

## *A Methodology for Adjusting Pesticide Use Data For the Toxicity of Active Ingredients*

### **A. Introduction**

The most sustainable way to reduce reliance on pesticides, and hence narrow the range and limit the severity of adverse impacts from pesticide use, is to promote progress along the Integrated Pest Management (IPM) continuum toward biointensive IPM<sup>1</sup>. For this reason, interest is growing throughout the agricultural community in refining IPM tools and systems, and both state and federal pesticide regulatory agencies have initiated or are participating in programs designed to promote adoption of IPM as a positive approach to attain risk-reduction goals. Many environmental groups, including the World Wildlife Fund, are also exploring ways to promote and reward IPM adoption through marketplace initiatives (Hoppin, 1996).

Progress along the IPM continuum is typically achieved incrementally over several years and requires a dynamic approach to pest management over time and space. Three sorts of changes in IPM practices and farming systems must be wisely integrated to assure that pest damage is minimized both profitability and reliably.

An important first step, especially in chemical-intensive systems, is to lessen the negative impacts of pesticides on plant health and root development, and on beneficial organisms. Toward this end, broad spectrum, highly toxic and/or persistent materials need to be used more sparingly, especially those that can trigger secondary pest outbreaks or impair the diversity or functions of soil microbial communities.

Second, in the design of IPM systems and integration of practices and tactics, the focus of pest managers must shift incrementally toward prevention and away from treatments, especially those involving application of broad-spectrum pesticides. The crux of biointensive IPM is information-driven integration of multiple biologically based farming and pest management tactics. Biointensive IPM strives for and depends on redundancy in control processes and options, since different combinations of cropping patterns, weather and soil conditions favor different pests and beneficials in a given season.

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<sup>1</sup> Biointensive IPM in agriculture is defined as – “a systems approach to pest management that is based on an understanding of pest ecology. It relies on resistant varieties and promoting plant health, crop rotation, disrupting pest reproduction, and the management of biological processes to diversify and build populations of beneficial organisms. Reduced risk pesticides, including biopesticides, are used only as a last resort and only in ways to minimize risks.” (From *Pest Management at the Crossroads*, pages 178-179, Benbrook, C., Groth, E., Hansen, M., Halloran, J., and S. Marquart, Consumers Union, 1996. See also the PMAC website, <http://www.pmac.net>, and the WWF-WPVGA Potato IPM Project Web-page, <http://www.pmac.net/wwfwpvga/bioipm.htm>

And third, other measures need to be incorporated into farming and IPM systems to enhance the health and vigor of plants so that they will produce near-optimal yields despite a seeding can limit weed pressure. In fruit and vegetable crops, irrigation and nitrogen management can improve root health, lower pathogen pressure, and reduce the

## 1. Factors Driving Change in Pest Management Systems

A compelling statement of the need for progress toward prevention-oriented biointensive IPM appears as a "Perspective" piece in the November 1997 *Proceedings of the National Academy of Sciences*.<sup>2</sup> The authors state --

"In this report, we argue that the central weakness in how we think about pest management as a component of agricultural systems has not been addressed. We must go beyond replacing toxic chemicals with more sophisticated, biologically based agents...

"The foundation of pest management in agricultural systems should be an understanding and shoring up of the full composite of inherent plant defenses, plant mixtures, soil, natural enemies, and other components of the system. These natural 'built in' regulators are linked in a web of feedback loops and are renewable and sustainable. The use of pesticides and other 'treat-the-symptoms' approaches are unsustainable and should be the last rather than first line of defense."

Better measures of IPM adoption, linked to pesticide use and risk reduction, are needed for many purposes. Key among them is the rapid pace of innovation in the design and practice of pest management systems as a result of the --

- Introduction of several new diagnostic tools, expert systems, and phenology-based growth and pest management models;
- Discovery of promising biopesticides and other lower-risk pesticides,
- Emergence of new techniques and tools to make biologically-based tactics like mating disruption and augmentation of soil microbial activity more profitable and reliable;
- Marketing of seeds and production inputs enhanced through genetic engineering and other applications of biotechnology<sup>3</sup>; and
- Renewed grower and farm community interest in biointensive IPM systems.

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<sup>2</sup> "A Total System Approach to Sustainable Pest Management," Lewis, W.J., van Lenteren, J.C., Phatak, S.C., and J.H. Tumlinson, *Proc. Nat. Acad. of Sci.*, Vol. 94, pp. 12243-12248, November 1997. (Accessible via the PNAS website at <http://www.pnas.org>, search for article by lead author's name).

<sup>3</sup> Two contemporary applications of biotechnology -- *Bt*-transgenic and herbicide tolerant crop varieties -- are commanding major commercial attention but may not prove compatible with biointensive IPM because of the emergence of resistance and/or heightened reliance on pesticide applications. For further information why in the case of *Bt*-transgenics, see the "Genetic Engineering" section of the PMAC website at <http://www.pmac.net/btftp.htm>; in the case of herbicide tolerance, <http://www.pmac.net/geherb.htm>.

Other factors are also bound to further challenge pest managers and reward successful innovators. The “Food Quality Protection Act of 1996” (FQPA) is likely to narrow the selection of insecticides and fungicides, especially in many minor crops. Resistance continues to worsen, especially in weeds. The phase out of methyl bromide in the year 2001 will dramatically change IPM systems in a number of high-value crops, especially strawberries and tomatoes.

## 2. Need for New Tools

The ability of many pest managers -- and most policy-makers -- to project and manage the consequences of change in pest management systems is not keeping pace with pests or the technology accessible to manage them. Two traditional measures of pesticide use -- pounds of active applied per acre, and number of applications -- are increasingly meaningless when used to estimate the agronomic, environmental and public health gains stemming from progress toward biointensive IPM.<sup>4</sup> A review of several efforts to develop new measurement tools appears in *Pest Management at the Crossroads*<sup>5</sup> (PMAC); the PMAC website contains several documents describing and critiquing various risk index and indicator methodologies (see <http://www.pmac.net/measind.htm>).<sup>6</sup>

New and improved analytical tools are needed to meet a variety of needs -- tracking change on the farm, recognizing and quantifying tradeoffs, IPM program evaluation, compliance with the “Government Performance and Results Act” (GPRA), assessing the impacts of the FQPA, crafting risk-mitigation actions, and carrying out IPM labeling projects. These applications share common challenges, among them finding ways to compare the environmental, public health and agronomic performance of pest management systems "before" and "after" changes are made in the selection and use of pesticides and/or in the mix of farming and IPM practices. The need for new tools is heightened by the need for farmers and pest managers to evaluate ever-more complex tradeoffs that are increasingly difficult to avoid and sort through. Some examples follow.

Some conventional pesticides are effective at very low doses because of their specific modes of action and persistence, but some of these products are unforgiving and prone to resistance. An untimely rain or dry spell can lead to the need for re-application. If not applied carefully with a thorough understanding of the soil-climate-cropping system factors that can affect their environmental fate, such products may cause --

- carry-over damage in a rotational crop, or drift damage to nearby crops;
- quick shifts in pest species, resistance, and/or the emergence of new pests;

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<sup>4</sup> Several reasons why are set forth in "Alternative Measures of Pesticide Use," Barnard, C., Daberkow, S., Padgett, M., Smith, M.E., and N.D. Uri, *The Science of the Total Environment*, 203 (1997): 229-244.

<sup>5</sup> See page 82, *PMAC* (Benbrook et al., 1996).

<sup>6</sup> The index for the section "Recent IPM Measurement Activities" from the PMAC website lists a number of resource materials. "An Overview of Pesticide Impact Assessment Systems (a.k.a. 'Pesticide Risk Indicators') based on Indexing or Ranking Pesticides by Environmental Impact," an April 1997 paper by Dr. Lois Levitan, Cornell University, is particularly comprehensive and detailed, and is accessible at <http://www.pmac.net/lois.htm>.

- impairment of root health and nutrient uptake, physiological problems like loss of bolls in cotton or whirling in corn, or other impacts leading to a loss of plant health and vigor and consequently, yield and/or quality.

While the general public tends to focus on risk outcomes, tradeoffs involving costs and efficacy are among the important challenges facing farmers. Such tradeoffs are rapidly growing more consequential. Pests continue to be a major cause of crop failures, and pest management costs are among the most rapidly rising costs of production in many crops. Problems managing cotton pests, despite record-high pesticide expenditures, are among the major causes of significant reductions in planted acreage in 1998.

The costs per acre-treatment with new products, including many of today's low-risk biopesticides, are typically higher than the old stand-bys. Short-term economic factors are often a constraint to progress along the IPM continuum, since it takes time, knowledge, and management attention to effectively change IPM systems. Until recently, the constraint most often identified by farmers was lack of information and proven alternatives (A. Sorensen, 1994).

Now, growers are working hard to remain current with new technology and information, especially the unique factors that may influence how new technology and practices might work in the context of their farming systems. It also takes effort to choose among a steady flow of new information-based tools and biologically based products. Integrating both into ongoing pest management systems requires management focus well in excess of relatively simple "count-and-spray" control programs, particularly during transition phases when multiple tradeoffs must be evaluated.

Some biopesticides need to be applied twice as often as conventional products to achieve comparable results, a tradeoff most growers accept up to a point where price differentials become too large to justify. But cost is not the only variable affecting choice. Some growers lack experience with the circumstances that can increase or decrease the likelihood of success with new biologically based approaches; others are driven to change by external factors. Predictability and variability in efficacy are growing worries with *all* pest management systems.

Most farmers recognize that alternative approaches pose new risks and new demands for information and expert guidance. Some of the potentially most rewarding changes are among the most expensive and riskiest, at least in the short-term. Hence, the need for new kinds of support from the research community, consultants, the private sector, and the marketplace. Finding new ways to provide such help is one of the basic goals of the WWF-WPVGA potato IPM project.

## **B. Toxicity-Adjusted Pesticide Use**

A method to measure the linkages between IPM adoption and pesticide reliance and risk reduction in the Wisconsin potato industry is being developed by the World Wildlife Fund (WWF) and the Wisconsin Potato and Vegetable Growers Association (WPVGA), in

collaboration with scientists at the University of Wisconsin. The new methodology is needed to monitor attainment of specific industry-wide pesticide use and risk reduction goals that have been agreed to by WWF and WPVGA (discussed later). It will also serve as a tool for growers, researchers, the WPVGA and others as they assess the consequences of pest management system choices.

This paper describes the WWF-WPVGA project's methodology for adjusting the pounds of pesticides applied in accord with the inherent toxicity and properties of pesticides. The methodology, and the database supporting its application, will continue to evolve over the life of the project. In addition, other research teams are developing pesticide risk indices and concepts that will be drawn upon as the system is refined.

### **1. Need for a Flexible, Transparent System**

The methodology is designed to be flexible and can be adapted for use in several different applications. Toxicity adjustment factors can be calculated in order to compare multiattribute risk impacts following changes in pesticide use patterns. Different risks can be emphasized by adjusting the weights assigned to different risk parameters.

