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## Measuring Integrated Pest Management Adoption in South Florida Vegetable Crops

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Abstract: South Florida vegetable pest management programs were surveyed to determine the level of integrated pest management (IPM) used in tomatoes (*Lycopersicon esculentum* Mill.), peppers (*Capsicum annuum* L.) and potatoes (*Solanum tuberosum* L.). The measurement technique incorporated the results of an IPM questionnaire and a review of each respondent's pesticide applications. Responses to the questionnaire were weighted according to their importance in a completely integrated, biologically oriented pest management program and the frequency and intensity of use. The amounts of pesticide active ingredients were weighted for acute and chronic mammalian toxicity. The IPM survey score was divided by the total mammalian toxicity score to produce a numerical ranking of growers according to their place on the IPM continuum. This measurement technique allowed a more detailed analysis of IPM implementation than previous surveys. Growers' placement on the IPM continuum was influenced heavily by the amounts of EBDC fungicides and organophosphate insecticides applied. IPM continuum scores were generally highest among pepper growers, followed by tomato and potato growers in that order.

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### **Introduction**

Florida vegetable growers face some of the most intense insect and disease pressure in the United States. Their response has been to develop sophisticated integrated pest management (IPM) systems. These frequently include important IPM components such as regular scouting and the use of economic or damage-related thresholds, securing disease-free planting material and a range of other practices and tactics (Swisher, 1995; Funderburk and Chellemi, 1996; Bauske, et al, 1998). Still, pesticides continue to bear the major burden in managing pests. Non-chemical control options have not become established to the extent

that is technically and economically feasible. The hesitance to adopt new approaches reflects concern about potential economic losses, given the high value of the major fruit and vegetable crops and low market tolerance for blemishes in fresh produce like tomatoes and peppers.

Growers face changes in the regulatory and marketing arenas. Proposed changes in the registrations of commonly used insecticides and fungicides under the Food Quality Protection Act threaten to greatly change the choices growers have at their disposal. The resulting regulations could severely limit the use of critical pesticides, which although seldom used, or used only in small amounts, may spell the difference between success and crop failure.

Surveys of Florida vegetable growers' IPM practices indicate that there is a high level of basic IPM adoption; i.e., the use of scouting and thresholds to trigger pesticide applications (Bauske, et al, 1997; Swisher, 1995). These surveys indicate some level of IPM adoption on over 75% of tomato acreage and 97% of potato acreage. Yet, the surveys fail to provide a means of evaluating in detail the impact of these IPM programs on pesticide reliance and use, and on the total agroecosystem including soils, water, crops, pests, and non-target organisms ranging from beneficial biological control agents to local wildlife, farm workers and consumers.

Florida's vegetable growers could benefit from an analytical tool which accurately describes their pest management practices, providing detailed information on the wide variety of non-pesticidal practices employed and on the exact amounts and types of pesticides that are integrated into these practices.

Our focus was to develop and test a method to measure the linkages between IPM adoption, pesticide reliance and use, and pesticide risks in the context of intensive Florida vegetable production. This work builds on the IPM measurement methodology set forth in Benbrook, et al, 1996, and incorporates preliminary results from a multiattribute toxicity ranking model under development for monitoring the impacts of Food Quality Protection Act (FQPA) implementation (C.M. Benbrook, personal communication).

### **Materials and Methods**

The IPM measurement method used in this survey consisted of three parts: a survey of growers' pest management practices, a review of their pesticide applications for representative fields, and the construction of an IPM continuum.

IPM Survey: To establish points for growers' IPM practices, a questionnaire was prepared which addressed preventive practices for insect and disease management and issues of sound crop production. Respondents provided information on farm size, basic cultural practices, crop production and economics. Each item on the survey was weighted according to its contribution to biologically intensive pest management. Weights ranged from 1 to 8. Sample questions and weights are presented in Table 1.

Respondents were asked how frequently or intensively each item was practiced. The possible responses, never, seldom, sometimes, often and always, were assigned values of 0, 0.25, 0.50, 0.75, and 1, respectively. The final point value of each item was obtained by multiplying this weight by the response value.

