward rational decision making in pest control (Pedigo et al., 1986).

In this paper EIL's are generated for combinations of costs of control, expected yields, and expected prices, based on an experimentally calculated k. The EILs are presented in tabular form, for use by farmers or extension agents.

Materials and Methods

This experiment was conducted at the Sébaco Valley Regional Experiment Station near San Isidro, Matagalpa province, Nicaragua (Lat 012° 15' N, Long 860° 14' W, Alt 540 m, mean annual T° 24.4°c, mean annual precipitation 840 mm, mean relative humidity 72.1%).

The indeterminate tomato variety 'Tropic' (110 days), which is standard for fresh market production in Nicaragua, was direct-seeded on September 27, 1982, during the dry season. The rows were spaced 1.2 m apart, and the tomato seedlings were thinned to 0.4 m between plants (20,833 plants/ha). 183 kg/ha of 10-30-10 NPK fertilizer was applied in bands at the time of planting, and an additional 91.5 kg/ha of urea (46% N) was applied as a side dressing 38 days after planting (DAP), both of which are standard practice at the Experiment Station. The herbicide metribuzin (Sencor® 70% wettable powder) was used at a rate of 0.5 kg/ha at the time of planting. The experiment was irrigated weekly with sprinklers. At 46 DAP the tomato plants were trained on wire running between wooden stakes.

The experiment consisted of 30 10 m X 6 row (7.2 m) plots, divided into six treatments in a randomized complete block design with 5 blocks. There were five different weekly insecticide treatments, applied at 32 DAP, 37 DAP, and on the day following each subsequent sampling date, and a control. The insecticide treatments were *Bacillus thuringiensis* (Dipel®) at 140 g/ha and at 425 g/ha, endosulfan (Thiodan®) at 2 l/ha, a mixture of Dipel at 140 g/ha with Thiodan at 1 l/ha, and a weekly rotation of methamidophous (Monitor®) at 1.4 l/ha, decamethrin (Decis®) at 570 cc/ha, or methomyl (Lannate®) at 250 g/ha. This last treatment is used normally at the field station to control tomato pests.

Weekly insect sampling was begun at 43 DAP, using two fixed sampling stations in each plot. One station was placed at random in each of the two center rows, excluding the outer 1 m on each side to avoid edge effects. Each station consisted of 2 m of row (6 plants), marked with plastic flagging.

Although one original purpose of this experiment was to study the effect of selective (Dipel and Thiodan) versus non-selective insecticides (i.e. the normally used rotation at the Experiment Station of Monitor, Decis and Lannate) on lepidopterous pests, none were encountered during the course of the growing season. The only insect pests that appeared in sufficiently high levels to analyze statistically were the vegetable leafminer, *Liriomyza sativae* , and the cotton whitefly, *Bemisia tabaci* , for which Dipel is non-toxic. The data for *L. sativae* showed no correlation between numbers and yield, and are analyzed elsewhere (Rosset et al., 1983).

For *B. tabaci* two sampling methods were used, for purposes of comparison. The "**apical**" method was to examine all leaflets on each of the top four fully developed compound leaves. For the "**basal**" method all leaflets were examined on each of four semirandomly chosen compound leaves from the lower half of the plant. This was done for each plant in each of the two sampling stations, for a total of 12 plants examined per plot. The leaflets were carefully turned over so as not to the disturb whitefly adults present on the undersides. The number of these *B. tabaci* adults encountered was recorded. No immatures were found during the course of the experiment.

At the end of the season the tomato fruits were harvested three times, at 100, 109 and 120 DAP. At 120 DAP all fruit remaining on the plants were harvested. The number and weight in kilograms of marketable fruit harvested from each sampling station was recorded, and converted into per hectare values.

Results

Bemisia tabaci showed two major popualtion peaks during the season, at 43 DAP and at 57-66 DAP (Figure 1). Although there is no clear separation of means (Duncan's Multiple Range Test; see Table 3),on the first the three treatments with synthetic insecticides, known to be toxic to whiteflies, tend to have lower population densities than the three treatments without insecticides toxic to *B. tabaci*. There is a slight nonsignificant tendency for this pattern to reverse itself during the second peak. The overall pattern can be seen more clearly in Figure 2, which pools the treatments into two groups: those with synthetic insecticides, and those with either no insecticide (control) or with only Dipel, which is toxic only to Lepidoptera.

The large variation observed allowed for a detailed analysis of the relationship between whitefly density over time and final tomato yields (kg/ha). Tables 1 and 2 are correlation matrices of final yields per plot and numbers of *B. tabaci* encountered on the 8 sampling dates, for the two sampling methods (StatSoft, 1985). For both sampling methods whitefly numbers were significantly correlated with final yields on only one sampling date, 43 DAP. The correlation coefficient, **r**, between numbers at 43 DAP and final yields in kilograms, was equal to -0.506 ($P < 0.05$) for the apical sampling method, and -0.576 ($P < 0.01$) for the basal sampling method. Thus the basal method is a better predictor of final yield, and is the method used in the subsequent analyses.

B. tabaci numbers at 43 DAP, for the basal sampling method, and final yields in kilograms and numbers of fruits per hectare, were analyzed separately using a 6 X 5 (treatments X blocks) randomized block ANOVA

(Little and Hills, 1978). There was a significant effect of the pesticide treatments on whitefly numbers at 43 DAP ($P < 0.05$), on final yields in weight ($P < 0.05$) and on final numerical yields ($P < 0.05$; Table 3). *Bemisia tabaci* numbers tended to be greater in the three treatments that received no "chemical" insecticides (control and the two doses of Dipel), compared to the other three. The final yield of tomatoes summed over harvest dates, was significantly less in the three treaments without insecticides than in the three with insecticides ($P < 0.05$), while there were no significant differences within either of the two groups. The overall pattern was similar for numerical yields, although the mean separations did not break down as clearly.

Looking at the same yields and whitefly numbers, pooled into "with–" and "without insecticide" treatments and analysed as an orthogonal comparison, there was a 51.8% reduction in mean whitefly numbers ($P < 0.001$, basal method), a 52.1% increase in mean yield in kg ($P < 0.001$), and a 48.1% increase in mean fruit production ($P < 0.001$), in the "with insecticide" treatment. Conversely, there was a 34.3% yield loss (kg) without insecticide. Insecticides were applied twice prior to the 43 DAP sampling date, at 32 and 37 DAP, so we will assume that 2 applications, 5 days apart, caused the observed 51.8% reduction in whitefly numbers.

Regressions were calculated between whitefly numbers at 43 DAP and final yield, based on the assumption that a there is a causal basis for the relationship between whitefly numbers at 43 DAP and yield(Tables 1 and 2). Yield in kilograms was chosen for this analysis because prices paid to the producer are more accurately determined by weight than by numbers. Strictly speaking there is an interaction between the two, because volume measured in baskets or*"cajas"* is the most common unit

used to determine value of production. However it is generally recognized that 1 basket is approximately equal to 25 lbs (interviews with technicians).

The final yields regressed on whitefly numbers at 43 DAP, along with scatter plots of the observed values, are presnted for the apical and basal sampling methods (Figures 3 and 4). The variation in whitefly numbers at 43 DAP, as estimated by the apical method, explains 25.6% of the variation in final yields ($P < 0.005$). The regression equation is,

$$y = 28.137 - 0.672x, \quad (7)$$

where x is the observed number of whitefly adults in the area sampled within the plot and y is the predicted yield in kilograms. Using the basal method instead improves the amount of variation explained to 33.1%, with a greater degree of confidence ($P < 0.001$). In this case the regression equation becomes,

$$y = 33.012 - 0.488x. \quad (8)$$

It is apparent from a comparison of Figures 3 and 4 that the variance and great number of zero values for low whitefly levels limits the predictivity of the apical sampling method under such conditions. In fact fully 31.4% of the observations over the entire growing season were zero values for the apical method, compared to only 9.5% for the basal method. Examination of the figures also shows clearly that the majority of the population is found on the basal leaves.

It might be hypothesized that combining the two methods, using the total as the sampling unit, might be better than either alone. Using the total is mathematically equivalent to using the data from each method as a separate independent variable in a multiple regression, where yield is still the dependent variable. It is then possible to estimate the additional variance explained by the second variable, and determine whether that additional

variance is statistically significant. Starting with the basal method which explains 33.1% of the variation in yields, adding the apical method explains an additional 5.3%, which is not significant ($P > 0.10$; Little and Hills, 1978.

Fitting logarithmic, exponential, or polynomial curves to the data in all cases explains the same amount or less of the variation than the linear model. It is therefore assumed, for the purposes of the economic analysis presented below, that the relationship between whitefly numbers at 43 DAP and final yield is linear over the range of values encountered (Little and Hills, 1978).

Figure 4 shows quite clearly the effect of insecticide application in reducing whitefly numbers, and the resulting increase in yield. All of the points on the graph representing the "with insecticide" treatment are grouped together in the low whitefly density and high yield quadrant of the graph.

The data presented in Figure 4 are shown in Figure 5 recalculated as a regression of % Yield Loss against the number of whitefly adults per 4 basal compound leaves (the single plant sampling unit). The equation is,

$$y = 8.869x, \qquad (9)$$

where y is % Yield loss and x is whitefly density, and 8.869 is the coefficient m from equation (4). Using the 51.8% reduction in whitefly numbers from the "with insecticide" treatment, we obtain 0.518 as E(r), the expected proportionate reduction in pest density in equation (4). Solving for k, we get $k = 0.0459$. We can then calculate the Economic Injury Level for any combination of cost of the control measure, C (c$/ha), expected yield without whitefly attack, E(y) (kg/ha), and expected price to be paid to the producer, E(p) (c$/kg),

$$EIL = C/0.0459\ E(y)\ E(p). \qquad (10)$$

For example, our yield predicted by regression equation (8) for zero whitefly attack is 33.012 kg/7.2 m^2, or 45,850 kg/ha. We can assume a price of 20 c$/basket, or 1.76 c$/kg, used by the bank in its estimated crop budget for tomatoes (BND, 1983). Finally, we use the banks budget to calculate the cost of 2 insecticide applications (materials and labor), which is 720 c$/ha. Substituting these values in equation (10), we get an EIL = 0.19 adult whiteflies on 4 basal leaves per plant. This is the break even point at which the cost of control would exactly equal the benefit of control, for the given combination of values. The expected yield of 45,850 kg/ha is an "experiment station" yield, much higher than farmers usually achieve. A more reasonable yield might be 15,710 kg/ha, the average yield that the National Food Crops Program expected from private sector farmers during the 1982-83 growing season (PAN, 1982). Holding the other factors constant, this would give an EIL = 0.56. Prices and yields strongly influence the EIL, as can be seen in Table 5, which presents EILs calculated over a range of values. In practice inflation will also change costs from year to year, so that a new table or series of tables needs to calculated from equation (10) every year.

Discussion

Sampling Methods: In the comparison of sampling units, the **basal** method of sampling 4 compound leaves, selected semirandomly from the lower half of each plant, proved a better predictor of final yield than the **apical** method, in which the top four leaves were examined. On the surface this appears contradictory in light of the assertion by Costa (1969) that whiteflies more efficiently transmit viral pathogens when they feed on younger foliage. However the results presented here are only germane to the

issue of the adequacy of the sampling units as predictive *indices*; the finding that older foliage is better as such does not demonstrate a direct causal relationship. For example it may be that, although better transmission occurs on young foliage, the lower relative variation and greater mean density present on older leaves make them a better index of total density. Regardless of the causal explanation, however, the conclusion of this study is that the basal sampling unit is the method of choice.

The low EIL, discussed below, suggests that a large number of plants should be sampled in each tomato field, particularly in light of the large confidence intervals presented herein. The actual number of plants examined, however, will need to be determined based on not only the data offered in this paper, but also on a consideration of the effort and cost involved in sampling, and on the need to concomitantly sample other pests (Wellik et al., 1979; Pohronezny et al., 1980).

Yield Reduction: In this study *B. tabaci* infestations at 43 DAP caused a > 34% reduction in final tomato yield, while infestations from 50 DAP on had no apparent effect on yield. This is consistent with the literature reviewed earlier, in which it is commonly reported that the susceptibility of tomatoes to whitefly transmitted viruses is greatest when the plants are young (e.g. Shaheen, 1983; Anzola and Lastra, 1978). It seems reasonable to conclude from the present study that *B. tabaci* populations do not pose a threat to tomato yield after about 48 DAP. Based on this conclusion it is recommended that farmers in Nicaragua discontinue their practice of insecticide applications directed at *B. tabaci* after 48 DAP, while measures to reduce whitefly populations before that time are to be encouraged.

During the seedling stage (< 48 DAP), however, a strong positive relationship was found between whitefly density and yield loss (Figure 5 and Equation 9). The relationship was apparently linear, although several authors (Poston et al., 1983; Pedigo et al., 1986) have recently cautioned that linearity may only apply over the range of values tested. In the case of a vector it seems that there must be a point in increasing density where the response would level off, corresponding to the point where the vast majority of the plants are already infected with the disease. This is generally not a problem for the calculation of EILs, however, because the non-linearity probably enters at a far higher density than the EIL.

A comparison of the means of the "with-" and "without insecticide" treatments reveals a 34.3% yield reduction attributable to *B. tabaci* (Table 4). This is consistent with the 30-40% yield reductions reported in the New World for tomatoes infected with TYM transmitted by *B. tabaci* (Anzola and Lastra, 1978). Because the present yield loss occurred at whitefly densities far below those needed to cause yield loss due to honeydew production alone (Linquist et al., 1972), and because many of the plants were stunted, with leaf curling and yellowing, we can conclude that *B. tabaci* in Nicaragua carries a virus related to or identical to other New World tomato viruses vectored by *B. tabaci* , namely TYM and TGM (refer to earlier discussion of these diseases).

The fact that *B. tabaci* is a vector means that all generalizations of yield reduction estimates are based on the assumption that the proportion carrying the virus is constant, which may not be true in practice (Power, 1985). This is still a difficult assumption to test, because no serological assays exist to test for whitefly transmitted tomato viruses.

Economic Injury Levels: The EILs calculated in this paper for various combinations of expected yields and prices are extremely low (Table 5). For example, the EIL calculated for an expected yield of 25,000 kg/ha and a moderate tomato price of 5.28 c$/ha is 0.12 adults of *B. tabaci* on 4 basal compound leaves per plant. If this EIL were to be used as an economic threshold, it would mean that if the farmer found more than 2 whiteflies on 20 plants, the decision would be to spray 2 times over a 5 day period (the basis for this EIL). In practice this might very well lead to "calendar" type spraying, which in the short term might be economically rational according to the EIL model. The problem, of course, is the contribution such spraying might make to *B. tabaci* 's resistance to insecticides. What makes economic sense for the individual in the short term may be deleterious to all farmers in the medium to long term.

From a purely biological point of view there are two reasons why this potential problem may not be as serious as it first appears. First of all, a very small proportion of the total *B. tabaci* population in Nicaragua is on tomatoes. Wild species and cotton are the most important hosts (Comité de Control Integrado, 1979); *B. tabaci* apparently does not even reproduce on tomatoes. Also total tomato hectarage in 1983 was only 1.6 % of total cotton hectarage (comparison between figures in PAN, 1983, and Swezey et al., 1984), which received an average of more than 20 insecticide applications that year (Swezey et al., 1984). Thus it seems unlikely, given any reasonable level of gene flow, that insecticide use in tomatoes has a significant effect on resistance in the whitefly population. Secondly, farmers currently spray tomatoes for whitefly control whenever *B. tabaci* occurs during the growing season, while the work presented here indicates that all applications after 48 DAP should be suspended. In other words, while following the

recommendations presented herein might result in increased applications between germination and 48 DAP, the overall effect might well be to reduce total applications directed at *B. tabaci* . This fits perfectly with one of the major goals of IPM, which is not to *eliminate* pesticide use, but rather to employ it in a rational manner (Flint and van den Bosch, 1981).

It is important to emphasize that the EIL has been presented here, and not the economic theshold. The economic threshold is the pest density at which control should be initiated so that the density does not exceed the EIL in the future, assuming that the population is growing. Additional items of information that are needed to determine this value, beyond the EIL, are a quantitative model of the population dynamics of the pest, the delay between sampling and control, the probability of error inherent in the sampling method and the model, and the degree of risk sensitivity of the producer (Poston et al., 1983; Andow and Kiritani, 1983; Pedigo et al., 1986). This information has rarely, if ever, been available for management of a pest. Thus in practice the EIL, the few times that it has even been calculated, has been used in combination with a good deal of *gestalt* to come up with a practical economic theshold, which sometimes is even equal to the EIL (see Poston et al., 1983, and Pedigo et al., 1986, for reviews).

Other Management Options for *B. tabaci* : The EIL and economic theshold are generally used as "responsive" (*sensu* Vandermeer and Andow, in press), or "curative" (*sensu* Pedigo et al., 1986) management tools. That is they are used to determined when a control action should be initiated in response to pest density. The purpose is to eliminate unnecessary applications of pesticides, thereby minimizing the likelihood of resistance and other environmental problems. When used with selective, narrow

spectrum, pesticides, they are even more effective in avoiding these problems (Flint and van den Bosch, 1981). Mineral oil sprays have been used for some time, to control aphid-borne, non-persistent viruses. They inactivate the viral partcles adhering to the stylet, and are not toxic to the aphid, the plant, or the natural enemy fauna (Simons and Zitter, 1980). They are not effective against persistent viruses such as those borne by whiteflies, but the oil can be a very effective control measure for the whitefly itself. It can be sprayed on the crop, or used to coat yellow boards that are placed in the field to serve as traps. The whiteflies adhere to the oil, which is soaked up by the characteristic white scales on the wings, producing rapid mortality (Hein, 1984; Costa, 1976). The oil cannot be mixed with insecticide (Hein, 1984), although virtually any light oil will do. Shaheen (1984) reports that mineral, cootonseed, sesame, and peanut oil are all effective.