Adjustment factors unique to a region and a given mix of environmental concerns can be estimated – for example, a region where drinking water risks associated with herbicide use is the most prominent concern. In such a case acute and chronic mammalian toxicity indices might be adjusted for pesticide leachability or environmental fate parameters. In assessing farm worker risks, the acute toxicity index can be adjusted for leaf tissue half-lives, producing a more accurate approximation of exposure and risks.

As better data is obtained on pesticide impacts on beneficial organisms, soil microbial communities, and resistance, the methodology can also be applied to project impacts of pesticide use on the viability of biointensive IPM, a major concern among farmers.

A flexible system is also needed in light of a basic ecological principle – pests have always and will continue to adapt to changes in farming and IPM systems, the central point made in the previously quoted article in the *Proceedings of the National Academy of Sciences*. In general, the more dramatic the change in a farming system, the more significant and sometimes unexpected the shifts in pest complexes and pest management system outcomes. Toxicity-adjustment methodologies need to encompass such consequences, and provide a mechanism to systematically weigh tradeoffs in human and ecological risk outcomes. Limited ability to project such tradeoffs today reflects gaps in knowledge and the historic lack of attention to the ecological and farming system impacts of pesticide use.

Multiattribute ranking systems are a tool useful in weighing systematically the different properties and impacts of a product, process, or technology, typically across several dimensions of impacts. The design and application of such systems requires a number of assumptions and value judgements in order to assign weights to different types of impacts,

and to deal with varying levels of certainty in measures of impact, and the underlying data used to estimate impacts, including risks.

The design and application of multiattribute indices in evaluating pesticide risks are treated in detail in a 1995 Masters of Science thesis by D. Landy, a student working with Dr. Bill Pease, then a professor at the University of California School of Public Health (Landy, 1995). In 1992, Dr. Joe Kovach and colleagues at Cornell University developed the “Environmental Impact Quotient,” the first multiattribute index of pesticide impacts to gain prominent attention and use in the United States (Kovach, et al., 1992). These and other risk indices are reviewed in *Pest Management at the Crossroads* (Benbrook et al., 1996) and in the extensive background paper prepared for OECD by Dr. Lois Levitan (Levitan, 1997).

## **2. Evaluating Tradeoffs to Guide Choices**

Farmers make several basic decisions annually that have enormous implications on pest pressure and IPM challenges. First, the decision whether to farm a given field, and then what to grow in a given year, and over a crop rotation cycle. Choices of tillage and planting systems will affect pest pressure, especially weed emergence and the vigor of seedlings. Selecting crop varieties is a series of choices regarding what traits to seek out – for example, drought tolerance, those conferring resistance to local pests, or those that can produce high yields if pests are otherwise controlled

Once decisions made to plant certain crops in certain fields, attention turns to other decisions, including the choice of pesticides to rely on. One product might be toxic to birds, but not small mammals or aquatic species, and work better on broadleaf weeds, in contrast to a competing product that works better on grasses. Another product might be relatively non-toxic to mammals, but very damaging to a key class of beneficial organisms, while differing in other ways in terms of effectiveness compared to other products.

As farmers progress along the IPM continuum they must manage more complex systems where the interactions *among* organisms become as important as the population dynamics of single organisms. They need access to information projecting a growing array of potential impacts and interactions between pests, pesticides, beneficials, and farming practices. Those analyzing the consequences of change in pest management systems face comparable information needs.

Toxicity adjusted methods need to encompass impacts on humans, non-target organisms, ecological integrity, and the biology of cropping and pest management systems. They need to be dynamic and pliable, and offer a structured framework within which to pose and answer questions about the impacts of changes in pest management systems. The structure should make explicit gaps in knowledge, value judgements, and assumptions, while also facilitating the integration of expert judgement and new information.

The necessary components of a multiattribute risk index will vary as a function of the types of pesticides being used, the cropping systems they are used within, soil and climatic conditions, and dominant risk and environmental concerns in the geographic region

under study. Measurement tools should support assessment of different categories of pesticide risks, singly or in combination. Adjustment factors will fit some but clearly not all situations. The more broad the application, the more challenging the task of coming up with indicators that are equally applicable to different circumstances.

There is no "right way" to construct and use multiattribute adjustment factors; there are many inappropriate ways that may produce spurious, misleading or biased results. Problems can arise from inconsistency in the way different types of pesticides are treated, how data gaps are handled, weighting and scaling factors, and when and how adjustments in data are made in response to unique circumstances or when new information becomes available on some, but not all active ingredients.

The method described herein, and most other risk indices, are too crude to distinguish reliably between two pesticides that are closely related and are found to cause comparable effects at similar dose rates. Risk indices are most reliable and useful in monitoring changes in average levels of toxicity over time, and in comparing the toxicity and risks associated with groups of pesticides. For example on a given crop, the average acute mammalian toxicity units per acre associated with the pesticides applied by growers at the "No" and "Low" levels along the IPM continuum often exceed by a 100-fold or more the average acute toxicity units of pesticides applied by growers at the biointensive end of the continuum. Such comparisons provide insights into the magnitude of environmental and public health gains possible from progress along the IPM continuum.

### **C. Four Major Component Indices**

The WWF-WPVGA project multiattribute toxicity index will include four component indices, each reflecting a broad area of potential risks: acute mammalian, chronic mammalian, ecological, and impacts on beneficial organisms and IPM systems. Here, the basic structure and components of the multiattribute index are described.

It is important to remember what these indices typically do not encompass when applied to state-level or national pesticide use patterns. Because of the lack of data and methods, the indices are based largely on pound-for-pound-applied comparisons of toxicity to a common set of organisms. They do not include many clearly important factors affecting human exposure and hence risk – formulation differences, application methods, pre-harvest intervals, and safety equipment used and required. In terms of ecological impacts, the indices also do not adequately take into account many of the factors influencing environmental fate (soil conditions, weather patterns, formulation, and geographic limitations on use), and the data underlying them clearly do not cover some of the most important ways pesticides can harm non-target species (loss of habitat, foodchain disruption, multigeneration endocrine effects).

The indices also typically do not encompass economic impacts, although future applications are likely to include tradeoffs between reductions in toxicity units and the cost and reliability of control.

## 1. Acute Mammalian Toxicity

The first component index reflects acute mammalian toxicity, and is based on oral LD-50s. Data on LD-50 values are derived predominantly from the “WHO Recommended Classification of Pesticides by Hazard and Guidelines to Classification 1996-1997” (International Programme on Chemical Safety, 1996). LD-50 values for recently registered active ingredients are derived from EPA tolerance documents appearing in the Federal Register. In a few cases, LD-50 values were derived from “Farm Chemicals Handbook ‘98” (Meister Publishing Company, 1998), company, or other sources.

The index is measured by the formula:  $\text{Inverse LD-50 Pesticide}_x = 1/(\text{LD-50}_x)$ .

The inverse of LD-50s is calculated so that rising index values correlate with rising toxicity. Of currently registered pesticides, aldicarb has the lowest LD-50 value of 0.93 mg/kg, and an inverse LD-50 value of 1.07. Several pesticides have LD-50s of 5,000 mg/kg or higher, the largest dose EPA testing guidelines require manufacturers to test. Pesticides with LD-50s of 5,000 mg/kg have inverse LD-50 values of 0.0002.

In any application of the methodology, “Inverse LD-50” values need to be scaled by multiplying all values by a constant numeric factor. In the current application, 500 is used as the scaling factor, and is multiplied by each active ingredient’s Inverse LD-50. The purpose is to make the maximum “Scaled Inverse LD-50” values for the most acutely toxic pesticides roughly comparable to the maximum scaled values in the other three component indices. If this were not the case, the choice of scaling factors, including a scaling factor of one, would be an implicit weighting factor across the four indices.

If maximum “Scaled Inverse LD-50” values are markedly higher than maximum values in other component indices, this would implicitly increase the weight assigned to acute mammalian toxicity compared to other indices. If maximum values are lower, it would reflect a decision to reduce the weight, or importance of acute toxicity relative to the other three component indices.

At the direction of the WWF-WPVGA project advisory committee, a second adjustment is made in acute and chronic mammalian toxicity index values in light of the dominance of drinking water exposure as a potential source of human health risk. “Inverse LD-50” were adjusted as a function of each active ingredient’s propensity to leach to groundwater or reach surface water. The EPA model SCI-GROW was used to produce the index, based on a pesticide’s KOC value and soil half-lives.

Using the same assumptions – one application at one pound per acre – SCI-GROW values were computed for each pesticide applied in Wisconsin. The higher the SCI-GROW value (see column one, Table 6), the greater the propensity of a pesticide to leach. In order to scale the values and truncate their range, the following formula was used: “Scaled Leaching Index” =  $3.5/(4 - \text{SCI-GROW value})$  (see column 2, Table 6).

The pesticide used in Wisconsin with the highest SCI-GROW value is oxamyl. The 3.6 value for oxamyl in the above formula results in a “Scaled Leaching Index” value of 8.83 – by far the largest. Different formulas were tried, resulting in a wider distribution of “Scaled Leaching Index” values. The above formula was chosen to constrain the adjustment within a relatively narrow range in light of uncertainty in the degree to which SCI-GROW values accurately reflect leaching potential in central Wisconsin.

In calculating the “Scaled Inverse LD-50” value for oxamyl, its “Inverse LD-50” value of 83.3 (500/6) was multiplied by the “Scaled Leaching Index” value of 8.38 to produce the final value of 698.3. Most “Scaled Inverse LD-50” values in Table 2 fall in the range 0.1 to 10. Carbofuran, an insecticides that is nearly as toxic, has a “Scaled Inverse LD 50” value of 68.6 – one-tenth of oxamyl’s. On this basis, oxamyl’s value is identified as an outlier in need of adjustment to better reflect the weight of evidence in comparing oxamyl’s acute toxicity to other toxic OPs and carbamates.

Adjusting Outlier Values The distribution of values in index determines whether there are any outliers. Any value in an index that is more than twice as large as the next highest value is reviewed to determine if the difference accurately reflects actual differences in toxicity, or whether the difference is an artifact of the data accessible to estimate a given index value.

The need to adjust an outlier requires a review of other toxicological data on comparable endpoints from a set of similar studies, or from similar studies in related species. If the difference between an outlier and the next most toxic pesticide is consistently large, the value is not adjusted. But when the data show that there are equally, or even more toxic pesticides, based on different studies or endpoints, an adjustment is needed.

It is also known that certain animal and ecotoxicology models are more sensitive than others when testing different families of chemistry. Differences arise from the presence or absence of certain detoxifying enzymes or other pharmacokinetic factors. For this and other reasons, risk assessors generally place greater confidence in values that are found nearer the mean in a distribution of values across several active ingredients and/or across several similar studies.

In all cases where an adjustment was judged necessary, the mean and standard deviation of unadjusted values within the index were calculated. An estimated maximum value was calculated by adding a multiple of the standard deviation in values to the mean of values. For example, the “Scaled Inverse LD-50” value of oxamyl was adjusted downward to 86.05, two standard deviations above the mean of “Scaled Inverse LD-50” values for pesticides appearing in Table 2. This value is about 30 percent higher than any other pesticide, but about one-eighth of the unadjusted level.

