Monitoring Progress in Reducing Reliance on High-Risk Pesticides in Wisconsin Potato Production

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ABSTRACT

A methodology is presented to monitor progress in reducing use of high-risk pesticides in potato production. Multiattribute toxicity factors are calculated by active ingredient that reflect each pesticide's inherent acute and chronic toxicity to mammals; toxicity to birds, fish and small aquatic organisms; and compatibility with biointensive Integrated Pest Management. These factors are then used to estimate pesticide-specific toxicity units (toxicity factor values multiplied by pounds of active ingredient applied). Wisconsin potato industry baseline toxicity units by type of pesticide and for 11-targeted higher-risk pesticides are presented for 1995, reductions in toxicity units are reported in 1997 and 1999, and reductions achieved in a commercial scale experimental field in 2000 are presented.

INTRODUCTION

Potatoes are produced in Wisconsin under irrigation on predominately sandy soils. The Central Sands, a major potato growing region, is characterized by shallow and vulnerable groundwater and high-quality surface waters that support a variety of fish and bird species and an active tourist industry. Potatoes are grown in rotation with a number of field crops and canning vegetables in intensive, high-yield production systems. Pest pressure is often intense and poses major management challenges with significant regional economic and environmental consequences.

For over two decades Wisconsin water quality monitoring results have highlighted the need for careful management of nitrogen inputs and soil-incorporated pesticides. Groundwater contamination with the insecticide aldicarb in the early 1980s threatened the industry's survival and triggered heightened regulatory activity. It also convinced growers and industry leaders that more should be done to develop and support adoption of "softer" prevention-based IPM systems and technologies.

Grower check-off funds have helped support a multidisciplinary team of University of Wisconsin-Madison researchers. The team works closely with growers and pest management consultants on a range of applied onfarm pest management and cropping system research projects. In close cooperation with the UW potato IPM team, the Wisconsin Potato and Vegetable Growers Association (WPVGA) established a collaborative project with the World Wildlife Fund (WWF) in 1996. The WPVGA-WWF collaboration set goals for reducing use of 11 high-risk pesticides and for progress along the IPM continuum toward biointensive IPM (Nowak, et.al, *in preparation*). A key related goal was to develop measurement methods suitable for monitoring and documentation of grower adoption of biointensive IPM practices, and for exploring the linkages between IPM adoption and lessened reliance on high-risk pesticides.

A multistakeholder advisory committee was formed and met several times in 1996 and 1997. Criteria were agreed upon to identify pesticides used in Wisconsin potato production that should be subject to risk reduction goals based on acute and chronic mammalian toxicity, as well as ecological risks and compatibility with biointensive IPM systems.

Four pesticides used in Wisconsin potato production in 1995 triggered the acute toxicity criterion: methamidophos, azinphos-methyl, carbofuran, and oxamyl. Seven pesticides triggered the chronic mammalian toxicity criteria -- the fungicides mancozeb, maneb, chlorothalonil, and triphenyltin hydroxide; the insecticides permethrin and endosulfan, and the herbicide metribuzin.

Incremental goals for reducing the toxicity units associated with use of high-risk pesticides were established for applicable to crop seasons 1997, 1999, and 2001. Pesticide use in 1995 was used in establishing the baseline because the U.S. Department of Agriculture's National Agricultural Statistics Service (USDA/NASS) did not survey potato pesticide use in Wisconsin in 1996. Hence, the collaboration's "first year" goal actually applies to changes in pesticide use from 1995 to 1997. The acute, chronic and combined toxicity percent reduction goals for 1997 were 25, 15, and 20% respectively. In 1999, (3rd year) these goals were 50, 30, and 40% respectively.

In addition to monitoring industry-wide changes in toxicity units, toxicity factor values are useful in assessing trade-offs stemming from changes in pest management systems on an "acre treated" basis. For example, many potato growers applying imidacloprid were able to drop an application of an organophosphate like methamidophos and/or a synthetic pyrethroid like permethrin. Based on average rates of application, the reduction in per acre toxicity units can readily be calculated when farmers make such a switch. In response to grower-interest, the team is incorporating the costs of alternative pesticides and management systems into the analysis, producing estimates of the marginal economic costs of reducing toxicity units through adoption of lower-risk chemistry and IPM system changes.

BACKGROUND

Interest is growing worldwide in the potential of IPM to reduce the direct and indirect health and environmental costs associated with pesticide use. State, federal, and international agencies and organizations are funding or participating in programs designed to promote IPM adoption. Environmental and consumer groups are exploring ways to promote and reward IPM adoption through marketplace initiatives (Hoppin, 1996). Several groups are pursuing "green labels" (see the recently launched "Consumers Union Guide to Environmental Ecolabels" site, http://www.ecolabels.org/home.cfm). The WWF/WPVGA/UW collaboration is developing standards for potato production and pest management in preparation for marketing eco-labeled fresh market potatoes in 2001 (Lynch et al., 2001).

Pest managers, researchers, and policy-makers need better tools to monitor the consequences of changes in pest pressure, resistance, and IPM systems (Ehler and Bottrell, 2000). Two traditional measures of pesticide use -- pounds of active ingredient applied per acre, and number of applications -- are inadequate in estimating the agronomic, environmental and public health consequences of pesticide use (Barnard et al., 1997). A review of several efforts to develop new measurement tools appears in the 1996 Consumers Union book *Pest Management at the Crossroads* (Benbrook et al., 1996). Levitan prepared a detailed comparative assessment of pesticide impact measurement systems under development both in the Untied States and abroad (Levitan, 1997).

Improved measurement systems and tools are needed to track trends and address tradeoffs. Many exogenous factors can alter pest pressure and/or pest management system efficacy – landscape diversity, pest resistance to pesticides, pest aggressiveness to pesticides (e.g. new, more aggressive strains of pests) regulation, new products, changes in pesticide prices, new IPM tactics, and resistant cultivars. Potato processors and buyers and farm lenders also periodically impose contract or loan provisions impacting pest management systems.

Measurement systems need to be dynamic and pliable and should focus on reducing use of higher-risk pesticides (Ehler and Bottrell, 2000). Such systems are a structured framework within which to pose and answer questions about the human health, environmental, ecological, and cost-related impacts of changes in pest management systems. The necessary components of a pesticide risk measurement system will vary as a function of cropping systems, soil and climatic conditions, and the dominant risk and environmental concerns in the geographic region under study.

There is no inherently "right way" to measure pesticide toxicity and risks. All systems must somehow take into account the volume of pesticides applied, exposure patterns, and the inherent toxicity of active ingredients. A variety of factors can influence exposure levels and frequency, and hence risk. Our measure “toxicity units” reflects potential toxic impact; factors affecting exposures in and stemming from a given cropping system will determine whether the inherent toxicity of an applied pesticide results in real harm.

Comparative pesticide risk indices and toxicity factor values are most reliably used in monitoring changes over time and in comparing the risks associated with groups of pesticides or alternative pest management systems. Such comparisons provide insights into the magnitude of environmental and public health gains possible from progress along the IPM continuum, changes in regulatory policy, or an infusion of research support for biointensive IPM.

CALCULATING TOXICITY FACTOR VALUES

Several properties and parameters contribute to a pesticide’s mammalian and ecotoxicity and compatibility with biointensive IPM. Four component indices are used in our system within a multiattribute toxicity factor value equation: acute mammalian toxicity (AM), chronic mammalian toxicity (CM), ecological impacts (ECO), and impacts on beneficial organisms and IPM systems (BioIPM). The later two indices are, in turn, made up of multiple subindices, as explained below.

In the process of calculating component index values for each active ingredient and combining them into a multiattribute measure of relative pesticide toxicity, several issues typically arise (Landy, 1995). Component indices are structured such that larger values imply higher toxicity or risk. In the case of toxicological measures of dose such as LD-50s (lethal dose at which 50 percent of test animals are killed) or EC-50s (environmental concentration at which 50 percent of test organisms are killed), we calculate inverse values so that rising numbers equate with rising toxicity.

Scaling entails conversion of the range of actual values within a component index or subindex to roughly the same range of values. It is a necessary step to keep one component index – chronic mammalian toxicity, for example -- from dominating multiattribute toxicity factor values. In the absence of scaling, the index with the highest values and greatest variability will tend to account for a disproportionate share of the variability in a multiattribute index. The same point applies to the subindices that are used to calculate index values (e.g., the avian, fish, Daphnia subindices that are part of the Ecotoxicity index). Further details on how each subindex was scaled are presented in the next section.

Outlier values also require attention. Any maximum value in a component index that is more than twice as large as the next highest value has been reviewed as a potential outlier. In such cases, we assess available data to determine if the difference in values indeed reflects actual differences in toxicity or an artifact of the accessible data. In cases where an adjustment was found necessary, guidance regarding how to do so was sought from the WWF-WPVGA-UW project advisory committee. In all component indices and subindices, the maximum value allowed is 200.