If a responsive, sampling based program is in use, "prophylactic" (*sensu* Vandermeer and Andow, in press) or "preventative" (*sensu* Pedigo et al., 1986) measures may be used to lower overall pest density, resulting in less recourse to spraying through the responsive program, because thesholds are not reached as often. The critical factor with *B. tabaci* is to *delay* the infestation of tomatoes, because virus infection after the early susceptible stage has been passed does not result in yield reduction.

Hein (1984) reports that 4 insecticide applications were saved through the use of a green straw mulch. The whiteflies were attracted to the mulch in preference to the crop until the straw began to yellow, at which point spraying had to be initiated. This might be worth pursuing in Central America, since mulch can also help reduce high soil temperatures, which often limit tomato production in the tropics (Villareal, 1980).

Al-Musa (1982) successfully used cucumbers interplanted with tomatoes as a trap crop. *B. tabaci* in Jordan, which is certainly a different host race than in Central America, prefers cucumbers to tomatoes. The intercrop produced a > 75% reduction in whitefly density on tomatoes as late as 39 days after transplanting. Similar studies should be undertaken with the Central American host race, to determine if potential trap crops exist. Preliminary, non-quantitative observations in Nicaragua by this author suggest common beans (*Phaseolus vulgaris* L., Leguminosae) as a strong candidate.

Anzola and Lastra (1978) compared different preventative seedbed treatments for their efficacy in control *B. tabaci* transmitted TYM in Venzuela. Their experiments were on seedlings grown in flats for later transplant, to address the common problem of seedlings that are already infected by the time of transplant. They found that two systemic insecticides applied to the soil, thiofanox (Dacamox®) and disulfoton (Di–Syston®), were ineffective. Howeyer, simply covering the seedbed with nylon screening completely protected the seedlings, resulting in an increase in final yield of 45%.

Literature Cited

Al-Musa, A. 1982. Incidence, economic importance, and control of Tomato Yellow Leaf Curl in Jordan. Plant Disease 66(7):561-563.

Andow, D.A., and K. Kiritani. 1983. The economic injury level and the control threshold. Japan Pesticide Information 43:3-9.

Anzola, D., and R. Lastra. 1978. Protección de semilleros de tomate y su relación con la incidencia del virus mosaico amarillo del tomate. Agronomía Tropical (Maracay, Venezuela) XXVIII(5):473-482.

Anzola, D., and R. Lastra. 1985. Whiteflies population and its impact on the incidence of Tomato Yellow Mosaic virus in Venezuela. Phytopath. Z. 112:363-366.

BND. 1983. *Presupuestos de Financiamientos para Hortalizas y Farinaceas. Crédito Rural. Ciclo - 1983/1984.* Managua, Nicaragua: Banco Nacional de Desarrollo (BND), 72 pp.

Cohen, S., and I. Harpaz. 1964. Periodic, rather than continual acquisition of a new tomato virus by its vector, the tobacco whitefly (*Bemisia tabaci* Gennadius). Ent. exp. & appl. 7:155-166.

Cohen, S., V. Melamed-Madjar and J. Hameiri. 1974. Prevention of the spread of tomato yellow leaf curl virus transmitted by *Bemisia tabaci* (Gennadius) (Homoptera, Aleyrodidae) in Israel. Bull. ent. Res. 64:193-197.

Cohen, S., and F.E. Nitzany. 1966. Transmission and host range of the Tomato Yellow Leaf Curl Virus. Phytopathology 56:1127-1131.

Comité de Control Integrado de Plagas del Algodonero. 1979. *Manual de Manejo Integrado de Plagas del Algodonero.* Managua: Banco Nacional de Nicaragua, unnumbered.

Costa, A.S. 1969. White flies as virus vectors. In *Viruses, Vectors and Vegetation*, K. Maramorosch (ed.). New York: Wiley, 95-119.

Costa, A.S. 1976. Whitefly-transmitted plant diseases. Ann. Rev. Phytopath. 14:429-449.

El-Helaly, M.S., A.Y. El-Shazli and F.H. El-Gayar. 1971. Biological studies on *Bemisia tabaci* Genn. (Homopt., Aleyrodidae) in Egypt. Z. ang. Ent. 69:48-55.

Flint, M.L., and R. van den Bosch. 1981. *Introduction to Integrated Pest Management.* New York: Plenum, 240 pp.

Flores, E., and K. Silberschmidt. 1958. Relations between insect and host plant in transmission experiments with Infectious Chlorosis of Malvaceae. Ann. Acad. brasileira Cis. (Brazil) 30:535-560.

Flores, E., K. Silberschmidt and M. Kramer. 1960. Observações de <<clorose infecciosa>> das malváceas em tomateiros do campo. O Biológico (São Paulo, Brazil) 26(4):65-69.

Gamez, R. 1971. Los virus del frijol en Centroamérica. I. Transmisión por moscas blancas (*Bemisia tabaci* Genn.) y plantas hospedantes del virus del mosaico dorado. Turrialba 21:21-27.

Hein, A. 1984. The leaf curl virus in tomatoes and possibilities of its control - a review. Acta Horticulturae 143:439-450.

Kramer, P. 1966. Serious increase of Cotton Whitefly and virus transmission in Central America. J. Econ. Entomol. 59:1531.

Lindquist, R.K., W.L. Bauerle and R.R. Spadafora. 1972. Effect of the Greenhouse Whitefly on yields of greenhouse tomatoes. J. Econ. Entomol. 65(5):1406-1408.

Little, T.M., and F.J. Hills. 1978. *Agricultural Experimentation: Design and Analysis*. New York: Wiley, 350 pp.

PAN. 1982. *Propuesta de Metas de Producción Hortícola para el Año 1982/1983*. Managua: MIDINRA, Programa Alimentario Nicaraguense (PAN), Dirección de Horticultura, unnumbered.

PAN. 1983. *Programa Operativo de la Producción Hortícola - ciclo 83/84* . Managua: MIDINRA, Programa Alimentario Nicaraguense (PAN), Dirección de Horticultura, unnumbered.

Pedigo, L.P., S.H. Hutchins and L.G. Higley. 1986. Economic injury levels in theory and practice. Ann. Rev. Entomol. 31:341-368.

Pohronezny, K.L., J. Francis and V. Waddill. 1980. Tomato pest management program - guidelines for scouts. Univ. of Fla. Extension Plant Pathology Rept. No. 28, 10 p.

Pohronezny, K.L., and V. Waddill. 1978. Integrated pest management - development of an alternative approach to control of tomato pests in Florida. Univ. of Fla. Extension Plant Pathology Rept. No. 22, 7 p.

Pollard, D.G. 1955. Feeding habits of the Cotton Whitefly, *Bemisia tabaci* Genn. (Homoptera: Aleyrodidae). Ann. Appl. Biol. 43:664-71.

Poston, F.L., L.P. Pedigo and S.M. Welch. 1983. Economic injury levels: reality and practicality. Bull. Entomol. Soc. Am. 29(1):49-53.

Power, A.G. 1985. Plant community diversity, insect movement, and the dynamics of an insect-transmitted plant disease. Unpublished Ph.D. dissertation, University of Washington, Seattle, 147 pp.

Rosset, P.M., A. Power, R. Argentina and A. Lara. 1983. Plagas del tomate: investigaciones de dinámica poblacional, el uso de insecticidas selectivos y la relación con rendimiento, en el Valle de Sébaco. Informe de la Estación Experimental de Valle de Sébaco, MIDINRA Región VI, Nicaragua,13 pp.

Russo, M., S. Cohen and G.P. Martelli. 1980. Virus-like particles in tomato plants affected by yellow leaf curl disease. J. Genet. Virol. 49(1):209-213.

Sears, M.K., A.M. Shelton, T.C. Quick, J.A. Wyman and S.E. Webb. 1985. Evaluation of partial plant sampling procedures and corresponding action thresholds for management of Lepidoptera on cabbage. J. Econ. Entomol. 78(4):913-916.

Shaheen, A.H. 1983. Some ecological aspects on the white fly *Bemisia tabaci* Genn., the main insect vector transmitting tomato leaf curl virus diseases. Ann. Agric. Sci. Moshtohor (Moshtohor - Tukh. A.R.E.) 19(2):453-457.

Simons, J.N., and T.A. Zitter. 1980. Use of oils to control aphid-borne viruses. Plant Disease 64(6):542-546.

Swezey, S.L., and R. Daxl. 1983. Breaking the circle of poison: the integrated pest management revolution in Nicaragua. Food First Research Report (San Francisco: Institute for Food and Development Policy), 23 pp.

Swezey, S.L., R.G. Daxl and D.L. Murray. 1984. Getting off the pesticide treadmill in the developing world: Nicaragua's revolution in pesticide policy. Manuscript.

de Uzcátegui, R.C., and R. Lastra. 1978. Transmission and physical properties of the causal agent of Mosaico Amarillo del Tomate (Tomato Yellow Mosaic). Phytopathology 68:985-988.

Vandermeer, J., and D.A. Andow. In press. Prophylactic and responsive components of an integrated pest management program. J. Econ. Entomol.

Vaughn, M.A., and G. Leon. 1977. Pesticide management on a major crop with severe resistance problems. Proceedings of the XV International Congress of Entomology (Washington, DC): 812-815.

Villareal, R.L. 1980. *Tomatoes in the Tropics*. Boulder, CO: Westview, 174 pp.

Wellik, M.J., J.E. Slosser and R.D. Kirby. 1979. Evaluation of procedures for sampling *Heliothis zea* and *Keiferia lycopersicella* on tomatoes. J. Econ. Entomol. 72(5):777-780.

Yassin, A.M. 1984. Leaf curl epidemic in tomato and possible control strategies. Acta Horticulturae 143:457-468.

Zalom, F.G., L.T. Wislon, M.P. Hoffmann, W.H. Lange and C.V. Weakley. 1983. Monitoring lepidopterous pest damage to processing tomatoes. California Agriculture, March-April:25-26.

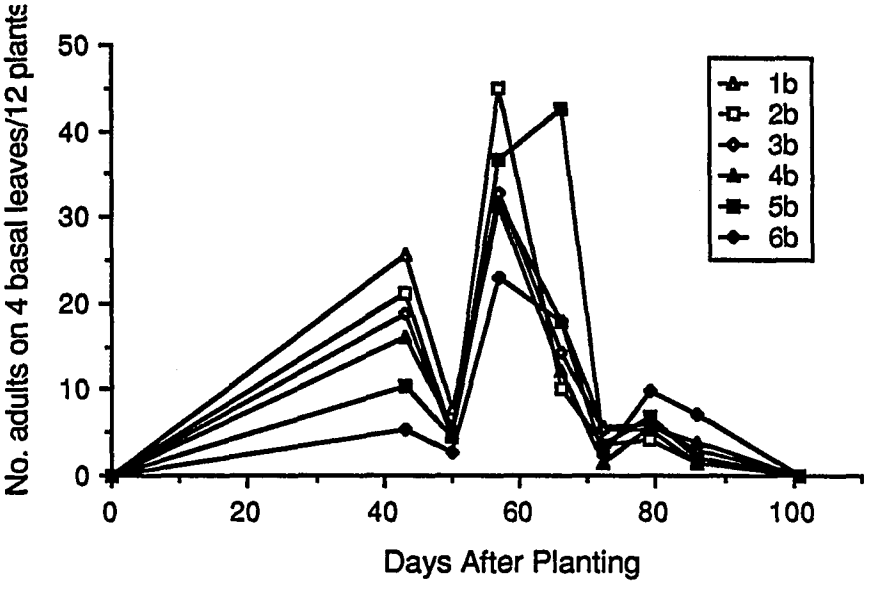


Figure 1. Population dynamics of Bemisia tabaci adults on basal leaflets during the growing season in six treatments: 1B=control, 2B=Dipel 140 g/ha, 3B=Dipel 425 g/ha, 4B=Thiodan 2 l/ha, 5B=Dipel 140 g/ha mixed with Thiodan 1 l/ha, and 6B=weekly rotation among Monitor 1.4 l/ha, Decis 570 cc/ha and Lannate 250 g/ha. 95% confidence intervals are not shown because they overlap at all dates except 43 DAP. Refer to Table 3 for mean separations on that date.

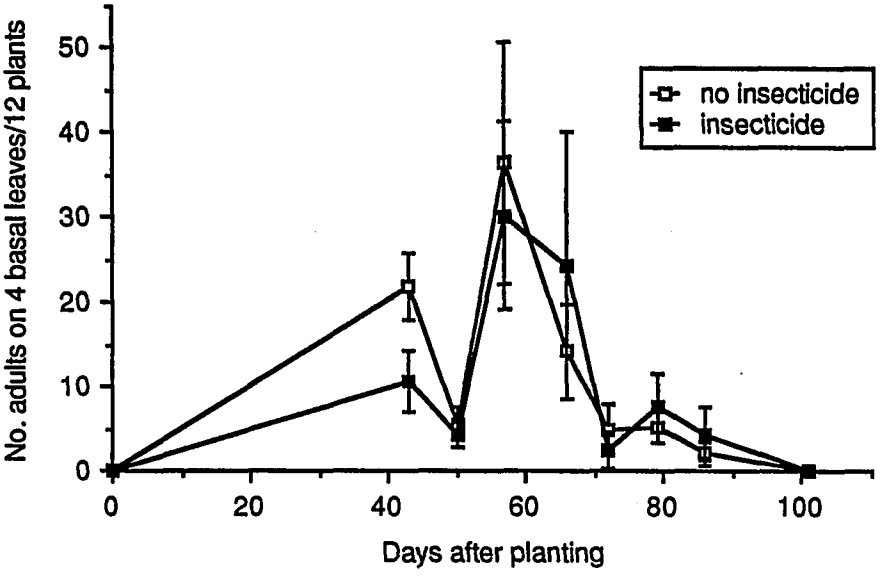


Figure 2. *Bemisia tabaci* numbers in pooled treatments: with and without synthetic insecticides toxic to it. Data is from **basal** sampling method. 95% confidence intervals are shown.

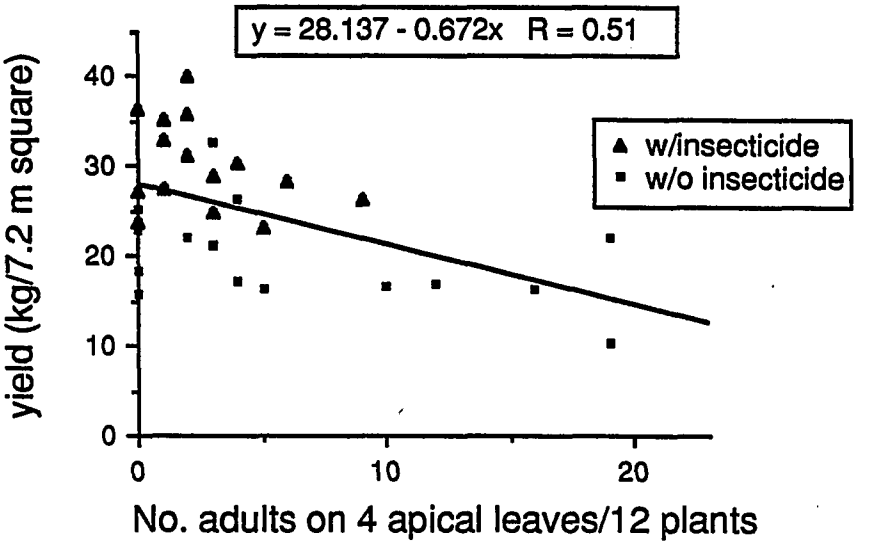


Figure 3. Regression of final yield in kg against whitefly density at 43 DAP as estimated by the **apical** sampling method. "With-" and "without insectide" treatments are indicated.

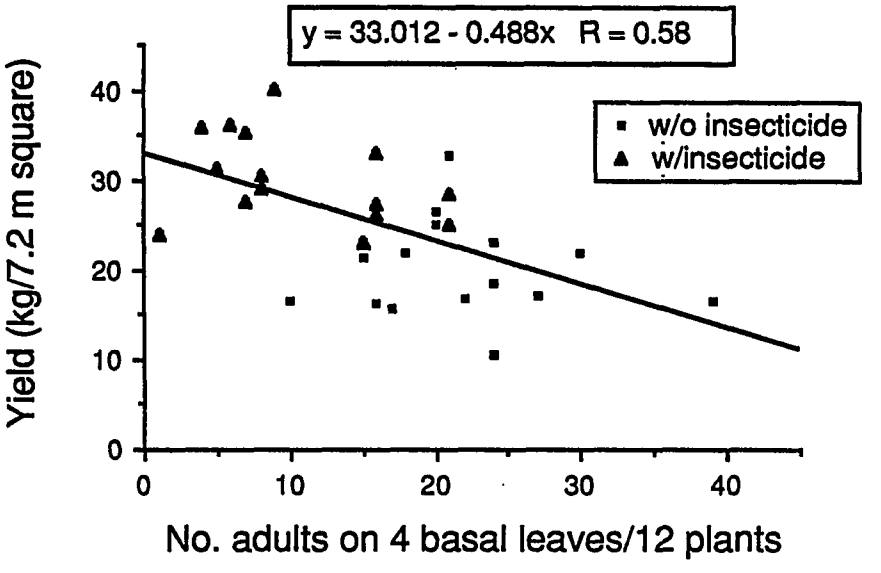


Figure 4. Regression of final tomato yield in kg against whitefly density at 43 days after planting as estimated by the **basal** sampling method. "With-" and "without insectide" treatments are indicated.