Applications of the Index Table 1 presents data on pesticides used in Wisconsin potato production in 1995 ranked by pounds applied within each major class of pesticides. Table 2 presents pesticide use ranked by “Acute Toxicity Units.” The fourth column in

Table 2 reports “Scaled Inverse LD-50” values appear, and are based on a scaling factor of 500, using the formula: “Scaled Inverse LD-50 Pesticide<sub>x</sub> = 500/(LD-50<sub>x</sub>).

A comparison of results in these two tables highlights the importance of taking toxicity into account when evaluating changes in pesticide reliance and pest management systems --

- Insecticides account for 95 percent of acute toxicity units across all herbicides, insecticides, and fungicides applied – 3.436 million units out of a total of 3,617 million;
- Four insecticides account for 89 percent of insecticide acute toxicity units;
- The average per acre toxicity units associated with herbicide use is only 0.3, and for fungicides 2.0, compared to 41 in the case of insecticides; and
- Based on current measures of acute toxicity<sup>7</sup>, fungicides as a class are far less acutely toxic than insecticides, and variability within this class is much less than for insecticides and "Other Chemicals."

This "acute mammalian" (AM) index is most useful in comparing the applicator and worker exposure consequences of potato pest management systems. Acutely toxic potato pesticides rarely appear as drinking water contaminants, now that the carbamate insecticide aldicarb is no longer used by the vast majority of Wisconsin potato producers.

Pesticide residues in potato products as consumed are also reasonably rare, with the exception of methamidophos, a high-risk organophosphate insecticide. Based on recent USDA and FDA residue testing, between 10 percent and 15 percent of potato samples contain detectable levels of methamidophos. Other possible exceptions include any systemic products that gain wider use in the future, and post-harvest materials applied to protect potatoes in storage.

Acute Risk Reduction Goal WWF-WPVGA risk reduction goals apply to high-risk pesticides that trigger an acute or chronic toxicity trigger. In the case of acute risk, any active ingredient appearing in the WHO categories Class Ia, “Extremely Hazardous” and Class Ib, “Highly Hazardous” is subject to the 25 percent reduction goal between crop years 1995 and 1997. Four pesticides used in Wisconsin potato production in 1995 meet this criterion: azinphos-methyl, carbofuran, oxamyl, and methamidophos (see the fourth column in Table 7). Another seven active ingredients fall under the chronic toxicity reduction goal, for a total of 11 pesticides out of a total of 31 applied in 1995.

The goal of the WWF-WPVGA project is to promote adoption of biointensive IPM as a proven means of reducing reliance on pesticides posing risk to humans, wildlife and IPM systems. To assure that risks are reduced comprehensively, the pounds applied of the four active ingredients subject to the 25 percent reduction target are converted to Toxicity

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<sup>7</sup> Some fungicides are known to disrupt endocrine system development and functions. Very low levels of exposure for short duration (i.e. part of a day to a few weeks) during critical periods of fetal development, and as the child grows, can lead to irreversible functional deficits in the immune, neurological, or reproductive system. Since such effects can result from acute exposures, it can be argued they properly fall under the category of acute effects.

Units by multiplying the pounds applied by the multiattribute toxicity index values (see the third column in Table 7). The resulting estimates of toxicity units are then summed across the four active ingredients. This total is divided by the acres planted – 83,000 – to estimate per acre planted toxicity units. The reduction goal is then applied to this estimate.

In 1995, there were about 25.9 million toxicity units associated with the four pesticides triggering the acute risk reduction criterion, or 312 per planted acre. To meet the reduction goal in crop season 1997, the toxicity units associated with active ingredients meeting the acute risk trigger must not exceed 234 per planted acre.

It is important to note that the reduction goals apply to any and all pesticides applied in 1997 that meet a toxicity criterion, possibly including active ingredients not applied in 1995, and hence not contributing to the baseline of toxicity units.

## 2. Chronic Mammalian Toxicity

The second component index is most relevant for assessing longer-term drinking water, occupational, and dietary risks. It encompasses chronic mammalian toxicity (CM) – the capacity of an active ingredient to cause adverse health impacts (cancer, birth defects, impaired immune system function, reproductive impacts) as a result of long-term, low-level exposures. It is based largely on a pesticide active ingredient's Reference Dose (RfD). Other factors in the algorithm include oncogenic potential and potency, and the capacity to disrupt endocrine system mediated functions.

The index is calculated using a composite variable "Mam Tox Score" that was first calculated to evaluate long-term trends in pesticide chronic toxicity as part of the analysis reported in the Consumers Union book *Pest Management at the Crossroads* (Benbrook et al., 1996). In settling on the Mam Tox Score formula, over 20 formulas were compared. Consultations with experts and sensitivity analysis were relied upon in choosing the formula that best represented an estimate of comparative chronic mammalian risks, drawing upon readily available EPA toxicological data. The Mam Tox Score variables and formula are:

RfD: EPA reference dose (or other available estimate)

ED: Endocrine disruptor -- if yes, value=3; if no information or no evidence from appropriate assays<sup>8</sup>, value=1

Q\*: EPA cancer potency factor (or "best" estimate available)

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

Mam Tox Score Pesticide<sub>x</sub> = [(0.01/RfD<sub>x</sub>) x ED<sub>x</sub>] + [Q\*<sub>x</sub> x 50 x CLASS<sub>x</sub>]

An example – the fungicide mancozeb's Mam Tox Score is calculated as --

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<sup>8</sup> In future work, data on pesticides and endocrine effects will be reviewed in order to differentiate between active ingredients that have been tested and found to produce no observable effects, in contrast to those that have just not been tested. Untested compounds will be assigned an intermediate default value.

$$[(0.1/0.003) \times 3] + [.06 \times 50 \times 10] =$$
$$100 + 30 = 130$$

Basis for Mam Tox Formula Note that the formula contains two components -- the first based on reference doses adjusted by the potential to affect endocrine functions, and the second based on oncogenicity. The endocrine disruptor adjustment is applied to the RfD component of the formula because all pesticides have a RfD, whereas only some have been shown to possess oncogenic potential. The use of a Reference Dose adjustment factor for evidence of endocrine effects is consistent with the endocrine disruptor and ten-fold safety factor provisions in the “Food Quality Protection Act.” The FQPA compels EPA to apply an additional 10-fold safety factor in setting reference doses in the absence of complete information on an active ingredient’s potential to pose perinatal risks and risks to infants and children, or inadequate data on exposure.

The reference dose component of the Mam Tox Score formula uses an adjustment factor of 3, instead of the 10-fold factor required by the FQPA, and in this sense could be viewed as conservative relative to the new mandate imposed by the FQPA. Once a pesticide’s RfD is adjusted by EPA in compliance with the FQPA, with the benefit of a thorough battery of endocrine system assays, it may be appropriate to remove the endocrine disruptor adjustment in calculating Mam Tox Score.

The second factor in the Mam Tox Score formula has a non-zero value for those pesticides shown to cause cancer and for which a Q\*, or cancer potency factor, is available. The points assigned to the EPA cancer classification are an attempt to more heavily weight those pesticides with more complete and compelling evidence of carcinogenicity. The scaling factor of 50 was chosen in response to guidance from experts. The purpose of the scaling factor is to provide the appropriate weight to the values in the reference dose component of the formula, in contrast to the cancer component, for those pesticides known to pose oncogenic risks. The higher the scaling factor, the more weight given to pesticide oncogenic potential. Without a scaling factor, the cancer portion of the Mam Tox Score formula accounted for less than 2 percent of the variability in Mam Tox Score values for the approximate 50 pesticides with Q\* values.

Scaling factors in increments of five were tested, from 10 to 100. Based on expert guidance, the scaling factor of 50 was chosen because it resulted in about 60 percent of the variance in Mam Tox Score values resulting from the reference dose component, and about 40 percent of the variance from the cancer component. In calculating Mam Tox Score values, all data were obtained from EPA and are current as of early 1998.

Table 3 presents data on the range and distribution of “Scaled Mam Tox Score” values for pesticides applied in potato production in Wisconsin in 1995. “Scaled Mam Tox Score” values were obtained by multiplying Mam Tox Score by the leaching index values for each active ingredient that appear in Table 7. The unadjusted value of the triphenyltin hydroxide Mam Tox Score – 2,400 -- was clearly an outlier. It is 2.4 times the next highest

values of any currently registered pesticide (metiram and ethropop have values equal to 1,000)

In a number of chronic toxicology studies and for several endpoints, many pesticides are more chronically toxic than triphenyltin. Accordingly, the Scaled Mam Tox Score value of triphenyltin hydroxide was set at 286.7, one-half a standard deviation above the mean value across the pesticides included in Table 3. This value is about 60 percent greater than the next highest, dimethoate's value of 176. Triphenyltin was the only pesticide with an outlier value in this index.

In Table 3, active ingredients within each major class of pesticides are ranked by share of total chronic toxicity units. Key insights include –

- Fungicides account for 82 percent of the chronic toxicity units associated with use of herbicides, insecticides, and fungicides;
- The average chronic toxicity units per acre based on all herbicide applications was 14, compared to 153 in the case of insecticides, and 721 from fungicide use;
- A single fungicide, mancozeb, accounts for 79 percent of total fungicide chronic toxicity units, and metribuzin accounts for 90 percent of herbicide chronic toxicity units; and
- The fungicide chlorothalonil accounts for 41 percent of the total pounds of fungicides applied, yet only 5.3 percent of chronic toxicity units from all fungicides applied.

### **3. Ecological Toxicity and Risks**

The third major index is designed to capture the relative ecological toxicity of pesticides. It integrates avian, aquatic and small invertebrate ecological risks. Impacts on organisms that can play a role in biointensive IPM (beneficial arthropods) or enhancing soil quality (worms and soil microorganisms) are included in the Biointensive IPM index, described next.

The ecological risk index (ECO) is composed of sub-indices covering toxicity to two fish species (Rainbow trout and Bluegill), several bird species, and daphnia, a small aquatic organism. The potential impacts captured in this index are of considerable importance in the context of the WWF-WPVGGA project, given the environmental attributes of the Central Wisconsin region and the presence of highly valued blue-ribbon trout streams and state-endangered species, including Sandhill Cranes and Karner blue butterflies.

Avian Toxicity Substantial data and field experience confirm that the organophosphate and carbamate insecticides are by far the most toxic major groups of pesticides to birds. For this reason, organophosphate and carbamate avian toxicity values were sought from Dr. Pierre Mineau, an avian toxicologist working for the Canadian Fish and Wildlife Service. With colleagues in Germany, Netherlands, and the United States, Dr. Mineau has developed a comprehensive avian toxicity model, drawing on a database with over 1,300 values for 146 pesticides and 61 species (Baril and Mineau, 1998). The model uses multiple studies to estimate safety factors, based on a given protection threshold.

Avian toxicity values provided by Mineau assume a 95 percent protection threshold – i.e. dosage levels that would result in 95 percent of the exposed birds surviving. Mineau values for nine OP and carbamate insecticides appear in column three, Table 4, and apply to birds weighting 20 grams (mid-size song birds). Carbofuran accounted for 7 percent of the total pounds of insecticides applied in 1995, and 44 percent of total insecticide avian toxicity units (data not shown). Endosulfan accounts for another 25 percent; methamidophos 16 percent and both azinphos-methyl and oxamyl, 7 percent. No other insecticide accounts for more than 1 percent of total avian insecticide toxicity units.