Data gaps are pervasive when calculating pesticide toxicity factor values. For example, even basic mammalian toxicity data are lacking for most biopesticides and copper based fungicides since the EPA has exempted pesticides containing these ingredients from testing and tolerance requirements. Fish toxicity data is limited on fungicides and relatively few herbicides have been tested for impacts on beneficial arthropods. Various default and provisional values have been established in such cases, as discussed in each of the following sections.

In most cases, data gaps reflect a lack of concern because of the inherent and known properties of a pesticide or the way a pesticide is used. Likewise, the most complete and highest quality data typically exist for those parameters associated with known and recognized risks. For this reason, most default values apply to low risk parameters and hence even inaccurate estimates are not likely to significantly influence final toxicity factor values.

COMPONENT INDICES

The **acute mammalian (AM) toxicity index** is based on oral LD-50s from rat assays. 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 published in the

Federal Register (Table 1). In a few cases, LD-50 values were derived from "Farm Chemicals Handbook 2000, Volume 86" (Meister, 2000), company, or other sources.

Inverse LD-50 values are calculated so that rising index values correlate with rising toxicity. A scaling factor of 500 is used in calculating acute mammalian (AM) values. For example, the LD-50 of the organophosphate insecticide azinphos-methyl is 16 mg/kg, so the scaled inverse acute mammalian toxicity index value is 31.25 (500/16). The most acutely toxic pesticide used in Wisconsin potato production is phorate, which has an LD-50 of 2 mg/kg and a scaled inverse LD-50 value of 250, which was capped in Table 1 at the maximum allowed value, 200. The least acutely toxic pesticides have LD-50 values of 5,000 mg/kg or higher (5,000 mg/kg is typically the highest dose tested). When scaled, AM values of 0.1 are generated for these active ingredients (e.g., chlorothalonil, the EBDCs, and strobilurin fungicides). The 0.09 AM value for pymetrozine reflects an LD-50 of 5,820 mg/kg, a level above the maximum dose typically tested.

The table shows clearly why acute mammalian toxicity contributes little to the total toxicity factor values for many widely used pesticides. AM values for 28 active ingredients are below 1. Only two organophosphate insecticides – phorate and disulfoton – have values over 100.

The **chronic mammalian (CM) toxicity index** captures risks stemming from longer-term, low-level drinking water, occupational, and dietary exposures. It encompasses the capacity of an active ingredient to cause adverse health impacts such as cancer or impaired immune system function and is driven largely by Environmental

Protection Agency population-adjusted chronic Reference Doses (otherwise referred to as long-term "Acceptable Daily Intakes") (Office of Pesticide Programs, 2000).

The index is a composite variable developed and 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). The CM index formula is:

$$\text{CM Value Pesticide}_x = [(0.1/\text{cRfD}_x) \times \text{ED}_x] + [Q^*_x \times 50 \times \text{CLASS}_x]$$

Where:

RfD: EPA chronic Reference Dose (or default value or provisional estimate)

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

Q*: EPA oncogenic potency factor (slope of the dose-response curve)

CLASS: EPA Oncogenicity Classification. If Class A or B_2, value=10; if C, value=5; if D, value=2.

Table 1 reports CM values by active ingredient, as well as chronic Reference Doses (cRfD) and oncogenic potency factors for those active ingredients deemed carcinogenic by EPA. Chronic RfDs are derived from Federal Register notices (pesticide Federal Register notices are accessible at http://www.epa.gov/fedrgstr/EPA-PEST/index.html) and are current through July 2000. Oncogenic potency factors are from EPA's periodic summary of data on pesticides shown to cause cancer (Burnam, 1999) or recent Federal Register documents reporting revised risk assessments.

Pesticides known to be endocrine disruptors are treated differently in calculating CM values; note that the cRfD portion of the above CM formula includes an added three-fold safety factor for such pesticides. An EPA-sponsored symposium in 1995 adopted the following consensus definition of endocrine disruptor:

> "An exogenous agent that interferes with the production, release, transport, metabolism, binding, action, or elimination of natural hormones in the body responsible for the maintenance of homeostasis and the regulation of developmental processes (Kavlock, et al., 1996).

The WWF/WPVGA/UW collaboration relies on the WWF's Wildlife and Contaminants Program (WWF-WCP) staff, and their extensive endocrine disruptor research database, to identify pesticides that are endocrine disruptors, as defined above. A member of the WCP team, Dr. Francoise Brucker-Davis has published a thorough review on endocrine-related thyroid effects (Brucker-Davis, 1998). This review discussed evidence of thyroid effects covering nine of the 12 pesticides now identified by the collaboration as known or suspect endocrine disruptors. The collaboration's original 1995 list of five endocrine disruptors was derived from a 1993 *Environmental Health Perspectives* article (Colborn, et al., 1993) and has twice been updated on the basis of new information. A review of the estrogenic potential of four synthetic pyrethroids supported inclusion of esfenvalerate and permethrin on the list (Go, et al., 1999). Pesticide impacts on neural development can also be endocrine related and supports the placement of several organophosphate and carbamate insecticides on the list (Repetto et al., 1996, Bigbee et al., 1998 OR 1999).

A special issue of *Toxicology and Industrial Health: An International Journal* (Colborn et al., 1999) surveys much of the new evidence linking pesticides to endocrine-mediated effects. This important contribution was co-edited by Dr. Theo Colborn, WWF-WCP director, Polly Short, a member of the WWF-WCP staff, and Michael Gilbertson, Secretary of the Work Group on Ecosystem Health of the International Joint Commission. The volume's 21 papers synthesize the evidence supporting the collaboration's current list of endocrine disruptors, as well as the possible need to add a few additional active ingredients to the list in future updates.

In setting cRfDs, the EPA assesses evidence of heightened toxicity to pregnant and/or young animals (Kimel, 1995). The most common tests where such effects are seen include two-generation reproduction studies and developmental neurotoxicity studies. In such cases, EPA often adds a three-fold (3-X) to 10-X added safety factor to account for endocrine-related risks and other heightened risks faced by vulnerable populations (Office of Pesticide Programs, 1999).

The 10-X provision in the 1996 Food Quality Protection Act (FQPA) codified EPA's existing practice of adding up to an additional 10-X safety factor in stetting the RfDs of chemicals that have been shown to be more toxic to young or pregnant animals or for chemicals with significant data gaps. Even prior to passage of the FQPA though, EPA had imposed a 3-X added factor in 21 cases, a 10-X added factor in 22, and greater than 10-X in six cases involving widely used food use pesticides (Office of Pesticide Programs, 1995). In the majority of these cases, poorly designed studies, a lack of a "No Observed Effect Level," or a major data gap led EPA to impose an added safety factor, although evidence of birth or other developmental effects was also a reason in a few cases.

When the FQPA is fully implemented, pesticide cRfDs will presumably reflect any heightened risk faced by pregnant or young animals, including endocrine effects.

This process will take at least another five to seven years, given the time needed for EPA to develop new endocrine disruptor test protocols and for industry to generate new data, and then for EPA to evaluate the new data. In the interim, the collaboration advisory committee felt it appropriate to include an added safety factor reflecting potential endocrine effects, set at 3-X. While this safety factor is less than the 10-X called for by the FQPA, in many cases EPA has already added an additional safety factor for reasons that overlap to some degree with endocrine-related concerns.

The unadjusted CM index value of the fungicide triphenyltin hydroxide was clearly an outlier – 2,400 compared to 1,000 (value for metiram and ethropop). These pesticides are among seven in Table 1 that have CM index values capped at 200. Five of the seven are organophosphate (OP) insecticides with very low chronic Reference Doses (cRfD). Any cRfD below 0.0005 mg/kg/day will result in a CM index value over 200, just from the factor in the equation driven by cRfDs. For active ingredients that are suspect endocrine disruptors, a cRfD at or below 0.0015 mg/kg/day will result in a CM index value capped at 200.

Several relatively new pesticides including the herbicide rimsulfuron, the insecticides spinosad, imidacloprid, and pymetrozine, and the fungicides azoxystrobin, dimethomorph, and cymoxanil have highly favorable mammalian toxicity profiles. These active ingredients are components of the biointensive IPM program that has made significant reductions in pesticide toxicity risks in Wisconsin potato production (Lynch et al., 2000). The EPA's emphasis on accelerated registration of several reduced risk, "softer" pesticides has and continues to cut one to two years off the time required for products to reach the commercial market in Wisconsin. Our experience suggests that accelerating full registration of reduced risk alternatives is one of the most important steps the agency can take to help growers of minor use crops transition away from higher-risk, FQPA-targeted pesticides.

