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Issue

Assessing Compatibility of a Pesticide in an IPM Program

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Abstract

Judicious use of pesticides is generally accepted as an important pest-control tactic in integrated pest management programs, but not all pesticides are equally appropriate. When this project began, there was not an appropriate tool or set of criteria available to evaluate how well a proposed pesticide use fit within an IPM program. The Western Integrated Pest Management Center and Western Inter-Regional Project #4 (IR-4) collaborated to develop the IPM Compatibility Guidance Document—a set of criteria and instructions for evaluating the potential IPM fit of a proposed pesticide use. The IPM Criteria Guidance Document includes a set of instructions and examples to help IR-4 project requestors develop a ranking and a short narrative description (termed an IPM Fit Statement by the IR-4 Project) of a proposed pesticide use within an IPM program. The IPM Criteria Guidance Document lists 21 specific factors in eight categories—efficacy, economic benefit, nontarget effects, resistance concerns, environmental fate, worker risk, compatibility with monitoring, and utility as a preventative—with descriptors of affirmative, intermediate, and negative compatibility attributes. A survey of project requestors and their IPM Fit Statement submissions indicates that the IPM Criteria Guidance Document is helpful and its use increased the breadth of IPM factors addressed in IR-4 project requests. The IPM Criteria Guidance Document, as a model for formalizing pesticide 'fit' assessment, may have broader application in evaluating pest-management tools for their compatibility in IPM programs.

Key words: IPM, pesticide, criteria, evaluation

The original vision for integrated pest management has at its foundation the integrated control concept developed by Stern, where grower's economic interests were best served through the rational deployment of chemical controls that were better integrated with biological controls and other tactics. Pest managers of the time were constrained by a chemical control arsenal for insects that was characterized as being broadly toxic. The solution at the time was to moderate frequency and rates of insecticides used (Stern et al. 1959). Since then, major advances have been made in insect chemical controls that now include narrow spectrum and highly selective insecticides and plant-incorporated protectants. Such advances enable the very integration of chemical and biological controls to maximize ecosystem services, with dramatic examples of system recovery and stabilization saving millions of dollars to growers and reducing the usage of broadly toxic insecticides (e.g., US GAO 2001; Naranjo and Ellsworth 2009; Epstein and Zhang 2014; Naranjo et al. 2015; Sharma and Peshin 2016). While integrated pest management generally accepts that the judicious use of pesticides is an important tool for pest suppression, it also recognizes that not all pesticides are equally appropriate in IPM systems. A variety of tools have been developed to quantify pesticide risk (Kovach et al. 1992, Levitan et al. 1995, Jepson et al. 2014) and scoring tools have been developed to quantify the amount and diversity of tactics in an integrated pest management program (e.g., Fair Trade USA's Agricultural Production Standard, Red Tomato's Eco Apple certification, Salmon Safe, Green Shield Certification; Food Alliance IPM Standard). However, there was not an adequate tool or set of criteria available to evaluate how well a proposed pesticide use might fit within an IPM program.

The Western Integrated Pest Management Center and the Western Unit of the Interregional Research Project #4 (IR-4) are regional programs within organizations of national scope. All four of the Regional Integrated Pest Management Centers, as well as the four regional and one national coordinating programs within IR-4, are funded by the U.S. Department of Agriculture-National Institute of Food and Agriculture (USDA-NIFA). Both programs address pest-management. The IR-4 project focuses on registration of pesticides for minor uses—uses on minor crops (those under 300,000 acres), specialty crops, and minor uses on larger-acreage crops. The Regional IPM Centers promote adoption of IPM to reduce the risks of pests and pest-management practices. USDA-NIFA directed the Regional IPM Centers and the IR-4 programs to work collaboratively to address pest-management issues.

In addition, both programs routinely interact with the U.S. Environmental Protection Agency (EPA) on pesticide-related issues. The IR-4 program develops data on pesticide residues, crop safety and efficacy for pesticide registrations. In the EPA's pesticide registration review process, the Regional IPM Centers provide information on pesticide use and usage patterns, products' importance in IPM programs, and other benefits or concerns relevant to the review. As specialty crops are leading agricultural products in several western states, the Western IPM Center devotes significant effort and resources to IPM on specialty crops. This overlaps with the Western Region IR-4 program's focus on specialty crops and created an opportunity to support both organizations' missions by evaluating proposed specialty-crop pesticide uses and their compatibility within IPM systems.