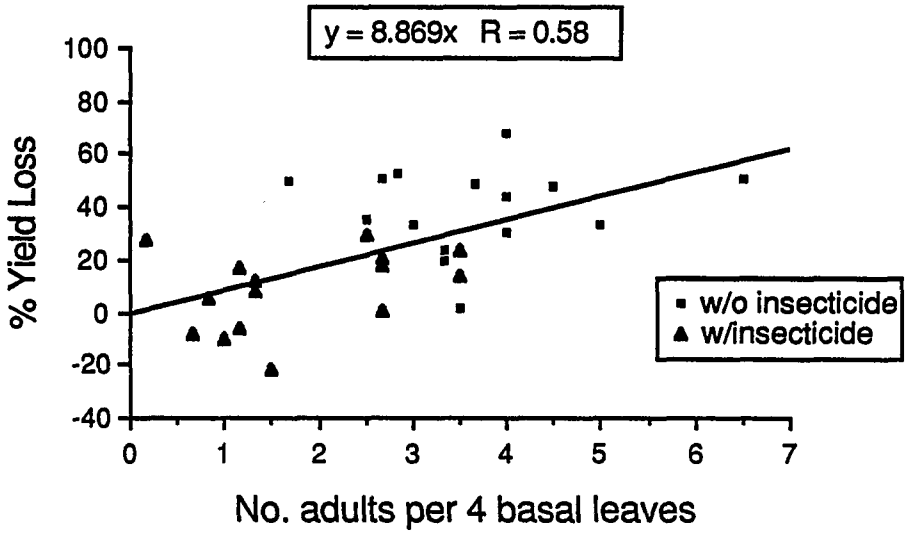


Figure 5. Regression of % Final Yield Loss (weight) against whitefly density at 43 DAP as estimated by the basal sampling method. "With-" and "without insecticide" treatments are indicated.

Table 1: Correlation matrix of final tomato yields in kg and numbers of fruit, and *Bemisia tabaci* numbers over the season for **apical** sampling method (values of the correlation coefficient **r** shown, n=30). * = P < 0.05, ** = P < 0.01, *** = P < 0.001, DAP = days after planting.

Yield (kg)	1.000									
Yield (no.)	0.895***	1.000								
B.t. 43 DAP	-0.506*	-0.475*	1.000							
B.t. 50 DAP	-0.326	-0.359	0.349	1.000						
B.t. 57 DAP	0.315	0.205	-0.500*	-0.249	1.000					
B.t. 66 DAP	0.179	0.234	0.000	0.168	0.323	1.000				
B.t. 72 DAP	-0.451	-0.274	0.285	0.409	-0.250	0.269	1.000			
B.t. 79 DAP	0.307	0.197	-0.160	-0.113	0.314	0.448	-0.303	1.000		
B.t. 86 DAP	0.183	0.078	0.179	0.135	0.085	0.276	-0.269	0.131	1.000	
B.t. 101 DAP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
	Yield (kg)	Yield (no.)	43	50	57	66	72	79	86	101

Table 2: Correlation matrix of final tomato yields and *Bemisia tabaci* numbers over the season for **basal** sampling method (values of the correlation coefficient **r** shown, n=30). * = P < 0.05, ** = P < 0.01, *** = P < 0.001, DAP = days after planting.

Yield (kg)	1.000									
Yield (no.)	0.895***	1.000								
B.t. 43 DAP	-0.576**	-0.578**	1.000							
B.t. 50 DAP	-0.035	-0.046	0.206	1.000						
B.t. 57 DAP	-0.119	-0.121	0.127	0.269	1.000					
B.t. 66 DAP	0.096	0.197	-0.306	0.154	0.229	1.000				
B.t. 72 DAP	-0.231	-0.170	0.111	0.412	0.420	0.544*	1.000			
B.t. 79 DAP	0.206	0.254	-0.418	0.354	0.213	0.583	0.359	1.000		
B.t. 86 DAP	0.169	0.330	-0.242	0.010	0.129	0.088	0.037	0.417	1.000	
*B.t.*101 DAP	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
	Yield (kg)	Yield (no.)	43	50	57	66	72	79	86	101

Table 3. Final yields (kg and numbers) of tomatoes and *Bemisia tabaci* numbers (number per 4 leaves over twelve plants) from the **basal** sampling method at 43 DAP. Values denoted by the same letter do not differ significantly at the $P < 0.05$ level according to Duncan's Multiple-Range Test.

Treatment	*B. tabaci* numbers	Final Yield (kg/ha)	Final Yield (no./ha)
Control	25.6^{a}	$35,105^{a}$	$122,915^{ab}$
Dipel 140 g/ha	21.0^{ab}	$37,625^{a}$	$122,570^{ab}$
Dipel 425 g/ha	18.8^{ab}	$30,560^{a}$	$88,195^{a}$
Thiodan 2 l/ha	16.2^{bc}	$51,670^{b}$	$152,780^{b}$
Thiodan 1 l/ha + Dipel 140 g/ha	10.4^{cd}	$48,665^{b}$	$150,695^{b}$
Monitor 1.4 l/ha or Decis 570 cc/ha or Lannate 250 g/ha	5.4^{d}	$56,810^{b}$	$190,625^{c}$

Table 4. Final yields (kg and numbers) and whitefly numbers (number per 4 leaves over twelve plants) from the **basal** sampling method at 43 DAP, for pooled treatments (with and without insecticides). *** = $P < 0.001$.

Treatment	*B. tabaci* numbers	Final Yield (kg/ha)	Final Yield (no./ha)
without insecticide	21.8	34,430	111,225
with insecticide	10.7***	52,380***	164,700***

Table 5. Economic Injury Level (EIL) for *Bemisia tabaci* on tomatoes in Nicaragua in 1983, based on equation (6) from the text, with k=0.0427. The expected yields cover the range predicted for the 1982-1983 growing season (10,000 - 40,000 kg/ha), for different regions and land tenure patterns, as presented in PAN (1982), plus the "experiment station" maximum value obtained in the study reported herein (45,000 kg/ha). The expected prices cover a range from the predicted 1983 price (20 c$/basket = 1.76 c$/kg; BND, 1983) past the 1982 high (80 c$/basket = 7.04 c$/kg) obtained from unpublished CIERA and INEC data. The EIL is based on a per ha cost of 720 c$ for two insecticide applications, obtained from estimated 1983 crop budgets (BND, 1983).

ECONOMIC INJURY LEVELS (EIL)

Expected Yield (kg/ha)	Expected Price (c$/kg)				
	1.76	3.52	5.28	7.04	8.80
10,000	0.891	0.446	0.297	0.223	0.178
15,000	0.594	0.297	0.198	0.149	0.119
20,000	0.446	0.223	0.149	0.111	0.089
25,000	0.357	0.178	0.119	0.089	0.071
30,000	0.297	0.149	0.099	0.074	0.059
35,000	0.255	0.127	0.085	0.064	0.051
40,000	0.223	0.111	0.074	0.056	0.045
45,000	0.198	0.099	0.066	0.050	0.040

CHAPTER 3

YIELDING PROPERTIES OF POLYCULTURES OF TOMATO AND BEAN IN COSTA RICA*

Introduction

This chapter presents a preliminary investigation of the yielding properties of a tomato and bean polyculture in Costa Rica. As has been discussed earlier, tomatoes are one of the Central American region's most important commercial vegetable crops, while beans are one of the most important staple crops (Chapter 1 of this dissertation).

A number of factors suggest that under certain circumstances polycultures may be more appropriate cropping systems than monocultures. In particular the potential for higher yields per unit area and/or per unit of capital inputs, plus the possibility of reduced pest populations, makes polycultures important alternatives where these are the important evaluative criteria. The principle drawback of polycultures is evident when the criterion employed is labor productivity. This is because it is more difficult to design a mechanical harvester, an important labor-saving device in "modern" agriculture, to harvest two or more crops

* The material in this chapter has been published elsewhere as Rosset et al. (1984).

simultaneously than it is to design one to harvest a single crop (see Horwith, 1985, for a review of these issues). In Central America, non-export crops like tomatoes are unlikely to be mechanically harvested in the foreseeable future, and given the economic problems of the region (see Chapter 1 of this dissertation) yield per unit of capital input may well be the most important criterion by which to evaluate cropping systems.

Polycultures, which are ubiquitous cropping systems in traditional tropical agriculture, have become a focal point of current agricultural research in the tropics. Studies have demonstrated that polycultures produce greater crop yields per unit area than respective monocultures in many cropping systems, including corn and beans (Soria et al., 1975); corn, beans and cassava (Hart, 1974); tomatoes and cucumbers (Schultz et al., 1982); tomatoes and soybeans (Vandermeer et al., 1984); and other crop combinations. A considerable number of comprehensive reviews have been published in the last decade (Papendick, 1976; Sanchez, 1976; Kass, 1978; Willey, 1979; Vandermeer, 1981; Schultz, 1984; Beets, 1985; Horwith, 1985; etc.).

Higher yields in polycultures may result from three kinds of ecological interactions: plant/plant, plant/pest, and plant/symbiont. Competition has long been recognized as a major determinant of plant growth and yield (de Wit, 1960; Trenbath, 1974; Hall, 1974). Vandermeer (1981) has shown that ecology's competitive exclusion principle (Gause's axiom) is mathematically equivalent to agronomy's measure of polyculture performance, the Land Equivalency Ratio, or LER (Mead and Willey, 1980). Just as Gause's axiom says that two species will coexist if they do not use the same resources, Vandermeer's "interference production principle" predicts that a polyculture will overyield if the mutual interference of two

crops is sufficiently weak; i.e. if interspecific competition is less than intraspecific competition.

Since intraspecific density response may be modified by interspecific interference (Antonovics and Levin, 1980), yield-density relationships in polycultures are not as straightforward as in single species stands. Huxley and Maingu (1978) found that the optimal planting density of maize and cowpea in polyculture cannot be predicted from the density responses of the two crops in monocultures. In an attempt to overcome this problem, Vandermeer et al. (1984) developed a model based on competition theory to predict the optimal combinations of crop densities in polycultures. A clear conclusion is that when examining yielding properties of polycultures it is useful to examine more than single density of each crop, to avoid missing a potential advantage.

The common practice of intercropping with legumes illustrates another type of plant interaction important in polycultures. Nitrogen fixation by legumes may provide nutrient benefits to associated plants (for discussion see Sanchez, 1976; and Kass, 1978). Furthermore, it appears that intercropping enhances this fixation by legume symbionts. Dalal (1974) showed that maize/pigeon pea polycultures produced more nitrogen per hectare than did either crop planted in monoculture. Boucher and Espinoza (1982) found that nodulation in beans increases when they are grown in polyculture with maize. Thus, nodulation may increase under interspecific competitive stress, resulting in a mutualistic interaction between the legume and the other crop.

Crop phenology and planting time also affect crop interaction in polycultures (Sanchez, 1976). Crops exhibit a critical period in their growth cycle during which competition significantly decreases yield.

Competitive effects on yields in polycultures may depend on the amount of critical period overlap in the phenologies of the associated crops. Sanchez (1976) therefore suggests that patterns of nutrient uptake over time may determine the success of polycultures. For example, a short-cycle legume intercropped with a longer-cycle crop may provide a pulse of nitrogen from decaying roots at a critical period in the phenology of the associated crop, thus positively affecting yield.

In addition to these plant/plant interactions, plant/pest interactions may also have important effects on polyculture performance. There is an extensive literature indicating that the severity of insect attack (Way, 1977; Root, 1973; Perrin, 1977; Chapter 4 of this dissertation) and pathogen attack (van der Plank, 1963; Trenbath, 1977) in plant communities decreases with increasing plant species diversity. Since insects and pathogens have profound effects on crop yields, any decrease in pest abundance afforded by the increased plant diversity of polycultures could contribute to their yield advantage.

The strong ecological foundation that underlies the production capability of polycultures suggests to us that the full potential of these cropping systems has not been realized. When coupled with socioeconomic benefits that may accrue from polycultures, such as the simultaneous production of a basic food and a cash crop, further research on polyculture systems seems warranted.

Materials and Methods

Tomatoes (cv. 'Tropic'), and red beans (cv. 'Mexico 80') were grown in monocultures and dicultures at the Fabio Baudrit M. Agricultural

Experiment Station of the University of Costa Rica, 5 km. west of Alajuela, Costa Rica. The station is in the Meseta Central of Costa Rica, at an elevation of 840 m, with a mean temperature of 22°C with maximums of 34°C in March and minimums of 10.5°C in December. The average annual precipitation is 1900 mm, distributed from May to November. The soil is of the Saenz series. The pH (in water) is 5.0-5.4, with an organic matter content of 5%. Minerals are present in the following levels: Cu[1], 3.1 - 20.9 µg/ml; Fe[1], 21 - 80 µg/ml; Ca[2], 2.0 - 4.0 meq/100 ml; Mg[2], 0.81 - 2.00 meq/100 ml; Mn[1], 5.1 - 10.9 µg/ml; K[2], 0.16 - 0.30 meq/100 ml; Zn[2], 0.0 - 3.0 µg/ml.; Al[1], 0.0 - 3.0 µg/ml.

Crops were grown from February through May 1982, from the end of the dry season into the beginning of the rainy season. Ten treatments were arranged in a randomized block design with four replications. Each treatment plot was 4.8 m X 4.8 m with a 1.2 m border separating plots. Table 1 presents the various treatments.

The crops were grown according to recommendations provided by agronomists at the Experimental Station. At planting, bean rows were fertilized in lines at a rate of 16.7 kg N (urea), 50 kg P (P_2O_5) and 16.7 kg K (K_2O) per hectare and the tomatoes at a rate of 75 kg. N, 225 kg P, and 75 kg. K per hectare, applied next to the seeds. Two months after planting, the tomatoes were fertilized again with 75 kg N, 225 kg P and 75 kg K per hectare, applied in bands. Pesticides were applied at planting, to the soil (Cytrolame®, 25 kg/ha), and to the seed (Captan®, 50% and Benlate®, 50%, at 302 g/4 kg of seed). Insecticides (Orthene® and Lorsban®, 15 g/16 L), fungicide (Difolatan®, 40 g/16 L), and fertilizer (Fertilon®, 10 g/16 L)

[1] Sample depth of 30-60 cm.
[2] Sample depth of 0-30 cm.

were applied during the first three weeks of germination. Fungicide (Dithane M-45®, and Difolatan®, once each) was applied to the tomatoes in the last month of the experiments.

The plots were hand weeded throughout the season, and irrigated for 2-3 hours per week during the first three months, before the start of the rainy season.

Tomatoes were tied to wire suspended from poles in the tomato rows when necessary. Bean germination was very high (>90%), but tomato germination was lower because of dry conditions. Tomato seedlings were transplanted to fill holes left by ungerminated plants during the first month.

During the last month of the experiment the tomato plants were severely affected by viral diseases. The effect of these diseases in each treatment was scored on a subjective scale of one to four (see Table 5). The number of tomato plants with aphid colonies was also recorded.

Beans were allowed to dry in the field, then harvested at 90 days after planting. Yield data were taken on a total of 1.8 m of plants distributed in three rows per plot, leaving at least a 0.6 m border. Whole bean plants were removed from the plots for further drying. In dicultures with tomatoes, the bean plants were cut at the base, to leave roots and nodules in the soil. After drying, the beans were shelled, cleaned and weighed. The moisture content of each sample was determined using a Dickey-John™ Grain Moisture Tester, and yields were adjusted to 15% moisture.

Tomatoes were harvested and weighed as they ripened during the last month of the experiment, then tomatoes remaining on the plants were harvested at 116 days after planting. Yield data were collected from 7.2 m

of tomato plants in each plot: 3.6 m in each of two rows, leaving a 0.6 m border on each edge.

To be as conservative as possible LER values were calculated using the monocultural yields of the best monocultural treatment (low density for tomatoes -- in bean there was only one density). Values were calculated within each block, using the best monocultural treatment as the monoculture value from each block.

Results

I assessed the advantages of the polyculture using the LER's subjected to analysis of variance. Rao and Willey (1980) argue that the larger-than-normal standard errors of LER distributions makes parametric tests conservative. The analysis of variance of the effect of cropping system on relative yield (as measured by LER) showed the overall effect of cropping systems to be highly significant ($p < 0.01$). Table 2 presents these LERs as tested for significant differences by Duncan's multiple range test (Little and Hills, 1978). The high density tomato density polyculture overyielded with an LER value of 2.41, which is significantly different ($P < 0.05$) from the relative yield of the monocultures (defined as LER = 1). The low density tomato polyculture also overyielded (LER = 1.92), although because of high experimental variance this overyield was not significantly different from the monoculture yield. Within tomato monocultures the trend (not significant) was for the low density treatment to have greater yields, but within polycultures this trend was reversed (also a non-significant trend), with high density polycultures yielding best.

The average yields of tomatoes per hectare for the various treatments are presented in Table 3. Polycultures tend to produce more tomatoes than the monocultures, although this trend is not significant. Because of severe problems early in the season with irrigation, and late in the season with pathogens, the absolute tomato yields were very low, less than 50% of optimum.

Average bean yields per hectare for each treatment are presented in Table 4. Since beans were planted in half as many rows in polycultures as in monocultures, the bean yield in polyculture should be 50% of the monocultural yield if there was no effect of cropping system. There is a non-significant trend towards greater than 50% yield in the polycultures, suggesting that cropping system positively affected bean yield. The highest bean yield was in the high density tomato polyculture. The bean yields, unlike tomato yields, were well within normal levels for Costa Rica.