The **ecological (ECO) toxicity index** integrates avian, aquatic and small invertebrate ecological risks. The ECO index is composed of three subindices.

Avian toxicity values were provided by Dr. Pierre Mineau, Canadian Fish and Wildlife Service. While there are over 10,000 bird species in the world, pesticides are generally tested in just one to three species for acute toxicity. With an international team, Mineau developed an avian toxicity model, drawing on a database with over 2,300 acceptable LD-50 values for 872 pesticides (Mineau et al., 2001). These valid LD-50 studies were used to estimate dosage levels expected to protect 95 percent of bird species. The resulting values are a robust index of relative avian toxicity following acute exposures and have been subject to extensive international peer review. Work is underway to expand the model to encompass sub-acute and reproductive effects. As in the case with other parameters, updated values will be incorporated in our estimates of avian toxicity when available.

Impacts of pesticides on small aquatic organisms are estimated based on data on water fleas, *Daphnia magna*, the most frequently treated crustacean species in the EPA-Ecotoxicology database (Montague, 1999). Comparable studies were selected from the EPA database in terms of the concentration of the material tested (at least 90 percent concentration and usually 100 percent technical material), as well as the length of exposure (usually 48 hours). Average values were calculated when more than one comparable study was available.

Extensive data on pesticide impacts on several fish species are available from studies in EPA files, much of it from a comprehensive report by U.S. Fish and Wildlife biologists (Mayer and Ellersieck, 1986). Rainbow trout, *Oncorhynchus mykiss*, and bluegill, *Lepomis macrochirus*, are the two most widely used test species known to thrive in Wisconsin surface waters. Comparable studies were selected by active ingredient, most with concentrations between 100 percent and 75 percent active ingredient. When there were two or more studies, LC-50 values in trout and bluegill studies were averaged.

To produce Daphnia, trout and bluegill subindices, LC-50 values were inverted, so that the higher the subindex value, the more toxic the pesticide in a given assay. The resulting inverted values vary over as many as seven orders of magnitude. Plus, the values for insecticides are routinely much higher than herbicide and fungicide values. For example, the average insecticide Daphnia subindex value is over 50 times greater than the average fungicide value.

Scaling factors were applied to deal with these wide ranges in subindex values. Values were capped at 200, so that the dozen or so very toxic insecticides would not dominate the scores for these variables. We used a ten-fold lower scaling factor for insecticides where the greatest impact would be expected in contrast to herbicides and fungicides to reflect the greater toxicity. The Daphnia scaling factor for insecticides was 0.025 and for herbicides and fungicides, 0.25. The trout-scaling factor was 0.1 for insecticides and 1.0 for other pesticides. The bluegill values were 0.25 and 2.5 for insecticides and other active ingredients. Subindex values are reported in Table 2. Avian, Daphnia, and fish values in Table 2 for each pesticide active ingredient were then added, producing final Ecotoxicity Index values. As expected, the high Ecotoxicity values for esfenvalerate and endosulfan reflect largely aquatic toxicity, while the relatively high values for carbofuran and some OPs are largely from avian toxicity.

Better data are needed on secondary and tertiary ecosystem impacts to estimate more accurate, complete ecotoxicity values. Developing study protocols and supporting needed research warrant more attention by regulators, federal research agencies, and the pesticide industry. Priority research topics should include:

- Decreased abundance and diversity of invertebrates;
- Impairment of long-term reproductive success; and
- Reduction in the number of plants that serve as hosts for invertebrates or as critical elements in the food chain.

The **BioIPM Index** encompasses impacts of pesticides on the ability of farmers to progress along the IPM continuum toward more prevention- and biologically-based IPM systems (such as those described in Lewis et al., 1997). The components of the BioIPM index include resistance management, impacts on beneficial non-target organisms, and bee toxicity. With the exception of impacts on bees, the data needed to rigorously calculate the other two BioIPM subindices are not universally available. A team of Wisconsin potato growers, pest management experts, and university faculty was convened to develop preliminary estimates based on collective knowledge and experience. Values in Table 3 reflect pesticide use patterns, soils and cropping systems in Central Wisconsin and are not necessarily appropriate for other potato growing regions.

The team of experts developed an estimate of each pesticide’s likelihood of triggering resistance in target pests (see column one, Table 3). For insecticides, values were computed from estimates of the ability of insects to adapt to each insecticide's mode of action (scale 1, "less likely" to 3, "prone to develop resistance"), the active ingredient's spectrum of activity (scale 1 to 10, narrow to broad spectrum of activity), and foliar half-life values. The pyrethroid, esfenvalerate had the highest score of 192 which reflects widespread resistance in CPB (Graphius, 1997). For fungicides, values were computed taking into account leaf-half lives and an estimate of the ability of pathogens to adapt to each fungicide's mode of action. A scale of 1 to 5 was used, with 1 assigned to active ingredients with a "remote" chance of leading to resistance and 5 assigned to those "likely" to lead to resistant phenotypes. Metalaxyl, mefenoxam, rimsulfuron, and pendimethalin have the highest subindex value of 100; the use of each active ingredient has led to documented cases of resistance (Weed Science Society of America, 2001; IRAC, 2001; FRAC, 1999.

Insecticide impacts on beneficial arthropods were derived from the "Toxic Effect" index developed at Oregon State University (Theiling and Croft, 1988). "Scaled Impacts on Beneficial" values were derived from "Toxic Effect" values using the formula:

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

"Toxic Effect" values were not available for most other pesticides. Values in column two, Table 3 for these other classes of pesticides are derived predominantly from data developed to estimate the Cornell University "Environmental Impact Quotient" (Kovach et al., 1992). The team of experts projected values not otherwise available.

Many species of soil microorganisms play important roles in enhancing nitrogen retention and availability, promoting healthy root development, and suppressing nematodes and related plant pathogens. Further work is needed to develop a subindex within the BioIPM index that captures pesticide impacts on soil microorganisms. Development of such a subindex remains a collaboration priority.

Pesticide impacts on bees are among the most significant economic losses associated with pesticide use, especially where fruit and vegetable yields depend on pollination. Bee toxicity data was obtained from Dr. Pieter Oomen, a scientist working for the Dutch Ministry of Agriculture. The Oomen dataset is considered one of the most authoritative in the world and includes data on both contact and oral routes of exposures (Heneghan, 1998). In a few cases, values were also extrapolated from the acute bee toxicity ratings in “Farm Chemicals Handbook” (Meister, R., 1998, 1999).

The bee toxicity value for imidacloprid required adjustment because of the large difference in bee toxicity as a function of formulation and when and how this pesticide is applied. When applied as a liquid foliar spray, imidacloprid’s scaled bee toxicity value is the highest of any pesticide used in Wisconsin potato production and would be capped at 200. But when applied as a soil insecticide at or soon after planting, there is little risk of exposure to bees. We project that the at or near planting use pattern accounts for over 75 percent of pounds applied and results in a bee toxicity rating of 50 (National Agricultural Statistics Service, 1999). A weighted average imidacloprid bee impact value of 87.5 was calculated using the formula [.75(50) + .25(200)]. The scaled bee toxicity value for spinosad was set at 100, a mid-range value based on conflicting data on spinosad bee toxicity levels (Heneghan, 1998; Montague, 2001).

BioIPM index values are calculated by summing the values of the three subindices as reported in Table 3, and then multiplying the result by 0.5, a scaling factor.

In general, average values of insecticides are substantially higher than for other classes of pesticides. Also note relatively high scores for many recently registered single site reduced-risk pesticides. These scores reflect the potential for newer, often more selective pesticides to select for resistance, as well as sometimes-significant impacts on non-target organisms, particularly bees. The project advisory committee decided that values for resistance and bee impacts should ideally be adjusted in response to clear label directions that preclude use of a pesticide in a way that gives rise to resistance or significant risk of bee impacts. For example, the azoxystrobin and spinosad labels have explicit and enforceable resistance management provisions built into them; the collaboration team took these and similar label directions into account in setting BioIPM values. Ongoing work is needed to review other new and revised pesticide product labels that may also contain binding use pattern restrictions that markedly lesson the risk of impacts on bees or beneficials, or the risk of selecting resistant pest biotypes. As toxicity factor values are reviewed each year in response to new data and/or refined methods, we will assess all risk indices and subindices to determine whether similar adjustments, driven by enforceable risk-mitigation measures on pesticide labels, are warranted and practical.