For non-OP and carbamate insecticides, herbicides, fungicides, and other chemicals applied in Wisconsin, a method was developed to calculate an approximation of acute avian toxicity levels comparable to the OP-carbamate values provided by Mineau. The method relied on Bobwhite and Mallard duck avian toxicity data provided by EPA in the “Ecotoxicology Database” (EPA-Ectox) managed by Dr. Brian Montague (Montague, 1998). For each active ingredient, avian studies were extracted from the EPA-Ecotox database.

Valid Bobwhite and Mallard duck studies producing LD-50 values were identified, using 72 percent to 100 percent technical grade materials.<sup>9</sup> In some cases, there were more than one valid study, so LD-50 values were averaged in the two or more studies. In a few cases, acute avian toxicity data was derived from company sources (Dupont, cymoxanil) or Farm Chemicals Handbook '98 (Meister Publishing, 1998).

In order to assess the validity of this approach in contrast to the Mineau model, values for several OPs and carbamates were calculated using the averaging approach just described. The resulting values compared closely to Mineau for relatively toxic active ingredients with LD-50 values less than about 400 ppm. Mineau values dropped much more slowly than the calculated average values for OPs with LD-50s over 1,000 ppm., pointing to the need for an adjustment factor. Four OPs and carbamates with LD-50 values over 400 ppm were chosen, and the ratio of Mineau values to the averaging method was calculated. In the case of Bobwhite quail, the ratio was 17, and for Mallard ducks, 15. These were subsequently used as adjustment factors for all pesticides with relatively high LD-50s.

While this method produces only a rough estimate, it is important to note that the acute avian toxicity of most herbicides and fungicides is known to be very low relative to high-risk OP and carbamates. According to Mineau, the most acutely toxic OPs and carbamates to birds are at least 2,000 times more toxic than the least. Compared to most herbicides and fungicides, the range is even larger. Accordingly, even an order of magnitude error in estimating acute avian toxicity values using the averaging technique is not likely to matter significantly in the overall calculation of ecotoxicity units.

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<sup>9</sup> At the suggestion of Dr. Pierre Mineau, studies were selected that produced LD-50 values, in contrast to those reporting LC-50 values. The reasons Dr. Mineau strongly prefers LD-50 values are set forth in “A Critique of the Avian 5-Day Dietary Test (LC-50) as the Basis of Avian Risk Assessment,” (Mineau et al., 1994).

Work is in the planning stages to collaborate with Dr. Mineau in the calculation of Mineau model avian toxicity values for additional active ingredients. Additional effort is needed, as well, to refine Mineau estimates through consideration of chronic effects, including endocrine system impacts as described by Dr. Theo Colborn and colleagues in the 1993 article “Developmental Effects of Endocrine-Disrupting Chemicals in Wildlife and Humans” (Colborn et al., 1993).

Fish Toxicity Unlike in the case of birds, no team of scientists has developed a comprehensive model to synthesize and interpret existing fish acute toxicity data. There is, however, extensive data on pesticide impacts on several fish species. Most studies in the files of the EPA are summarized in the EPA-Ecotox database, the source of data used to construct the fish sub-index. Many of the values in the EPA-Ecotox database came from a comprehensive 1986 report by U.S. Fish and Wildlife biologists.<sup>10</sup>

Through review of the fish studies in the EPA database, it was determined that rainbow trout and bluegill were the two species tested in nearly all pesticides used in Wisconsin in 1995 by potato farmers. Valid studies were selected by active ingredient, most of which involved between 75 percent and 100 percent active ingredient in the test substance. When there were two or more studies, LC-50 values were averaged. The same process was used in the case of bluegill.

Both the rainbow trout and bluegill data were inverted, so that rising values were associated with increasing toxicity, and a scaling factor was used so that the maximum value in each inverted index was roughly the same. The values for the two species were then averaged, producing the final fish toxicity values that appear in column 2 of Table 4.

Just like birds, the most toxic pesticides to fish are several thousand times more toxic than the least toxic pesticides. The range in unadjusted fish toxicity values Table 4 is over 500,000-fold. Esfenvalerate, a synthetic pyrethroid insecticide, is by far the most acutely toxic pesticide in Table 4, with an unadjusted fish toxicity sub-index value of 500. Since this value was four times higher the next most toxic pesticide to fish (endosulfan), the esfenvalerate value was adjusted 164.7, two standard deviations above the mean fish toxicity value across the pesticides in Table 4. As in the case of avian toxicity, the majority of herbicides and fungicides are considerably less toxic than most insecticides.

Small Aquatic Invertebrates Pesticides can place fish and bird species at jeopardy through impacts on aquatic food chains. In order to capture this potential in the Ecotoxicity index, a small aquatic organism sub-index was calculated, drawing on data in the EPA-Ecotox database on *Daphnia*, the most frequently treated crustacean species.

Using the approach previously described, comparable studies were selected out of the EPA database, and average values were calculated when there was more than one study. The values were then inverted and scaled, to produce the numbers in column 1, Table 4. Again, esfenvalerate was by far the most toxic pesticide, with an unadjusted value of 166.7,

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<sup>10</sup> *Manual of Acute Toxicity: Interpretation and Data Base for 410 Chemicals and 66 Species of Freshwater Animals*, F.L. Mayer and M.R. Ellersieck, U.S. Fish and Wildlife Service, 1986.

compared to a value of 13.3 for the next most toxic pesticide – another synthetic pyrethroid (permethrin). This value was adjusted downward to 52.7, two standard deviations above the mean. Not surprisingly, esfenvalerate still has the highest overall Ecotoxicity Index value – 219, about 25 percent higher than the OPs carbofuran and phorate.

Calculating Ecotoxicity Values To calculate Ecotoxicity values, the Daphnia, fish, and avian values for each pesticide active ingredient were summed. Note that the high Ecotoxicity values for esfenvalerate and endosulfan reflect largely aquatic toxicity, while the relatively high values for the carbamates carbofuran and aldicarb are largely from avian toxicity. The significant variability in ecotoxicity across classes of organisms is evident in Table 4. For all active ingredients, the lowest value in one of the three sub-indices is 10 to 100-fold less than the value in the sub-index with the highest value. This variability complicates the selection of pesticides but also makes it possible, with good information and field knowledge, to choose insecticides less likely to harm the dominant species sharing an agricultural landscape with crop fields.

While there are substantial data on the acute toxicological effects of pesticides on several non-target organisms, there are scant data to evaluate most sub-chronic and chronic effects involving immune system development and function, or neurological integrity and behavior. Scientists are reasonably confident they have identified and studied the acute toxicological properties of most commonly used pesticides that can, and sometimes do poison fish or birds. They are much less confident in their ability to identify pesticides reducing fish and bird populations through other chronic and indirect mechanisms, such as:

- Reduction in the abundance and diversity of invertebrates, an important food source, especially during avian breeding seasons;
- Impairment of long-term reproductive success as a result of subtle, endocrine system impacts; and
- Reduction in the number of plants that serve as hosts for invertebrates, play a role in successful breeding, or which serve as food sources during parts of the season.

There is also relatively little data on ecosystem-scale and multigeneration impacts, yet growing concern about such effects as a result of the increasing homogeneity of agricultural cropping patterns and pesticide use increases.

#### **4. Impacts on the Viability of Biointensive IPM Systems**

The fourth major index – BioIPM -- is also a composite of four sub-indices. Its purpose is to capture the differing impacts of pesticides on beneficial arthropods, resistance, soil microorganisms, and bees.

BioIPM encompasses impacts of vital significance to farmers, their neighbors, and the agricultural industry as a whole. Progress along the IPM continuum cannot be sustained without reducing the adverse impacts of pesticides on a range of beneficial organisms and on biodiversity. As above- and below-ground biodiversity increases, new options emerge

to manage species interactions in ways that disadvantage pests and strengthen a plant's ability to cope with or out-grow pest pressure.

Indeed, the structured management of biodiversity and species interactions are the nuts and bolts of biointensive IPM. Much like building a house, the pieces must first be present, and then organisms must be fit together into a structurally sound whole able to withstand and adapt to the elements.

The data needed to calculate BioIPM sub-indices is far from universally available, especially in the case of resistance and impacts on soil microorganisms. In the case of these two sub-indices, published studies and the experience of University of Wisconsin IPM experts were drawn upon in making preliminary estimates. Values for these subindices in Table 5 reflect pesticide use patterns and agroecosystems in central Wisconsin, and should not be accepted as relevant to other regions and cropping systems.

Efforts are underway to obtain more data on these impacts to use in the development of refined methods to capture BioIPM impacts. As progress is made in this effort, and as new technologies are adopted, BioIPM values will need to be updated. In subsequent reports, changes in BioIPM (and other indices) will be described, and the impact on overall values highlighted.

Beneficial Arthropods The first component is impacts on beneficial arthropods that play direct roles in biological control processes. In the case of insecticides, values in Table 4 are derived from the "Toxic Effect" index developed by Dr. Brian Croft and Karen Theiling at Oregon State University.<sup>11</sup>

For insecticides, "Scaled Impacts on Beneficial" values were derived from "Toxic Effect" values using the formula:

$$\text{"Scaled Impact on Beneficials Pesticide}_x\text{"} = 100/(5-\text{Toxic Effect Pesticide}_x)$$

This formula was selected as a way to expand the relatively narrow range of values from those reported by Theiling and Croft, and to increase the maximum values comparable to other BioIPM sub-indices. Highly selective materials like *Bt* and propargite have "Toxic Effect" values around 2, whereas the most damaging, least selective pesticide (oxamyl) has the highest value of 4.28 – a little over twice the value for *Bt*. The formula produces "Scaled Impact on Beneficials" values of 34 for *Bt* and 139 for oxamyl – expanding the range from a factor of two to a factor of about 4. Even this differential probably underestimates the significance of the difference in the relative impact of biopesticides like *Bt* and broad-spectrum chemicals like oxamyl on beneficials.

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<sup>11</sup> See pages 60-63 of *Pest Management at the Crossroads* for a general discussion of the "Toxic Effect Scale" and the methodology developed by Theiling and Croft. Under the direction of Dr. Paul Jepson, key work is underway in the Department of Entomology at Oregon State University. The goal is to extend and refine the database covering impacts of pesticides on arthropods, and to develop new measures of both the direct and indirect effects on communities of organisms. As new measures are developed, they will be incorporated in this methodology.

“Toxic Effect” values were not available for most other pesticides, so other sources of data were sought. Values in column two, Table 4 for these other classes of pesticides are derived predominantly from the work of Dr. Joe Kovach and colleagues at Cornell University.<sup>12</sup> The Kovach paper sets forth an "Environmental Impact Quotient" (EIQ) composed of three major components. Within the “Ecological Component” of the EIQ, there is a sub-index called “Beneficials Effects,” which is based on data compiled by Theiling and Croft in the SELECTV database. Hence, the values in the Cornell paper were adopted as a "first approximation" of “Scaled Impact on Beneficials” values for herbicides, fungicides, and other pesticides.