Tables 5 and 6 show non-significant trends for higher levels of virus and greater numbers of aphids, respectively, on tomatoes in monocultures than on tomatoes in polycultures.

Discussion

Practical Implications: The 2.41 LER value for the bean and high density tomato polyculture is a dramatic result in view of previous polyculture research. Sanchez (1976) and Kass (1978) report a total of sixteen LER values for different cropping systems, the greatest being 2.00 for a sugarcane and cowpea polyculture. With the exception of a few studies on corn-bean mixtures (e.g. Soria et al., 1975), our results appear to be among the greatest LERs yet reported for two species polycultures.

A common criticism of the use of the LER statistic is that it assumes that the farmer wants both crops in the proportion produced by the polyculture (Kass, 1978; Mead and Willey, 1980). This a problem particularly when the combination is of a commercial crop and a basic food crop (as it is with tomatoes and beans). A farmer will usually wish to maximize the yield of the commercial crop rather than the LER, or combination of crops. This consideration does not pose a problem with this experiment, however, as the polycultures tended to maximize LER as well as the production of the tomato commercial crop. Thus this system could provide a useful bonus of beans in commercial tomato plantings without adversely affecting tomato yield.

Although some fertilizer was added to the bean rows during planting in the polycultures, this fertilization probably was unnecessary, since the amount used was insignificant in comparison with the amount of fertilizer the tomato rows received. Our data suggest that it should be possible to add beans to tomato fields with no extra cost beyond that of seeds and labor for planting and harvesting, though further experiments are needed to verify this prediction.

The results presented should be considered applicable to production under poor conditions because of the poor tomato yields. Experiments under a wider range of conditions and at different times of the year are necessary to confirm the potential of tomato-bean intercropping systems.

Biological Mechanisms: Although these experiments were not explicitly designed to examine the biological mechanisms of overyielding, they do allow some discussion of this topic. The trend for beans in polyculture to produce more than 50% of the monoculture yield, despite

having one-half of monoculture density, indicates that tomato rows provide less competitive interference for bean rows than do other bean rows. Thus this data support the "interference production principle" (Vandermeer, 1981), which suggests overyielding will occur when interspecific competition is less strong than intraspecific competition.

No such comparison is possible based on the tomato data because the number of tomato rows was constant in polycultures and monocultures; but the trend of increased absolute production of both tomatoes and beans in polycultures with increased tomato density, suggests a mutualistic interaction, possibly related to nutrient relations between beans and tomatoes. Boucher and Espinoza (1982) found greater N fixation by beans correlated with increased interspecific competition. Nodulation data was not collected in this study, although casual observation indicated a relatively high density of nodules.

Another mechanism that may have contributed to overyielding in these polycultures is the moderating effect of crop diversity on pathogen attack (van der Plank, 1963; Trenbath, 1977). Because of the heavy pathogen damage to the tomatoes (virus, bacteria, and fungus), any effect the beans had in reducing pathogen spread could have contributed to the trend for greater tomato yields in polycultures. The trend towards increased viral attack in monocultures, which may be related to a similar trend in aphid attack (since aphids are commonly virus vectors), indicates that disease control may have been a factor in higher yields. It is well established the increased ground cover in polycultures generally reduces aphid attack (see Power, 1985, for a recent review).

In interpreting these results, it should be realized that several sources of interaction exist which allow no clear conclusions to be drawn: different

levels of N fertilizer used, the population effect of adding beans, the effect of N on nodulation, the effect of poor tomato performance, and the effects of pests. All of these are worthy of further study.

A separate paper (Power et al., in press) reports on population levels of insects attacking beans in the various experimental treatments, although none of them reached economically damaging levels.

Literature Cited

Antonovics, J. and Levin, D.A. (1980) "The ecological and genetic consequences of density-dependent regulation in plants." Ann. Rev. Ecolog. Sys. 11,411-452.

Beets, W.C. (1985) Multiple cropping and tropical farming systems. Westview, Boulder. 156 pp.

Boucher, D.H. and Espinoza, J. (1982) "Cropping system, growth and nodulation responses of beans to nitrogen in Tabasco, Mexico." Trop. Agric. (Trinidad), in press.

Burns, R.C., and Hardy, R.W.F. (1975) Nitrogen fixation in bacteria and higher plants. Springer-Verlag, New York.

Dalal, R.C. (1974) "Effects of intercropping maize with pigeon peas on grain yields and nutrient uptake." Expl. Agric. 10,219-224.

de Wit, C.T. (1960) On competition. Vers. Landbouw. Ondezoekingen. 665 Wageningen. 82 pp.

Hall, R.L. (1974) "Analysis of the nature of interference between plants and species. I. concepts and extension of the de Wit analysis to examine effects." Aust. J. Agric. Res. 25,749-756.

Hart, R.D. (1974) "A bean, corn and manioc polyculture cropping system. I. The effect of interspecific competition on crop yield." Turrialbà 25,294-301.

Horwith, B. 1985. "A role for intercropping in modern agriculture." BioScience 35:286-291.

Huxley, P.A. and Maingu, Z. (1978) "Use of a systematic spacing design as an aid to the study of intercropping: some general considerations." Expl. Agric. 14,49–56.

Kass, D.C.L. (1978) "Polyculture cropping systems: review and analysis." Cornell Int. Agric. Bull. 32, 69 pp.

Little, T.M. and Hills, F.J. (1978) Agricultural Experimentation: Design and Analysis. Wiley, New York. 350 pp.

Mead, R. and Willey, R.W. (1980) "The concept of a 'Land Equivalent Ratio' and advantages in yields from intercropping." Expl. Agric. 16,2117-228.

Papendick, R.I. ed. (1976) Multiple Cropping. Amer. Soc. Agron. Sp. Pub. 27, Madison, Wisconsin.

Perrin, R.M. (1977) "Pest management in multiple cropping systems." Agro- ecosystems. 3,93-118.

Power, A.G. 1985. "Plant community diversity, insect movement, and the dynamics of insect transmitted disease." Unpublished Ph.D. dissertation, University of Washington, Seattle. 147 pp.

Power, A.G., Rosset, P.M., Ambrose, R.J., and Hruska, A.J. (in press). "Population responses of bean insects to inter- and intraspecific plant diversity." Turrialba.

Rao, R.R. and Willey, R.W. (1980). "Preliminary studies of intercropping combinations based on pigeon pea or sorghum." Exp. Agr. 16,29-39.

Root, R.B. (1973) "Organization of a plant-arthropod association in simple and diverse habitats: the fauna of collards (Brassica oleracea)." Ecol. Monogr. 43,95-124.

Rosset, P.M., Ambrose, R.A., Power, A.G. and A.J. Hruska. (1984) Overyielding in polycultures of tomato and bean in Costa Rica. Tropical Agriculture (Trinidad) 61,208-212.

Sanchez, P.A. (1976) Properties and Management of Soils in the Tropics. Wiley, New York.

Schultz, B.B. 1984. Ecological aspects of stability in polycultures versus sets of monocultures of annual crops. Unpublished Ph.D. dissertation, University of Michigan, Ann Arbor. 215 pp.

Schultz, B.B., Phillips, C., Rosset, P.M. and Vandermeer, J.H. (1982) "An experiment in intercropping cucumbers and tomatoes in Southern Michigan, U.S.A." Scient. Hortic. 8,1-8.

Sokal, R.R. and Rohlf, F.J. (1969) Biometry. Freeman, San Francisco. 776 pp.

Soria, J., Bazan, R., Princhinat, A.M., Paiez, G., Mateo, N., Moreno, R., Fargas, J., and Forsythe, W. (1975) "Investigacion sobre sistemas de produccion agricola para el pequeno agricultor del tropico." Turrialba 25,283-293.

Trenbath, B.R. (1974) "Biomass productivities of mixtures." Adv. Agron. 26,177-210.

Trenbath, B.R. (1977) "Interactions among diverse hosts and diverse parasites." Ann. N.Y. Acad. Sci. 287,124-150.

Vandermeer, J. (1981) "The interference production principle: an ecological theory for agriculture." Bioscience 31,361-364.

Vandermeer, J.H., Ambrose, R.J., Hansen, M., McGuinness, H., Perfecto, I., Phillips, C., Rosset, P.M., and Schultz, B.B. (1984). "Evaluation of an ecologically-based approach to the design of intercrop agroecosystems: an intercropping system of soybeans and tomatoes in southern Michigan." Ecological Modelling 25:151-150.

van der Plank, J.E. (1963) Plant Diseases: Epidemics and Control. Academic Press, New York.

Way, M.J. (1977) Pest and disease status in mixed stands versus monocultures, the relevance of ecosystem stability. In Origins of Pest, Parasite, Disease, and Weed Problems. J.M. Cherret and G.R. Sagar, eds. Blackwell Sci. Publ., Oxford. 127 pp.

Willey, R.W. (1979) "Intercropping - its importance and research needs. I and II" Field Crop Abstracts 32,1-10, 73-83.

Table 1 Treatments used in the experiments

Monocultures

a) Tomato, low plant density: 0.5 m between plants, 1.2 m between rows.
b) Tomato, high plant density: 0.3 m between plants, 1.2 m between rows.
c) Bean: 0.6 m between rows, 10 cm between plants.

Polycultures

a) Bean and low plant density tomato:
   tomato: 0.5 m between plants, 1.2 m between rows.
   bean: 1.2 m between rows, 10 cm between plants.
b) Bean and high plant density tomato:
   tomato: 0.3 m between plants, 1.2 m between rows.
   bean: 1.2 m between rows, 10 cm between plants.

Table 2 Relative yields obtained in the experiments

Tomato stand density	Cropping system	
	Tomato monoculture	Polyculture
low	1.00ab	1.92bc
high	0.81a	2.41c

The relative yields are calculated relative to the monocultural treatment with the best yield (low density tomato). Values designated with the same letter are not significantly different at the $P < 0.05$ level using Duncan's Multiple Range Test. The bean monoculture has, by definition, an LER = 1.0, and thus is in category 'a'

Table 3 Tomato yields (kg ha^{-1}) obtained in the experiments

Tomato stand density	Cropping system	
	Monoculture	Polyculture
low	3733 ± 878	4348 ± 848
high	3023 ± 939	6043 ± 1360

Yields are presented with standard errors. The differences were not significantly different

Table 4 Bean yields (kg ha^{-1}, 15% moisture) obtained in the experiments

Cropping system		
	Polyculture	
Bean monoculture	High population density tomato	Low population density tomato
1.116 ± 189	695 ± 78	742 ± 76

Bean yields are presented with standard errors. The beans in the polycultures were planted at 50% of the monocultural density.The differences between the monocultural yield and two times the polycultural yield were not significantly different

Table 5 Virus levels on tomato found in the experiments

Tomato stand density	Cropping system	
	Monoculture	Polyculture
low	2.54 ± 0.54	2.27 ± 0.34
high	2.90 ± 0.19	2.56 ± 0.23

Virus levels on tomato were measured on a subjective scale of 1–4 (1 = 0–25%, 2 = 26–50%, 3 = 51–75%, 4 = 76–100% of leaves affected), and are presented (untransformed) with standard errors. The differences were not significant

Table 6 Percentage tomato plants with aphid colonies

Date	Monocultures	Polycultures
April 21	35.8% ± 18.6%	6.2% ± 6.2%
May 6	43.3% ± 25.0%	8.7% ± 3.4%

The percentages (untransformed) are presented with standard errors. The differences were not significant using Friedman's test (Sokal & Rohlf, 1969)

CHAPTER 4

EVALUATION OF A TOMATO AND BEAN POLYCULTURAL CROPPING SYSTEM AS A COMPONENT OF THE INTEGRATED PEST MANAGEMENT OF TOMATOES IN NICARAGUA*

Introduction

The purpose of this study is to evaluate the potential of a tomato and bean polyculture as a prophylactic component of a program for the integrated management of tomato pests in Nicaragua. A related objective is to further evaluate the yielding properties of this cropping system.

As reported in the previous chapter this cropping system has excellent yielding potential, and a review of the literature suggests that it might also diminish pest populations. In particular, other studies have shown that the attack of several tomato pests may be reduced, including *Manduca spp.* (Lepidoptera: Sphingidae; Vandermeer et al., ms.), *Spodoptera sunia* Guenée (Rosset, Vandermeer, et al., in press; Chapter 6 of this dissertation) and possibly aphids (Rosset at al., 1984; Chapter 3 of this dissertation). Preliminary, non-quantified observations in Nicaragua by this author also suggest that attack by the cotton whitefly, *Bemisia tabaci* Gennadius

* The material in this chapter is being published elsewhere as Rosset, Diaz, et al., in press

(Homoptera:Aleyrodidae), on tomatoes, may be reduced by the presence of beans.

A major focus of research involving polycultures has been the effect of plant community diversity on the populations of herbivorous insects. Recent reviews have cited many basic ecological studies showing decreased herbivore abundance with increased plant diversity (Altierri et al., 1977; Andow, 1983; Atsatt and O'Dowd, 1976; Cromartie, 1981; Dempster and Coaker, 1974; Kareiva, 1983; Litsinger and Moody, 1976; Norton, 1975; Perrin, 1977; Perrin and Phillips, 1978; Risch et al., 1983; Stanton, 1983; Way, 1977). A number of basic mechanisms leading to lower herbivore populations emerge from this literature. They can be grouped into three general categories as follows:

1) Attraction: A wide variety of factors can reduce the attractiveness of the crop in a polyculture, including greater percent ground cover, physical barriers, high diversity of chemical cues, presence of diversionary hosts, complex crop architecture, etc.
2) Tenure time: In the case of highly mobile pests, the length of time that they remain in the crop may be reduced by such factors as contact with non-hosts, chemical repellents, increased shade, etc.
3) Mortality: A higher natural enemy abundance may lead to greater mortality in a polyculture.

Despite this abundance of promising basic scientific work, however, there are few examples where intercropping has actually gone from basic research to practical application *as an explicit pest control strategy* (for a theoretical discussion of how this might be done see Vandermeer, 1984, and

Vandermeer and Andow, in press). The major examples reported in the literature are based on strip cropping, which differs significantly from the type of intercropping reported here (Swezey and Daxl, 1983; Stern, 1969).

Chemical control of tomato pests in Nicaragua is difficult because the source of 2 of the key pests, the *Heliothis spp.* complex (Lepidoptera: Noctuidae), and the *Spodoptera spp.* complex (Noctuidae), is the cotton producing zone of the Pacific, where they have acquired powerful resistance to most insecticides in use (Vaughn and Leon, 1977). A third pest, the vegetable leafminer, *Liriomyza sativae* Blanchard (Diptera: Agromyzidae), is widely known as a secondary outbreak pest provoked by excessive insecticide use (Oatman and Kennedy, 1976), as is the cotton whitefly, *Bemisia tabaci,* discussed in an earlier chapter. Within this context, therefore, it is imperative to develop non-chemical chemical alternatives such as polycultures to reduce reliance on insecticides of doubtful effectiveness.

The *Heliothis* complex in Nicaragua is made up of two species, *H. zea* Boddie and *H. virescens* Fabricius, with the former predominant. They are considered major pests of cotton, tobacco and tomatoes. They attack corn too, but are not considered of major economic importance on that crop. They are present throughout the year, with major population peaks in May-June and September-January (Comité de Control Integrado, 1979). They do not oviposit on tomatoes until flowers are present, at which time single eggs are deposited on terminal leaflets near flowers or fruit. After eclosion they move directly to fruit if available, or to flowers. They bore deeply into the fruit, where they are difficult to reach with insecticides. The larvae leave deep watery cavities in the fruit that are contaminated with feces and cast skins. Such fruit usually rot and fall to the ground. When the fruit are small

each larva may damage several (IPM Manual Group, 1982). Wolfenbarger et al. (1971, 1973) reported that *H. zea* in Nicaragua was 44 times more resistant to methyl parathion than in Texas, and 23 times more resistant to endrin than in Mississippi.

The *Spodoptera* complex on tomatoes in Nicaragua consists of *S. exigua* Hbn., the beet armyworm, *S. sunia* and *S. latifascia* Walk. They are pests of cotton, beans and tomatoes. Peak adult populations, as estimated from light trap data, are in January-March (Hellpap, 1985). They are highly resistant to insecticides and are known as secondary outbreak pests in cotton, with an explosive potential for population growth (Vaughn and Leon, 1977). Eggs are deposited on the leaves in masses, and the newly hatched larvae feed on foliage. They soon move to the fruit where they excavate shallow holes that characteristically scar over (IPM Manual Group, 1985). In Nicaragua they feed at night, spending the hot daytime hours sheltered in litter on the ground. As a result of this habit they more frequently damage those fruit in contact with the ground than those higher up on the plant.

Liriomyza sativae can attack tomatoes at any point during the growing cycle, although it is most common between the seedling and the flowering stage. The larvae make characteristic serpentine mines in the leaves, and can only be controlled with insecticides that have some translaminar action. In California it is resistant to all available insecticides except Monitor® (IPM Manual Group, 1985). There is some confusion in the literature as to whether or not *L. sativae* actually affects tomato yields. Linquist (1974) in Ohio and Rosset et al. (1983) in Nicaragua found no relationship between leafminer populations and yield, while Wolfenbarger and Wolfenbarger (1966) found a possible relationship. It seems that only when the density of leaf mines is so high that severe defoliation occurs, does the leafminer

depress yields (IPM Manual Group, 1985; Schuster et al., 1980). Tomatoes can tolerate significant defoliation, and in fact indeterminate varieties are often pruned because excess foliage depresses yields (IPM Manual Group, 1985).