Pesticide Use Survey: Respondents supplied detailed information about the pesticide programs for fall and spring tomato and pepper crops and for whole-season potatoes. Fall crop fields were planted in August and September, 1996, and spring crops in December, 1996 and January, 1997. The potato crop was planted throughout October, November and December, 1996.

The average number of applications and average rates of application of each pesticide were determined. Using these figures and the active ingredient (a.i.) content of each product, the amount of a.i. applied per acre was determined for each product.

Pesticide Impact Evaluation: A weighting method was used to adjust pesticide use for the inherent toxicity of active ingredients. Acute and chronic mammalian toxicity values were obtained from the database and toxicity adjustment model used in Benbrook, et al., 1996; and C.M. Benbrook, personal communication. The active ingredients identified in the pesticide use survey were assigned relative weights reflecting their contribution to the overall mammalian toxicity and risk. The values used for these weights consisted of "Acute Toxicity Units" and a measure of chronic mammalian toxicity that is derived from U.S. EPA data (Benbrook, et al., 1996). The acute mammalian toxicity score incorporated the inverse of each chemical's LD-50 and a scaling factor.

The chronic mammalian score incorporated the following variables:

RfD = Reference Dose or other available estimate

ED = Endocrine Disrupter: if yes, ED = 3; if no, ED = 1

Q\* = EPA cancer potency or best estimate available

CLASS = EPA Oncogenicity Class: if A of B/2, value = 10; if C, value = 5; if D, value = 2.

These variables were combined in the formula:

$$\text{Chronic Mammalian Toxicity Score} = [(0.01/\text{RfD}) \times (\text{ED})] + [50 \times (\text{Q}^*) \times (\text{CLASS})]$$

The mammalian toxicity weight, consisting of the sum of the acute and chronic scores, for each a.i. was multiplied by the pounds of a.i. applied per acre in each of the crops. This allowed the evaluation of human risk factors, a key step in assessing the overall risk profile associated with the pesticides applied on each farm.

IPM Continuum Score Determination: The IPM Continuum Score for each crop was determined by the method described in Benbrook, et al, 1996. Scores for preventive practices (PPP) identified in the IPM survey were totaled for each of the three portions of the survey, General, Insect Management, and Disease Management. Three continuum scores were determined using these PPP's and the weighted pesticide data, generated using the methods described under the pesticide use survey: a Total IPM Continuum Score, a Disease Management IPM Continuum Score, and an Insect Management IPM Continuum Score. These scores were calculated by dividing the PPP's by the appropriate mammalian toxicity unit values using the following formulas:

- Disease IPM Continuum Score =  $[(\text{General PPP} + \text{Disease Management PPP}) / (\text{Total Mammalian Toxicity Score} / \text{Acre for fungicide a.i.'s})]$
- Insect Management IPM Continuum Score =  $[(\text{General PPP} + \text{Insect Management PPP}) / (\text{Total Mammalian Toxicity Score} / \text{Acre for insecticide and miticide a.i.'s})]$
- Total IPM Continuum Score =  $[(\text{General PPP} + \text{Insect Management PPP} + \text{Disease Management PPP}) / (\text{Total Mammalian Toxicity Score} / \text{Acre for all groups of a.i.'s})]$

### **Results and Discussion**

Seventeen responses were obtained which represent nearly 9,600 acres of potatoes, tomatoes and peppers and a geographical area approximately 160 miles in diameter centered in Immokalee, FL. Farm size ranged from 35 acres to 1,800 acres. Average farm acreage by crop was 665 acres in potatoes, 757 tomatoes, and 343 peppers.

General IPM Practices: The results of the growers' IPM practices survey show that south Florida vegetable growers regularly use multiple tactics to manage insect and disease pests of potatoes, tomatoes and peppers. In the general IPM practices section, growers most often responded positively to five practices:

- remaining up to date regarding insect and disease problems;
- scouting their crops regularly, whether in person or using a consultant;
- maintaining and using written scouting records;
- using best management practices to ensure crop vigor; and,
- destroying the crop and its residue according to insect and disease threats.