Final multiattribute **toxicity factor values** are calculated from the four component indices: AM, CM, ECO, and BioIPM. While researchers are often interested primarily in a single dimension of pesticide risk and impact, farmers and society face the need to balance multiple risks and benefits in identifying the least disruptive and dangerous product across all categories of risk and impacts. The equation used to calculate the Wisconsin collaboration’s multiattribute index is:

$$\text{Value for Pesticide}_x = (0.5)*AM_x + CM_x + ECO_x + (1.5)*BioIPM_x$$

The project Advisory Committee decided to apply a (0.5) weight to the acute mammalian toxicity component because of the relative lack of circumstances leading to acute worker and applicator exposure. In addition, U.S. Department of Agriculture pesticide residue data were reviewed and show low frequency and levels of residues of acutely toxic pesticides in potatoes, especially after washing, peeling, cooking and/or processing (Agricultural Marketing Service, 1996). The project Advisory Committee placed a weight of (1.5) on the BioIPM component index in order to emphasize the importance of the impacts of pesticides on the viability of biointensive IPM systems.

In light of the relatively high average BioIPM values and the added weight placed on this component index (the 1.5 weighting factor in the formula), BioIPM values account, on average, for about 65 percent of the multiattribute values across the pesticides used in Wisconsin potato production. For 19 of 67 active ingredients studied, BioIPM values account for over 90 percent of multiattribute toxicity factor values. The Ecotox component accounts for the smallest share, just under 13 percent. The two mammalian toxicity components account for about 23 percent. The project team believes that the BioIPM component index accounts now for more weight than appropriate and that the Ecotox index warrants heavier weight. Options to shift the weights through changes in scaling factors and/or different weights will be explored when the toxicity factor values are updated for crop year 2002.

Multiattribute toxicity factor values per pound of active ingredient in Table 4 vary from below 40 for several fungicides, a few herbicides, and the foliar insecticide *Bacillus thuringiensis*, to as high as 621 for the organophosphate insecticide phorate (used rarely in Wisconsin). Pesticides scoring above 300 tend to have higher than average mammalian toxicity and Ecotox factor values.

DISCUSSION

Toxicity factor values are used in several ways in setting goals and monitoring progress in the WWF-WPVGA-UW project. Table 5 summarizes industry-wide trends since 1995 in reducing pesticide use and aggregate toxicity units by active ingredient and type of pesticide. Toxicity units per planted acre resulting from fungicide use declined 4 percent and 19 percent in 1997 and 1999, respectively, compared with the 1995 baseline and despite severe pathogen pressure. In 1997 there was a significant shift, but little overall reduction from less use mancozeb and greater reliance on chlorothalonil. In 1999 azoxystrobin was registered and 83 percent of potato acreage was treated an average of 3 times with this low-risk fungicide. The widespread adoption of azoxystrobin as a low-risk alternative is attributable to its superior efficacy against early blight, often accompanied by an increase in yield, which was demonstrated in 1998 in fields treated under an experimental use permit granted by the EPA.

The low toxicity factor value for azoxystrobin (46) and its low application rates (0.11 lbs a.i./A) combine to generate only 5 toxicity units per acre-treatment, compared with about 185 and 254 toxicity units from typical one-pound applications of mancozeb and metiram, respectively. Thus, azoxystrobin and other reduced risk fungicides in the EPA pipeline will significantly reduce toxicity units associated with disease control. In 1999 there was a clear drop in use of mancozeb and maneb. But since azoxystrobin must be alternated with broad-spectrum fungicides to avoid selection for resistance, chlorothalonil and metiram use increased in 1999 relative to 1995. Adoption of azoxystrobin largely accounts for the 19 percent drop in fungicide toxicity units per acre in 1999 compared to 1995.

As growers learn to optimally use newly registered low-risk strobilurin fungicides in rotation with established products such as chlorothalonil and new fungicide active ingredients in development, further reductions in toxicity units from disease management should be achieved. However, since there are concerns of the development of resistance to these new active ingredients, they must be applied in rotation with chemistries with difference modes of action to maintain the effectiveness of the reduced-risk materials as long as possible.

Toxicity units associated with insecticide use varied considerably between years (Table 5). In 1997 a dramatic decrease (62 percent) in total toxicity units per planted acre occurred. This decrease resulted largely from the registration of imidacloprid in 1995. The excellent efficacy of imidacloprid against key potato pests, Colorado potato beetle, *Leptinotarsa decemlineata*, green peach aphid, *Myzus persicae* and potato aphid, *Macrosiphum euphorbiae* resulted in widespread application of imidacloprid and accompanying reductions in the use of insecticides that had been targeted at these pests previously. The most significant use changes included elimination of azinphos-methyl, carbofuran and oxamyl; an 83 percent reduction in endosulfan toxicity; and, a 75 percent drop in methamidophos toxicity units. The total drop in insecticide toxicity units would have been even greater if growers had not needed to almost triple the pounds applied of dimethoate to address potato leafhopper, *Empoasca fabae*, pressure in 1997.

Toxicity units per acre from insecticide use rose from 279 in 1997 to 505 in 1999, still a 31 percent drop from the 1995 baseline. The increase in insecticide use in 1999 resulted from intense pest pressure from potato leafhopper, *Empoasca fabae*, which migrated into Wisconsin earlier and in higher numbers than had been previously recorded, along with heavy Colorado potato beetle pressure. Imidacloprid use increased by 43 percent over 1997 but high CPB populations in fields not treated with imidacloprid required more foliar applications than typically needed. As a result, endosulfan use increased almost to 1995 levels, esfenvalerate use doubled compared to 1995 levels (accompanied by an 500 percent increase in piperonyl butoxide to combat resistance) and small acreages were treated with azinphos-methyl, oxamyl and phosmet.

The year-to-year variability in toxicity units associated with insect control reflects the routine, often extreme variability in insect population pressure. Our experience in Wisconsin confirms that fluctuations in individual pesticide use patterns should be anticipated and that three- to five-year moving average measures of pesticide use should be tracked whenever possible in large-scale IPM implementation and pesticide risk reduction projects. Otherwise it is likely that growers, researchers, and other stakeholders will be overly encouraged in years when population pressure is low, and inappropriately alarmed over use in bad years. Projects need to focus on the overall trend in average per acre toxicity units, a measure that has clearly declined over the last five years in Wisconsin potato production, despite sometimes quite dramatic year-to-year swings and a dramatic increase in blight disease pressure. Newly registered low-risk insecticides such as spinosad for Colorado potato beetle (8 toxicity units/application) and pymetrozine for aphids (20 toxicity units/application) will continue to strengthen this downward trend in average toxicity units per acre.

Toxicity units associated with herbicide use are generally low with current weed management systems. Major products applied are metribuzin (58 toxicity units/application), rimsulfuron (3 toxicity units/application) and sethoxydim (9 toxicity units/application), with variable use of metolachlor (43 toxicity units/application), linuron (31 toxicity units/application) and pendimethalin (85 toxicity units/application). Such programs typically generate a total of 80-110 toxicity units/acre. Metribuzin and pendimethalin use have remained relatively constant since 1995 and these herbicides represent the bulk of toxicity units associated with the total herbicide program (Table 5). Rimsulfuron was registered during this period and represents an effective low toxicity herbicide alternative that has been widely adopted by growers. Concerns over resistance and the spectrum of weeds controlled, however, dictate that rimsulfuron be used in combination with other herbicides and thus constrains potential to reduce toxicity units. The 1995 toxicity unit baseline for insecticides was 730 per planted acre – about seven-times herbicide toxicity units per acre.

USING TOXICITY VALUES TO OBTIAN MARKETPLACE REWARDS

Toxicity factor values have proven useful in determining grower and industry-wide progress toward specific pesticide risk reduction goals as outlined by the collaboration. They also are useful when analyzing pesticide use trends over time and sorting out the influence of changes in pest pressure and pesticide product availability and efficacy. This year (2001) the collaboration is taking another step in an ongoing effort to capture rewards for grower-innovation in the market place. We have established toxicity factor-based pesticide use ecolabel standards for fresh market potatoes, as well as IPM adoption standards (Sexson and Dlott, 2001). About 20 growers are now working to meet the ecolabel standards and a third-party certifier will assess progress later in the season.

Growers producing short-season fresh market potatoes (less than 90 days from emergence to vine-kill) must remain within a cap of 800 total toxicity units per acre for the season; long-season growers (more than 90 days from emergence to vine-kill) must remain under 1,200 toxicity units. The collaboration has been concerned from its first meeting with how to incorporate changes in pest pressure in quantitative goals, without risking major crop and economic losses for the industry or individual growers. In 2001, participating fresh market growers within 25 miles of a field with late blight will have 400 more toxicity units to cover fungicide use if 18 severity values for late blight are reached on their farm by June 1st, or 200 more units if late blight hits 18 severity values by June 15th. These adjustments reflect our first attempt to explicitly build pest pressure into our measurement system. Other adjustments are likely to be developed and applied in the future.