The Western IPM Center and Western Region IR-4 collaborated to develop the IPM Criteria Guidance Document—a set of instructions for evaluating the IPM fit of a proposed pesticide use. We wanted a set of criteria that was both easy to use and yet complete enough to capture the essential elements of complex integrated pest management decisions. Although the IPM Criteria Guidance Document was developed to address a specific need in the IR-4 project prioritization process, we designed the criteria to have broad application in evaluating pesticides for their compatibility in IPM programs.

Background

Pesticide manufacturers have little economic incentive to invest in the efficacy, crop-safety, and residue studies necessary to register pesticides for new uses in specialty crops due to the limited market and low economic returns they can expect in small-acreage crops. The IR-4 program was established by USDA to conduct these studies and submit requests for minor-use registrations to the EPA. The IR-4 program solicits project requests from a variety of stakeholders, including growers, researchers and commodity groups, and identifies priority projects to pursue at an annual Food Use Workshop. Completed IR-4 studies are submitted to EPA to support product registrations for these new uses.

Registration requests are typically subject to fees paid by the registrant to EPA (US EPA 2016). However, the Pesticide Registration Improvement Act allows exemption from fees if the request is solely associated with a pesticide-tolerance petition from IR-4 and it is in the public interest (Caulkins 2013). One criterion for documenting that a particular pesticide registration is in the public interest is the significance of its use in an IPM program. However, before 2013, IR-4 did not have a process for assessing IPM compatibility. The collaboration between the Western IPM Center and the Western Region IR-4 led to the development of the IPM Criteria Guidance Document to address this gap.

Development and Adoption of the IPM Criteria Document to Assess IPM Compatibility

The IPM Criteria Guidance Document formalizes consideration of IPM compatibility as a factor in IR-4's selection of priority projects. The Document was made available to applicants on the Western Region IR-4 website in July 2015 to support IR-4 project requestors' ranking and description of how IPM can be considered as a factor in the project-review process (Western Region IR-4 2015). While applicants were not required to review the Document, they were required to rank and then describe the IPM compatibility of the proposed product use in a one- to four-sentence IPM Fit Statement as part of the project submission process.

The IPM Criteria Guidance Document includes instructions and examples to help IR-4 project requestors develop the IPM ranking and IPM Fit Statement. These instructions include examples of IPM compatibility statements, an IPM criteria matrix, a blank matrix worksheet, and simple and complex examples of potential pesticide uses analyzed using the matrix worksheet. The IPM criteria matrix describes the ways that proposed pesticide uses could possibly fit into an IPM program. It encompasses 21 specific factors in eight categories: efficacy, economics, nontarget effects, resistance concerns, environmental fate, worker risk, compatibility with monitoring and utility as a preventative. Each factor can be assessed with descriptors of affirmative, intermediate and negative compatibility attributes (Fig. 1). Together, the factors described in the IPM Criteria Guidance Document integrate the principles of IPM as a systematic method of addressing pest management problems with the pragmatic requirements of economically viable farming (Rosenberger 2003, Flint 2012, Zhan and Zhang 2014, Barzman et al. 2015).

To enhance understanding of the IPM Criteria Guidance Document, we developed a 'simple' and a 'complex' example and include them as part of the Document. The simple example (a hypothetical fungicide for use as a curative of a foliar fungal disease in a vegetable crop; wrir4.ucdavis.edu/pst/IPM/SimpleExample.pdf) illustrates the flexibility and utility of the matrix system by showing 1) how both affirmative and negative aspects of a single criterion can be operational, and 2) that even when all of the information is not gathered or available, an IPM fit assessment is still possible. It might be unusual for there to be complete information to assess all 21 factors in the matrix, and in this example, the applicant did not search for all nontarget-organism toxicities or environmental-fate data. Usage can be supported and contraindicated by the same criterion for example, when the fungicide is considered a new mode of action in the specific vegetable crop, but is already used broadly for similar diseases in neighboring crops.

The complex example is a real contrast of two insecticides for use in an oilseed crop that also plays an important role in an area-wide IPM program involving other crops (wrir4.ucdavis.edu/pst/IPM/ComplexExample.pdf). The example is complex because the crop-pest dynamics are complex. Safflower is grown in Central California in rotation with cotton and processing tomatoes. It is a low-value crop, but a critical rotational crop for the area since it mitigates compaction (biotillage effects), has a short enough season to allow field operations before the next crop, is drought tolerant, enhances soil condition and structure, contributes to salinity management, and reduces soilborne pathogen load for subsequent cotton or tomato crops.