Less frequently used practices were intercropping, manipulating planting schedules, and cleaning field equipment when moving from field to field. High land rents, intensive land preparation, crop maintenance schedules, and crop marketing demands are likely causes for the low level of use for these practices.

Disease IPM Practices: Responses to this part of the survey were reflective of the current disease problems: late blight in potatoes and bacterial spot in tomatoes and peppers. Frequently used practices included:

- inspection and care of transplanting material for disease reduction and exclusion;
- a high willingness to reject diseased planting material;
- disinfecting workers' hands during pruning and tying tasks to minimize disease spread
- resistant varieties;
- management of water tables as a means of managing root and stem diseases; and
- choosing liming and fertilization as disease management tools.

Crop rotation and the addition of mycorrhizal organisms to soil were generally not used, due in large part to market-driven farming decisions and lack of clearly demonstrated efficacy, respectively.

Insect IPM Practices: Frequently used practices included:

- scouting for both pest and beneficial insects;
- using thresholds in making spray decisions;
- delaying insecticide applications when sufficient beneficial insects were present;

- biologically friendly pesticides, such as *Bacillus thuringiensis* (*B.t.*);
- using adjuvants such as crop oils or spreader/stickers to enhance the activity of insecticides to allow a lower a.i. use rate; and
- rotating among classes of insecticides to delay the development of pesticide resistance.

Infrequently used practices included the maintenance of unsprayed refugia or the use of cover crops in non-crop areas specifically for promotion of beneficial insects. Weed control as an insect pest management tool was more frequently cited by tomato growers than potato or pepper growers. Releasing beneficial insects and the use of pheromone traps as monitoring tools were seldom used.

Overall preventive practice scores from the IPM surveys are summarized in Table 2. All respondents scored between 50.80% and 68.75% of all possible points in all questionnaire sections.

Pesticide Use Survey: Fungicides: In potatoes, fungicides were directed primarily against late blight disease, caused by *Phytophthora infestans* (Mont.) de Bary, US 8 and US 17, which was epidemic during the 1996 - 97 season. The most commonly used protectant fungicides were chlorothalonil and mancozeb, plus other less often used protectants, metiram and triphenyltin hydroxide. Propamocarb and metalaxyl saw rare use.

In peppers control was needed primarily for bacterial spot disease, and maneb, was commonly used as a tank mix with one of several copper formulations, usually copper hydroxide or copper sulfate.

Tomatoes were threatened by both bacterial spot disease and a late blight epidemic caused by strain US 17 of *P. infestans*. The EBDC's, maneb, and mancozeb and chlorothalonil were heavily used for late blight control. The EBDC's were usually tank mixed with either copper hydroxide or copper sulfate for bacterial spot control. Amounts of the coppers and EBDC's were higher in the fall crop, reflecting the higher incidence of bacterial spot disease during the rainy fall season, while chlorothalonil use increased due to elevated late blight pressure during the cooler, drier spring season.

Herbicides: The highest amounts and diversity occurred in the potato crop. The commonly used active ingredients were paraquat dichloride and metribuzin. In tomatoes and peppers paraquat dibromide was the most commonly used, followed by metolachlor and sethoxydim in peppers and by metribuzin and sethoxydim in tomatoes.

Insecticides: The highest amounts were used in potatoes, primarily the granular insecticides, aldicarb, ethoprop and phorate applied at planting or at lay by. Oxamyl and methamidophos were also used.

The most commonly used pepper and tomato insecticide was *B.t.* Other uses in tomatoes and peppers reflected differential pest pressures between the fall and spring crops. *B.t.*, chlorpyrifos and methomyl use was higher in the fall due to high armyworm pressure in September and October. The leafminer controls, avermectin and cyromazine, were mostly used in the spring when this pest was prevalent. In peppers, both methomyl and oxamyl are used to manage pepper weevils, *Anthonomus eugeni* Cano, which can become crop threatening in the spring.

