

Chapter 2. The Evolution of Tomato Pest Management Systems and Impacts on Pesticide Use and Reliance

Change is the only constant in the history of pest management technology and pesticide use in the production of South Florida vegetable crops. Biological adaptation of pest complexes has been perhaps the dominant cause of change. Pest problems are constantly evolving because of the emergence of resistance and new strains of established pests and diseases, and the introduction of exotic species. These changes have, in turn, been shaped, if not directly triggered by past pest management efforts. In particular, pesticide use patterns in the 1970s and 1980s imposed extremely heavy selection pressure on pest populations.

Today the nature of selection pressure imposed on pest populations has clearly changed both qualitatively and quantitatively. In general, the modes of action of newer materials are more specific and narrow. Other things being equal, the risk of resistance to highly active low-dose compounds with a specific, biochemical mode of action is greater than the risk associated with many older products that work through a complex mix of modes of action. For example, if the new strobilurin fungicides were used today as intensively as the EBDC's and copper compounds were used in the early 1980s, we would be fortunate to keep them in the program for two or three years.

Tomato pest management systems have changed for the good in other important ways that tend to lessen the risk of resistance. Our systems are more prevention-oriented and include many more practices, beginning with the growth and management of transplants through all agronomic stages, crop scouting, staking, pruning, harvest, and handling of the crop, as well as post-harvest management of residues and possible sources of disease inoculum or habitat for insects. Our increased focus on prevention is spreading out the control burden, reducing the frequency of spikes in populations at times when crops are threatened, and lessening the selection pressure imposed by any single practice or pesticide.

Our systems also reflect increasingly complex decision-processes in which several people typically participate to one degree or another. Different operations have varying degrees of tolerance for risk, and long-term experience (and habit) plays a surprisingly major role in how pests are managed across farms in a given region. The diversity of approaches and systems in place also can and often does accelerate innovation.

Factors Shaping IPM Systems and Decision-making on the Farm

For a variety of reasons Florida tomato pest management systems have entered a critical period of accelerated transition. Part of the pressure comes from the loss of materials because of the Food Quality Protection Act (FQPA) and the methyl bromide phase out.

Other pressures are driven by the need to reduce farm worker exposure and risks, along with agriculture's overall impacts on the environment. With the multi-billion dollar Everglades restoration project just getting underway, we anticipate renewed interest in the impacts of pesticide use on water quality and a range of nontarget species.

The ever-growing movement of people, horticultural products, and produce in international trade has also clearly increased vulnerability to exotic introduced species. In the 1970s and 1980s, a new pest or strain of a disease organism might emerge every two to five years. Today the frequency has clearly increased as have the difficulty controlling newly introduced or established pests. The short-list of major new pests in the 1990s includes the melon thrips, the silverleaf whitefly, the US17 strain of late blight and races 4 and 6 of the bacterial spot pathogen on peppers.

Within this ever-changing environment, growers, pest management specialists and crop consultants must strive, from crop to crop, to manage pests in a manner that maximizes not only efficacy and produce quality, but also worker and consumer safety and environmental compatibility. Moreover, all these goals must be achieved while preserving an adequate margin of profit for the grower.

Pest management is not the major cost center in South Florida vegetable production nor the category of expenditures that has proven most volatile and worrisome in efforts to compete with Mexican winter produce. Nevertheless, the performance of pest management systems joins the weather and market conditions as one of the three major wild cards that can trigger disaster or insure a profitable crop. It is not uncommon for the net income from an acre of tomatoes to vary more than \$10,000 per acre above or below a pre-season "best estimate" reflecting recent market conditions, yields, and costs of production.

Pest complexes and pest management systems are changing rapidly and are so important in sustaining a profitable South Florida vegetable industry. Therefore, it is increasingly important to understand how and why pest complexes change, and to judge whether IPM system performance, or some key component within our IPM systems, is slipping or improving. This chapter presents detailed data on these changes, with special focus on the insect and disease pests that have driven the evolution of our IPM systems. In Chapter 5, we draw on the data presented here to demonstrate the utility of a series of novel IPM and pesticide use measurement methodologies under development by Glades Crop Care, Inc.

We have invested much time in developing these systems and the extensive databases needed to apply them because of the clear need for a more sophisticated way to discuss the following topics with our grower-clients during pre-season planning and post-season evaluation sessions:

1. Where they stand in their adoption of IPM compared to other growers in the area.
2. What additional practices and system-changes they need to make to progress along the continuum to the next level of IPM adoption, with special focus on whatever pest or problem emerged in the last crop cycle as most worrisome or costly to deal with.
3. How their cropping system, yields and crop quality are likely to change as a result of progress or slippage along the IPM continuum.
4. How progress or slippage along the IPM continuum is likely to impact their overall pest management costs, net income, and pesticide use.
5. The possible impacts of new pests, newly registered pesticides, or new technologies in changing IPM systems or their performance.