Soil Microorganisms Many species of soil microorganisms play an important positive role by improving soil quality, enhancing nitrogen cycling and availability in the soil, promoting healthy root development, and suppressing nematodes and related plant pathogens.

“Scaled Impacts on Soil Microorganisms” values in column four were derived from estimates provided by the University of Wisconsin IPM team including Dr. Jeff Wyman, an entomologist, Dr. Walt Stevenson, a plant pathologist, Dr. Larry Binning, a weed scientist, and Dr. Tim Connell, a farming systems expert in the Department of Horticulture. The UW research team provided “Impacts on Soil Microorganisms” values ranging from 1 to 10. A scaling factor of 10 was used to produce a range of values roughly comparable to the other sub-indices.

As farming and IPM systems evolve in Wisconsin, it is likely that soil microbial communities will grow more diverse. A major goal of ongoing research at the University is to promote microbial biocontrol of soil pathogens, as an alternative to periodic fumigation with metam-sodium. Improving soil structure and microbial activity are viewed as critical challenges in rebuilding the quality of soils in the intensively farmed regions of central Wisconsin. As progress is made toward this goal, the team will revisit these values, since the impacts of different pesticides on soil microorganisms is bound to change as the diversity of species increases.

Resistance The emergence of resistance can undermine the efficacy of a pesticide, and hence undermine the ability of farmers to use otherwise effective pest management tools. In the case of relatively safe pesticides like *Bt* and glyphosate, the emergence of resistance is bound to lead to increased reliance and use of higher-risk products. This concern has led Consumers Union to take a strong stand against the approval and use of *Bt*-transgenic and herbicide tolerant plant varieties (Benbrook et al., 1996; also see comments on *Bt*-resistance by Dr. Michael Hansen at <<http://www.pmac.net/mhremark.htm>>).

An estimate of each pesticide’s likelihood of triggering the evolution of resistance was provided by the University of Wisconsin IPM research team, using a 1 to 40 scale. A

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<sup>12</sup> "A Method to Measure the Environmental Impact of Pesticides," Kovach, J., et al., New York Food and Life Sciences Bulletin Number 139, 1992.

scaling factor of three was then used to produce a maximum value, and range of values, comparable to the other three sub-indices within the BioIPM index. It should be noted that the very low value for *Bt* is based on foliar applications of the formulated insecticide, not the planting of *Bt*-transgenic varieties, which would have a much higher likelihood of triggering resistance.

Bee Toxicity Bees play a critical role in the pollination of both agricultural crops and native species. Pesticide impacts on bees are among the most significant economic losses associated with pesticide use, and are a growing concern worldwide. In some regions, vegetable and fruit crop yield reductions of 40 percent or more have been attributed to poor pollination caused by pesticide impacts on bees (for further information, see <<http://www.pmac.net/benefimp.htm>>).

Bee toxicity data was extracted from the EPA-Ecotox database and appears in column five, table 5. In some cases, values were extrapolated from the three acute bee toxicity ratings in “Farm Chemicals Handbook ‘98” – “Practically Non-toxic,” “Moderately Toxic,” and “Highly Toxic.” For several active ingredients falling in each “Farm Chemicals” category, average bee toxicity values were calculated from data in the EPA database. These average values were then used for pesticides in the “Farm Chemicals Handbook” classes, but not in the EPA database.

The formula used to invert and scale bee toxicity data to produce “Scaled Bee Toxicity” values reported in column six is:

$$\text{“Scaled Bee Toxicity Pesticide}_x\text{”} = 10/\text{Bee Toxicity Pesticide}_x$$

The bee toxicity value for imidacloprid required adjustment because of the very large difference in bee toxicity between the granular and foliar formulations of this insecticide. When applied as a liquid foliar spray, imidacloprid’s scaled bee toxicity value is by far the highest of any pesticide used in Wisconsin potato production. But a significant portion of imidacloprid is applied at planting time as a granular, essentially eliminated exposure to bee. Plus, there are rarely foraging bees in potato fields later in the season when foliar imidacloprid products are applied, according to University of Wisconsin entomologist Dr. Jeffrey Wyman. Accordingly, the imidacloprid scaled bee toxicity value was adjusted downward to 20.

BioIPM Values Final BioIPM values were derived by summing the values of the four sub-indices, as reported in column 7, Table 5. These values were then scaled using a factor of 0.4 to produce a maximum value and range comparable to the other major indices. As expected, the average value of insecticides is substantially higher than the average value for other classes of pesticides. But like other indices, there is large variability within and across categories of pesticides.

Less is known about the impacts of pesticides on biointensive IPM than is known about other sorts of impacts, especially acute effects on people, birds, and fish. For many but not all insecticides, there is reasonably solid data and methods to capture the impacts on

major beneficial arthropods. Such adverse impacts are not hard to miss in the field, as once innocuous or intermittent pests emerge as major problems. Much less is known about the impacts of other types of pesticides on beneficial arthropods, although in many cases the impacts are likely to be modest or non-existent.

Pesticide impacts on beneficial soil microorganisms are likely among the most significant to farmers, rural communities, and in terms of economic consequences, yet have received modest research attention, at least until recently. Use of soil fumigants and insecticides, certain herbicides and other pesticides can dramatically change soil microbial communities in ways that lead to degradation in soil quality, greater soil-borne disease pressure, and higher production costs through one or more mechanisms.

Across the country, teams of farmers and scientists are rediscovering and documenting the economic consequences of soil degradation and the cost-savings and agronomic gains possible when soil quality is enhanced. The impact of pesticides on microbial communities is emerging as one of the profound factors explaining changes in soil quality. Long overdue research is beginning to attract some support, in large part fueled by the impending loss of methyl bromide. Much more field research, and data gathering and synthesis, will be required to improve the accuracy and completeness of the database supporting the BioIPM index. The need is most pressing for research focusing on the impact of pesticides on microbial communities, other beneficial organisms, and biocontrol processes.

#### **D. Integrating the Component Indices into a Single Index**

Index values and toxicity-adjustment factors are intended to more accurately characterize the tradeoffs inherent in the selection of pesticides and pest management systems. While regulators or researchers are often interested primarily in a single dimension of risk, farmers and society as a whole have to live with all risk, efficacy, and economic impacts, positive and negative. Hence, the complexity of the challenge to identify the least disruptive and dangerous product across all categories of risk and impacts from those products available to address a given problem pest.

Toxicity-adjustment methodologies are tools to help make more informed choices. To be useful, several methodological issues have to be addressed in ways that do not skew results. A first step is deciding upon the component indices to include in a multiattribute index. Four component indices are described above: acute mammalian (AM), chronic mammalian (CM), ecological (ECO), and beneficial organisms and IPM (BioIPM). The general functional form of the equation used to calculate multiattribute index values is:

$$\text{Value for Pesticide}_x = (a)\text{AM}_x + (b)\text{CM}_x + (c)\text{ECO}_x + (d)\text{BioIPM}_x$$

Where, (a), (b), (c), and (d) are weights assigned to each component index.

## 1. Assigning Weights: An Example Involving Potato Production in Wisconsin

Decisions regarding the importance to place on the four component indices must be made and incorporated in the equation through the weighting factors (a), (b), (c), and (d). Guidance was sought from the WWF-WPVGGA Advisory Committee, and technical consultants, regarding what weights to use for the purpose of establishing baseline multiattribute toxicity units subject to project risk reduction goals. The committee recommended that four different formulas be calculated, reflecting different environmental and public health concerns. The formulas are –

Wisconsin Project Risk Index =  $(0.5)*AM_x + CM_x + ECO_x + (1.5)*BioIPM_x$

Equal Weight Index =  $AM_x + CM_x + ECO_x + BioIPM_x$

Human Health Focus Index =  $(1.5)*AM_x + (2.0)*CM_x + (0.5)*ECO_x + BioIPM_x$

Environment Focus Index =  $(0.3)*AM_x + (0.5)*CM_x + (2.0)*ECO_x + (2)*BioIPM_x$

The “Wisconsin Project Risk Index” was chosen for use in setting the toxicity unit baseline and for monitoring risk reduction progress because, in the judgement of the advisory committee, it best reflects the balance of concerns associated with pesticide use on central Wisconsin potato farms.

The weight assigned the acute mammalian toxicity component is set at (0.5), reducing its significance relative to other component indices. This adjustment reflects the relative lack of circumstances leading to worker and applicator exposure and the low frequency of residues of acutely toxic pesticides in harvested potatoes, especially after washing, peeling, cooking and/or processing.

The adjustment was not applied to the chronic mammalian toxicity index because low-level exposures are more widespread in the region from pesticides in drinking water, the air, and as a result of occupational exposure. To the extent the general public faces risks from pesticide residues in potatoes, they are likely to be chronic in nature.

A (1.5) weight has been assigned to the BioIPM component because BioIPM index impacts, especially resistance management and impacts on soil microorganisms and beneficial arthropods, are particularly important as Wisconsin potato producers progress along the IPM continuum toward more biologically based methods to manage pests. In recent years, secondary pests have been a recurrent concern and pest managers have invested considerable effort in devising and implementing resistance management plans. Efforts are also underway to build soil quality by raising organic matter content. Progress in enhancing soil quality is seen by many growers as critical in their efforts to improve nitrogen management efficiency, a key goal in reducing production costs.

Results using these four formulas are presented in columns 7, 8, 9, and 10 in Table 6 for pesticides used in potato production in 1995 in all states according to National Agricultural Statistics Survey (NASS) data. There are about 15 pesticides in Tables 4, 5, and 6 that were not used in Wisconsin in 1995, and hence these active ingredients do not appear in Tables 1, 2, 3, and 7.

Note the significant differences in the rankings of pesticides across the four formulas. Under the “Environmental Effects Focus Index,” pesticides that score high on “Scaled Ecotoxicity” top the list – esfenvalerate at 695, carbofuran at 566, and phorate, 560. But under the “Health Effects Focus Index,” esfenvalerate drops to 11<sup>th</sup> out of 18 insecticides, aldicarb rises to number one, and carbofuran drops to number 14. Under an environmental focus, carbaryl scores almost five times higher than in the health focus index. The botanical pyrethrins score about seven times higher.

Some fungicides, on the other hand, score significantly higher in the human health focus index than the environmental effects index. The differential is greatest in the case of metiram, which has a human health focus value of 439 (driven by its maximum value under chronic effects) and an environmental focus value of only 139. Among herbicides, all environmental focus index values are higher than health focus values mostly because of their relatively high “Scaled BioIPM Index” values. The environmental index value for the herbicide pendimethalin exceeds its human health focus value by 6.5 fold. While these indices are not accurate enough to express such differences to two significant digits, they are generally reliable in highlighting the very significant differences that exist in the relative hazards posed by different pesticides.

## **2. Maximum Values and Scaling Across Indices and Sub-Indices**

The scaling of the component indices and sub-indices is another way to implicitly weight equations more heavily toward one, or a combination of risk-related concerns. Scaling refers to the relative range of values in one index or sub-index compared to others. Scaling choices become implicit weighting decisions if not done consistently.