In addition all ecolabel program growers need to comply with a “Do Not Use” list including 11 active ingredients (aldicarb, azinphos-methyl, disulfoton, methamidophos, carbofuran, carbaryl, oxamyl, endosulfan, phorate, diazinon, permethrin, and paraquat). Resistance management conditions are placed on several other moderate- to high-risk pesticides including dimethoate, esfenvalerate, the EBDC fungicides, triphenyltin hydroxide, azoxystrobin, and the soil fumigant metam-sodium.

Ecolabel growers also face IPM implementation challenges. Short-season growers must score a minimum of 204 points in an IPM practices survey, and long-season growers must score 211 points if the potatoes are being stored. Short season growers who do not store their potatoes must receive 195 points and long season growers must earn 202 points. The points are derived from an extensive survey of IPM practices, with each practice assigned weights (points) reflecting its importance in supporting progress along the IPM continuum (Sexson and Dlott, 2001).

EVALUATING REDUCED RISK TRANSITION STRATEGIES IN COMMERCIAL POTATOES

In addition to activities supporting the emergence of ecolabeled Wisconsin potatoes in 2001, growers, crop consultants, and University of Wisconsin pest management specialists are currently developing and testing complex, multitactic transition strategies applicable to all major potato pests. Toxicity factor values, coupled with data on costs per acre-treated with alternative pesticides or cultural practices, are proving helpful in evaluating the potential impact of various pest management systems and technologies.

Reduced-risk insect and disease management programs integrating the basic components of successful potato IPM (crop scouting, pest prediction and thresholds) with use of low toxicity pesticides have been developed with growers and tested in large-scale replicated trials. This protocol has enabled us to evaluate various insect and disease management programs separately and in combination on 12 commercial fields in 2000 and 2001. As an example, we present data here from a combined insect/disease evaluation conducted in central Wisconsin in 2000. Russet Burbank variety potatoes were planted on April 25th, 2000 in a center pivot irrigated field at Coloma, Wisconsin. Conventional and reduced-risk foliar disease programs, combined with conventional and reduced-risk systemic (Table 6) and foliar (Table 7) insect programs were applied to 48 row x 1200' plots (3.3 acres) replicated 3 times in a randomized complete block design. Treatment decisions were based on weekly scouting and disease prediction and applications were made by the grower.

Disease pressure was high in 2000 with moderate early blight in the field and late blight in the immediate vicinity. Late blight severity valves passed the threshold of 18 in early June and spray programs were initiated on June 9 and continued on a 7-day schedule until September 5. The conventional fungicide program required 17 applications, primarily mancozeb, chlorothalonil and tin and cost $111.00 per acre. Toxicity units totaled 2,421 per acre, about twice the level allowed in the ecolabel standard for season-long potatoes. The reduced-risk program used 3 applications of azoxystrobin in early season in rotation with chlorothalonil and relied on chlorothalonil thereafter for a toxicity unit total of 1,169 (60 percent reduction) at a cost of $153.00 per acre (27 percent increase). Disease control was more effective in the reduced-risk program with significantly lower incidence of early blight. No late blight was found in either program.

Two insect management approaches involving foliar and systemic insecticides were evaluated. Insect populations were moderate in this field. Colorado potato beetle larvae in the conventional foliar program required one application of esfenvalerate for 1st generation control, timed to target 2nd instar larvae and a follow-up application of cyfluthrin for 2nd generation larvae. In the reduced-risk foliar program two applications were also required using spinosad and *Btt*. Toxicity units were 55 percent lower in the reduced risk foliar program and costs were increased by $12.00 per acre. Both programs held Colorado potato beetle larvae at low levels throughout the season and no defoliation was recorded. Potato leafhopper populations were held below threshold (1 adult/sweep) with a single insecticide application in both programs. Aphids did not require treatment.

In the systemic treatment evaluation, imidacloprid performed well in both conventional and reduced risk programs (where the imidacloprid rate was reduced) with few larvae and no defoliation observed. Potato leafhoppers required one application in both programs to hold adults and nymphs below threshold. Toxicity units were 31 percent lower in the reduced-risk program and pesticide costs were also $10.00 per acre lower.

The impact of the combined insect and disease programs on yield and costs are shown in Tables 6 and 7. For systemic insect and foliar disease control, the reduced-risk program was more expensive ($32.00 per acre), but yield was significantly higher (15 cwt/A) as a result of the improved early blight control associated with use of azoxystrobin. The cost of the reduced risk program per cwt was only marginally higher (5.6 cents per cwt) (Table 6) and at a $5.00/cwt selling price this reduced risk program would thus result in a net gain of $43.00/A. The toxicity units associated with this program were reduced by 51 percent (Table 6).

For foliar insect and disease control (Table 7), reduced-risk program costs were $54.00 per acre higher, reflecting the increased cost of low-risk foliar insecticides, but yields were again increased (20 cwt/A), and the cost/cwt was increased by only 10.3 cents/cwt (Table 7). At $5.00/cwt, the reduced-risk foliar program would result in a net gain of $21.00/A to growers based on the significant yield increase achieved. Toxicity units associated with the reduced-risk foliar program were reduced by 1,328 per acre (52 percent).

The results illustrate the utility of the toxicity measurement system described and the potential to markedly reduce per acre toxicity units. This research clearly demonstrates that under commercial production conditions, reduced risk fungicides and insecticides can provide effective pest control with significantly less overall toxicity. While no direct monetary value can be placed on lowering toxicity units at this time, the dramatic reductions that were achieved in this field experiment would allow Wisconsin growers to meet the crop year 2001 target for total toxicity units for ecolabeled potatoes. The collaboration's environmental and consumer participants consider these findings credible and encouraging.

Further progress is expected in improving the effectiveness and lowering the cost of reduced-risk pesticide programs for potatoes as growers gain experience and as new low-risk pesticides (such as additional strobilurin fungicides and the insecticide thiamethoxam) are registered for potatoes. However, deployment of these new, low-risk pesticides must proceed in accord with sound resistance management plans to maintain product efficacy. We also see potential for new sorts of area-wide population suppression methods, many based on cultural practices, in the early and late part of the season.

CONCLUSIONS

Pesticides pose highly variable environmental and human health risks. A wide range of activity is underway to promote more biologically based, less disruptive and hazardous pest management systems. Most entail setting goals for reduction in high-risk pesticide use and/or IPM adoption, and ways to monitor progress. All will benefit from new tools to track changes in the toxicity of pesticides required to support a given IPM system (Ehler and Bottrell, 2000).

The toxicity unit methodology developed by the collaborative potato project in Wisconsin has produced information now serving several useful purposes. Progress in reducing reliance on high-risk pesticides has been monitored since 1995. Tradeoffs are made explicit as new pesticides and technologies replace older, higher-risk products. The need for attention to the management of new sorts of risk – resistance management and toxicity to bees, for example – is evident.

Growers and researchers are calculating the per acre toxicity units associated with alternative IPM systems. By factoring cost consequences into the equation, the Wisconsin project is working toward analytical tools responsive to the needs and concerns of both farmers and environmentalists.

Despite data gaps and less than complete coverage of environmental and BioIPM impacts, the methodology does highlight the potential to reduce the impact of pesticides on a given field or industry-wide through targeted research, use of new pesticide chemistry, and IPM implementation. A longer-term goal is establishment of an information base to forge consensus on future regulatory policies and research and education priorities.

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Table 1: Acute (AM) and Chronic Mammalian (CM) Toxicity Index Components and Values