In this study damage on tomatoes caused by *Heliothis, Spodoptera* and *L. sativae* was monitored in polycultures and monocultures, to see if the damage was indeed reduced by intercropping.

Some workers have suggested that polycultures may also reduce disease spread, by decreasing the proportion of susceptible hosts in a field. On the other hand a polyculture may improve the microclimate (temperature, humidity) for microbial pathogens, and lead to greater problems (see van der Plank, 1963, and Zadoks and Schein, 1979, for reviews). A secondary feature of this study was therefore to monitor pathogen attack.

Materials and Methods

Study Site: This experiment was conducted at the Sébaco Valley Regional Experiment Station, near San Isidro, Matagalpa, Nicaragua (see Chapter 2 of this dissertation for further details of this site), during the 1982-83 dry season. The experimental field had been previously cultivated with rice, and therefore had a high density of the weed purple nutsedge, *Cyperus rotundus* L. (Cyperaceae), known locally as *coyollio* . Table 1 shows an analysis of soil samples taken from the field shortly before planting.

Agronomic Practices: Separate monocultures and polycultures of beans and tomatoes were direct seeded during the dry season on January 14,

1983. A determinate tomato cultivar, UC-82, was used, which is the standard processing variety utilized in the Sébaco Valley. The bean cultivar used was Revolución 79, a red bean variety common in Nicaragua.

The crops were planted on raised beds that were 1.2 m wide and 0.4 m apart, which is the normal commericial practice for large-scale irrigated production of both beans and tomatoes in Nicaragua. Ten tomato seeds or two bean seeds were planted in shallow holes (1-2 cm in depth), and the tomatoes were later thinned to one plant per hole.

260 kg/ha of 12-30-10 NPK fertilizer was applied in bands adjacent to the tomato rows at the time of planting, and two additional broadcast applications of 130 kg/ha each of urea (46% N) were made at 38 and 62 days after planting (DAP). No fertilizer was applied to the bean rows at any time.

The plots were weeded by hand at 10, 19 (block 1 only), 39, and 67 (tomatoes only) DAP. Earth was hilled around the tomato plants at 39 DAP. The experiment was irrigated by sprinkler approximately once every 8 days. The insecticide Lannate® (against *Diabrotica sp.* attacking the seedlings of both crops) and the fungicide Benlate® (against *Phythium*) were applied at 12 DDS. No other pesticide applications were made during the course of the experiment, so as not interfere with insect and pathogen populations.

Experimental Design: The size of each experimental plot was 10 m X 6 beds (9.6 m), with an unplanted but weeded border between plots of 1 m or 1 bed (1.4 m). The experimental design consisted of 5 randomized blocks with the following three treatments:

1) Tomato monoculture: 2 rows of tomatoes on the center of each bed, with 0.4 m between them and 0.3 m between each row and the edge of the bed. The plants were

thinned along the rows to one every 0.25 m (50,000 plants/ha).

2) Bean Monoculture: 4 rows of beans on each bed, with 0.4 m between the center rows, and 0.3 m between each center row and the adjacent outside row, planted on the edge of the bed. The bean seeds were planted in holes that were spaced 0.1 m apart apart along the rows (two seeds per hole , $\leq$ 250,000 plants/ha).

3) Polyculture: 2 center rows of tomatoes and two edge rows of beans on each bed, planted at the same within row densities as the respective monocultures (50,000 plants/ha of tomatoes and $\leq$ 125,000 plants/ha of beans). The tomato rows were 0.4 m apart, with 0.3 m between each tomato row and its neighboring bean row.

Data Collected: The beans were harvested at 80 DAP. In each plot dry weights adjusted to 15% humidity were taken for the two center beds, plus the interior halves of the next two beds. Data was not taken from a 1 m border at the end of each row, to eliminate edge effects.

All tomatoes were harvested at 88 DAP, and the weight and number of commercial fruits from the four center beds of each plot was recorded, once again leaving a 1 m. border at the end of each row. A random sample of 100 rejected, or non-commercial, fruits was taken from the tomatoes harvested from each plot, and was graded according to categories of damage (see Table 5).

Pest insects and plant diseases were sampled weekly on the tomato plants. For insect sampling 4 sampling stations were randomly chosen and

marked with plastic flagging in each plot. Each station consisted of 5 adjacent plants along a row, for a total of 20 plants per plot. The only insect pests that appeared in analyzable numbers were *L. sativae*, *Heliothis spp.*, and *Spodoptera spp* . The cotton whitefly, *B. tabaci*, was observed attacking the beans in low numbers, but none were recorded in the tomato sampling. Bean pests were not sampled. The following data was collected for the plants sampled in each plot:

1) The number of *L. sativae* mines containing living larvae on all of the leaflets of the fourth fully expanded compound leaf from the top of the plant (modified from Rosset et al., 1983, and Pohronezny et al., 1980).
2) The number of fruits damaged by the larvae of *Heliothis spp.* and *Spodoptera spp.*, respectively. The damage caused caused by each was distinguished based on pictures and descriptions in an IPM manual from California, U.S.A. (the most recent edition of this is IPM Manual Group, 1985).

Disease sampling was carried out weekly and consisted of determining the percentage of tomato plants affected by wilt diseases in the four central beds of each plot (leaving a 1 m border). Samples sent to the Plant Pathology Laboratory of the Ministry of Agriculture (MIDINRA) in Managua indicated that all of the affected plants were infected with *Fusarium* wilt. The total number of fruit per plant and the percentage affected by fungal and bacterial pathogens was determined in a random sample of 10 plants per plot on weekly basis beginning at 61 DAP. All of the affected fruit had bacterial spot, *Xanthomonus vesicatoria,* except at harvest when late blight, *Phytophthora infestans* , appeared.

At 53 DAP 8 bean plants were chosen at random from each plot and the number of root nodules was counted on each plant.

Results:

Table 2 gives the relative and absolute yields for each crop for each block and for the entire experiment, along with Land Equivalent Ratios (LERs, see Sanchez, 1981, and Soría et al., 1975). A 2 X 5 (treatments X blocks) ANOVA of tomato yields showed no significant difference in means between polyculture and monoculture. A similar ANOVA for beans also showed no difference with regard to two null hypotheses, that polycultural yields equal monocultural, or that polycultural equal 50% of monocultural (because bean density in polyculture was 50% of that in monoculture).

The null hypothesis that the LER = 1 was evaluated using a transformation developed by Schultz (ms.). In each block a Transformed Monocultural Yield (TMY) was calculated,

$$TMY = Tm + k(Bm), \quad (1)$$

whre Tm and Bm are the respective monocultural yields of tomatoes and beans, and k is a constant,

$$k = Tm/Bm, \quad (2)$$

where this time Tm and Bm represent means for the entire experiment. Similarly, a Transformed Polycultural Yield (TPY) was calculated for each block,

$$TPY = Tp/Bp, \quad (3)$$

whre Tp and Bp are the polycultural yields and k is the same constant. With the values calculated in this way, the null hypothesis can be rewritten as,

$$TMY = TPM, \quad (4)$$

which is equaivalent to LER = 1.

Any paired comparisons test (Randomized block ANOVA, Wilcoxin's Test, etc.) can then be used to reject the null hypothesis. In this case the Sign's Test (Siegel, 1979) was used, and the hypothesis was rejected ($P < 0.03$). Thus the LER was significantly greater than 1, and the polyculture overyielded.

Table 3 presents the percentages of non-commercial fruits rejected by category of damage. The damage encountered was graded as due to late blight (*Phytophthora infestans*), bacterial spot (*Xanthomonas vesicatoria*), virus (not identified), or fruitworms (*Heliothis spp.* and *Spodoptera spp.*). The unidentified virus had symptoms that included stunted plants with a broom-like profusion of branches, and an excessive number of small fruit that never enlarged or ripened. None of the differences between polycultures and monocultures for these categories of damage were significant.

Figures 1, 2 and 3 show the population dynamics of the three tomato pests that appeared in analyzable numbers. Differences in mean numbers over the course of the season were tested using a repeated measures, randomized block ANOVA, (Treatments X Blocks X Sampling Dates), eliminating those sampling dates with zero values (Brecht and Woodward, 1984). *L. sativae* attacked early, in much greater numbers in the monoculture than in the polyculture ($P < 0.005$, Figure 1). The number of fruits damaged by *Heliothis* was significantly greater in the monocultures ($P < 0.015$, Figure 2). The same tendency was observed for *Spodoptera*, but was not significant due to the high variance ($0.05 > P < 0.10$, Figure 3). Although not explicitly sampled for, a number of *Spodoptera* egg masses were encountered on tomatoes during the sampling of leafminers. A total of 10 were found in monocultures, and 2 in polycultures. This difference is

highly sgnificant according to the Mann-Whitney U Test ($P < 0.001$; Siegel, 1979).

Bacterial spot peaked early in fruit formation, declining as harvest approached (Figure 4). There was no difference between polyculture and monoculture. The relatively constant number of fruit per plant over the time period sampled, combined with the declining percent damaged by bacterial spot, indicates two things. First, most affected fruit must have fallen to the ground before harvest, and second, the plants must have been producing a compensatory number of new fruit. What is unclear is whether this was in fact compensation, in which case yield would not be depressed, or if these new fruits would have been produced anyway, in which case yield would have been drastically reduced.

Fusarium wilt affected a large proportion of tomato plants in both monocultures and polycultures. Figure 5 shows the epidemiology during the season. There were no significant differences.

Figure 6 shows plant survivorship during the season. Once again there were no significant differences.

Overall root nodule numbers on beans were extremely low in all blocks and treatments (Table 4). There was no significant difference between polyculture and monoculture, and there was no correlation between nodule numbers and final bean yield.

Discussion

Plant Protection: The greater than 50% reduction in *Heliothis* damage in the polyculture suggests that the polyculture might effectively be used as a

prophlylactic control measure for this pest, reducing overall populations and thus also the need to spray (Vandermeer and Andow, in press).

Although this experiment was not designed to examine mechanisms reducing attack, it seems likely that reduced oviposition was the key factor. The natural enemy fauna at the Experiment Station is depauperate, presumably due to excessive pesticide use, and few predaceous insects were observed during this experiment. Also *Heliothis* larvae are not likely to move great distances, and *Heliothis* is not known as a bean pest in Nicaragua. Therefore it seems unlikely that reduced tenure time on tomatoes was a major factor. The bean rows were in physical contact with the tomatoes, forming a sort of inpenetrable wall. Since *Heliothis* oviposits on leaflets near flowers, and since there are few or no flowers on the uppermost (youngest) branches that extend above the beans, it may be that the beans blocked access to oviposition sites. Eggs were not sampled for, and only one was encountered by chance, so this hypothesis cannot be explicitly tested.

It is possible that *L. sativae* was affected by a similar mechanism, although it is questionable whether the reduction in attack by this pest affected yield (see earlier discussion). A related species, *L. bryonidae,* that attacks greenhouse tomatoes in England, oviposits on young lateral foliage in preference to apical foliage (Ledieu and Helyer, 1985). In this experiment casual, non-quantified observation of *L. sativae* in tomato monoculture revealed a similar pattern of hovering near lateral foliage. Thus it may be that preferred oviposition sites were blocked in the polyculture.

To the extent that *L. sativae* is a real pest, the polyculture appears to be a highly effective prophylactic technique. Whether or not it affects yield, however, farmers direct considerable amounts of insecticide toward it, in both Nicaragua and in the United States, and it is difficult to convince them

not to (personal interviews; Schuster et al., 1980; Oatman and Kennedy, 1976). Thus a reduction in density may lead to reduced spraying and associated benefits.

Although the differences between polyculture and monoculture were not significant for *Spodoptera* , the trend toward reduced attack in the polyculture is encouragement for future investigation. To the extent that the pattern may be real, the greater number of egg masses in the monoculture also points to an oviposition mechanism. Since all three *Spodoptera* species are bean pests, it may be that the beans act as a diversionary host or trap crop (see Chapter 6 of this disseration).

The greater percent ground cover in the polycultures may also have been a factor reducing attraction of adults of any of these species (Cromartie, 1981).

Although no advantage was noted for the polyculture in terms of tomato disease reduction, the fact that there were no differences means that control strategies would not have to modified with the use of this cropping system.

Yielding Properties: The LER = 1.72 means that the polyculture had a total yield of tomatoes and beans 75% greater per unit area than the separate monocultures. The fact that the Relative Yield of tomatoes was not significantly different from 1 (RR = 0.97) suggests that it is possible to plant beans within a tomato field without negatively affecting tomato yield. At the same time 75% of a monocultural bean yield was obtained from the polyculture (RY = 0.75).

These relative yields are impressive in light of the expectation that the increased overall density in the polyculture should reduce yields through

competitive interactions (assuming that the recommended monocultural densities are optimal). However relative yields and LERs represent the sums of various interactions, some negative and some positive. The beans certainly compete with the tomatoes for certain resources such as light, water, space and nutrients, and this must be negative for the tomatoes (Vandermeer, 1981). Yet there are other possible interactions with positive effects. Vandermeer's "Environmental Modification Principle" postulates that these positive effects may outweigh the negative ones, leading to overyielding (Vandermeer, 1984). For example, although not quantified it appeared during this experiment that the bean rows protected the tomatoes from the dessicating and damaging effects of the wind (see for example, Radke and Hagstrom, 1976). Shade from the beans must also reduce the soil temperature, which often limits tomato production in the tropics (Villareal, 1980). Plant protection effects may also contribute in this way to overyielding.

In this regard, there were no significant differences between polycultures and monocultures in terms of the percent fruit rejected because of disease or insect damage (Table 3, Figure 4). However many fruits damaged by insects dropped from the plants considerably prior to harvest, and thus are not taken into account by a harvest-time analysis. The greater attack in monocultures by *Heliothis* and *Spodoptera* may thus have contributed to the relatively strong polyculture performance. The polyculture was also an effective control measure for *L. sativae,* although since defoliation did not occur it is unlikely that this affected yield.

The RY of 0.97 for tomatoes is considerably lower than the 1.62 reported from Costa Rica (Rosset et al., 1984; Chapter 3 in this dissertation). First of all it should be noted that the planting design was different. Another

potential line of explanation lies with the tomato cultivars used. UC-82, used in this experiment, is a determinate variety, while Tropic, an indeterminate variety, was used in the Costa Rican experiment.

Another difference is that the rate of nodulation of the beans (Table 5) was much lower than in the Costa Rican experiments (casual observation). If it were possible for the beans to in some way supply nitrogen to the tomatoes, or if the beans compete less for available nitrogen when they nodulate well, this could explain the difference in LERs. This could be tested for in an experiment with different levels of nitrogen fertilizer, with and without innoculation with *Rhizobium*.

It must also be noted that the mean tomato yields in Costa Rica were lower than in Nicaragua; it appears that the polyculture may in some way protect tomatoes from particularly adverse conditions.

Absolute tomato yields in both polyculture and monoculture were low, although higher than in Costa Rica. The 9,055 kg/ha in the monoculture are equivalent to 560 baskets/manzana (local measurement = 0.7025 ha), and the National Development Bank bases its crop budgets for irrigated processing tomatoes on an expected yield of 800 baskets/mz (BND, 1983a). As discussed earlier, this low yield may have been due to early attack by bacterial spot. The heavy *Fusarium* wilt attack and the high plant mortality also undoubtedly suppressed overall yields considerably. Another possible explanation for the low yields is that no pesticides were applied during the major part of the growing season, which was done so that the effects of pest attack could be studied without interference. Nevertheless, if no fruits had been rejected for disease or insect damage, the yields would only have risen to 12-13,000 kg/ha (projected from the figures in Table 3).

Finally it is possible that available potassium was insufficient for optimal tomato production. Mg is antagonistic to potassium, and the ratio of Mg to K was 6.84/2.25, indicating that it may have been limiting (see Corey, 1973, and von Uexkull, 1979).

Economic Analysis: Pre-harvest and harvest costs were estimated for the polyculture and the monoculture, based on the inputs and the labor required, and their costs from the National Development Bank's estimated crop budgets (BND, 1983a, 1983b). Assuming a bean price of 390 c$/100 lbs, the minimum price guaranteed to producers by the National Basic Grains Corporation (ENABAS), Relative Value Totals (RVT, Schultz et al., 1982) were determined for different tomato prices. The RVT was calculated here as the ratio of net profit in the polyculture to net profit in the tomato monoculture (because this cropping system is directed at tomato producers, and because in general tomatoes are the more valuable crop). A range of tomato prices was used, from the 20c$/basket (25 lbs) that the National Development Bank bases its budgets on (BND, 1983a) to 80 c$/basket, the highest wholesale price recorded during 1982 (unpublished CIERA figures).

The polyculture overyielded economically (RVT > 1) at all price combinations (Figure 7). The RVT = 2.19 at a tomato price of 20 c$/basket means that the polyculture was 119% more profitable than a tomato monoculture, at that price. The RVT falls from that high value to 1.09 at the highest tomato price, 80 c$/basket. However it is unlikely that a producer would actually realize this price for the entire harvest, due to problems with transportation and resultant spoilage. At no price is the monoculture more

profitable than the polyculture. From an economic perspective the polyculture is an effective buffer for the farmer against fluctuations in the price of tomatoes (and in the yield of tomatoes).

Literature Cited

Altierri, M.A., A. van Schoonhoven and J. Doll. 1977. The ecological role of weeds in insect pest management systems: a review illustrated by bean (*Phaseolus vulgaris*) cropping systems. PANS 23(2):195-205.