Scaling choices are intrinsically linked with how maximum values are handled, especially in indices or sub-indices with very high outlier values. When just one active ingredient has an index value 100-fold higher than all other pesticides, it is likely to mask differences across other active ingredients. Limited confidence can be placed in such values in most cases since they are often artifacts of algorithms and not an accurate reflection of true differences in toxicity, as discussed earlier in the sections on the acute mammalian and chronic mammalian indices.

For example, if the values of the AM component index range from 1 to 1,000 and the values of the BioIPM component vary from 1 to 10, BioIPM index values are likely to account for very little of the variability compared to the AM index in multiattribute index calculations. The same would be true for any other pair of sub-indices within the ECO or BioIPM component indices.

A component index, or sub-index, that has a comparable maximum and minimum value, but which varies more significantly across active ingredients will account for a greater share of variability in a composite index or sub-index. To the full extent possible, maximum value and scaling decisions need to be made consistently in accord with explicit

guidelines. In this way, such decisions can be kept separate from weighting choices across indices or sub-indices.

In applications of this multiattribute toxicity index system, a number of different sets of assumptions and methods for dealing with maximum values and scaling issues will be explored. The resulting values will be assessed by experts and through sensitivity analyses in working toward the best way to keep these decisions explicit and grounded upon sound reasoning and clear statements of the justification for choices made.

### **3. Challenges and Next Steps**

Advisory committee members and reviewers have posed several challenges as this, or similar, toxicity adjustment methods are refined and applied. A number of activities are underway to collect better data and incorporate more sophisticated concepts and methods into the system. Some of the major areas in need of further work are discussed below.

Incorporating Synergism into the Model On most Wisconsin potato farms, many pesticides are applied on the same field in a given year. In some cases, their toxicological impacts – on mammals, birds and fish, and on beneficial organisms – are at least additive, and in some cases, synergistic. Research has documented, for example, that several combinations of fungicides and synthetic pyrethroid insecticides produce much more profound effects on bees than comparable levels of either pesticide alone (Pilling, 1992).

Research underway at the University of Wisconsin suggests that common combinations of pesticides and nitrates found in Wisconsin drinking water might produce adverse human immune and reproductive system impacts at exposure levels far below those studied using conventional toxicological tests (Dr. Warren Porter, comments made during a project technical committee meeting November 18, 1997). Additional work is clearly needed in both human and wildlife test systems to determine whether, and to what extent, synergism might be increasing the toxicity of common combinations of pesticides and fertilizer contaminants found in drinking water.

Adjustments for Exposure As emphasized earlier, more effort is needed to build explicit adjustments for exposure into the system, whether connected to changes in formulation, extensions in pre-harvest or field re-entry intervals, or limits on application rates and locations. The example cited involving imidacloprid and bee toxicity demonstrates how dramatically basic exposure information and adjustments can alter toxicity index values and outcomes.

Further work is also needed in refining “Scaled Leaching Index” values, a key exposure-related adjustment. The method used herein to develop the leaching index produces a limited range in values, with most pesticides clustered between 0.88 and 1.1. There are probably somewhat more significant differences in exposure potential as a result of leachability that ought to be captured in further, more refined applications of this system.

The potential for a pesticide to bioconcentrate in food chains is a key exposure related parameter in carrying out ecological and dietary risk assessments. As a result, an adjustment factor based on bioconcentration potential should be added to the system. Likewise, leaf half-life values also significantly impact worker exposure and residues in food, and should be added to the system.

Building Economic Impacts into the System The BioIPM component captures many of the adverse impacts of pesticide use on the sustainability and productivity of farming systems. Its relevance to farmers will be enhanced by building in an economic dimension whereby the cost of production, yield, and crop quality consequences of changes in pest management systems are systematically addressed. Doing so would allow system applications to encompass a broader range of tradeoffs on the farm, a key need to inform the decision process both among pest managers and policy makers.

Calibrating Model Predictions to Field Monitoring Data A last need and challenge is to develop methods to calibrate model projections against actual field data and experiences. Methods to do so will include efforts to predict past, observed changes in poisoning episodes, and other adverse impacts, based on toxicity unit estimates.

Prospectively, the system can be used to project changes in ecological and worker poisoning impacts in areas where pest management systems are changing dramatically. The system could be used to project per acre toxicity unit thresholds likely to be associated with the loss or return of a given sentinel species, like Wisconsin's Karner blue butterfly.

Projecting the Impacts of Genetically Engineered Production Inputs Transgenic plant varieties and production inputs are currently receiving much focus in the farm community. Many are marketed as "environmentally friendly," yet may pose significant BioIPM risks as a result of resistance, shifts in pest complexes, and impacts on soil microorganisms. New methods will be needed to incorporate toxicity and risk assessment parameters relevant to transgenic seeds and production inputs into the system, especially as it becomes more important to capture landscape and watershed scale impacts.

Future Applications With the benefit of these and other refinements, the system described herein will provide a solid basis to monitor progress toward biointensive IPM and pesticide risk reduction goals set as part of the WWF-WPVGA potato IPM project. Other partnerships involving farm groups and consumer and environmental organizations are likely to apply the system, or use it as a springboard in developing their own. Government agencies facing the need to evaluate the impacts and accomplishments of IPM programs are also working on development of improved impact indicators and program evaluation tools, some of which are expected to include applications of pesticide toxicity indices.

The system will provide valuable insights into long-term trends in pesticide toxicity levels, as well as the benefits of progress along the IPM continuum in reducing the average toxicity units associated with the production of major crops. It will also be applied in assessing the impacts of the "Food Quality Protection Act" as the implementation process moves forward.

These and other applications will gradually establish an information base useful in forging consensus on future regulatory policies and research and education needs. Sharper recognition of problems, constraints, and opportunities should help the nation proactively take steps needed to provide farmers with progressively safer and more effective tools, and the public with safer and higher quality foods grown with fewer adverse impacts on the environment.

[Note: The tables that follow include pages with “Comments” that serve as footnotes to the tables. They explain formulas, note data sources and adjustments, and otherwise explain the way the indices and sub-indices were calculated. The lower right corner of each table includes the file name and table number. These can be used to assure that the correct comment pages are associated with the proper table.]

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**Table 1. Pesticides Applied in Wisconsin Potato Production, 1995**

(Wisconsin Acres Planted: 83,000)	Area Applied	Acres Treated	Number of Applications	Rate per Application	Rate per Crop Year	Total Applied
	(Percent)		(Number)	(#s per acre)	(#s per acre)	(Pounds)
<b>Herbicides:</b>						
Metribuzin	89	73,870	1.1	0.46	0.52	39,000
Pendimethalin	36	29,880	1	0.8	0.81	24,000
Metolachlor	18	14,940	1	1.44	1.44	21,000
Linuron	9	7,470	1.1	0.89	0.97	7,000
Glyphosate	8	6,640	1.0	0.62	0.62	4,000
Sethoxydim	10	8,300	1.2	0.17	0.2	2,000
Total: All Herbicides	170	141,100				97,000
Per Planted Acre						1.17
<b>Insecticides:</b>						
Methamidophos	65	53,950	1.4	0.88	1.26	69,000
Endosulfan	66	54,780	1.5	0.75	1.09	60,000
Azinphos-methyl	26	21,580	2.1	0.57	1.19	26,000
Carbofuran	16	13,280	1	0.89	0.93	13,000
Dimethoate	28	23,240	1.3	0.38	0.48	11,000
Oxamyl	8	6,640	1.1	0.77	0.85	5,000
Permethrin	22	18,260	1.4	0.15	0.21	4,000
Esfenvalerate	60	49,800	1.7	0.04	0.06	3,000
Piperonyl butoxide	17	14,110	1	0.2	0.21	3,000
Pyrethrins	10	8,300	1	0.02	0.02	16
Total: All Insecticides	318	263,940				194,016
Per Planted Acre						2.34
<b>Fungicides:</b>						
Mancozeb	86	71,380	4.7	1.24	5.76	412,000
Chlorothalonil	88	73,040	5.9	0.95	5.61	408,000
Maneb	14	11,620	5.3	1.25	6.65	76,000
Copper hydroxide	38	31,540	2.4	0.54	1.26	40,000
Basic copper sulfate	5	4,150	1.9	1.57	2.92	13,000
Copper resinate	7	5,810	1.9	1.11	2.1	12,000
Triphenyltin hydrox.	46	38,180	2.9	0.11	0.31	12,000
Propamocarb hydroch.	12	9,960	1.1	0.9	0.96	9,000
Metalaxyl	15	12,450	1.5	0.21	0.31	4,000
Total: All Fungicides	311	258,130				986,000
Per Planted Acre						11.88
<b>Other Chemicals:</b>						
Sulfuric acid	13	10,790	1.1	142	150.35	1,632,000
Metam-sodium	8	6,640	1	152	152	970,000
Diquat	80	66,400	1.4	0.3	0.42	28,000
Maleic hydrazide	8	6,640	1	1.91	1.91	13,000
Endothall	11	9,130	1.1	0.76	0.82	7,000
Paraquat	7	5,810	1.2	0.44	0.54	3,000
Total: Other Chemicals	127	105,410				2,653,000
Per Planted Acre						31.96
<b>Total Herbicides, Insecticides, and Fungicides:</b>	799	663,170				1,277,016
Per Planted Acre						15.39
<b>Totals: All Chemicals</b>	926	768,580				3,930,016
Per Planted Acre						47.35