The Importance of Individual Preferences and Experience in Pest Management

In our major production regions most tomato growers face similar environmental conditions and pests and are working land that shares many similarities. Likewise, most growers have access to and in fact use similar pest management technologies and decision tools including scouting reports, pest alerts from the cooperative extension service, and advice from crop consulting firms. Still, growers sometimes make vastly different pest management decisions; this has clearly been the experience of Glades Crop Care, Inc. over the years. Whether divergent decisions are the result of differences in personal experience, marketing demands, willingness to experiment or risk crop losses, or uncontrollable factors such as localized harsh weather, the consequences include significant pesticide use variability from farm to farm.

To illustrate this point, detailed pesticide records were examined for two tomato growers for the 1982-83 and 1997-98 seasons. These growers were located within a few miles of each other in southwest Florida and both were clients of Glades Crop Care, Inc. Their financial and material resources were roughly equivalent in both seasons. Both used the same methods to monitor pest population levels in the field in order to make spray decisions. Yet, their spray records reveal important differences in pesticide use, as evident in Tables 2.1 and 2.2.

Major, indeed striking, differences on Farm G in contrast to Farm F in the 1982-1983 season include:

1. More than double the pounds of mancozeb plus copper hydroxide were applied per acre on Farm F in the fall crop, and Farm F needed about nine times the streptomycin sulfate per acre.
2. Farm F also needed about three times the broad-spectrum insecticide.
3. In the spring crop, both farms were managed by the same person and the major differences evident in fall crop pesticide use patterns had, for all intents and purposes, disappeared.

Table 2.1. Comparison of pesticide use (lb AI/ acre) on two south Florida tomato farms for the 1982-83 season. Pesticides targeted for action under the FQPA are highlighted in boldface.

Farm Code		G	F	G	F
Active Ingredient	Pesticide Type	Fall	Fall	Spring	Spring
Benomyl	Fungicide	0.00	0.25	0.64	0.83
Chlorothalonil	Fungicide	0.00	0.00	3.83	4.95
Copper Hydroxide	Fungicide	41.42	84.09	46.47	42.65
Mancozeb	Fungicide	19.40	58.42	23.58	22.66
Streptomycin Sulfate	Fungicide	0.10	0.99	0.00	0.05
Bacillus thuringiensis	Insecticide	0.10	0.08	0.06	0.08
Methamidophos	Insecticide	0.00	0.35	0.90	1.13
Methomyl	Insecticide	1.44	3.48	0.69	0.60
Permethrin	Insecticide	0.00	0.00	0.28	0.21

The data presented in Tables 2.1-2.3 are derived from several sources. Pesticide use data for 1982-1990 and for fall 1996 and spring 1997 come from the spray records of tomato farms in Collier, Lee and Hendry counties. Data in Table 2.3 for fall 1997 and spring 1998 were collected during grower interviews as part of the preparation of a crop profile for tomatoes grown south of Lake Okeechobee (Glades Crop Care, Inc. 1999). Data in Table 2.3, designated FASS were generated by the Florida Agricultural Statistics Service (USDA NASS), 1222 Woodward Street, Orlando, Florida 32803 (FASS, 1997).

Remarkably Intensive Fungicide Use was Common in the Early 1980s

It is worth noting that the remarkably intensive use of fungicides in the fall tomato crop in 1982-1983 on Farm F was not unusual in the late 1970s and early 1980s. Many growers would apply an EBDC fungicide 20 to 25 times during the 10 to 14 weeks when the crop is vulnerable to disease. Rates of application were as high as 3 pounds of active ingredient per treatment. The intensity of use in this era periodically resulted in significant residue and food safety concerns, and triggered review by the Environmental Protection Agency. Indeed, the EBDC's have been under almost constant reassessment since the early 1980s. Many label and use pattern changes have been made, each

imposing additional limits on when, how and how much of a given product can be applied. Today, mancozeb use is capped at 16.8 pounds of active ingredient per acre at rates not to exceed 2.2 pounds of active ingredient per acre, allowing about one-fourth the use that was common in the early 1980s.

Disease management practices on Florida tomato farms, beginning in 1982, have focused on control of bacterial spot disease, caused by *Xanthomonas campestris* pv *vesicatoria*. Cultural controls at the time consisted of destroying the previous crop promptly to limit sources of disease inoculum, controlling volunteer tomatoes in newly planted fields, and managing hand-labor operations to prevent physical disease spread.

An important factor not in the control of growers was access to disease-free transplants. During the fall 1982 season, both growers received shipments of transplants with apparent bacterial spot infections. Disease development was much less severe at Farm G than at Farm F due to the grower's refusal to use the infected transplants, along with greater caution in scheduling pruning and tying operations in infected areas. The result of these two decisions was that copper hydroxide use was over twice as high at Farm F than at Farm G, while the amount of mancozeb used was three times higher and streptomycin use was increased nearly tenfold. In the spring crop, both farms were placed under the supervision of Farm G's manager, and pesticide use was approximately the same on both farms, as noted above.