Safflower also plays a key role in the regional seasonal dynamics of *Lygus hesperus* (Knight; Hemiptera: Miridae) (Carriere et al. 2012), a pest insect whose populations develop in safflower and then move into cotton and tomato. While safflower itself is generally insensitive to Lygus damage and grower incentive to use chemical controls is minimal, treating Lygus in safflower on a coordinated, area-wide basis keeps the insects from migrating to sensitive crops like cotton and tomato. Effective, well-timed insecticide sprays limit the role safflower plays as a reservoir of damaging Lygus, and, in effect, change safflower from a source crop to a trap crop that

Attribute	Affirmative Criteria	Intermediate Criteria	Negative Criteria
Efficacy			
Efficacy	Data from field trials under similar environmental/climatic conditions demonstrate good efficacy against target pest	Data demonstrating efficacy against target pest is from a different set of environmental/climatic conditions.	Data from field trials under similar environmental/climatic conditions demonstrate marginal or inconsistent efficacy
Efficacy level under different pest pressure	Product effective under high pest pressure	Product effective under moderate pest pressure	Product only effective under low pest pressure
Economics			
Price	Treatment costs lower than other registered products with equivalent efficacy	Treatment costs similar to other registered products with equivalent efficacy	Treatment costs higher than other registered products with equivalent efficacy
Value in overall management	Total number of applications needed to achieve economic control decreased	Total number of applications needed to achieve economic control remains constant	Total number of applications needed to achieve economic control increased
Non-target Effects			
Selectivity - Toxicity to pollinators (honey bees and native pollinators)	Non-toxic to pollinators	Relatively non-toxic to pollinators only if applied during periods when pollinators are not active	Toxic to pollinators
Selectivity - Toxicity to beneficial arthropods	Non-toxic to beneficial arthropods	Non-toxic to some beneficial arthropods; toxic to others.	Toxic to many beneficial arthropods; likely to result in secondary pest
Selectivity - Toxicity to other beneficial organisms (for example, earthworms, mycorrhizal fungi)	Non-toxic to other beneficial organisms / low ipmPRiME* earthworm risk score	Non-toxic to some other beneficial organisms; toxic to others / medium ipmPRiME* earthworm risk score	Toxic to many other beneficial organisms / high ipmPRiME* earthworm risk score
Selectivity - toxicity to non-target organisms (algae, Daphnia etc)	Non-toxic to non-target organisms / low ipmPRiME* algae and Daphnia risk scores	Non-toxic to some non-target organisms; toxic to others / medium ipmPRiME* algae and Daphnia risk scores	Toxic to many non-target organisms / high ipmPRiME* algae and Daphnia risk scores
Post-application movement as vapor or within plant	Pesticide does not move in plant or movement within plant does not increase risk to pollinators, beneficial arthropods, other beneficial organisms, or non-target organisms	Pesticide movement within plant may increase risk to some pollinators, beneficial arthropods, other beneficial organisms, or non-target organisms	Pesticide movement within plant increases risk to pollinators, beneficial arthropods, other beneficial organisms, or non-target organisms
Compatible with cultural pest management practices (for example, resistant varieties, crop rotation, sanitation, vegetation management)	Use of pesticide is additive or synergistic with cultural pest management practices	Use of pesticide does not decrease effectiveness or impede implementation of cultural pest management practices	Use of pesticide is not compatible with or decreases the effectiveness of cultural pest management practices
Resistance concerns			
Mode of Action	pesticide has unique MOA for crop/pest combination	one or two other pesticides with the same MOA are available for crop/pest combination	several pesticides with same MOA are available for crop/pest combination
Resistance potential	When used according to label instructions, there is low risk of pests developing resistance to the pesticide	When used according to label instructions, there is moderate risk of pests developing resistance to the pesticide	When used according to label instructions, there is significant risk of pests developing resistance to the pesticide
Resistance management	Useful in controlling pests which commonly develop resistance to other pesticides	Potentially useful in controlling pests which occassionally develop resistance to other pesticides	Not likely to be useful in resistance management because of existing resistance to the a.i., cross resistance with a.i.s with same mode of action, or pest has
Number of crops, uses, applications enabled through this use pattern	Pest monophagous (one host) or not mobile	Pest either polyphagous (wide host range) or high mobility	Pest polyphagous (or wide host range) and high mobility
Environmental Fate			
Off-site movement - Drift potential	Pesticide formulation or application method has little or no potential for drift (for example, granular formulations or chemigation through drip irrigation lines)	Pesticide application method has some potential for drift (for example boom sprayer applications)	Pesticide application method has potential for drift (for example aerial or airblast sprayer applications)
Off-site movement - Run-off potential	Pesticide or pesticide application method result in little or no potential for run-off to surface water	Pesticide or pesticide application method result in some potential for run-off to surface water	Pesticide or pesticide application method result in potential for run-off to surface water
Off-site movement - Leaching potential	Pesticide or pesticide application method result in little or no potential for leaching to water groundwater	Pesticide or pesticide application method result in some potential for leaching to water groundwater	Pesticide or pesticide application method result in potential for leaching to water groundwater
Persistence of parent and breakdown products	Relatively short-half life	Moderate half-life	Long half-life which increases risk of off-site movement or non-target exposure
Other IPM factors			
Worker risk	Signal word CAUTION / low ipmPRiME* inhalation risk	Signal word WARNING / medium ipmPRiME* inhalation risk	Signal word DANGER / high ipmPRiME* inhalation risk
Compatibility with pest monitoring or forecasting	Tight connection between pest population (or forecast) and economic damage threshhold	Lack good data on connection between pest population (or forecast) and economic damage threshold	Applications must be made preventatively (and see below)
Preventative applications	Reduce need for additional pest management inputs later		Increase pest management or production inputs