Andow, D. 1983. Effect of agricultural diversity on insect populations. pp 91-115 in *Environmentally Sound Agriculture,* W. Lockeretz (ed.). New York: Praeger.

Atsatt, P.R. and D.J. O'Dowd. 1976. Plant defense guilds. Science 193:24-29.

BND. 1983a. *Presupuestos de Financiamientos para Hortalizas y Farinaceas. Crédito Rural. Ciclo 1983/1984.* Managua, Nicaragua: Banco Nacional de Desarrollo.

BND. 1983b. *Presupuestos de Financiamientos Agrícolas. Crédito Rural. Ciclo 1983/1984.* Managua, Nicaragua: Banco Nacional de Desarrollo.

Boucher, D.H., J. Espinoza and M.F. Amador. Manuscript. Increasing mutualism through competition: nodulation in corn-legume polycultures.

Brecht, M.L. and J.A. Woodward. 1984. *GANOVA: General Analysis of Variance Program.* Tulsa, OK: Statsoft. 34 pp.

Comité de Control Integrado de Plagas del Algodonero. 1979. *Manual de Manejo Integrado de Plagas del Algodonero.* Managua: Banco Nacional de Nicaragua, unnumbered.

Corey, R.B. 1973. Factors affecting the availability of nutrients to plants. pp 23-33 in *Soil Testing and Plant Analysis,* L.M. Walsh and J.D. Beadon (eds.). Madison, Wisconsin: Soil Science Society of America.

Cromartie, W. 1981. The environmental control of insects using crop diversity. In *CRC Handbook of Pest Management in Agriculture,* Vol. I, D. Pimental (ed). Boca Raton, FL: CRC.

Dempster, J.P. and T.H. Coaker. 1974. Diversification of crop ecosystems as a means of controlling pests. Proc. 13th Symp. Brit. Ecol. Soc. 13:106-114.

Hart, R.D. 1974. A bean, corn and manioc polyculture system. I. The effect of interspecific competition on crop yield. Turrialba 25:294-301.

Hellpap, C. 1985. Ecología poblacional y control biológico-biotécnico de *Spodoptera* en Nicaragua. Unpublished Ph.D. dissertation. Frankfurt, West Germany: J.W. Goethe University (Spanish translation).

IPM Manual Group. 1985. *Integrated Pest Management for Tomatoes.* University of California Statewide IPM Project. Division of Agricultural Sciences Publication No. 3274. 104pp.

Kareiva, P. 1983. Influence of vegetational texture on herbivore populations: resource concentration and herbivore movement. In *Variable Plants and Herbivores in Natural and Managed Systems,* R.F. Denno and M.S. McClure (eds.) New York: Academic Press.

Kass, D.C. 1978. Polyculture cropping systems: review and analysis. Cornell Int. Agric. Bull. 32:1-69.

Ledieu, M.S. and N.L. Helyer. 1985. Observations on the economic importance of tomato leaf miner (*Liriomyza bryoniae*) (Agromyzidae). Agriculture, Ecosystems and Environment 13:103–109.

Lindquist, R.K. 1974. Effect of leaf miner larvae on yields of greenhouse tomatoes: a preliminary report. Ohio Agric. Res. Dev. Summ. 73:25–29.

Litsinger, J.A. and K. Moody. 1976. Integrated pest management in multiple cropping systems. American Society of Agronomy Special Publication No. 27:293-316.

Norton, G.A. 1975. Multiple cropping and pest control: an economic perspective. Meded. Fac. Landbouww. Rijks. Univ. Gent. 40:219–226.

Oatman, E.E., and G.G. Kennedy. 1976. Methomyl induced outbreaks of *Liriomyza sativae* on tomato. J. Econ. Entomology 69:667-668.

Perrin, R.M. 1977. Pest Management in multiple cropping systems. Agroecosystems 3:93-118.

Perrin, R.M. and M.L. Phillips. 1978. Some effects of mixed cropping on the population dynamics of insect pests. Ent. exp. & appl. 24:383-393.

Pohronezny, K.L., J. Francis and V. Waddill. 1980. Tomato pest management program - guidelines for scouts. Univ. of Fla. Extension Plant Pathology Rept. No. 28, 10 p.

Radke, J.K., and R.T. Hagstrom. 1976. Strip intercropping for wind protection. American Society of Agronomy Special Publication No. 27:201-222.

Risch, S.J., D. Andow and M.A. Altieri. 1983. Agroecosystem diversity and pest control: data, tentative conclusions, and new research directions. Environ. Entomology 12(3):625-629.

Rosset, P.M., R.J. Ambrose, A.G. Power and A. Hruska. 1984. Overyielding in polycultures of tomato and bean in Costa Rica. Tropical Agriculture (Trinidad) 61:208-212.

Rosset, P.M., I. Díaz, R. Ambrose, M. Cano, G. Varrela and A. Snook. In press. Evaluación del policultivo de tomate y frijol como componente de un programa de manejo integrado de plagas de tomate en Nicaragua. Turrialba.

Rosset, P.M., A. Power, R. Argentina and A. Lara. 1983. Plagas del tomate: investigaciones de dinámica poblacional, el uso de insecticidas selectivos y la relación con rendimiento, en el Valle de Sébaco. Informe de la Estación Experimental de Valle de Sébaco, MIDINRA Región VI, Nicaragua,13 pp.

Rosset, P.M., J. Vandermeer, M. Cano, G. Varrela, A. Snook and C. Hellpap. In press. El frijol como cultivo trampa para el control de *Spodoptera sunia* Guenée (Lepidoptera: Noctuidae) en plántulas de tomate. Agronomía Costarricense.

Schultz, B. Manuscript. A significance test for overyielding indicated by the land equivalent ratio (LER).

Schultz, B.B., Phillips, C., Rosset, P.M. and Vandermeer, J.H. 1982. An experiment in intercropping cucumbers and tomatoes in Southern Michigan, U.S.A. Scient. Hortic. 8:1-8.

Schuster, D.J., R.T. Montgomery, D.L. Gibbs, G.A. Marlowe, Jr., J.P. Jones and A.J. Overman. 1980. The tomato pest management program in Manatee and Hillsborough counties, 1978-1980. Proc. Fla. State Hort. Soc. 93:235-239.

Siegel, S. 1979. *Estadística no paramétrica.* Mexico: Editorial Trillas. 346 pp.

Stanton, M.L. 1983. Spatial patterns in the plant community and their effects upon insect search. In *Herbivorous Insects: Host-seeking Behavior and Mechanisms,* S. Ahmad (ed.) New York: Academic Press.

Stern, V.M. 1969. Interplanting alfalfa in cotton to control Lygus bugs and other insect pests. Proc. Tall Timb. Ecol. Contr. Animal Conf. 1:55–69.

Swezey, S.L., and R. Daxl. 1983. *Breaking the circle of poison: the integrated pest management revolution in Nicaragua.* Food First Research Report (San Francisco: Institute for Food and Development Policy), 23 pp.

Vandermeer, J. 1981. The interference production principle: an ecological theory for agriculture. Bioscience 31:361-364.

Vandermeer, J. 1984. The interpretation and design of intercrop systems involving environmental modification by one of the components: a theoretical framework. Biological Agriculture and Horticulture 2:135-156.

Vandermeer, J., and D.A. Andow. In press. Prophylactic and responsive components of an integrated pest management program. J. Econ. Entomol.

Vandermeer, J., A. Dos Santos, B. Horwith, H. McGuinness, I. Perfecto and B. Schultz. Manuscript. Altering plant apparency with intercropping: a test case with tobacco hornworm and a tomato/bean intercrop.

van der Plank, J.E. 1963. *Plant Diseases: Epidemics and Control.* New York: Academic Press.

Vaughn, M.A., and G. Leon. 1977. Pesticide management on a major crop with severe resistance problems. Proceedings of the XV International Congress of Entomology (Washington, DC): 812-815.

Villareal, R. 1982. *Tomates*. San José, Costa Rica: IICA. 184 pp.

von Uexkull, H.R. 1979. Tomato: nutrition and fertilizer requirements in the tropics. Proceedings of the 1st International Symp. on Tropical Tomato, Oct. 23-27, 1978, at Shanshua, Taiwan. Asian Vegetable Research and Development Center, Taiwan.

Way, M.J. 1977. Pest and disease status in mixed stands versus monocultures, the relevance of ecosystem stability. In *Origins of Pest, Parasite, Disease, and Weed Problems*, J.M. Cherret and G.R. Sagar (eds.) Oxford: Blackwell Sci. Publ.

Wolfenbarger, D.A., M.J. Lukefahr and H.M. Graham. 1971. A field population of bollworms resistant methyl parathion. J. Econ. Entomol. 63(3):755-6.

Wolfenbarger, D.A., M.J. Lukefahr and H.M. Graham. 1973. LD_{50} values of methyl parathion and endrin to tobacco budworms and bollworms collected in the Americas and hypothesis on the spread of resistance in these lepidopterans to these insecticides. J. Econ. Entomol. 66(1):211-16.

Wolfenbarger, D.A. and D.O. Wolfenbarger. 1966. Tomato yields and leafminer infestations and a sequential sampling plan to determine need for control treatments. J. Econ. Entomol. 50:279-283.

Zadoks, J.C. and R.D. Schein. 1979. *Epidemiology and Plant Disease Management*. New York: Oxford University Press. 427 pp.

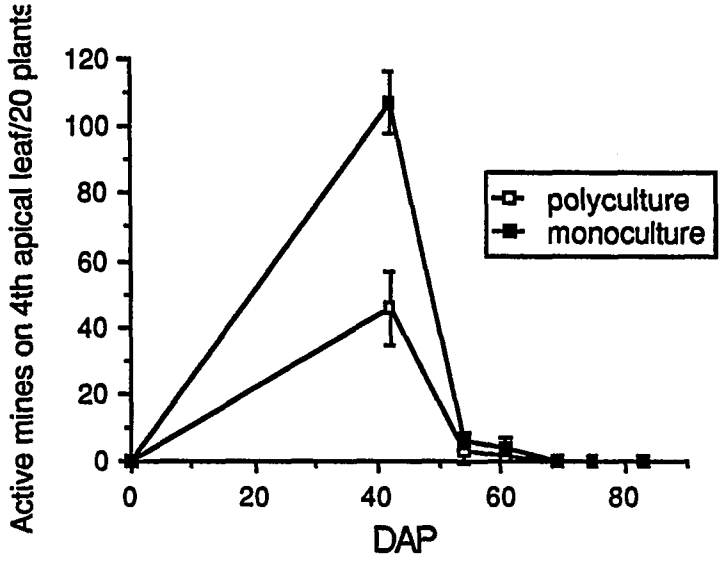


Figure 1. Population dynamics of *Liriomyza sativae* on tomatoes as estimated by the number of active mines on the the fourth fully expanded compound leaf from the top of the plant (± standard deviation).

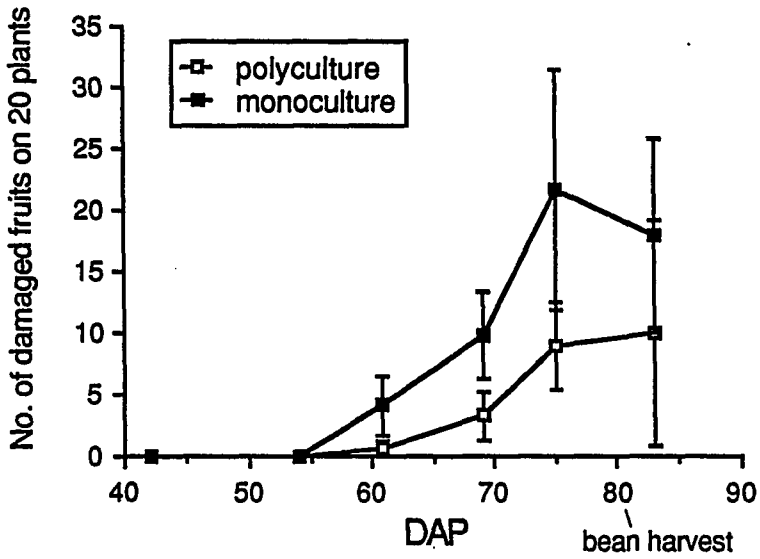


Figure 2: Population dynamics of *Heliothis spp.* on tomatoes as estimated by the number of damaged fruits per 20 plants (± standard deviation).

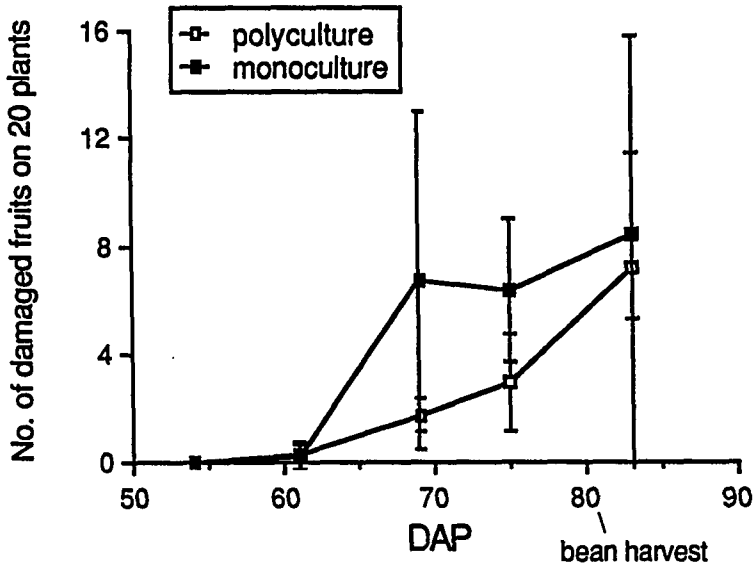


Figure 3. Population dynamics of *Spodoptera spp.* on tomatoes as estimated by the number of damaged fruit per 20 plants (± standard deviation).

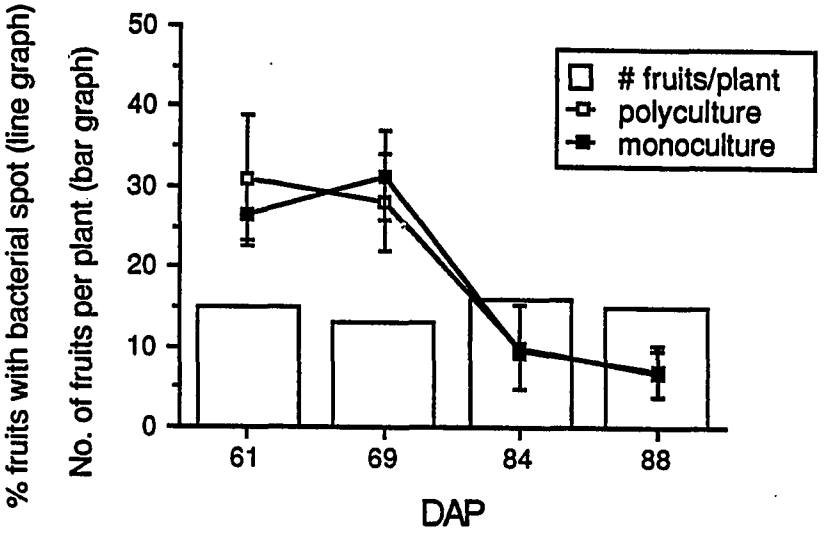


Figure 4. Percent tomato fruit infected with bacterial spot, and number of fruits per tomato plant (± standard deviation). Note that the x-axis is not linear.

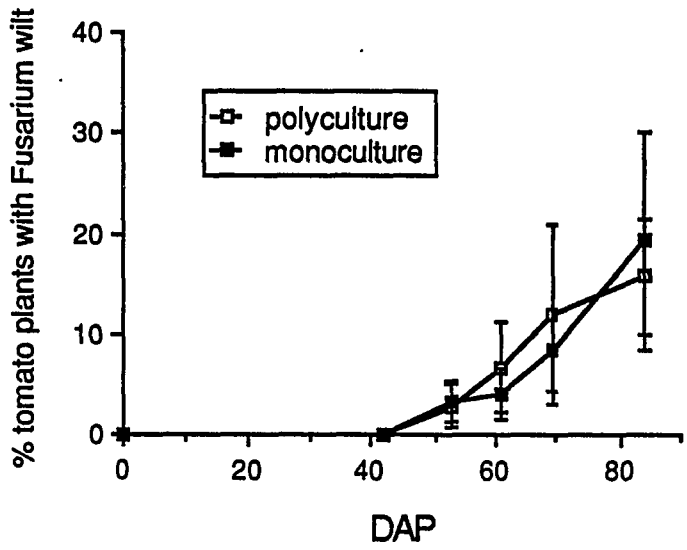


Figure 5. Percent tomato plants with symptoms of *Fusarium* wilt (± standard deviation).