Similarly, the amount of insecticide used in the fall crop was much higher at Farm F than at Farm G, driven largely by methomyl and methamidophos used to control worms (mostly *Spodoptera* spp.) and leafminers (*Liriomyza trifolii* Burgess). As with fungicide use, after the change in management, insecticide use was virtually identical between the two locations.

Seasonal differences in the program are notable, in that more chlorothalonil and benomyl were used in the spring crop than in the fall. This was in response to differences in disease pressure, with fungal diseases, such as early blight and target spot posing a greater threat in the spring. Methamidophos was also used more in the spring, as it was the only effective leafminer control material available in 1982. Leafminer control has historically been a problem in young spring plantings, which receive large numbers of immigrating adult leafminers from nearby fall crops.

Table 2.2. Comparison of pesticide use (lb AI/ acre) on two south Florida tomato farms for the 1997-98 season. Pesticides targeted for action under the FQPA are highlighted in boldface.

Farm Code		DE	~U
Active Ingredient	Pesticide Type	Fall	Fall
Chloropicrin	Fumigant	4.00	4.00
Methyl Bromide	Fumigant	196.00	196.00
Azoxystrobin	Fungicide	0.07	0.20
Chlorothalonil	Fungicide	20.97	3.78
Copper Hydroxide	Fungicide	30.80	15.06
Mancozeb	Fungicide	15.52	15.75
Mefenoxam	Fungicide	0.06	0.00
Propamocarb	Fungicide	0.00	0.78
Glyphosate	Herbicide	0.00	1.00
MCDS	Herbicide	34.88	0.00
Metribuzin	Herbicide	0.25	0.00
Paraquat Dichloride	Herbicide	2.94	0.94
Bacillus thuringiensis	Insecticide	0.30	0.00
Chlorpyrifos	Insecticide	0.38	0.00
Cyromazine	Insecticide	0.00	0.13
Detergent	Insecticide	3.00	0.00
Endosulfan	Insecticide	0.00	3.00
Imidacloprid	Insecticide	0.25	0.25
Methomyl	Insecticide	0.34	0.90
Oxamyl	Insecticide	0.00	1.00
Permethrin	Insecticide	0.00	0.40
Spinosad	Insecticide	0.00	0.19

Significant Differences Persist in Pesticide Use in the late 1990s

Pesticide use data collected in the 1997-1998 season also shows clear differences on two otherwise similar tomato farms, DE and ~U (see Table 2.2) :

1. Twice the pounds of fungicides per acre are applied on Farm DE compared to Farm ~U.
2. While the two farms use similar amounts of the EBDC mancozeb (essentially the full amount allowed by the label), Farm DE relied on increased of long-established and inexpensive products (chlorothalonil and copper hydroxide). Farm ~U, on the other hand, worked two relatively new, more expensive fungicides into their program (azoxystrobin and propamocarb).
3. Insecticide use on Farm ~U was more reliant on disruptive, broad-spectrum materials, and consequently, the farm required a more diverse mix of products to cover both primary and secondary pests.

In Table 2.2, the greater diversity of both fungicide and insecticide use is striking when compared to use in 1982-1983 (Table 2.1). Yet, the pest management program in the 1997-1998 fall crop is still focused on control of bacterial spot and armyworms. In terms of disease management, the growers at Farms DE and ~U had one advantage over the 1982 growers. Their transplants were locally produced in a facility where sanitation was strictly enforced, and where the transplants were systematically scouted by either farm personnel or by an independent crop consultant for the presence of insects and diseases. Striking differences still occurred in fungicide use. In particular, Farm DE used much greater amounts of chlorothalonil and copper hydroxide. The justification for these decisions is discussed in detail below.

Mancozeb use dropped dramatically between 1982 and 1997 because of restrictions on the number of applications and the total application rate allowed for this active ingredient and for its sister compound, maneb. In the 1997 fall crop, mancozeb use was roughly equal between the two farms, each constrained by label limits.

The use of chlorothalonil at Farm DE was heavily influenced by an outbreak of late blight, caused by *Phytophthora infestans* (Mont.) de Bary. The protectant fungicide, chlorothalonil, was found to be very effective against the pathogen involved (Weingartner, 1997). Farm DE chose to apply chlorothalonil frequently, while Farm ~U used it in rotation with propamocarb, both to assure a somewhat broader range of disease control.

Previous losses to target spot, caused by *Corynespora cassiicola* (Berk. & M.A. Curtis) C.T. Wei, also affected the high amount of chlorothalonil used at Farm DE. Although the same disease occurred annually at Farm ~U, the grower did not consider it a major threat, since his fields showed a high incidence of *Fusarium oxysporum* f. sp. *radicis-lycopersici* W.R. Jarvis & Shoemaker, a fungus which causes Fusarium crown and root rot (FCR). The FCR losses were high enough to prevent harvesting significant tonnage from a field more than once. As FCR tends to be more damaging to second-pick yield, there is a logical basis for this decision.