Encouraging signs of the adoption of alternative management tools can be found in the tomato and pepper crops. Nuclear polyhedrosis virus was used on one respondent's farm for control of the beet armyworm, *Spodoptera exigua* Hübner, while azadirachtin and the oil extract from the neem seed were used on several farms for control of worms and weevils. Sulfur has largely replaced the chlorinated hydrocarbon, dicofol, as the miticide of choice in peppers for control of the broadmite, *Polyphagotarsonemus latus* (Banks).

Pesticide Impact Evaluation: The raw mammalian toxicity scores ranged from a low value of 0.074 for glyphosate to a high value of 2400 for triphenyltin hydroxide. The value two hundred was selected as a cap since a few of the values were so high that legitimate IPM tactics were disguised. The highest contribution was from methyl bromide. Even though this a.i. has a moderate mammalian toxicity adjustment factor, high application rates resulted in disproportionately high mammalian toxicity unit values per acre. Therefore, to allow for a more consistent comparison of the three surveyed crops, methyl bromide and chloropicrin were not considered when calculating the IPM continuum scores.

A small number of a.i.'s significantly increased the mammalian toxicity units per acre. These included mancozeb, ethoprop, aldicarb and metiram in potatoes, mancozeb and maneb in tomatoes, and maneb, methomyl, chlorpyrifos and dicofol in peppers. These eight a.i.'s contribute over 80% of the mammalian toxicity units in the crops included in this survey (Table 3).

While these results are important regarding the pesticide use in south Florida vegetable crops, it is critical to understand that the only factor considered was mammalian toxicity, which is most relevant to

farm worker and pesticide applicator safety. Should other weighting factors be applied, such as ecological toxicities and biointensive IPM impacts the profiles of risk factors could be completely different. Synthetic pyrethroids, for example, have significant environmental impacts. These and other a.i.'s with high non-target organism toxicity, but relatively low or moderate mammalian toxicity values, would have had increased importance in a profile emphasizing ecological impacts.

IPM Continuum Score Determination: Separate scores were determined for spring, fall, and whole season crops in tomatoes and peppers. These scores were further broken down into disease management, insect management, and total IPM scores. To aid in interpreting the results, all scores were scaled by a factor of 100.

The results of the IPM continuum determination (Table 4) for potato growers show a low value of 3.2 for Farm H and a high score of 5.2 for Farm A. The intensive insect management program at Farm H resulted in this farm having both the lowest overall and the lowest insect management scores.

Significant in the tomato and pepper crops was that most growers scored considerably higher in insect management than in disease or overall pest management. This should be expected, as the major mammalian toxicity contributors were the EBDC fungicides, mancozeb and maneb. This difference was less striking in peppers than in tomatoes. Pepper growers who used the "soft" program of *B.t.* and sulfur scored better than those who relied on the "conventional" pesticides, methomyl, chlorpyrifos and dicofol for control of the fall pepper pest complex.

The near elimination of copper-based fungicides from the spray program at Farm E provided this grower with the highest disease management score of the tomato growers. This farm also had an extremely high insect management score, as well as the highest total continuum score. Scores for all growers were negatively affected where high amounts of EBDC's, methomyl and/or chlorpyrifos were used.

In order to put our analysis of IPM adoption into perspective, our continuum scores are presented along with the results of two IPM surveys (Bauske, et al, 1998; Vandeman, et al, 1994). All survey respondents' IPM programs show a moderate or high level of IPM implementation according to the selected criteria. The method of measuring IPM adoption used in the current approach provided a significantly more detailed analysis, especially with regard to mammalian toxicity.

The primary objective of this study was to apply a measurement method (Benbrook, et al, 1996) to pest management programs used by south Florida vegetable growers. This method involved quantifying non-pesticidal management practices and a weighted analysis of actual pesticide applications associated with these practices. This provided a powerful tool for analyzing the impact of the complete integrated pest management system on individual farms in terms of their potential human health impacts.

In addition to ranking individual growers on a continuum and linking IPM adoption to pesticide use, the analytical technique described here has important additional uses for field personnel, policy makers, those administering IPM labeling programs, and regulators.