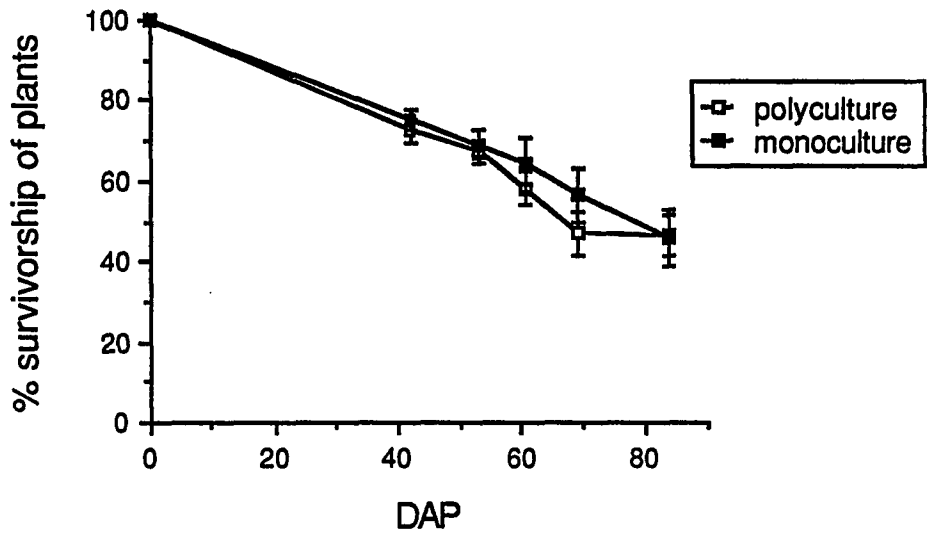


Figure 6. Percent survivorship of tomato plants (± standard deviation).

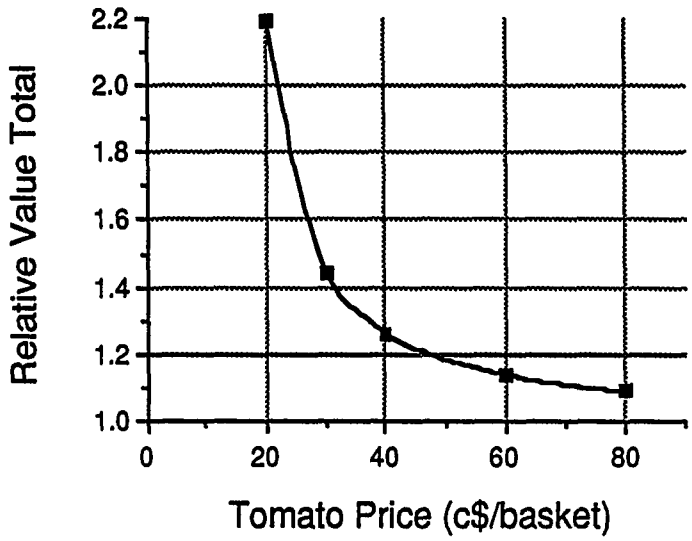


Figure 7. Relative Value Total (RVT) of the polyculture at different tomato prices.

Table 1. Soil characteristics at the Sébaco Valley Regional Experiment Station, near San Isidro, Matagalpa, Nicaragua.

Texture: loam
Sand: 46%
Silt: 34%
Clay: 20%
pH: 6.8
Organic carbon: 0.99%
Organic matter: 1.71%
Total nitrogen: 0.11%
Al: 1.6 me/100 g
P: 27 µg/ml

Exchangable ions, me/100 g: Ca, 19.50; Mg, 6.84;
Na, 0.31; K, 2.25; H, 5.

Cation exchange capacity: Total = 33.90; NH_4OAc = 30.5
Base saturation: Total = 85%; NH_4OAc = 95%

Table 2. Absolute and relative yields (kg/ha) of polycultures and monocultures, and land equivalent ratios (LERs).

	Monoculture		Polyculture		Relative Yields in Polyculture		
Block	Tomato Yield	Bean Yield[a]	Tomato Yield	Bean Yield	Tomato RY	Bean RY	LER
I	5,426	717	6,445	662	1.19	0.92	2.11
II	6,566	347	7,253	223	1.10	0.64	1.75
III	11,628	779	8,372	336	0.72	0.43	1.15
IV	10,022	594	12,430	728	1.24	1.22	2.46
V	11,633	1,080	7,077	567	0.61	0.53	1.14
mean± std. deviation	9,055± 2,897	703± 268	8,315± 2,403	503± 216	0.97[b]	0.75[c]	1.72[d]

[a] 15% moisture content.

[b] Tomato RY is not significantly different from 1.

[c] Bean RY is not significantly different from 1 or from 0.5.

[d] LER is significantly greater than 1 ($P < 0.05$).

Table 3. Percent tomato fruits rejected at harvest by category of damage, in polyculture (P) and monoculture (M). None of the differences in means are significant.

Block	late blight P/M	bacterial spot P/M	virus P/M	insect damage P/M	total P/M
I	3.2/6.1	11.1/11.6	10.1/16.51	5.3/6.1	29.7/40.4
II	0.9/2.6	8.3/7.9	7.4/14.3	9.3/6.9	26.0/31.7
III	2.5/1.2	5.3/4.3	5.7/5.9	8.8/7.4	22.3/18.8
IV	1.1/2.6	5.1/7.5	3.4/6.1	7.1/7.9	16.8/24.2
V	1.2/0.9	3.9/3.8	4.8/3.8	7.9/7.0	17.9/15.5
mean	1.8/2.7	6.7/7.0	6.3/9.3	7.7/7.1	22.5/26.1

Table 4. Mean number of root nodules per bean plant. The difference in means is not significant.

Block	Polyculture	Monoculture
I	3.88	6.63
II	10.13	5.75
III	5.88	9.63
IV	5.13	3.13
V	2.75	3.38
mean	5.55	5.70

CHAPTER 5

LARGE SCALE VALIDATION OF PEST POPULATION SUPPRESSION IN A POLYCULTURE OF TOMATOES AND BEANS*

Introduction

The results presented in Chapter 4 showed a significant reduction in damage to tomatoes by the *Heliothis* complex ($P < 0.015$) and by the vegetable leafminer, *Liriomyza sativae* ($P < 0.005$), when the tomatoes were interplanted with beans. There was also a non-significant trend toward a reduction in damage by the armyworm complex, *Spodoptera* spp. ($0.05 > P < 0.10$). These results were obtained from an experimental comparison of monocultures and polycultures of tomatoes and beans using 10 X 9.6 m plots.

Without validation of these results with larger plot sizes the possibility would remain that they were an artifact of the small plot size used in the experiments. Although the issue of plot size effects in entomological experiments has not often been addressed, some caveats can be found in the literature. Wiseman et al. (1980) found that the outcome of sorghum resistance trials with *Spodoptera frugiperda* was partially dependent on the

* The material presented in this chapter is being published elsewhere in Rosset et al., in press.

adjacent varieties in the factorial plot design. Cromartie (1975) found that different species respond in characteristic ways to plot size.

Kareiva (1983) and Andow (1983) both address the question of plot size as a "methodological pitfall" common in experiments that compare monocultures and polycultures. It is clear that for a given observed difference in herbivore density between a polyculture and a monoculture, the mechanism causing that difference will determine the importance of plot size. For mechanisms based on immigration and emigration into and out of plots, the perimeter to area ratio will be a key factor in determining observed density. For example, if movement can be modeled as a diffusion process (e.g., Wetzler and Risch, 1984), and contact with a non-host increases movement and thus decreases tenure time (e.g., Bach, 1980), then smaller plots would lead to greater differences between polycultures and monocultures than would be expected in larger fields.

Different species of herbivores probably have characteristic "areas of search" within which short range attraction to host plants occurs; that is they respond to characteristic patch sizes (Hassell and Southwood, 1978). It is possible that monocultures may be more attractive than polycultures for local search, but that no such difference exists for long range orientation. If furthermore the plot size is smaller than the effective range of local or within-patch search, then predictions generated for commercial-size polycultures based on plot experiments would be misleading. As Kareiva (1983) puts it, the observed reduction in density in the polyculture might be due to a preference by mobile herbivores for "neighboring monoculture sinks."

On the other hand, if the dominant mechanism is based on an enhanced predator-prey relationship in the polyculture, for example, then one might

expect a small plot experiment to underestimate pest reduction in the polyculture. This is because a larger area might be necessary to stabilize the interaction.

Because of these and similar potential "pitfalls," it is necessary to validate the results of polyculture experiments in plots as close to production size as possible, if the cropping system is to be recommended to farmers. There are good reasons why this validation is best done on farmers fields; the "acceptability" of the technology can be gauged, as well as its general compatibility with the farming practices employed by the farmer (Litsinger, 1976; CIMMYT Economics Staff, 1984).

Different methodological problems arise with large scale validation experiments. For instance, it is often difficult or impossible to obtain sufficient land and resources for a replicated experiment. Otherwise large plot sizes might have been used the first time, and large scale validation would be unnecessary. Thus it is usually impossible to use statistical tests to compare treatment effects. This is somewhat of a philosophical dilemma: with small plots one can have replication, but the results may be an artifact of plot size; with large plots the size is less likely to be a key factor, but replication becomes impossible. It seems reasonable therefore that a cropping systems research protocol should begin with basic research on small, replicated plots, and then pass to a validation stage using large on-farm plots, albeit without replication (e.g., Litsinger, 1976, CIMMYT Economics Staff, 1984). It is in this spirit that I report here on the large scale validation of the tomato and bean polyculture.

Materials and Methods

The on-farm validation was conducted under an agreement with the members of the Luciano Vilchez Agricultural Cooperative, located at kilometer 13 of the Old Leon Highway in the Department of Managua, Nicaragua. The membership consists of 15 families of Salvadoran refugees and one Nicaraguan family. During the dry season they generally plant about 4 ha of irrigated tomatoes, using processing varieties, which they market for both fresh market and processing.

There are three basic tomato production technologies used in Nicaragua, as follows:

1) Production for Fresh Market: Indeterminate, fresh market varieties are planted in rows, and the vines are trained on wire running between wooden stakes. This method is common during the rainy season, when fruits in contact with the ground would rot. The cost of the wire and the labor involved in setting it up are the major costs of production. This was the method reported in Chapter 3 of this dissertation.
2) Commercial Processing Production: Determinate, processing varieties are planted in double rows on raised beds. The produce is sold for both processing and fresh market consumption. This method is used in both the rainy and the dry season, although it is most common in the latter. It is the method reported in the previous chapter.

3) Peasant Production of Processing Varieties:
Determinate, processing varieties are planted in rows, and the produce sold for both processing and fresh market. This method is used during the dry season, and was employed in the present validation.

Both direct seeding and transplanting are used with all of these technologies. Peasant producers more often use transplants exclusively, while commercial producers frequently direct seed the majority of their hectarage, and use transplants on a small part of it. In this experiment transplants of the determininate processing variety 'Roma' were used.

The approximately 4 ha field was divided roughly in two, with half planted with tomato seedlings only, in rows 1 m apart with 1 m between plants. The other half was planted with alternate rows of tomatoes and beans, and the rows varied between 1 m and 0.5 m apart, with the result that the average tomato density in the polyculture was lower than in the monoculture.

Insect sampling was carried out on a regular basis during the season. The only pests that attacked after transplant in analyzable numbers were the *Spodoptera* and *Heliothis* complexes. The percent fruit damaged by each was recorded in 3 to 6 randomly chosen 5 m sections of row randomly chosen in each treatment. No statistical analysis was performed on the data, beyond calculating standard errors and graphing the results (Figures 1 and 2).

No yield data was taken due to problems with logistics and communications.

Results and Discussion

At the peak of *Heliothis* damage (45 Days After Transplant, DAT), there was a 14.4-times greater percentage of damaged fruits in the monoculture than in the polyculture (7.2%:0.5%; Figure 1). Peak *Spodoptera* damage was also recorded at 45 DAT, and there was a 12.5-fold increase in the monoculture over the polyculture (6.25%:0.5%; Figure 2). In both cases the percentage of fruits damaged dropped considerably before harvest, as damaged fruits presumably fell to the ground.

Without replication one cannot be sure that these differences are due to treatment effects rather than position effects, although the differences correspond in direction to those reported in Chapter 4. If the differences are in fact due to treatment effects, the question arises as to why the magnitude of the differences are so much greater than in the small plot experiments.

Two lines of explanation seem plausible. First, the planting design was different. In the small plots the tomato density was constant in polyculture and monoculture, while in the present experiment the polyculture had a lower tomato density and thus lower 'resource concentration' (*sensu* Root, 1973). Beans and tomatoes were also planted in alternate rows, in contrast to the small plots where double tomato rows were employed. If beans can block access to oviposition sites on tomatoes, then perhaps this effect is magnified in alternate row cropping. At the same time, if larval movement to a preferred host (or 'trap crop') is taking place, this might also be magnified with alternate rows because of the greater proximity.

The second line of explanation is based on plot size effects. If mortality is an important factor leading to the observed differences, then larger plots might magnify that effect. If long-range rather than local

orientation is the key mechanism, larger plots might again magnify the effect. Small plots might not be recognized as polycultures and monocultures, but rather as one large polyculture, masking differences.

Anecdotal Evidence on Farmers' Attitudes toward Polycultures: A common problem encountered with new agricultural technology developed on experiment stations is its low acceptability to peasant producers, particularly when that technology requires capital investment (CIMMYT Economics Staff, 1984). Peasant producers are often constrained by their financial resources and access to credit, and therefore hesitant to adopt expensive technologies.

Although formal interviews were not incorporated into this research program, several incidents reflect on the relative acceptabilty of intercropping as a technology.

On the first visit to the cooperative the concept of growing tomatoes and beans together was presented to the members. Their attitude was that it made sense because it was similar to the way they had planted corn and beans on the subsistence plots they had previously worked in El Salvador. In contrast, commercial tomato production was fairly new to them.

During the transplanting of tomato seedlings a single row of cabbage seedlings was also planted, in the polyculture, stretching across the entire field. Adding cabbage to the intercrop had not been discussed earlier. In response to my inquiry, the members said that they happened to have the cabbage on hand, and since they thought intercropping was such a good idea, they decided to add it to the mixture.

Later, during the middle of the growing season, an aquaintance of the author visited the cooperative, without knowing that experiments were

underway there. She saw the polyculture, and asked the members of the cooperative why they had planted it. They responded that tomato and bean polycultures were a traditional practice for them, and that these are more efficient in terms of the use of space and water, neither of which had been previously discussed with the author. They did not mention that the polyculture was part of a Ministry of Agriculture sponsored experiment.

If this anecdotal evidence means anything, it suggests that novel intercropping systems may be relatively acceptable to peasant producers.

Literature Cited

Andow, D. 1983. Effect of agricultural diversity on insect populations. pp 91-115 in *Environmentally Sound Agriculture*, W. Lockeretz (ed.). New York: Praeger.

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

Cromartie, W.J. 1975. The effect of stand size and vegetational background on the colonization of cruciferous plants by herbivorous insects. J. Appl. Ecol. 12:517-33.

CYMMYT Economics Staff. 1984. The farming systems perspective and farmer participation in the development of appropriate technology. In *Agricultural Development in the Third World,* C.K. Eicher and J.M. Staatz (eds.). Baltimore: Johns Hopkins University Press.

Hassell, M.P. and T.R.E. Southwood. 1978. Foraging strategies of insects. Ann. Rev. Ecol. Syst. 9:75-98.

Kareiva, P. 1983. Influence of vegetational texture on herbivore populations: resource concentration and herbivore movement. In *Variable Plants and Herbivores in Natural and Managed Systems,* R.F. Denno and M.S. McClure (eds.) New York: Academic Press.

Litsinger, J.A. 1976. Pest-management research methodology on farmers' fields in a cropping systems program. In *1976 Cropping Systems Symposiuum* . Los Baños, Phillipines: International Rice Research Institute.

Rosset, P.M., I. Díaz, R. Ambrose, M. Cano, G. Varrela and A. Snook. In press. Evaluación del policultivo de tomate y frijol como componente de un programa de manejo integrado de plagas de tomate en Nicaragua. Turrialba.

Wetzler, R.E. and S.J. Risch. 1984. Experimental studies of beetle diffusion in simple and complex crop habitats. J. Anim. Ecol. 53:1-19.

Wiseman, B.R., B.G. Mullinx and P.B. Martin. 1980. Insect resistance evaluations: effect of cultivar position and time of rating. J. Econ. Entomol. 73:454-457.

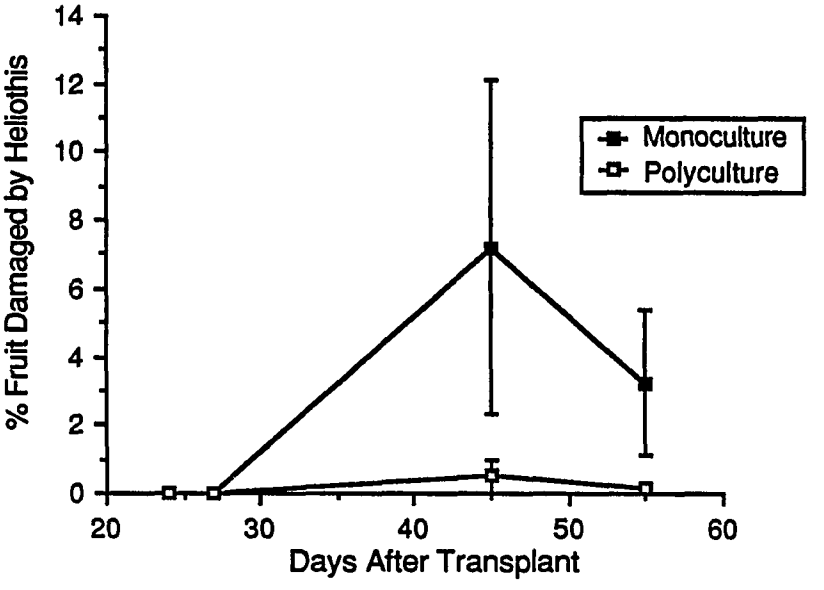


Figure 1. Damage by *Heliothis spp.* on tomatoes in monoculture and polyculture (± standard error).