The major difference in herbicide use at these farms lay in the program of paraquat dichloride and MCDS at Farm DE. This program targeted paraquat resistant nightshades, which were effectively controlled by MCDS. At Farm ~U, with its lighter herbicide program, populations of nightshade and nutsedge survived and increased throughout the farm for several years.

The most striking differences lie in the insect management program. In the 1988 season, the silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring, became an economic pest of Florida tomatoes, through its transmission of virus diseases and its role in causing Tomato Irregular Ripening syndrome. This pest had a profound and immediate impact on insecticide use patterns in Florida tomato production. Both farms applied imidacloprid at transplanting. This insecticide effectively controlled whiteflies for approximately 6-8 weeks, after which populations rebounded and additional

insecticide applications were needed. The supplemental whitefly controls used on Farm ~U included permethrin and endosulfan, and reflect the tendency at Farm ~U to rely on “harder” pesticides, while at Farm DE late season whiteflies are controlled with dish detergent along with a low rate of chlorpyrifos. While both programs were roughly equal in efficacy, the choice of active ingredients at Farm ~U represents an increased risk of pesticide resistance development, since permethrin and endosulfan share a common mode of action. The program at Farm DE was not only less expensive, but posed less risk of resistance development because of the different modes of action of detergent and chlorpyrifos. Their program also had significantly lower impact on beneficial insects, primarily leafminer parasites, because of the short residual activity of detergent.

Farm DE based its worm control program on the use of *Bacillus thuringiensis* Berliner (*B. t.*), while the grower at Farm ~U opted for other larvicides. The result was that Farm ~U used significantly more methomyl, permethrin and spinosad to control worms than Farm DE, where methomyl and chlorpyrifos were used sparingly to control SLW and clean up older worm larvae that were not susceptible to *B. t.*

The differences in SLW and worm control programs had an impact on a secondary pest, the leafminer. This pest seldom exceeds thresholds in the fall crop, since parasitic wasps can attack it in high enough numbers that the economic threshold governing spray decisions is usually not exceeded. At Farm ~U the combined effect of the “hard” SLW and worm control programs reduced the parasitic wasp population to the point that several additional insecticide applications were needed to control leafminers.

One clear result of the above series of decisions on Farms DE and ~U was that, with the exception of chlorothalonil, Farm DE’s spray program used significantly less of the FQPA targeted pesticides than Farm ~U’s spray program. Biological control agents were of greater use on Farm DE, as well.

Significant differences exist in the decision-making process and responsibility at the two farms. Decisions at Farm ~U were made by a single individual with strong personal beliefs about the best way to deal with pests, while those at Farm DE were made cooperatively by several levels of farm managers, typically after much discussion and exchange of information and ideas. Although the two farms made use of the same scouts and consultants, the responsiveness to their recommendations was greater at Farm DE. In addition to responsiveness to outside advice, Farm DE had established for many years a systematic program for reviewing past pesticide practices. Farm personnel, along with consultants, contributed to and used this process to evaluate changes in system efficacy and formulate plans for new approaches in the next crop cycle. Consequently, Farm DE is both more willing to experiment and more successful when doing so.

Table 2.3. Pesticides used by a south Florida tomato grower between 1982 and-1998 (pounds of AI per acre). NASS data represent average usage of major pesticides (applied to 50% of acreage) for the entire state of Florida for the specified year.