Cost and benefit analysis of components of the IPM system will be expedited by examination of the impact a component on the overall IPM continuum score. Such analyses would best be conducted as an ongoing part of designing IPM programs for individual growers.

Analyzing the effects of climatic and cultural developments on IPM programs can be expedited by this technique's detailed analysis of pesticide applications. By their very nature, these analyses would involve multi-year data collections.

Evaluating the impact of other inputs to the IPM system, such as scouting techniques, new pesticides, and interactions with the biotic components of an IPM system will all depend on analysis of multi-year data.

Providing positive reinforcement for growers who are making efforts to produce high-quality crops using more environmentally benign pest management systems is a major potential benefit of the survey technique described here. Through the interactive process of reviewing practices in the questionnaire portion and providing supportive analysis of pesticide programs, growers can get clear indications of aspects of their programs that are achieving the combined results of sound IPM and economic profitability.

A benefit for persons off the farm is the identification of alternative pest management tools that growers need or are willing to use. Growers expressed concerns about reliable supplies of innovative products and lack of a proven track record against tough pests, while recognizing the needs for such alternative tools primarily as a means of managing pesticide resistance development.

To conclude, the IPM evaluation method used in this survey is suitable for use in Florida's vegetable production systems. The greatest benefit of the resulting program scores will come about as historical trends are illuminated through multi-year surveys, and as changes are documented in the IPM systems typically found along the IPM continuum, thus forming a sound basis for projecting the pesticide risk reduction benefits of developing and adopting biologically based IPM systems.

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Table 1. Sample questions from the IPM preventive practices survey with their assigned weights.

How often or intensively would you use the following general integrated pest management practices in a representative field?	Weight
Employ an independent crop consultant for crop scouting and pest management	8
Take pest management issues into consideration when deciding where to plant a field	4
Scout fields for pests using farm personnel or in person: at least weekly	4
Treat your soil before planting for inoculum reduction, nematode control, weed control	4
Add mycorrhizal organisms to transplant or field soil to mitigate soil-borne diseases	3
Take disease management into consideration when making your fertilizer and/or liming decisions	4
Manage water table levels as a way of controlling root and stem rots	4
Scout for diseases during crop growth	4
Use disease or insect resistant varieties	4
Maintain unsprayed refuges for beneficial insects	4
Plant non-crop areas with cover crops to support beneficial insects	4
Scout the crop regularly for pest insects	4
Scout the crop regularly for the presence of beneficial insects	4
Choose biologically friendly pesticides over conventional pesticides if possible	4
Apply insecticides only when thresholds have been exceeded	4
Rotate among classes of insecticides on a planned basis to avoid resistance development	4

Table 2. Total IPM Questionnaire Scores

Farm	Crop	Total Possible Points	Score	% of Total
Farm A	Potato	180	93.75	52.08
Farm F	Potato		95.00	52.78
Farm H	Potato		105.25	58.47
Farm K	Potato		117.25	65.14
Farm D	Tomato	160	110	68.75
Farm E	Tomato		90.75	56.72
Farm I	Tomato		95.00	59.38
Farm N	Tomato		97.75	61.09
Farm O	Tomato		89.25	55.78
Farm Q	Tomato		92.75	57.97
Farm B	Pepper	157	101.50	64.65
Farm C	Pepper		102.00	64.97
Farm G	Pepper		79.75	50.80
Farm J	Pepper		101.00	64.33
Farm L	Pepper		102.25	65.13
Farm M	Pepper		89.25	56.85
Farm P	Pepper		94.25	60.03

Table 3. Pesticide active ingredients with the greatest contributions to mammalian toxicity profiles for surveyed crops.