Fig. 1. The following criteria are a guide for evaluating a pesticide's usefulness in an IPM program. Efficacy is the primary criterion since the worst pesticide application is one that does not work. The other criteria do not necessarily apply to all pest situations. The specific criteria used and the relative weight of each criterion in the decision making process are dependent on the specific pest/crop combination. Pesticide usefulness in an IPM program should be evaluated in the context of label language to mitigate risk and relative to the risk of the practice or product currently in use. *ipmPRiME.org (ipm Pesticide Risk Mitigation Engine; Jepson et al. 2014) or similar risk assessment tool.

serves as an effective regional sink for Lygus (Carriere et al. 2012, Ellsworth 2013).

However, no effective Lygus insecticides were available for safflower. The evaluation of novaluron and sulfoxaflor presented as the complex example addressed the areawide dynamics of Lygus, not the protection of safflower per se. This IPM analysis was conducted with criteria assessments from two different experts. The results demonstrated that the perspectives from different knowledgeable experts will likely result in somewhat different perspective of IPM fit for some criteria. There is seldom a single 'right' answer in such a complex scenario. As a cropping-system problem instead of a crop-centric problem, it made for an uncommon IR-4 project request. But the analysis and comparison of the two insecticides also illustrated the utility of the IPM fit criteria in evaluating multi-crop, area-wide IPM issues. Furthermore, it shows that broken down to its component parts, the IPM Criteria Guidance Document can help users identify both weaknesses and strengths of a candidate pesticide considered for a new minor use.

Use of the IPM Criteria Guidance Document

Awareness and use of the IPM Compatibility Guidance Document, and of the value of assessing IPM fit as part of the IR-4 project review process generally, were evaluated using an online survey sent to all 2015 Western IR-4 project requestors in October 2015. The response rate for the survey was 53% (16/30). However, because the IPM Criteria Guidance Document was posted to the website mid-year, project applicants who submitted projects earlier in the year did not have access to the Document.

The majority of respondents affirmed the importance of inclusion of IPM fit as an element of IR-4 project review. Specifically, 75% of respondents agreed (37.5%) or strongly agreed (37.5%) that the IR-4 program should consider how a proposed pesticide use may fit into an IPM strategy, while 25% were neutral and no respondents disagreed. Furthermore, 50% of respondents agreed (37.5%) or strongly agreed (12.5%) that addition of IPM compatibility to the IR-4 project request process was beneficial to them in developing their own project requests, while 12.5% disagreed with this statement and 37.5% were neutral.

Seven out of 16 respondents (43.75%) were aware of the IPM Criteria Guidance Document at the time they put in their project requests. Six people (37.5% of total, 85.7% of those who were aware) said that they used the Document. Regardless of whether they used the IPM Criteria Guidance Document, we asked all respondents to what degree they found it helpful to think about various IPM-fit criteria as they prepare a project request. The majority of respondents indicated that thinking about IPM fit for a project request was helpful (68.75%) or very helpful (25%).