Common Name	Type ^x	Fall	Spring	Fall	Fall	Spring	Fall	Spring	Fall	Spring	NASS	NASS	NASS	NASS	Fall	Spring	Fall	Spring
		82	83	85	87	88	88	89	89	90	90	92	94	96	96	97	97	98
Chloropicrin	Fm	^z	^z	^z	^z	^z	^z	^z	^z	^z	53.4	63.3	61.0	58.6	4.0	4.0	4.0	4.0
Methyl Bromide	Fm	^z	^z	^z	^z	^z	^z	^z	^z	^z	164.7	171.8	182.7	142.5	196.0	196.0	196.0	196.0
Azoxystrobin	Fg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
Benomyl	Fg	0.0	0.6	0.0	1.1	0.3	0.6	0.6	0.7	0.9	1.4	0.7	2.2	0.8	0.0	0.0	0.0	0.0
Chlorothalonil	Fg	0.0	3.8	10.0	7.2	8.0	1.8	1.5	1.8	1.2	9.1	6.2	11.0	8.3	7.4	10.6	21.0	25.0
Copper Hydroxide	Fg	41.4	46.5	32.8	49.5	49.5	27.0	19.6	23.6	28.9	11.9	9.9	15.0	7.4	29.6	18.8	30.8	27.0
Dichlone	Fg	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mancozeb	Fg	19.4	23.6	30.7	54.0	54.0	31.1	24.9	23.6	28.9	19.7	13.0	18.1	10.2	12.8	7.4	15.5	14.0
Maneb	Fg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	2.6	0.0	0.0
Mefenoxam	Fg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.5	0.7	0.2	0.1	0.1	0.1	0.1
Propamocarb	Fg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0
Streptomycin Sulfate	Fg	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MCDS	Hb	^z	^z	^z	^z	^z	^z	^z	^z	^z	0.0	0.0	0.0	0.0	0.0	0.0	34.9	34.9
Metribuzin	Hb	^z	^z	^z	^z	^z	^z	^z	^z	^z	0.6	0.5	0.3	0.6	0.3	1.1	0.3	0.3
Paraquat Dichloride	Hb	^z	^z	^z	^z	^z	^z	^z	^z	^z	1.0	0.7	0.7	0.9	0.5	0.6	2.9	2.9
Sethoxydim	Hb	^z	^z	^z	^z	^z	^z	^z	^z	^z	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.0
Avermectin	In	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.03	0.02	0.01	0.01	0.00	0.01
<i>Bacillus thuringiensis</i>	In	0.1	0.1	0.0	0.2	0.5	0.2	0.1	0.0	0.0 ^y	0.0	0.0 ^y	0.0 ^y	0.0 ^y	0.4	0.2	0.3	0.5
Chlorpyrifos	In	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.4	3.4 ^z		0.4	0.1	0.4	0.0
Crop Oil	In	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.7	4.4	0.0	6.6
Cyromazine	In	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Detergent	In	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0
Endosulfan	In	0.0	0.0	0.2	0.0	0.0	1.0	0.8	0.3	0.2	4.3	2.7	4.1	1.9	0.0	0.0	0.0	0.0
Esfenvalerate	In	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.6	0.6	0.2	0.1	0.3	0.1	0.0	0.0	0.0	0.0
Imidacloprid	In	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.2	0.2	0.3	0.3
Lambdacyhalothrin	In	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Methamidophos	In	0.0	0.9	1.4	1.9	3.0	0.1	0.2	0.0	0.0	3.5	2.4	3.8	3.0	0.0	0.0	0.0	0.5
Methomyl	In	1.4	0.7	1.6	3.6	2.3	0.5	0.3	2.7	3.0	2.0	1.5	2.0	1.3	0.5	0.8	0.3	0.2
Permethrin	In	0.0	0.3	0.1	0.0	0.5	0.0	0.0	0.0	0.0	0.8	0.5	1.1	0.5	0.0	0.0	0.0	0.0
Piperonyl Butoxide	In	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

^z Data for this AI were not available for this season/year. ^y This AI is not reported by NASS because of variability in AI content. ^x Fm = Fumigant, Fg = Fungicide, Hb = Herbicide, In = Insecticide

Impacts of Changes in Pesticide Regulatory Policy and Product Labels

Changes in pesticide regulatory policy can have profound impact on pesticide use. Table 2.3 contains the pesticide use records for Farm DE between 1982 and 1998. During this 16-year period, two significant changes in pesticide regulation occurred that directly impacted South Florida tomato pest management: new Worker Protection Standards were finalized in 1994, and changes in the pesticide labels for EBDC fungicides came in the late 1980's and most recently in 1992.

The impact of these changes is clearly seen in the amounts of copper hydroxide and mancozeb applied to control bacterial spot and other foliar diseases. Prior to the first label changes, per acre use of mancozeb and copper ranged from 19.4 to 54.0 pounds and from 32.8 to 49.5 pounds per acre, respectively. With the label changes, these amounts decreased by about a third. Although the amounts of copper hydroxide applied were largely unchanged following label changes, the amount of the EBDC fungicides mancozeb and maneb applied in 1992 fell dramatically to a range of 9.9 to 15.5 pounds of both active ingredients combined, about one-quarter of peak rates common in the 1980s.

These changes in fungicide use are significant from more than one perspective. First and most obvious, growers were forced to reduce use of EBDC's to stay within label restrictions on overall pounds applied and field re-entry intervals. Even though very high amounts of mancozeb and copper hydroxide were used in the early 1980s to a large degree, growers appear to be getting just as much benefit from well-timed applications of 10 to 15 pounds of EBDC's per acre.

The efficacy of chemical control of bacterial spot over the last two decades has remained largely unchanged. Seasonal differences in disease severity are clearly driven more by changes in grower practices and the weather than by the amount of fungicide applied. Notable among the grower changes that helped maintain disease control efficacy despite greatly reduced fungicide use was the significant investment in localized transplant production under the direct control of the grower.