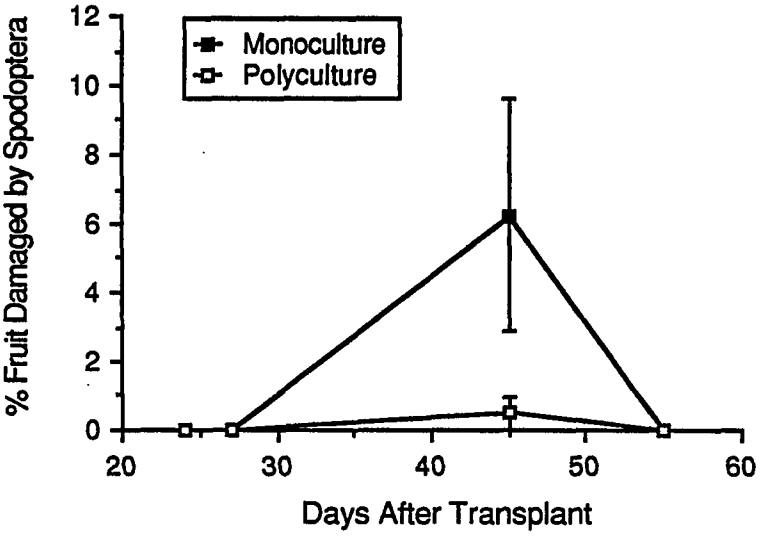


Figure 2. Damage by *Spodoptera spp.* on tomatoes in monoculture and polyculture (± standard error).

CHAPTER 6

BEANS AS A TRAP CROP TO PROTECT TOMATO SEEDLINGS FROM ATTACK BY *Spodoptera sunia* Guenée (Lepidoptera: Noctuidae)*

Introduction

This chapter is a report on a second large-scale validation of the tomato and bean polyculture as a prophylactic pest management strategy for tomatoes. The experiment was designed to verify the results of the small plot experiments of Chapter 4, at the level of commercial, large-scale production. In practice the experiment demonstrated a powerful "trap crop" effect of the beans in diverting an armyworm, *Spodoptera sunia* Guenée (Lepidoptera: Noctuidae), from attacking the tomatoes.

Several days after the germination of the crops in this experiment, there was a massive attack of *S. sunia*. The effects, while devastating in the tomato monoculture, were virtually absent in the polyculture due to the overwhelming preference of *S. sunia* for beans. *S. sunia* is a generalist herbivore, known as a pest of many crops, including peanuts (Buckmire, 1980), cotton (Vaissayre and Alvarado, 1982; Vaughn and Leon, 1977; Comité de Control Integrado, 1979), tomatoes (Gloria, 1976) and beans (Savoie, 1985).

* The material in this chapter is being published elsewhere as Rosset et al., in press.

In the case of polyphagous insects that exhibit preferences within their host ranges, a preferred species may act as a diversionary host or "trap crop," drawing pest individuals away a less preferred crop (Cromartie, 1981; Perrin, 1977). There are a number of examples in the literature where this effect has been utilized in practice as a pest management tactic.

In the United States, strips of alfalfa are planted to protect cotton from the lygus bug, *Lygus hesperus* Knight (Hemiptera: Lygaeidae; van den Bosch and Stern, 1969; Stern, 1981). Prior to the widespread introduction of organochlorine insecticides in the United States, corn was often planted as trap crop in cotton to attract the cotton bollworm, *Heliothis zea* Boddie (Lepdoptera: Noctuidae; Lincoln and Isley, 1947). In contemporary Nicaragua, islands of cotton stubble are left in each field during the dry season, where they attract the boll weevil, *Anthonomus grandis* Boh. (Coleoptera: Curculionidae; Centro Experimental de Algodón, 1983). In all cases the mechanism underlying the effectiveness is the greater attraction of the trap crop than the target crop, for the insect.

Materials and Methods

An arrangement was made with Agr. Mario Lopez, the manager of the El Limon Farm of the Oscar Benavides Production Complex in the Sébaco Valley of Matagalpa province, Nicaragua. This farm has about 40 irrigated ha of the determinate, processing tomato cultivar VF-134, during the dry season. Under the arrangement made, four large contiguous plots at the Southern end of the field were to be used for research purposes. Each plot was approximately 30 m X 60 m, and consisted of raised beds that were 1.2 m

wide. Two plots of each of two treatments were planted, alternating treatments in adjacent plots. The treatments were:

1) Tomato monoculture: two rows of tomatoes were planted in the center of each bed, with 0.4 m between them, and were thinned (after the insect sampling reported here) to one plant per 0.25 m of row.

2) Tomato and bean polyculture: two rows of tomatoes were planting in the same fashion as in the monoculture, plus one row of beans was planted on each edge of the bed, 0.3 m from the adjacent tomato row. The bean variety Revolución 81 was used, with single seeds planted every 0.1 m along the row.

The herbicides Sencor® and Bolero® were applied in the monoculture, and the herbicide Fusilade® was used in the polyculure. The tomatoes were planted mechanically on January 26, 1984, on the same day that the adjacent 40 ha monoculture was planted. The beans were then planted by hand on January 31, 1984. The entire area received sprinkler irrigtion on a weekly basis.

At 19 days after planting the tomatoes (DAP), insects were sampled in the polycultures and monocultures. At this time each tomato seedling had the cotyledons fully expanded, and some plants had 2-3 more small leaves. The bean seedlings were more developed, despite having been planted 5 days later. Each bean seedling had about 6-8 leaves.

Five points were chosen at random each large plot, and each plot was assigned to one of five individuals present. Beginning at their assigned point, each person moved down the row examining tomato or tomato and bean seedlings, and recorded the number of plants of each that had to be examined in order to encounter 5 larvae of *S. sunia*. This data was then used to estimate

the number of larvae per 100 plants of each species, which was the factor analyzed.

A 3 X 5 X 2 factorial ANOVA was used to analyze the data. The factors were the crop (tomatoes in monoculture, tomatoes in polyculture, and beans in polyculture), the person doing the sampling, and the block (two adjacent plots with different treatments). The philosophical question of replication in validation trials, that was discussed in the previous chapter, is also at issue here. This statistical design must be intepreted with caution when distinguishing between treatment and non-treatment effects determining insect numbers in each plot, as they are partially confounded. Significant differences should therefore be considered as a "tendency," rather than as "rejection" of the null hypothesis.

Orthogonal *a priori* comparisons were calculated for the number of larvae per 100 tomato plants in monoculture versus polyculture, and on beans versus on tomatoes. The latter comparison was for the number on tomatoes averaged over polyculture and monoculture; a comparison of the number on tomatoes in polyculture versus the number on beans in polyculture would not have been orthogonal (Little and Hills, 1978).

No further comparisons of pest populations were possible after this first sampling date, because the monocultures were completely eliminated. Later sampling in the polyculture revealed no further generations of *S. sunia*.

Results and Discussion

The mean number of larvae of *S. sunia* per 100 tomato seedlings at 19 days was almost 20 times higher in monoculture than in polyculture ($P < 0.05$; Tables 1 and 2). At the same time the number per 100 bean

seedlings was more than 3 times greater than the average on all tomato seedlings ($P < 0.001$, Tables 1 and 2).

An examination of the data in Table 1 also indicates that the reduced attack on tomatoes in the polyculture, occurred despite a greater density of larvae per unit area. Because the sampling was conducted before thinning, a precise estimate of density per unit area is impossible to calculate.

The tomato seedlings in the monoculture were completely eliminated by *S. sunia* feeding, while there was little or no apparent plant mortality in the polyculture. The 40 ha of commercial monoculture adjacent to the experimental plots were a complete loss, and the entire area had to be plowed under. The bean seedlings in the polyculture appeared to tolerate the *S. sunia* damage, despite a greater larval density than the tomatoes. This is probably due the greater amount of foliage on each bean seedling at that date.

These results demonstrate powerful protection of tomato seedlings by beans, assuming that these differences in plot means are based on treatments (as discussed above). It is also clear this effect is due to preference by *S. sunia* for beans over tomatoes, particularly in light of the greater per unit area density in the polyculture. What is not clear is whether this preference is realized through through adult oviposition choice or through larval movement. The only available indirect evidence, from the egg mass data in Chapter 4, suggests that oviposition choice may be a factor. However the species of *Spodoptera* in that case was unknown, there was a small sample size, and the suggestion that oviposition choice is operating in no way rules out larval movement as a mechanism.

There was clearly larval movement in the monocultures, as larvae must have moved to new seedlings after completely consuming the first one encountered. Since there was little damage and few larvae on the tomatoes in

the polyculture, any interplant movement there would have been from tomatoes to beans, or between beans, although the beans were not consumed completely so movement was not an absolute necessity.

Literature Cited

Buckmire, K.U. 1980. Potentials and problems of peanut production in St. Kitts. In*Caribbean Agricultural Research and Development Institute* (St. Kitts-Nevis-Anguilla), 234-247.

Centro Experimental de Algodón. 1983. *Proyecto Piloto Supresión del Picudo. Informe Final de la Temporada 1982-1983*. Nicaragua: MIDINRA, 45 pp.

Comité de Control Integrado de Plagas del Algodonero. 1979. *Manual de Manejo Integrado de Plagas del Algodonero*. Managua: Banco Nacional de Nicaragua, unnumbered.

Cromartie, W. 1981. The environmental control of insects using crop diversity. In *CRC Handbook of Pest Management in Agriculture*, Vol. I, D. Pimentel (ed). Boca Raton, FL: CRC.

Gloria B., R. 1976. Control químico del gusano ejército *Prodenia sunia* (G.) en tomatera. Revista Peruana de Entomología 18:120-123.

Lincoln, C. and D. Isley. 1947 Corn as a trap crop for the cotton bollworm. J. Econ. Entomol. 40(3):437-438.

Little, T.M., and F.J. Hills. 1978. *Agricultural Experimentation: Design and Analysis*. New York: Wiley, 350 pp.

Perrin, R.M. 1977. Pest Management in multiple cropping systems. Agroecosystems 3:93-118.

Rosset, P.M., J. Vandermeer, M. Cano, G. Varrela, A. Snook and C. Hellpap. In press. El frijol como cultivo trampa para el control de *Spodoptera sunia* Guenée (Lepidoptera: Noctuidae) en plántulas de tomate. Agronomía Costarricense.

Savoie, K. 1985. Nicaragua's program for basic grain production. New World Agriculture Group Newsletter 3:4-5.

Stern, V. 1981. Environmental control of insects using trap crops, sanitation, prevention, and harvesting. In *CRC Handbook of Pest Management in Agriculture*, Vol. I, D. Pimentel (ed). Boca Raton, FL: CRC.

Vaissayre, M., and M. Alvarado. 1982. Activité insecticide du méthyl-parathion en culture cotonnière en El Salvador. Coton et Fibres Tropicales 37:241-247.

van den Bosch, R., and V.M. Stern. 1969. The effect of harvesting practices on insect populations in alfalfa. Tall Timbers Conference on Ecological Animal Control by Habitat Management, Proceeds, 47-54.

Vaughn, M.A., and G. Leon. 1977. Pesticide management on a major crop with severe resistance problems. Proceedings of the XV International Congress of Entomology (Washington, DC): 812-815.

Table 1. Number of larvae of *Spodoptera sunia* per 100 seedlings in polyculture and monoculture.

Block	Person	Tomato		Beans
		Monoculture	Polyculture	
	1	5.25	0.00	23.80
	2	3.00	1.00	9.09
I	3	3.00	0.00	6.02
	4	10.86	0.00	1.00
	5	1.00	0.00	2.00
	1	2.00	0.00	4.00
	2	6.94	1.00	11.62
II	3	4.00	0.00	7.14
	4	2.00	0.00	1.00
	5	0.00	0.00	1.00
	mean	3.80	0.20	7.30

Table 2. ANOVA table, 3 X 5 X 2 factorial, Crop (Tomato in monoculture, tomato in polyculture, beans in polyculture) X Person X Block, with orthogonal comparisons.

Source	d.f.	F	P
Crop	2	13.15	< 0.005
tomato mono vs. tomato poly	1	6.26	< 0.05
tomato vs. beans	1	20.05	< 0.001
Person	4		ns
Block	1		ns
Error	14		
Total	29		

CHAPTER 7

GENERAL CONCLUSIONS

In this dissertation I have presented a program of Integrated Pest Management (IPM) for tomatoes in Nicaragua and other Central American countries with similar agroecosytems and economic constraints (i.e. El Salvador and Guatemala).

IPM is an agricultural technology that is compatible with the current Nicaraguan economic development model, as discussed in Chapter 1. The development policy of the Nicaraguan government emphasizes the substitution of local resources for costly imported inputs, the articulation, or linking, of the economy through agroindustry, and the promotion of self-sufficiency in basic grain production. Inappropriate agricultural technology can act as an obstacle to such a development model, as was shown by the example of insecticide use on cotton. The ecological impact of insecticides -- resistance, secondary pest outbreaks, environmental and health effects -- led to costs so great that they seriously impeded economic development.

IPM as a strategy to minimize the use of imported chemicals reduces the drain on foreign exchange, as well as secondary ecological effects and their resultant economic impact. In the case of cotton, local labor paid in local currency was employed effectively as a substitute for inputs purchased in dollars. The tomato industry in Nicaragua is another case where pesticide

use makes production financially risky for the producer, and makes the commodity, tomatoes, expensive for the nation because of imported inputs.

I developed two parallel strategies for the management of tomato pests; the prophylactic use of a cultural control, intercropping, for several pests, and Economic Injury Levels for use with responsive spraying directed toward the cotton whitefly.

The cotton whitefly, *Bemisia tabaci* Genn. (Homoptera: Aleyrodidae), is a vector of several closely related viral diseases of tomatoes. In Chapter 2, I presented the population dynamics of the whitefly over the course of a season, under different pesticide regimes. This provided treatments with widely different whitefly densities on the different sampling dates. These densities were then correlated with final tomato yields. Several conclusions emerged from this. First, no evidence was found for a correlation between whitefly density and yield after about 48 days after planting (DAP). Thus one recommendation is that farmers discontinue their current practice of spraying for the whitefly after that point. Second, very low whitefly densities during the seedling and early vegetative growth stage of plant development (< 48 DAP) caused an almost 35% reduction in final yield. A table of Economic Injury Levels was generated for different combinations of tomato prices and expected yields, for use in decision making. Further work is necessary to develop an Economic Threshold.

The remaining chapters (3-6) are devoted to the development and evaluation of a novel cropping system, a tomato and bean polyculture, as a cultural control tactic for several other tomato pests. The first experiment reported (Chapter 3) was a preliminary investigation of the yielding potential of this cropping system in Costa Rica. A dramatic pattern of overyielding was found, with Land Equivalent Ratios (LERs) of 1.92 and 2.41 for low and

high tomato densities. Overall yields were low, however, so that I concluded that the system had potential at least under poor yielding conditions for tomatoes.

A second polyculture experiment was conducted in Nicaragua (Chapter 4), designed to specifically monitor pest and pathogen attack in the polyculture versus in tomato monoculture. There were significant reductions in the polyculture of the density of the vegetable leafminer, *Liriomyza sativae* Blanchard (Diptera: Agromyzidae; $P < 0.005$), and of the number of fruit damaged by the tomato fruitworm complex, *Heliothis spp.* (Lepidoptera: Noctuidae; $P < 0.015$). A similar non-significant trend was observed for the armyworm complex, *Spodoptera spp.* (Lepidoptera: Noctuidae; $0.05 > P < 0.10$).

There were no significant differences between polyculture and monoculture in the attack of various pathogens of tomatoes.

Significant overyielding was again observed, with an LER of 1.72. An economic analysis was performed, based on estimated crop budgets for tomatoes and beans. A key factor was the price of tomatoes, although the polyculture outperformed the monoculture over all prices. The Relative Value Total (RVT) of the polyculture varied between 1.09 and 2.19 with tomato price.

It was concluded that, based on plot experiments, the polyculture showed great promise as a cultural pest control tactic, and as a cropping system with good yielding and profit properties. The last two chapters (5 and 6) are devoted to larger scale testing of the pest reduction result, to eliminate the possibility that it was merely an artifact of small plot size. In an unreplicated comparison in a peasant production cooperative (Chapter 5), the

percent fruit damaged by both the armyworm and fruitworm complexes was reduced in the polyculture to less than one tenth of that in the monoculture.

A second large-scale test performed with two replicates on a commercial production unit revealed a trap crop effect in the polyculture. A heavy attack shortly after germination by the armyworm *Spodoptera sunia* Guenée, devastated both monoculture replicates and an adjoining 40 ha tomato field, which had to be plowed under, while leaving the tomatoes in polyculture virtually untouched. Sampling revealed that while the larval density on tomatoes was indeed lower in the polyculture, the overall density on both crops was higher, with most of the larvae on beans. Thus the interplanted beans function as a diversionary host or trap crop, protecting the tomato seedlings from attack.

The overall conclusions, or recommendations from this dissertation can be summarized as follows. Beans planted between the rows of a tomato field offer several advantages to the farmer. They function as a prophylactic cultural control method, protecting tomatoes from attack by fruitworms, armyworms and the vegetable leafminer. They do not reduce or suppress tomato yields, and produce economically significant yields themselves. The economic benefits are greatest when tomato prices and/or yields are low; the beans thus act as a buffer for the farmer against uncertainty in pest attack, yield and price. Insecticide applications after 48 DAP, directed at the cotton whitefly on tomatoes, may be suspended without yield reduction of tomatoes. Applications before 48 DAP should be made only when a threshold population density of the whitefly is present, that threshold to be determined based on the Economic Injury Level and either further research or *"gestalt"* decision making.