	LD-50 Values (mg/kg)	**Scaled Inverse LD-50$^+$ (AM)**	**Chronic Reference Dose (mg/kg/day)**	**Oncogenic Potency Factor**	**Chronic Toxicity* (CM)**
2,4-D	375	1.33	0.003		100
alachlor	930	0.54	0.01		30
azinphos-methyl	16	31.25	0.0015		66.67
azoxystrobin	5,000	0.1	0.18		0.56
basic copper sulfate	2,500	0.2	0.33		0.3
carbofuran	8	62.5	0.005		60
chlorothalonil	5,000	0.1	0.02	0.0077	8.85
chlorpropham	3,800	0.13	0.05		2
clethodim	1,360	0.37	0.01		10
copper ammonium	300	1.67	0.33		0.3
copper hydroxide	1,000	0.5	0.33		0.3
copper resinate	5,000	0.1	0.33		0.3
copper sulfate	300	1.67	0.33		0.3
cyfluthrin	500	1	0.008		12.5
cymoxanil	960	0.52	0.013		7.69
diazinon	300	1.67	0.0007		142.86
dimethoate	150	3.33	0.0005		200
dimethomorph	3,900	0.13	0.1		1
diquat	231	2.16	0.005		20
disulfoton	3	192.31	0.0001		200
endosulfan	80	6.25	0.006		50
endothal	51	9.8	0.02		5
EPTC	1,652	0.3	0.0025		40
esfenvalerate	67	7.46	0.02		5
ethoprophos	26	19.23	0.0001	0.0281	200
fludioxonil	5,000	0.1	0.03		3.33
fonofos	8	62.5	0.002		50
glufosinate ammonium	1,510	0.33	0.02		5
glyphosate	4,230	0.12	2		0.05
imidacloprid	450	1.11	0.019		5.26
linuron	4,000	0.13	0.008		12.5
malathion	2,100	0.24	0.024		12.5
maleic hydrazide	5,000	0.1	0.25		0.4
mancozeb	5,000	0.1	0.003	0.06	130
maneb	5,000	0.1	0.005	0.06	90
mefenoxam	490	1.02	0.08		1.25
metalaxyl	670	0.75	0.074		1.35
metam sodium	285	1.75	0.01	0.198	109
methamidophos	30	16.67	0.0001		200
metiram	5,000	0.1	0.0003		200

metolachlor	2,780	0.18	0.1		1
metribuzin	2,200	0.23	0.013		23.08
oxamyl	6	83.33	0.001		100
paraquat dichloride	283	1.77	0.0045		22.22
pendimethalin	1,050	0.48	0.1		3
permethrin	500	1	0.05	0.0184	10.6
petroleum oils	5,000	0.1	0.25		0.4
phorate	2	250	0.0002		200
phosmet	230	2.17	0.011		9.09
piperonyl butoxide	5,000	0.1	0.0175		17.14
propamocarb hydrochloride	5,000	0.1	0.1		1
pymetrozine	5,820	0.09	0.0013		76.92
pyrethrins	1,500	0.33	0.064		4.69
quintozene	1,700	0.29	0.003		33.33
rimsulfuron	5,000	0.1	0.818		0.12
sethoxydim	3,200	0.16	0.09		1.11
spinosad	3,738	0.13	0.0268		3.73
sulfur	300	1.67	0.33		0.3
sulfuric acid	1,000	0.5	0.33		0.3
thiamethoxam	1,563	0.32	0.013		7.69
thiophanate-methyl	5,000	0.1	0.08		1.25
trifloxystrobin	5,050	0.1	0.05		2
trifluralin	5,000	0.1	0.024	0.0077	14.43
triphenyltin hydroxide	156	3.21	0	2.8	200

Notes: + "Scaled Inverse LD-50 is (500/ld-50)

* See text for the "Chronic Toxicity" index formula.

Table 2. EcoToxicity Factor Values from 1997 to 2001 and Percent Change from 2000 to 2001

Active Ingredient	**AI Type**	**2001 Component Indices**			**2001 Index [Col C+D+E]**	**1998 EcoTox Index**	**Percent Change 1998 to 2001**
		Scaled Daphnia	**Scaled Fish**	**Scaled Avian**			
triphenyltin hydroxide	Fungicide	25.00	52.60	40.61	118.20	118.20	0.00
azoxystrobin	Fungicide	1.00	5.60	1.29	7.94	41.29	-0.81
trifloxystrobin	Fungicide	1.00	5.60	1.29	7.94		
chlorothalonil	Fungicide	3.57	22.70	1.55	27.82	27.82	0.00
quintozene (PCNB)	Fungicide	14.80	0.33	1.17	16.30		
dimethomorph	Fungicide	1.00	10.00	1.44	12.44	12.44	0.00
basic copper sulfate	Fungicide	0.25	1.47	6.37	8.09	8.09	0.00
Maneb	Fungicide	0.07	7.08	0.87	8.02	8.02	0.00
fludioxonil	Fungicide	0.23	5.03	1.44	6.70		
copper sulfate	Fungicide	0.30	0.90	6.40	7.60	2.50	2.04
mefenoxam***	Fungicide	0.00	0.02	3.37	3.39		
metalaxyl	Fungicide	0.00	0.02	3.37	3.39	3.39	0.00
copper hydroxide	Fungicide	0.25	0.92	1.37	2.54	2.54	0.00
mancozeb	Fungicide	0.25	1.57	0.42	2.24	2.24	0.00
copper resinate	Fungicide	0.25	0.12	1.43	1.80	1.80	0.00
copper ammonium	Fungicide	0.25	0.12	1.40	1.77	1.77	0.00
cymoxanil	Fungicide	0.01	0.12	1.28	1.41	1.41	0.00
Metiram	Fungicide	0.04	0.01	1.20	1.25	1.25	0.00
propamocarb hydrochloride	Fungicide	0.00	0.00	0.93	0.94	0.94	0.00
thiophanate-methyl	Fungicide	0.01	0.08	0.62	0.71		
Sulfur	Fungicide	0.00	0.01	0.01	0.02	0.02	0.00
Trifluralin	Herbicide	0.42	171.50	1.22	173.18		
Diquat	Herbicide	0.04	0.01	16.84	16.89	16.89	0.00
EPTC	Herbicide	0.03	0.08	11.85	11.98		
pendimethalin	Herbicide	0.89	4.98	5.00	10.87	10.87	0.00
Endothal	Herbicide	0.00	0.04	10.27	10.31	10.31	0.00
metribuzin	Herbicide	0.06	0.02	7.14	7.22	7.22	0.00
Linuron	Herbicide	1.25	0.30	4.61	6.16	6.16	0.00
paraquat dichloride	Herbicide	0.21	0.11	3.39	3.71	3.71	0.00
2,4-D	Herbicide	0.05	0.32	2.26	2.63	2.63	0.00
chlorpropham	Herbicide	0.07	0.31	1.55	1.93		
rimsulfuron	Herbicide	0.00	0.00	1.87	1.87	1.87	0.00
metolachlor	Herbicide	0.01	0.25	1.24	1.50	1.50	0.00
Clethodim	Herbicide	0.01	0.06	1.29	1.37		
glufosinate ammonium	Herbicide	0.00	0.02	1.29	1.31		
glyphosate	Herbicide	0.00	0.01	1.29	1.31	1.31	0.00
Alachlor	Herbicide	0.01	0.25	0.91	1.17	1.17	0.00
sethoxydim	Herbicide	0.00	0.01	0.62	0.63	0.63	0.00
Cyfluthrin	Insecticide	177.30	156.86	0.06	200.00		
esfenvalerate	Insecticide	166.67	200.00	0.23	200.00	200.00	0.00
Phorate	Insecticide	0.68	86.46	88.24	175.37	180.56	-0.03
carbofuran	Insecticide	0.74	1.30	140.58	142.62	144.90	-0.02

endosulfan	Insecticide	0.15	115.08	3.15	118.38	118.38	0.00
Diazinon	Insecticide	2.60	0.71	50.85	54.16		
permethrin	Insecticide	13.30	28.16	0.01	41.47	41.47	0.00
Oxamyl	Insecticide	0.01	0.03	38.46	38.50	38.50	0.00
disulfoton	Insecticide	0.36	0.00	37.04	37.40	36.35	0.03
Azinphos-methyl	Insecticide	0.01	16.69	13.13	29.84	29.84	0.00
Fonofos	Insecticide	12.50	5.81	7.77	26.09	28.80	-0.09
Phosmet	Insecticide	0.00	0.00	24.19	24.20	24.20	0.00
methamidophos	Insecticide	0.74	0.00	17.62	18.36	18.36	0.00
dimethoate	Insecticide	10.00	0.03	5.19	15.22	15.22	0.00
ethoprophos	Insecticide	0.37	0.11	12.46	12.94	12.95	0.00
pyrethrins	Insecticide	2.16	8.86	0.03	11.05	11.05	0.00
pymetrozine	Insecticide	3.00	4.00	0.14	7.14		
thiamethoxam	Insecticide	0.00	0.00	3.56	3.56		
imidacloprid	Insecticide	0.00	0.00	3.56	3.56	3.56	0.00
Spinosad	Insecticide	0.00	0.45	0.11	0.56		
malathion	Insecticide	0.10	0.10	0.22	0.42	0.42	0.00
piperonyl butoxide	Insecticide	0.02	0.04	0.11	0.18	0.18	0.00
Bt	Insecticide	0.00	0.08	0.06	0.14	0.14	0.00
metam sodium	Other	0.11	2.47	5.17	7.74	7.74	0.00
maleic hydrazide	Other	0.00	0.02	1.38	1.40	1.40	0.00
sulfuric acid	Other	0.00	0.01	0.01	0.02	0.02	0.00

Table 3. BioIPM Factor Values for 2001, Changes Since 1997, and Percent Change from 2000 to 2001