Greenhouse Scouting Emerges as a Key New Task

This key change in cultural practices was begun in 1983 and is the most critical preventive practice available to a grower. No other practice has resulted in a greater decrease in disease risk. Early efforts to produce disease-free local transplants were hampered by proximity of greenhouses to tomato production fields. The presence of some disease in locally grown transplants convinced growers to institute a greenhouse disease prevention program, which Glades Crop Care, Inc. helped design and field-test. Cooperatively, a set of cultural and preventive practices evolved over a period of several years that have significantly reduced the incidence of bacterial spot in transplant shipments.

Frequent scouting of greenhouse transplant operations began in 1983. By identifying the inoculum sources for transplant infection in the greenhouses, we were able to take and monitor the effectiveness of corrective steps. These included primarily the further isolation of transplant production sites in the fall of 1988, an action that resulted in dramatic reductions in the frequency of bacterial spot infections on transplants.

As clean transplants became more universally available, overall disease pressure fell and other prevention-based measures became more effective. It is now clear that this single prevention-based strategy, assuring a supply of clean transplants, has paid major dividends to the grower by reducing fungicide expenditures and stabilizing EBDC use at a much lower level that falls within the new, more restricted product labels.

Recent reductions in EBDC use across the rest of the Florida tomato industry have clearly been driven by label changes. EPA cut back on EBDC use because of the carcinogenic risk of a byproduct in all EBDC fungicides, ethylene thiourea (ETU). Interestingly, although EBDC use in 1996-98 is roughly half that of the preceding years and a quarter of peak use in the early 1980s, control of bacterial spot has remained fairly steady (Glades Crop Care, Inc. unpublished data). This is largely due to changes in cultural practices, notably the sourcing of disease-free transplants discussed above, along with steps to reduce disease dissemination by people and equipment moving from field to field.

Prevention Requires Many Steps on Multiple Fronts

Reducing the spread of disease from one location to the next has required a broad-based effort and the cooperation of many people. Growers and pest managers have had to develop and refine lists of phytosanitary practices and protocols for different activities and different employees. On farms that have made a sustained commitment to good sanitation, employees have discovered many ways to lessen the chance of disease spread. The cumulative impact of dozens of small measures to isolate sources of disease can be quite profound, delaying the onset of disease symptoms and lessening their severity. On such farms, the amount of EBDC formerly used, but now prohibited by the stricter label, is hardly missed.

Still, the combination of mancozeb and copper hydroxide remains one of the most economical and effective control measures for fungal diseases, such as early blight, caused by *Alternaria solani* Sorauer. Despite the bacterial spot pathogen's resistance to copper, the elimination of this common tank mix is still not justified since some control of bacterial spot is still obtained from its use. The combination of grower determination to perfect sanitation practices, access to clean transplants, improved cultural practices and regulatory change has reduced the use of EBDC fungicides in South Florida tomato production as far as is currently feasible without incurring significant losses.

Fortunately, evidence compiled by the EPA suggests that the frequency and level of EBDC residues in tomatoes have been markedly reduced compared to a decade ago. But tomato growers in Florida are concerned that the FQPA might trigger another round of restrictions, which in the absence of new alternatives might place the entire industry in jeopardy of catastrophic losses to bacterial spot and other pathogens.

The Impacts of Change in Pest Complexes

Preventing pest problems from arising is a basic building block of bio-based integrated pest management. At the individual farm level, this tactic may involve not planting a susceptible crop in a field where a certain disease pathogen is known to occur. On a larger state- or nation-wide scale, this tactic involves keeping non-native pests from invading domestic farming areas. Despite the extensive efforts of organizations such as USDA's Animal and Plant Health Inspection Service (APHIS) and Florida's Division of Plant Industry to inspect incoming plant materials for hitchhiking pests, introductions inevitably occur. Some of these accidentally introduced pests can cause many millions of dollars of damage.

Silverleaf Whitefly Emerges as a Major Pest

An outstanding case in point is the sweetpotato whitefly, *Bemisia tabaci* Gennadius, the B biotype of which has been named the silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring (SLW). This pest has caused economic losses in the hundreds of millions of dollars in several states in many crops, including cotton, melons and tomatoes (Norman et al., 1996). The geminivirus diseases and physiological ripening problems associated with it have hit Florida's tomato industry particularly hard. Losses were estimated at \$125 million for the 1990-91 season alone (Norman et al., 1996).

Faced with such potential losses, management of this one pest has become the centerpiece of insect control programs in Florida tomato crops. The following discussion tracks the evolution of the insect control program at Farm DE. Details of the grower's spray program are presented in Table 2.3. The grower's records were not available for the fall 1990 to spring 1996 seasons. These data were obtained for the state of Florida for the complete year, not broken down by season, from the Florida Agricultural Statistics Service, 1997. Based on our experience with Farm DE and many other tomato clients, we feel the FASS data are reasonably representative of typical pesticide use patterns on most of our client-farms, including Farm DE during the period when Farm DE-specific data are lacking.