**Table 2. Pesticides Used in Wisconsin Potato Production  
Ranked by Acute Toxicity Units, 1995**

(Wisconsin Acres Planted: 83,000)	Acres Treated	Total Pounds Applied	LD-50 Value	Scaled Inverse LD-50	Acute Toxicity Units	Share of Acute Toxicity Units by Type of Pesticide
<b>Herbicides:</b>						
Metribuzin	73,870	39,000	2,200	0.26	10,140	40.2%
Pendimethalin	29,880	24,000	1,050	0.42	10,057	39.9%
Metolachlor	14,940	21,000	2,780	0.17	3,570	14.2%
Linuron	7,470	7,000	4,000	0.11	770	3.1%
Glyphosate	6,640	4,000	4,230	0.1	400	1.6%
Sethoxydim	8,300	2,000	3,200	0.14	280	1.1%
Total: All Herbicides	141,100	97,000			25,217	
Per Planted Acre		1.17			0.3	
<b>Insecticides:</b>						
Methamidophos	53,950	69,000	30	14.6	1,007,400	29.3%
Carbofuran	13,280	13,000	8	68.56	891,280	25.9%
Azinphos-methyl	21,580	26,000	16	27.69	719,940	21.0%
Oxamyl	6,640	5,000	6	86.05	430,249	12.5%
Endosulfan	54,780	60,000	80	5.53	331,800	9.7%
Dimethoate	23,240	11,000	150	2.93	32,230	0.9%
Esfenvalerate	49,800	3,000	67	6.55	19,650	0.6%
Permethrin	18,260	4,000	500	0.88	3,520	0.1%
Piperonyl butoxide	14,110	3,000	5,000	0.09	270	0.0%
Pyrethrins	8,300	16	500	0.88	14	0.0%
Total: All Insecticides	263,940	194,016			3,436,353	
Per Planted Acre		2.34			41	
<b>Fungicides:</b>						
Mancozeb	71,380	412,000	5,000	0.09	37,080	23.8%
Chlorothalonil	73,040	408,000	5,000	0.09	36,720	23.6%
Triphenyltin hydrox.	38,180	12,000	156	2.81	33,720	21.6%
Basic copper sulfate	4,150	13,000	300	1.46	18,980	12.2%
Copper hydroxide	31,540	40,000	1,000	0.44	17,600	11.3%
Maneb	11,620	76,000	5,000	0.09	6,840	4.4%
Metalaxyl	12,450	4,000	670	0.75	3,000	1.9%
Copper resinate	5,810	12,000	5,000	0.09	1,080	0.7%
Propamocarb hydroch.	9,960	9,000	5,000	0.09	810	0.5%
Total: All Fungicides	258,130	986,000			155,830	
Per Planted Acre		12			2	
<b>Other Chemicals:</b>						
Metam-sodium	6,640	970,000	285	1.54	1,493,800	64.0%
Sulfuric acid	10,790	1,632,000	1,000	0.44	718,080	30.7%
Endothall	9,130	7,000	51	8.62	60,340	2.6%
Diquat	66,400	28,000	231	1.90	53,200	2.3%
Paraquat	5,810	3,000	150	2.92	8,760	0.4%
Maleic hydrazide	6,640	13,000	5,000	0.11	1,430	0.1%
Total: Other Chemicals	105,410	2,653,000			2,335,610	
Per Planted Acre		32			28	
<b>Total Herbicides, Insecticides, and Fungicides</b>						
Per Planted Acre	663,170	1,277,016			3,617,400	
Per Planted Acre		15			44	
<b>All Chemicals:</b>						
Per Planted Acre	768,580	3,930,016			5,953,010	
Per Planted Acre		47.35			72	

**Table 3. Chronic Toxicity of Pesticides Used in Wisconsin Potato Production, 1995**

(Wisconsin Acres Planted: 83,000)	Total Pounds Applied	Percent Pounds Applied	Scaled Mam Tox Score	Chronic Toxicity Units	Share of Chronic Toxicity Units by Type of Pesticide
<b>Herbicides:</b>					
Metribuzin	39,000	40%	26.77	1,044,139	89.9%
Linuron	7,000	7%	11.25	78,750	6.8%
Metolachlor	21,000	22%	0.93	19,530	1.7%
Pendimethalin	24,000	25%	0.68	16,262	1.4%
Sethoxydim	2,000	2%	1.00	1,998	0.2%
Glyphosate	4,000	4%	0.04	176	0.0%
Total: All Herbicides	97,000	100%		1,160,856	
Per Planted Acre	1.17			14	
<b>Insecticides:</b>					
Methamidophos	69,000	36%	88.00	6,072,000	47.8%
Endosulfan	60,000	31%	44.00	2,640,000	20.8%
Dimethoate	11,000	6%	176.00	1,936,000	15.2%
Azinphos-methyl	26,000	13%	59.36	1,543,438	12.1%
Carbofuran	13,000	7%	22.00	286,000	2.3%
Oxamyl	5,000	3%	33.52	167,600	1.3%
Permethrin	4,000	2%	9.33	37,312	0.3%
Piperonyl butoxide	3,000	2%	5.03	15,086	0.1%
Esfenvalerate	3,000	2%	4.40	13,200	0.1%
Pyrethrins	16	0%	1.38	22	0.0%
Total: All Insecticides	194,016	100%		12,710,658	
Per Planted Acre	2.34			153	
<b>Fungicides:</b>					
Mancozeb	412,000	42%	114.40	47,132,800	78.8%
Maneb	76,000	8%	79.20	6,019,200	10.1%
Triphenyltin hydrox.	12,000	1%	286.73	3,440,808	5.8%
Chlorothalonil	408,000	41%	7.79	3,177,504	5.3%
Copper hydroxide	40,000	4%	0.29	11,616	0.0%
Propamocarb hydroch.	9,000	1%	0.88	7,920	0.0%
Metalaxyl	4,000	0%	1.36	5,454	0.0%
Basic copper sulfate	13,000	1%	0.29	3,775	0.0%
Copper resinate	12,000	1%	0.29	3,485	0.0%
Total: All Fungicides	986,000	100%		59,802,562	
Per Planted Acre	12			721	
<b>Other Chemicals:</b>					
Metam-sodium	970,000	37%	95.92	93,042,400	98.2%
Diquat	28,000	1%	40.04	1,121,120	1.2%
Sulfuric acid	1,632,000	62%	0.29	473,933	0.5%
Paraquat	3,000	0%	19.54	58,608	0.1%
Endothall	7,000	0%	4.40	30,800	0.0%
Maleic hydrazide	13,000	0%	0.46	5,980	0.0%
Total: Other Chemicals	2,653,000	100%		94,732,841	
Per Planted Acre	32			1,141	
<b>Total Herbicides, Insecticides, and Fungicides:</b>					
	1,277,016			73,674,075	
Per Planted Acre	15			888	
<b>All Chemicals:</b>					
	3,930,016			168,406,916	
Per Planted Acre	47.35			2,029	

**Table 4. Ecotoxicity Index Components and Values**

	Daphnia	Fish	Birds	Sum of Components
<b>Herbicides:</b>				
EPTC	0.003	0.008	0.34	0.35
Glyphosate	0.000	0.001	0.14	0.14
Linuron	0.125	0.030	0.21	0.36
Metolachlor	0.001	0.025	0.08	0.11
Metribuzin	0.006	0.002	0.29	0.30
Pendimethalin	0.089	0.990	0.21	1.29
Paraquat	0.021	0.002	2.08	2.11
Rimsulfuron	0.000	0.000	0.28	0.28
Sethoxydim	0.000	0.001	0.15	0.15
Trifluralin	0.042	0.000	0.30	0.34
<b>Insecticides:</b>				
Aldicarb	0.061	2.493	65.22	67.77
Azinphos Methyl	0.009	16.695	12.15	28.85
<i>Bt</i>	0.002	0.074	1.30	1.38
Carbaryl	3.676	0.028	0.61	4.31
Carbofuran	0.740	1.297	157.89	159.93
Dimethoate	10.000	0.028	5.04	15.07
Endosulfan	0.151	115.079	19.54	134.77
Esfenvalerate	52.654	164.754	1.84	219.25
Ethoprop	0.368	0.112	11.72	12.20
Fonofos	12.500	5.815	7.35	25.67
Imidachloprid	0.000	0.002	1.88	1.88
Methamidophos	0.735	0.005	10.91	11.65
Oxamyl	0.008	0.027	63.83	63.87
Permethrin	13.298	28.162	1.64	43.10
Phorate	0.676	86.458	75.00	162.13
Piperonyl butoxide	0.023	0.043	1.60	1.67
Propargite	0.275	1.172	1.94	3.39
Pymetrozine				4.00
Pyrethrin	2.155	8.859	0.90	11.91
<b>Fungicides:</b>				
Chlorothalonil	0.357	2.270	0.00	2.63
Copper ammonium	0.025	0.012	0.10	0.13
Copper Chloride Hydroxide	0.025	0.092	0.47	0.58
Copper resinate	0.025	0.012	0.47	0.50
Copper sulfate, basic	0.025	0.147	0.47	0.64
Cymoxanil	0.001	0.005	0.47	0.47
Iprodione	0.010	0.037	0.27	0.31
Mancozeb	0.025	0.157	0.10	0.28
Maneb	0.007	0.708	0.06	0.77
Metalaxyl	0.000	0.002	0.07	0.07
Metiram	0.004	0.001	0.10	0.11
Propamocarb	0.000	0.000	0.16	0.16
Sulfur	0.000	0.001	0.13	0.13
Triphenyltin Hydroxide	2.500	5.260	0.11	7.87
<b>Other Chemicals:</b>				
Dichloropropene	0.008	0.031	0.00	0.04
Diquat	0.004	0.001	0.12	0.12
Endothal	0.000	0.003	0.15	0.15
Maleic Hydrazide	0.000	0.002	1.81	1.81
Metam sodium	0.011	0.247	0.08	0.34
Sulfuric acid	0.01	0.01	0.1	0.12

**Table 5. BioIPM Index Components and Values**

	Toxic Effect Scale	Scaled Impacts on Beneficials	Scaled Resistance	Scaled Impacts on Soil Micro-organisms	Bee Toxicity	Scaled Bee Toxicity	Sum of Components	Scaled BioIPM Index
<b>Herbicides:</b>								
EPTC	2.95	17	75	100	12.1 ugB	0.83	192.83	77.1
Glyphosate	2.95	41.3	6	80	>100 ugB	0.10	127.40	51.0
Linuron	2.95	51	6	40	>120.9 ugB	0.08	97.08	38.8
Metolachlor	2.95	17	9	50	>100 ugB	0.10	76.10	30.4
Metribuzin	2.95	51	60	50	60.4 ugB	0.17	161.17	64.5
Pendimethalin	2.95	17	18	60	49.8 ugB	0.20	95.20	38.1
Rimsulfuron	2.95	51	120	70	>100 ugB	0.10	241.10	96.4
Paraquat	2.95	65	6	60	6 ugB	1.67	132.67	53.1
Sethoxydim	2.95	15	45	60	>10 ugB	1.00	121.00	48.4
Trifluralin	2.95	6	18	60	24.17 ugB	0.41	84.41	33.8
<b>Insecticides:</b>								
Aldicarb	3.28	58.14	30	100	.285 ugB	35.09	223.23	89.3
Azinphos-methyl	3.58	70.42	75	40	.82 ugB	12.20	197.62	79.0
<i>Bacillus thuringiensis</i>	2.06	34.01	6	10	>100 ugB	0.10	50.11	20.0
Carbaryl	3.83	85.47	45	40	1.3 ugB	7.69	178.16	71.3
Carbofuran	3.6	71.43	45	100	.16 ugB	62.50	278.93	111.6
Dimethoate	3.6	71.43	15	40	.13 ugB	76.92	203.35	81.3
Endosulfan	3.37	61.35	75	40	6.2 ugB	1.61	177.96	71.2
Esfenvalerate	3.5	66.67	120	30	.1 ugB	100.00	316.67	126.7
Ethoprop	3.5	66.67	15	80	4.1 ugB	2.44	164.11	65.6
Fonofos	3.2	55.56	15	80	6.8 ugB	1.47	152.03	60.8
Imidachloprid	2.5	40.00	75	50	0.041 ugB	20.00	185.00	74.0
Methamidophos	3.7	76.92	21	50	1.37 ugB	7.30	155.22	62.1
Oxamyl	4.28	138.89	45	50	5.21 ugB	1.92	235.81	94.3
Permethrin	4.03	103.09	120	30	.1 ugB	100.00	353.09	141.2
Phorate	4	100.00	30	80	3.61 ugB	2.77	212.77	85.1
Piperonyl butoxide	2.5	40.00	9	20	>10 ugB	1.00	70.00	28.0
Propargite	2	33.33	12	30	>10 ugB	1.00	76.33	30.5
Pymetrozine	2.4	30	10	20	>200 ugB	0.05	60.05	24.0
Pyrethrins	4	100.00	120	30	>10 ugB	1.00	251.00	100.4
<b>Fungicides:</b>								
Chlorothalonil	2.59	50	6	20	181 ugB	0.06	76.06	30.4
Copper ammonium	2.59	38	6	30	>10 ugB	1.00	75.00	30.0
Copper hydroxide	2.59	38.3	6	30	>10 ugB	1.00	75.30	30.1
Copper resinate	2.59	38.3	6	30	>10 ugB	1.00	75.30	30.1
Copper sulfate	2.59	10.9	6	40	>10 ugB	1.00	57.90	23.2
Cymoxanil	2.59	35	30	20	>25 ugB	0.40	85.40	34.2
Iprodione	2.59	38.3	60	20	>10 ugB	1.00	119.30	47.7
Mancozeb	2.3	78	6	20	178 ugB	0.06	104.06	41.6
Maneb	2.3	83.3	6	20	12 ugB	0.83	110.13	44.1
Metalaxyl	2.59	52.5	150	80	100 ugB	0.10	282.60	113.0
Metiram	2.3	54.8	6	20	>10 ugB	1.00	81.80	32.7
Propamocarb hydroch.	2.59	30	30	20	>10 ugB	1.00	81.00	32.4
Sulfur	2.59	87	6	20	>100 ugB	0.10	113.10	45.2
Triphenyltin hydrox.	2.59	70	6	20	114.8 ugB	0.09	96.09	38.4
<b>Other Chemicals:</b>								
Dichloropropene		50.00	6	60	>10 ugB	1.00	117.00	46.8
Diquat		40.00	6	20	>1 ugB	10.00	76.00	30.4
Endothal		40.00	6	20	>10 ugB	1.00	67.00	26.8
Maleic hydrazide		40.00	6	20	36.3 ugB	0.28	66.28	26.5
Metam-sodium		60.00	6	80	36.2 ugB	0.28	146.28	58.5
Sulfuric acid		20.00	6	20	>10 ugB	1.00	47.00	18.8