Active Ingredient	**AI Type**	**2001 Component Indices**			**2001 BioIPM [(C+D+E) x0.5]**	**1997 BioIPM**	**1998 BioIPM Index**	**2000 BioIPM**	**Percent Change 2000 to 2001**
		Resis-tance	**Bene-ficials**	**Scaled Oomen**					
Mefenoxam	Fungicide	100	50	0.1	**75**	113.0	113.0	113.0	-33.6%
Metalaxyl	Fungicide	100	50	0.1	**75**	113.0	113.0	113.0	-33.6%
Sulfur	Fungicide	6	80	0.0	**43**	45.2	45.2	45.2	-4.9%
Mancozeb	Fungicide	10	60	0.6	**35**	41.6	43.5	43.5	-18.7%
triphenyltin hydroxide	Fungicide	18	70	0.1	**44**	38.4	43.2	43.2	1.9%
maneb	Fungicide	10	60	0.8	**35**	44.1	42.9	42.9	-17.4%
azoxystrobin	Fungicide	40	10	0.1	**25**		34.8	34.8	-28.0%
trifloxystrobin	Fungicide	40	10	0.1	**25**				
metiram	Fungicide	10	60	0.6	**35**	32.7	33.0	33.0	7.1%
propamocarb hydrochloride	Fungicide	30	30	1.0	**31**	32.4	32.4	32.4	-5.9%
chlorothalonil	Fungicide	10	50	0.1	**30**	30.4	30.0	30.0	0.0%
cymoxanil	Fungicide	14	30	0.4	**22**	34.2	27.8	27.8	-20.0%
quintozene (PCNB)	Fungicide	15	30	0.1	**23**				
copper hydroxide	Fungicide	5	40	1.0	**23**	30.1	29.7	29.7	-22.6%
copper resinate	Fungicide	5	40	1.0	**23**	30.1	29.7	29.7	-22.6%
copper ammonium	Fungicide	5	40	1.0	**23**	30.0	29.6	29.6	-22.3%
Fludioxonil	Fungicide	15	20	0.0	**18**				
dimethomorph	Fungicide	14	20	0.1	**17**		21.6	21.6	-21.2%
thiophanate-methyl	Fungicide	20	20	0.1	**20**				
basic copper sulfate	Fungicide	5	10	1.0	**8**		22.8	22.8	-64.9%
copper sulfate	Fungicide	5	10	1.0	**8**	23.2	22.8	22.8	-64.9%
rimsulfuron	Herbicide	100	51	0.1	**86**	53.1	96.4	96.4	-11.3%
pendimethalin	Herbicide	100	17	0.2	**69**	96.4	78.9	78.9	-13.0%
metribuzin	Herbicide	60	51	0.6	**56**	64.5	64.7	64.7	-13.7%
paraquat dichloride	Herbicide	6	65	0.2	**36**	38.1	52.5	52.5	-32.2%
sethoxydim	Herbicide	45	15	1.0	**31**	38.8	48.4	48.4	-37.0%
linuron	Herbicide	6	51	0.6	**29**	38.8	39.1	39.1	-26.2%
alachlor	Herbicide	6	41	0.6	**24**		51.2	51.2	-53.2%
glyphosate	Herbicide	6	41	0.1	**24**	51.0	51.0	51.0	-53.5%
glufosinate ammonium	Herbicide	6	41	0.1	**24**				
endothal	Herbicide	6	40	1.0	**24**	26.8	26.8	26.8	-12.3%
diquat	Herbicide	6	40	0.6	**23**	30.4	26.7	26.7	-12.5%
chlorpropham	Herbicide	10	30	0.6	**20**			24.3	-16.2%
metolachlor	Herbicide	9	17	0.1	**13**	30.4	30.4	30.4	-57.1%
trifluralin	Herbicide	6	20	0.1	**13**				
2,4-D	Herbicide	6	17	0.1	**12**		41.2	41.2	-72.0%
EPTC	Herbicide	6	15	0.6	**11**				
clethodim	Herbicide	6	15	0.1	**11**				
esfenvalerate	Insecticide	192	67	166.7	**200**	126.7	182.1	182.1	9.8%
cyfluthrin	Insecticide	168	100	100.0	**184**			159.2	15.6%

permethrin	Insecticide	168	103	90.9	**181**	141.2	156.8	156.8	15.4%
disulfoton	Insecticide	54	67	166.7	**144**		138.9	138.9	3.4%
azinphos-methyl	Insecticide	48	70	166.7	**143**	79.0	130.0	130.0	9.6%
pyrethrins	Insecticide	108	100	76.9	**142**	100.4	126.0	126.0	13.1%
spinosad	Insecticide	50	15	100.0	**83**			112.0	-26.3%
oxamyl	Insecticide	45	139	32.3	**108**	94.0	106.5	106.5	1.5%
imidacloprid	Insecticide	72	40	87.5	**100**	163.6	200.0	99.8	-0.1%
thiamethoxam	Insecticide	72	40	87.5	**100**				
dimethoate	Insecticide	36	71	83.3	**95**	81.3	92.3	92.3	3.3%
carbofuran	Insecticide	45	71	62.5	**89**	112.0	111.4	111.4	-19.9%
malathion	Insecticide	40	100	37.0	**89**		82.8	82.8	6.9%
diazinon	Insecticide	48	70	45.5	**82**	0.0		81.6	0.5%
phorate	Insecticide	24	100	37.0	**81**	85.1	96.4	96.4	-16.5%
methamidophos	Insecticide	48	77	11.6	**68**	62.1	74.6	74.6	-8.5%
endosulfan	Insecticide	63	61	1.4	**63**	71.2	66.3	66.3	-5.2%
ethoprophos	Insecticide	45	67	2.4	**57**	65.6	77.6	77.6	-26.5%
phosmet	Insecticide	45	33	16.4	**47**		49.9	49.9	-5.1%
fonofos	Insecticide	23	56	3.0	**41**	60.8	64.4	64.4	-37.1%
piperonyl butoxide	Insecticide	9	40	0.6	**25**	28.0	27.9	27.9	-10.9%
pymetrozine	Insecticide	30	10	5.0	**23**			26.0	-13.5%
bt	Insecticide	8	5	0.6	**7**			7.5	-8.5%
metam sodium	Other	6	60	0.3	**33**	58.5	58.5	58.5	-43.4%
maleic hydrazide	Other	6	40	0.6	**23**	26.5	26.7	26.7	-12.5%
sulfuric acid	Other	6	20	1.0	**14**	18.8	18.8	18.8	-28.2%
							Average % Change		**-16.2%**

1 Table 4. Collaboration Multiattribute Toxicity Factor Values for 2001

Pesticide	A.I Type	Acute Tox	Bio IPM	Chronic Index	Acute Index (.5 x Acute Tox)	EcoTOX Index	BioIPM Index (1.5 x BioIPM)	2001 Multiattribute Index [Col. E+F+G+H]	2000 Multi Index	Percent Change 2000 to 2001
				2001 Four Component Indices						
triphenyltin hydroxide	Fungicide	3.2	44	200	1.6	118	66	**386**	384	0.5%
Metiram	Fungicide	0.1	35	200	0.1	1.3	53	**254**	251	1.2%
Mancozeb	Fungicide	0.1	35	130	0.1	2.2	53	**185**	197	-6.4%
Maneb	Fungicide	0.1	35	90	0.1	8.0	53	**151**	162	-7.3%
Metalaxyl	Fungicide	0.7	75	1.4	0.4	3.4	113	**118**	175	-32.7%
Mefenoxam	Fungicide	0.1	75	1.3	0.0	3.4	113	**117**	175	-32.9%
quintozene (PCNB)	Fungicide	0.3	23	33.3	0.1	16.3	34	**84**		
Chlorothalonil	Fungicide	0.1	30	8.9	0.1	27.8	45	**82**	82	0.0%
Sulfur	Fungicide	1.7	43	0.3	0.8	0.0	65	**66**	68	-3.8%
Trifloxystrobin	Fungicide	0.1	25	2.0	0.0	7.9	38	**47**		
propamocarb hydrochloride	Fungicide	0.1	31	1.0	0.1	0.9	46	**48**	51	-5.6%
Azoxystrobin	Fungicide	0.1	25	0.6	0.1	7.9	38	**46**	94	-51.1%
Cymoxanil	Fungicide	0.5	22	7.7	0.3	1.4	33	**42**	50	-14.5%
Dimethomorph	Fungicide	0.1	17	1.0	0.1	12.4	26	**39**	46	-15.0%
Fludioxonil	Fungicide	0.1	18	3.3	0.1	6.7	26	**37**		
copper hydroxide	Fungicide	0.5	23	0.3	0.3	2.5	35	**38**	48	-21.2%
copper ammonium	Fungicide	1.7	23	0.3	0.8	1.8	35	**37**	47	-21.0%
copper resinate	Fungicide	0.1	23	0.3	0.1	1.8	35	**37**	47	-21.6%
thiophanate-methyl	Fungicide	0.1	20	1.3	0.1	0.7	30	**32**		
copper sulfate	Fungicide	1.7	8	0.3	0.8	7.6	13	**21**	43	-50.1%
basic copper sulfate	Fungicide	0.2	8	0.3	0.1	8.1	13	**21**	43	-50.4%
Trifluralin	Herbicide	0.1	13	14.4	0.1	173	20	**207**		
2,4-D	Herbicide	1.3	12	100	0.7	2.6	17	**121**	165	-27.0%
Rimsulfuron	Herbicide	0.1	76	0.1	0.1	1.9	113	**115**	147	-21.4%