Prior to the appearance of SLW, Florida growers were chiefly concerned with managing leafminers and several species of worms, especially the southern and beet armyworms, *Spodoptera eridania* (Cramer) and *S. exigua* (Hübner). The primary pesticides used in the early 1980s were methamidophos and methomyl, both of which now appear on the FQPA list of pesticides targeted for regulatory action. Smaller amounts of permethrin and *B. t.* were also applied periodically.

This situation began to change when the SLW, at first known to attack only the state's poinsettia crop, began to show up in tomatoes in the fall of 1987. Control of this initial outbreak was attempted with increased amounts of methamidophos and methomyl. Permethrin was added to this program in the spring of 1988. Control with these products at the rates and frequencies used during the 1987-88 season was largely unsuccessful. Serious economic losses, \$15 million statewide were incurred during the spring of 1988, the result of Tomato Irregular Ripening (TIRR) disorder, a new malady never before seen outside Florida (Schuster et al., 1989).

In the following fall, control tactics on many farms, including Farm DE, changed dramatically in addressing TIRR. The spray program was now centered on applications of endosulfan, esfenvalerate and piperonyl butoxide (PBO). While methamidophos and methomyl were still in use, the amounts applied fell markedly. Using this program, a low population of SLW was maintained and TIRR problems were not encountered.

Unfortunately, acceptable levels of control did not persist very long. In September 1989 a geminivirus, spread by SLW was detected for the first time in samples submitted to the University of Florida by Glades Crop Care, Inc. (Cantliffe, 1990). This disease was later identified as Tomato Mottle Virus, ToMoV, (Polston, et al., 1992). The severity of this disease led to an immediate increase in the intensity of SLW management programs. While endosulfan use declined and the use of esfenvalerate and PBO remained about the same, the use of methomyl, directed at both worms and the adult SLW rebounded to historical levels of over 2 lb AI per acre, a several-fold increase over recent years.

This high level of methomyl use continued at least through the break in Farm DE's record following the spring of 1990. Taking the statewide FASS record as representing local practices, the use of methomyl continued at nearly this same level through 1996. Similarly, methamidophos, while not a central part of Farm DE's program, was commonly used by other tomato growers throughout the state, especially in tank mixes with pyrethroid insecticides, such as permethrin or esfenvalerate.

Beginning in 1990 chlorpyrifos, an FQPA-listed organophosphate, came into widespread use statewide. Farm DE's program included chlorpyrifos during the years not included in this survey (GCC, unpublished data). When the farm's record resumes in 1996, it is noteworthy that its use of chlorpyrifos is markedly lower than the state-average use reported by FASS in 1994.

The steadily rising volume of insecticides applied to manage SLW was sharply curtailed following the introduction of Bayer's new systemic neonicotinoid insecticide imidacloprid in 1996. The SLW control achieved with imidacloprid was so much better than with the previously available insecticides that many growers virtually abandoned the use of permethrin, esfenvalerate, chlorpyrifos and methamidophos. For the last two years covered in our survey the South Florida grower's foliar spray program shifted from

stressing SLW control to a greater focus on using “softer” chemistry, such as *B. t.* for worm control and crop oil and soap for late season SLW control.

SLW Worsens Leafminer Problems and Contributes to a New Disease Threat

This move away from the harsh spray program of the late 1980s and early 1990s was a welcome change, not only in terms of environmental and farm worker safety, but also in terms of restoring populations of beneficial organisms and progressing along the IPM continuum. The intensification of SLW control sprays between 1988 and 1996 had a dramatically negative impact on the populations of leafminers infesting tomatoes. These insects are usually kept under biological control by a diverse complex of parasitic wasps that attack the leafminer larvae and/or pupae. However, these wasps are highly susceptible to many insecticides. In the hostile environment resulting from intensive SLW spray programs, leafminers posed increasingly greater control problems. This is reflected in the relatively high amounts of avermectin and cyromazine recorded between 1987 and 1996.

During the peak seasons, such as 1990, leafminer controls were often needed by mid-October in fields approximately six weeks after transplanting. In the years since imidacloprid's introduction though, the first leafminer spray of the season has been pushed progressively back into November. This situation resembles the leafminer control scenarios of pre-SLW days.

A second SLW-borne geminivirus has recently been detected in South Florida tomato production areas. Tomato Yellow Leaf Curl (TYLCV) is known worldwide as a highly destructive tomato disease. The disease probably entered the state in Dade County in late 1996 or early 1997. Infected tomato transplants produced in Dade County were sold in retail outlets in several locations. Symptomatic plants originating in those retail outlets provided the first positive identification of TYLCV in Florida. The response from the Florida tomato industry was understandably aggressive, considering that up to 95 percent crop loss to this disease had been suffered a few years earlier in the Dominican Republic (Polston et al., 1998).

The industry's response to this new threat was to supplement the transplant drench application of imidacloprid with foliar insecticide applications beginning at approximately 6 to 8 weeks after transplanting. This increase in insecticide use appears in spring 1998 as the re-appearance of esfenvalerate and methamidophos in the grower's spray record (Table 2.3).