Open-ended comments were provided by eight of 16 respondents and were largely very positive. A common theme expressed by more than half of respondents was the idea that they were already thinking in terms of IPM when developing project requests before these tools were available, e.g., 'Good addition, but I was essentially doing this already'. Comments from two out of eight respondents indicated that IPM should not be the first consideration in getting needed tools to the market. 'Sometimes IPM is not the most important factor in the equation'. In some systems, products that are efficacious, safe and have registrant support need to move forward first through the IR-4 process, with IPM fit being considered 'towards the end'. Efficacy, economics, and safety are important elements in any IPM program, so we interpret the considerations mentioned by these respondents as compatible with IPM. As proponents of IPM, we hope that IPM is part of the entire thought process (as it was for most respondents) and not a separate or secondary factor when considering pesticides for pest control. While respondents' perspectives vary, the overall response regarding both the usefulness of the IPM Criteria Guidance Document and the inclusion of IPM fit as part of the project review process was very positive.

We quantitatively and qualitatively analyzed the 2014 and 2015 IPM Fit Statements submitted with IR-4 project requests. While the inclusion of an IPM Fit Statements was optional in 2014 and required in 2015, they are compared here in order to evaluate changes associated with availability of the IPM Criteria Guidance Document and shifting from an optional to required element of the project requests. For the quantitative analysis, rubric scores and word counts were used to quantify the IPM Fit Statements submitted with project requests before the release of the IPM Criteria Guidance Document (2014) and after their release (2015). Scores were assigned for each of the eight criteria outlined in the IPM Criteria Guidance Document: efficacy, economic benefit, nontarget effects, resistance concerns, environmental fate, worker risk, compatibility with monitoring, and utility as a preventative treatment. Scores (0–3) were assigned according to the description of the product fit to an IPM criteria. A score of three indicates a clear statement of product fit, two indicates a more general statement of fit, one indicates that fit could be inferred, and zero indicates the criteria was not addressed. The maximum cumulative score for a fit statement was 24 (3×8). Scoring and word-count data were analyzed between the 2 yr using a Wilcoxon signed-rank test (Crawley 2007). One hundred seventy-two (172) fit-statements were included in the analysis.

The median score and word-count increased significantly ($P < 0.001$) between 2014 and 2015. Median score increased from 0 to 3 and median word count increased from 0 to 17. The score and word-count changes reflected an increase in the number of IPM Fit Statements addressing resistance concerns, nontarget effects and efficacy. This change could be explained by the fact that there was a change in the requirement to supply a statement. There was an increase in how well certain IPM issues were addressed between 2014 and 2015. Comments that addressed resistance increased from 15% in 2014 to 43% in 2015. In 2014, 14% addressed nontarget effects and 15% addressed efficacy while in 2015, 36% addressed nontarget effects and 29% addressed efficacy.

IPM fit statements were also qualitatively analyzed using NVivo (QSR International, Melbourne, Australia). Each statement was coded for the type of statement (e.g., resistance concerns, worker risk, nontarget effects) and type of pest controlled. Codes were summarized and compared to determine if there was a qualitative improvement between 2014 and 2015 statements. The qualitative analysis supports the quantitative findings.

One way to visualize qualitative data is by generating a 'word cloud'. Words that are more often present in the text are presented as larger text. To conduct this analysis, words that are similar (e.g., resistance and resistant) are grouped together. Common words such as 'and' and 'the' are excluded. As shown in word clouds (Figs. 2 and 3), the quality of the IPM fit statements improved from 2014 to 2015. The word 'good' is in reference to the product having a 'good IPM fit' while the word 'none' indicates that an IPM Fit Statement was not provided. Beyond that, there were substantial increases between the numbers of IPM Fit Statements that referenced beneficials, targeted use of products, resistance management, and having more products to use in rotation.

Fig. 2. Qualitative analysis representation of 2014 IPM Fit Statements. The size of the word is indicative of its prominence in the IPM Fit Statements.

Fig. 3. Qualitative analysis representation of 2015 IPM Fit Statements. The size of the word is indicative of its prominence in the IPM Fit Statements.