Crop								
Pepper			Tomato			Potato		
Active Ingredient	Average Mammalian Toxicity Units per Acre	% Total Mammalian Toxicity Units	Active Ingredient	Average Mammalian Toxicity Units per Acre	% Total Mammalian Toxicity Units	Active Ingredient	Average Mammalian Toxicity Units per Acre	% Total Mammalian Toxicity Units
Maneb	903.294	71.0	Mancozeb	1088.510	72.4	Ethoprop	1850.385	34.9
Chlorpyrifos	137.376	10.8	Maneb	178.406	11.9	Mancozeb	1286.792	24.3
Methomyl	85.024	6.7	Chlorothalonal	115.219	7.7	Metiram	1145.477	21.6
Dicofol	61.420	4.8	Methomyl	26.181	1.7	Aldicarb	611.290	11.5
Paraquat Dichloride	20.058	1.6	Chlorpyrifos	22.073	1.5	Phorate	140.625	2.7
Oxamyl	17.298	1.4	Paraquat Dichloride	16.868	1.1	Triphenyltin Hydroxide	87.906	1.7

Table 4. Placement of Respondents in IPM Implementation Categories According to Different Criteria

Farm	Crop	Grower Responses	IPM Implementation Level	IPM Adoption Level Criteria											
				Disease Management				Insect Management				Overall Pest Management			
				Bauske, et al, 1997 <i>z,y</i>	Vandeman, et al, 1994 <i>z,x</i>	IPM Continuum Score	Proposed Ranking	Bauske, et al, 1997 <i>z,y</i>	Vandeman, et al, 1994 <i>z,x</i>	IPM Continuum Score	Proposed Ranking	Bauske, et al, 1997 <i>z,y</i>	Vandeman, et al, 1994 <i>z,x</i>	IPM Continuum Score	Proposed Ranking
A	Potato	YES	H	M	H	5.8	H	M	M	4.1	M	M	H	3.8	H
F	Potato	YES	H	M	H	1.9	L	L	L	1.9	L	M	H	1.4	L
H	Potato	YES	H	M	H	2.7	M	M	H	1.0	L	M	H	1.2	L
K	Potato	YES	H	M	H	5.2	H	M	M	8.1	H	M	H	4.7	H
D	Tomato	YES	M	M	H	4.6	M	M	M	48.1	L	M	H	5.5	M
E	Tomato	YES	H	M	M	8.2	H	M	M	553.1	H	M	H	11.3	H
I	Tomato	YES	H	M	H	5.8	M	M	M	86.6	L	M	H	7.4	M
N	Tomato	YES	H	M	H	7.7	H	M	M	153.6	M	M	H	9.7	H
O	Tomato	NO	N	M	H	3.2	L	L	M	56.3	L	M	H	3.8	L
Q	Tomato	YES	M	M	H	4.9	M	M	M	36.6	L	M	H	5.9	L
B	Pepper	YES	M	M	M	8.9	L	M	M	78.7	H	M	H	10.9	M
C	Pepper	YES	H	M	H	31.6	H	M	M	25.5	M	M	H	19.7	H

G	Pepper	YES	H	M	H	<b>27.3</b>	<i>H</i>	L	L	<b>17.1</b>	L	M	H	<b>15.4</b>	H
J	Pepper	YES	H	M	H	<b>9.4</b>	<i>M</i>	M	M	<b>22.5</b>	M	M	H	<b>9.6</b>	M
L	Pepper	YES	H	M	H	<b>7.0</b>	<i>L</i>	M	M	<b>29.0</b>	M	M	H	<b>7.7</b>	M
M	Pepper	NO	N	M	H	<b>6.2</b>	<i>L</i>	L	M	<b>41.3</b>	M	M	H	<b>7.0</b>	M
P	Pepper	YES	H	M	H	<b>5.2</b>	<i>L</i>	M	M	<b>6.4</b>	L	M	H	<b>4.2</b>	L

<sup>z</sup>N= None, L= Low, M= Medium, H= High

<sup>y</sup>Bauske, et al. 1997, Low (Score <50%), Medium (Score 50-74%), High (Score>75%)

<sup>x</sup>Vandeman, et al. 1994, Low (Scouting + Use of Thresholds), Medium (S + T plus 1 or 2 additional practices), High (S + T plus 3 or more additional practices)