To summarize the changes brought about in Farm DE's insecticide program, which is representative of similar changes statewide in the tomato industry:

1. Before the introduction of SLW, the insecticide program focused on controlling leafminers and worms, using primarily methamidophos and methomyl.
2. With the introduction of SLW, there was a marked increase in the use of endosulfan, esfenvalerate, permethrin and PBO, along with continued use of methomyl.
3. This increased insecticide use was stepped up even further following the discovery of ToMoV in 1989.
4. The introduction of imidacloprid provided sufficient SLW control that the industry dramatically reduced the amounts of endosulfan, esfenvalerate, permethrin, methomyl and PBO.
5. The introduction of imidacloprid and the resulting reduction in foliar insecticide use resulted in greater biological control of leafminers, shown by later and less frequent applications of avermectin and cyromazine for their control.
6. The trend toward a lower foliar insecticide load was again reversed when TYLCV was discovered in 1997.

These trends are noteworthy because they show that tomato producers are not only responsive to new pest problems, but are willing to back away from intense spray programs when highly effective products provide adequate control with reduced applications. Our experience confirms that well-designed IPM systems are sometimes dependent on intensive pesticide applications when some exogenous factor destabilizes the system and there are no alternatives for the grower other than walking away from the \$5,000 and \$7,000 per acre already invested in the crop (Glades Crop Care, Inc., 1999).

Gauging IPM System Performance and Stability

A critical measure of grower commitment to IPM and the effectiveness of the IPM delivery infrastructure supporting the industry is how long it takes for new approaches to be discovered and put in place in such instances and how quickly and widely innovative solutions are adopted across the industry. On both counts, we believe the South Florida tomato industry responded effectively and with considerable skill, and that its commitment to IPM served it well in ultimately crafting cost-effective solutions. Of course, the commercial introduction of imidacloprid came at a most opportune time. Without this highly effective new insecticide, the problem would have proven much more intractable.

The example of the SLW is not the only one that can illustrate the responsiveness of Florida growers to new pest problems. In 1997, South Florida was invaded by a distinct genotype of the late blight pathogen, *Phytophthora infestans*. This new strain, later identified as US-17, was aggressive on both potatoes and tomatoes (Weingartner,

1997, and Weingartner, personal communication). The situation was aggravated by the fact that the 1996-97 growing season was a rainy El Niño season. The combination of a destructive new pathogen strain and weather conditions highly favorable to disease development led to high levels of late blight in both susceptible crops throughout the southern part of the state (Glades Crop Care, Inc., unpublished scouting data). Tomato growers responded with an intensification of their fungicide programs.

This intensification resulted in the only time propamocarb was applied, along with a jump in chlorothalonil use from the historical levels of under 2 lb AI /A to over 10 lb AI/A (Table 2.3), an increase that was still evident in the following growing season of 1998. Late blight pressure is likely to change as weather conditions shift from wet, rainy El Niño seasons to more normal, dry winter conditions. However, at the end of the survey period in 1998, the grower had retained and even increased the amount of chlorothalonil applied, mostly because of the threat of disease spread from nearby potato farms. During the last two seasons, late blight incidence, while lower than during the spring of 1997, has remained a threat in south Florida.

Silverleaf whitefly, tomato mottle virus, and late blight management highlight the importance of the constantly changing pest complex threatening tomato crops in South Florida. Fortunately in the case of late blight, effective fungicides were available to deal with the problem, even though the most effective one, chlorothalonil, appears on the FQPA list. In the case of SLW prior to the introduction of imidacloprid, adequate control was achieved through very intense spraying but at very high and rising costs. Expenditures on insecticides doubled, even tripled on some farms and worker exposure and risk issues were significantly more frequent and worrisome. In addition, the highly disruptive broad-spectrum insecticides used triggered greater problems with a secondary pest, the leafminer, and in time might have virtually undermined the grower's ability to produce a profitable crop.

The response to SLW would have been much more acceptable if better alternatives had been available. Growers were forced to battle this destructive insect with ineffective insecticides for eight years before a truly effective insecticide, imidacloprid, was finally registered. However, once a better alternative was available, it was rapidly incorporated into the system.

Heavy reliance on imidacloprid was clearly preferable in contrast to earlier SLW control measures. However, with imidacloprid's specific mode of action, its persistence and systemic action, this insecticide imposes intense and sustained selection pressure and hence sets the stage for the onset of resistance. The lesson learned by Glades Crop Care, Inc. over the last 30 years in managing tomato pests is that growers must rely largely on multiple tactics and prevention to truly stabilize their pest management systems. No one pesticide or control tactic should be asked to bear most of the burden in managing any of destructive pest species. Time and again we have learned that pests and pest complexes will adapt, and the stronger the selection pressure imposed on them, the faster and more unforgiving the outcome.

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