Current and Future Uses

IPM depends on careful consideration of the multi-dimensional role that each tactic, including pesticides, may play as part of the strategy. Stern and colleagues (1959) recognized the importance of fitting the tactic to, rather than imposing it on, the system. Through strategic changes in product selection (a relatively selective organophosphate for an organochlorine), rates (lower rates of organophosphates that permitted some survival of key beneficial arthropods), and timing (spraying only when an economic threshold was reached), Stern and his colleagues demonstrated integrated control as a revolutionary concept. More than 50 yr later, there have been relatively few attempts to codify the attributes of a tactic that make it compatible with IPM and the production system it supports. IR-4 has a mandate to deliver new registrations for pesticides in support in minor-use system. IR-4 is now using these criteria in development of new project requests (IR-4 2016) as a result of this collaboration to codify 'IPM fit' criteria for pesticides. Western Region IR-4 provides the IPM Criteria Guidance Document on its website for project requestors to assess their potential project requests for compatibility in IPM systems (Western Region IR-4 2015). The IR-4 national program requires project requestors to rate of 'compatibility of this use with IPM' on a scale from very good fit to very poor fit and provide a narrative explanation or IPM Fit Statement with the rating (IR-4 2016). At both the 2015 and 2016 IR-4 Food Use Workshops, the IPM Fit Statements were provided to the workshop participants but were not explicitly considered during the priority-setting process. However, when IR-4 submits the data packages to EPA for setting pesticide tolerances, the IPM Fit Statements will be used to support the benefits and the public interest requirement for these EPA submissions. The information that EPA is seeking to meet the public-interest criteria includes pesticides that play a significant role in integrated pest management program. That is, a pesticide that provides a new method of control, more effectively targets critical pest life stages, avoids use of prophylactic treatments, is safer to beneficial organisms, allows for different timing intervals or novel placements for pest exposure. Much of this information is outlined in the IPM Criteria Guidance Document.

Portions of the IPM Criteria Guidance Document have also been used by the Reduced Risk Sub-Committee of CropLife America (Dan Kunkel, personal communication), which is being used by members when making reduced-risk requests of EPA. This adapted use by CropLife America illustrates the potential use of the criteria beyond those originally envisioned.

The IPM Criteria Guidance Document, although developed by the Western IPM Center and Western Region IR-4 program for use in the IR-4 prioritization process, can apply to tactics evaluation in general and have value in wider settings. Potentially, the Document will be of value to state IPM extension and research personnel in developing pest-management recommendations for their clientele.

Pesticides figure prominently in the social dialogue about feeding the world while protecting its natural assets. Tremendous interest abounds in food production systems and their impact on natural resources. Regulatory authorities around the world are placing new emphases on pollinator protections that place pressure on new pesticide registrations. At the same time, more than 50 yr after Stern's integrated control concept designed to stem overuse and dependence on the organochlorines, especially DDT, we have access to increasingly more complex and sophisticated pesticides and other pest-control tools. Yet, systems for assessing the fit of each potential pest-control tactic as part of an IPM strategy have lagged behind. The IPM Criteria Guidance Document produced here enables IR-4 project participants to better develop priority registrations that have greater compatibility with IPM in production systems they are mandated to serve. For others, this Document provides a much-needed heuristic that better illustrates and teaches about the multiple dimensions over which a pesticide may impact the stability of an IPM system. In other words, it shows how use of a pesticide as an IPM tactic may impact the overall IPM system for a crop. With the onset of a new set of genetic techniques for pest control (e.g., RNAi, CRISPR-CAS9 systems, gene drive, transgenesis), we also need to broaden understanding of systems-level approaches and how new technology and specific IPM tactics are best incorporated into an IPM strategy.

While the IPM Criteria Guidance Document provides a relatively manageable process for use in evaluating and comparing pesticides it is incomplete in certain respects. It does not, e.g., enable consideration of circumstances where readily adoptable preventative tactics might substitute for the need to apply a pesticide at all. Rather it assumes that a pesticide is a necessary part of a specific IPM program. It also does not factor in those circumstances where judicious use of a highly toxic and broad-spectrum pesticide may offer a rapid response option that limits pest outbreak potential, and thus contribute to IPM on an area-wide basis. There are trade-offs between toxicity, persistence, scale of use and impacts, both positive and negative, that make the role of pesticides in IPM a complex challenge, and the IPM Criteria Guidance Document represents a first step towards recognizing the need to capture pesticide compatibility in a more formal and transparent way that can be built upon in the future (Sherratt and Jepson 1993, Halley et al. 1996, Jepson and Sherrat 1996, Jepson 2009).

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