**Table 6. Preliminary Toxicity Adjustment Factors: Pesticides Used in Potato Production, 1995**

	Scaled Leaching Index	LD-50	Scaled Inverse LD-50	Scaled Chronic Toxicity	Scaled Ecotoxicity	Scaled BioIPM Index	WWF-WPVGPA Project Index	Equal Weight Index	Human Health Focus Index	Environment Effects Focus Index
<b>Herbicides:</b>										
2,4-D	0.89	375	1.17	30.00	8	45	106	84	61	114
EPTC	0.91	1,652	0.28	3.64	3.5	45.1	75	53	19	98
Glyphosate	0.88	4,230	0.10	0.04	1.4	51.0	78	53	14	105
Linuron	0.90	4,000	0.11	11.21	3.6	38.8	73	54	28	88
Metolachlor	0.93	2,780	0.17	0.93	1.1	30.4	48	33	10	63
Metribuzin	1.16	2,200	0.26	26.76	3.0	64.5	127	94	58	142
Paraquat	0.88	150	2.92	19.47	12.9	38.1	91	73	48	108
Pendimethalin	0.88	1,050	0.42	0.67	21.1	96.4	167	119	36	235
Rimsulfuron	1.14	5,000	0.11	7.12	2.8	53.1	90	63	25	114
Sethoxydim	0.90	3,200	0.14	1.00	1.5	38.8	61	41	12	81
Trifluralin	0.88	5,000	0.09	12.65	3.4	68.6	119	85	38	147
<b>Insecticides:</b>										
Aldicarb	1.05	1	86.05	286.73	67.8	89.3	531	530	572	407
Azinphos-methyl	0.89	16	27.69	59.07	28.8	79.0	220	195	150	237
<i>Bacillus thuringiensis</i>	0.88	5,000	0.09	0.01	1.4	20.0	31	22	6	43
Carbaryl	0.89	300	1.48	6.92	4.3	71.3	119	84	32	153
Carbofuran	1.10	8	68.56	21.94	159.9	111.6	384	362	209	566
Cryolite	0.88	5,000	0.09	0.88	20.0	20.0	51	41	16	80
Dimethoate	0.88	150	2.93	175.81	15.1	81.3	314	275	295	238
Endosulfan	0.88	80	5.53	44.22	134.8	71.2	289	256	157	424
Disulfoton	0.88	3	168.47	286.73	200.0	130.0	766	1622	1383	843
Esfenvalerate	0.88	67	6.55	4.39	219.3	126.7	417	357	154	695
Ethoprop	1.01	26	19.35	286.73	12.2	65.6	407	384	472	232
Fonofos	0.88	8	55.06	44.05	25.7	60.8	188	186	149	198
Imidachloprid	0.88	450	0.97	1.54	1.9	74.0	115	78	23	152
Methamidophos	0.88	30	14.60	87.62	11.6	62.1	200	176	167	173
Methyl parathion	0.88	14	31.32	286.73	100.0	90.0	537	508	534	460
Oxamyl	8.38	6	86.05	33.53	63.9	94.3	282	278	192	346
Permethrin	0.88	500	0.88	9.29	43.1	141.2	265	194	72	371
Phorate	0.88	2	86.05	176.26	162.1	85.1	509	510	453	560
Phosmet	0.88	230	1.91	33.30	20.0	30.0	99	85	69	109
Piperonyl butoxide	0.88	5,000	0.09	5.00	1.7	28.0	49	35	15	61
Propargite	0.88	2,200	0.20	9.69	3.4	30.5	59	44	24	70
Pymetrozine	0.88	5,280	0.08	15.44	4.0	24.0	55	44	31	60
Pyrethrins	0.88	500	0.88	1.37	11.9	100.4	164	115	34	225
<b>Fungicides:</b>										
Chlorothalonil	0.88	5,000	0.09	7.81	26.3	30.4	80	65	33	115
Copper ammonium	0.88	650	0.67	0.29	1.3	30.0	47	32	9	63
Copper hydroxide	0.88	1,000	0.44	0.29	5.8	30.1	52	37	11	72
Copper resinate	0.88	5,000	0.09	0.29	5.0	30.1	51	36	11	70
Copper sulfate	0.88	300	1.46	0.29	6.4	23.2	42	31	11	60
Cymoxanil	0.88	960	0.46	5.48	4.8	34.2	62	45	20	79
Dimethomorph	0.88	3,900	0.11	10.00	5.0	20.0	45	35	23	53
Iprodione	0.88	3,500	0.13	20.78	3.1	47.7	96	72	45	107
Mancozeb	0.88	5,000	0.09	114.72	2.8	41.6	180	159	184	118
Maneb	0.89	5,000	0.09	80.07	7.7	44.1	154	132	135	124
Metalaxyl	1.01	670	0.75	1.36	0.7	113.0	172	116	31	228
Metiram	0.88	5,000	0.09	286.73	1.1	32.7	337	321	439	139
Propamocarb hydroch.	0.88	5,000	0.09	0.88	1.6	32.4	51	35	10	68
Sulfur	0.88	3,000	0.15	0.09	1.3	45.2	69	47	12	93
Triphenyltin hydrox.	0.88	156	2.81	286.73	78.7	38.4	424	407	482	307
<b>Other Chemicals:</b>										
Chloropicrin	0.88	250	1.75	100	10.0	30.0	156	142	164	105
Dichloropropene	0.90	224	2.00	287	0.4	46.8	358	336	444	167
Diquat	0.88	231	1.90	39.83	1.2	30.4	88	73	70	74
Endothall	0.88	51	8.62	4.39	1.5	26.8	50	41	23	60
Maleic hydrazide	1.15	5,000	0.11	0.46	18.1	26.5	58	45	16	89
Metam-sodium	0.88	285	1.54	95.49	3.4	58.5	187	159	161	148
Sulfuric acid	0.88	1,000	0.44	0.29	1.2	18.8	30	21	6	40

**Table 7. Potato Production in Wisconsin: Year 1995 Baseline and 1997 Pesticide Toxicity Unit Reduction Goals**

	Acres Treated	Total Pounds Applied	WWF-WPVG A Toxicity Unit Values	WWF-WPVG A Toxicity Units Subject to Acute Toxicity Reduction Goal	WWF-WPVG A Toxicity Units Subject to Chronic Toxicity Reduction Goal
<b>Herbicides:</b>					
Glyphosate	6,640	4,000	78.0		
Linuron	7,470	7,000	73.1		
Metolachlor	14,940	21,000	47.8		
Metribuzin	73,870	39,000	126.6		4,937,400
Pendimethalin	29,880	24,000	166.6		
Sethoxydim	8,300	2,000	60.8		
Total: All Herbicides	141,100	97,000			
Per Planted Acre		1.17			
<b>Insecticides:</b>					
Azinphos-methyl	21,580	26,000	220.3	5,727,800	
Carbofuran	13,280	13,000	383.5	4,985,500	
Dimethoate	23,240	11,000	314.4		
Endosulfan	54,780	60,000	288.5		17,310,000
Esfenvalerate	49,800	3,000	417.0		
Methamidophos	53,950	69,000	199.7	13,779,300	
Oxamyl	6,640	5,000	282.0	1,410,000	
Permethrin	18,260	4,000	264.7		1,058,800
Piperonyl butoxide	14,110	3,000	48.7		
Pyrethrins	8,300	830	164.3		
Total: All Insecticides	263,940	194,830			
Per Planted Acre		2.30			
<b>Fungicides:</b>					
Basic copper sulfate	4,150	13,000	42.1		
Chlorothalonil	73,040	408,000	79.8		32,558,400
Copper hydroxide	31,540	40,000	51.5		
Copper resinate	5,810	12,000	50.5		
Mancozeb	71,380	412,000	180.0		74,160,000
Maneb	11,620	76,000	153.9		11,696,400
Metalaxyl	12,450	4,000	172.0		
Propamocarb hydroch.	9,960	9,000	51.1		
Triphenyltin hydrox.	38,180	12,000	424.0		5,088,000
Total: All Fungicides	258,130	986,000			
Per Planted Acre		12			
<b>Other Chemicals:</b>					
Diquat	66,400	28,000	87.6		
Endothall	9,130	7,000	50.4		
Maleic hydrazide	6,640	13,000	58.4		
Metam-sodium	6,640	970,000	187.4		
Paraquat	5,810	3,000	91.0		
Sulfuric acid	10,790	1,632,000	29.9		
Total: Other Chemicals	105,410	2,653,000			
Per Planted Acre		32			
<b>Total Herbicides, Insecticides, and Fungicides:</b>					
Per Planted Acre	663,170	1,277,830		25,902,600	146,809,000
		15		312	1,769
<b>Acute Tox Reduction Goals for 1997:</b>					
25% Toxicity Units				6,475,650	
Ave. Reduction Per Acre				78	
<b>Chronic Tox Reduction Goals for 1997:</b>					
15% Toxicity Units					22,021,350
Ave. Reduction per Acre					265