Metribuzin	Herbicide	0.2	56	23.1	0.1	7.2	84	**114**	127	-10.4%
Pendimethalin	Herbicide	0.5	59	3.0	0.2	10.9	88	**102**	132	-23.0%
paraquat dichloride	Herbicide	1.8	36	22.2	0.9	3.7	53	**80**	106	-24.0%
Diquat	Herbicide	2.2	23	20.0	1.1	16.9	35	**73**	103	-29.5%
EPTC	Herbicide	0.3	11	40.0	0.2	12.0	16	**68**		
Alachlor	Herbicide	0.5	24	30.0	0.3	1.2	36	**67**	108	-37.7%
Linuron	Herbicide	0.1	29	12.5	0.1	6.2	43	**62**	77	-19.9%
Endothal	Herbicide	9.8	24	5.0	4.9	10.3	35	**55**	60	-8.2%
Sethoxydim	Herbicide	0.2	31	1.1	0.1	0.6	46	**48**	74	-36.1%
glufosinate ammonium	Herbicide	0.3	24	5.0	0.2	1.3	35	**42**		
Glyphosate	Herbicide	0.1	24	0.1	0.1	1.3	36	**37**	78	-52.5%
Chlorpropham	Herbicide	0.1	20	2.0	0.1	1.9	30	**34**		
Clethodim	Herbicide	0.4	11	10.0	0.2	1.4	16	**27**		
Metolachlor	Herbicide	0.2	13	1.0	0.1	1.5	20	**22**	48	-54.1%
Phorate	Insecticide	250	81	200	125	175	121	**621**	620	0.2%
Disulfoton	Insecticide	192	144	200	96	37	216	**549**	542	1.3%
Esfenvalerate	Insecticide	7	200	5	4	200	300	**509**	482	5.6%
Cyfluthrin	Insecticide	1	184	13	1	200	276	**489**		
Carbofuran	Insecticide	63	89	60	31	143	134	**368**	401	-8.3%
Dimethoate	Insecticide	3	95	200	2	15	143	**360**	355	1.3%
Oxamyl	Insecticide	83	108	100	42	39	162	**342**	340	0.7%
Methamidophos	Insecticide	17	68	200	8	18	102	**329**	339	-2.8%
azinphos-methyl	Insecticide	31	143	67	16	30	214	**326**	307	6.1%
Permethrin	Insecticide	1	181	11	1	41	271	**324**	288	12.6%
Diazinon	Insecticide	2	82	143	1	54	123	**321**	320	0.2%
Ethoprophos	Insecticide	19	57	200	10	13	86	**308**	339	-9.1%
Endosulfan	Insecticide	6	63	50	3	118	94	**266**	271	-1.9%
Pyrethrins	Insecticide	0	142	5	0	11	214	**230**	205	12.1%
Fonofos	Insecticide	63	41	50	31	26	61	**168**	204	-17.6%
Thiamethoxam	Insecticide	0	100	8	0	4	150	**161**		
Imidacloprid	Insecticide	1	100	5	1	4	150	**159**	159	0.0%
Malathion	Insecticide	0	89	13	0	0	133	**146**	137	6.2%

Spinosad	Insecticide	0	83	4	0	1	124	**128**	172	-25.7%
Pymetrozine	Insecticide	0	23	77	0	7	34	**118**	123	-4.3%
Phosmet	Insecticide	2	47	9	1	24	71	**105**	109	-3.5%
piperonyl butoxide	Insecticide	0	25	17	0	0	37	**55**	59	-7.7%
Bt	Insecticide	0	7	0	0	0	10	**10**	10	0.0%
metam sodium	Other	2	33	109	1	8	50	**167**	205	-18.5%
maleic hydrazide	Other	0	23	0	0	1	35	**37**	42	-12.0%
sulfuric acid	Other	1	14	0	0	0	20	**21**		
							Average Change 2000-2001			**-14.3%**

2

TABLE 5: Industry-Wide Wisconsin Potato Pesticide Use and Toxicity Units: 1995, 1997 and 1999

Acres Planted 1995: 83,000 1997: 78,000 1999: 86,000	**Toxicity Factor Values**	**1995 Pounds Applied**	**1995 Toxicity Units**	**1997 Pounds Applied**	**1997 Toxicity Units**	**1999 Pounds Applied**	**1999 Toxicity Units**
Herbicides:							
Glyphosate	37	4,000	148,000	9,000	333,000	3,000	111,000
Linuron	62	7,000	434,000	3,000	186,000	1,000	62,000
Metolachlor	22	21,000	462,000	7,000	154,000	16,000	352,000
Metribuzin	114	39,000	4,446,000	34,000	3,876,000	37,000	4,218,000
Pendimethalin	102	24,000	2,448,000	16,000	1,632,000	21,000	2,142,000
Rimsulfuron	115	0	0	0	0	1,000	115,000
Sethoxydim	48	2,000	96,000	0	0	5,000	240,000
Total: All Herbicides		97,000	8,034,000	69,000	6,181,000	84,000	7,240,000
Per Planted Acre		1.17	97	0.88	79	0.98	84
Insecticides:							
Azinphos-methyl	326	26,000	8,476,000	0	0	6,000	1,956,000
Carbofuran	368	13,000	4,784,000	0	0	0	0
Diazinon	321	0	0	0	0	5,000	1,605,000
Dimethoate	360	11,000	3,960,000	30,000	10,800,000	27,000	9,720,000
Endosulfan	266	60,000	15,960,000	10,000	2,660,000	53,000	14,098,000
Esfenvalerate	509	3,000	1,527,000	2,000	1,018,000	6,000	3,054,000
Imidachloprid	159	0	0	8,000	1,272,000	14,000	2,226,000
Methamidophos	329	69,000	22,701,000	17,000	5,593,000	15,000	4,935,000
Oxamyl	342	5,000	1,710,000	0	0	5,000	1,710,000
Permethrin	324	4,000	1,296,000	0	0	1,000	324,000
Phosmet	105	0	0	0	0	27,000	2,835,000
Piperonyl butoxide	55	3,000	165,000	7,000	385,000	18,000	990,000
Pyrethrins	230	166	38,180	0	0	68	15,640
Total: All Insecticides		194,166	60,617,180	74,000	21,728,000	177,068	43,468,640
Per Planted Acre		2.3	730	0.95	279	2.06	505
Fungicides:							
Azoxystrobin	46	0	0	0	0	22,000	1,012,000
Basic copper sulfate	21	13,000	273,000	8,000	168,000	25,000	525,000
Chlorothalonil	82	408,000	33,456,000	591,000	48,462,000	501,000	41,082,000
Copper hydroxide	38	40,000	1,520,000	52,000	1,976,000	14,000	532,000

Copper resinate	37	12,000	444,000	2,000	74,000	0	0
Cymoxanil	42		17,940	5,000	210,000	5,000	210,000
Mancozeb	185	412,000	76,220,000	287,000	53,095,000	278,000	51,430,000
Maneb	151	76,000	11,476,000	62,000	9,362,000	0	0
Mefenoxam	117	0	0	0	0	3,000	351,000
Metalaxyl	118	4,000	472,000	0	0	3,000	354,000
Metiram	254	0	0	0	0	49,000	12,446,000
Propamocarb hydrochloride	48	9,000	432,000	0	0	0	0
Triphenyltin hydroxide	386	12,000	4,632,000	8,000	3,088,000	2,000	772,000
Total: All Fungicides		986,000	128,942,940	1,015,000	116,435,000	902,000	108,714,000
Per Planted Acre		12	1,554	13	1,493	10	1,264
Other Chemicals:							
Diquat	73	28,000	2,044,000	26,000	1,898,000	46,000	56,160
Endothall	55	7,000	385,000	0	0	5,000	0
Maleic hydrazide	37	13,000	481,000	0	0	0	0
Metam-sodium	167	970,000	161,990,000	0	0	0	0
Paraquat	80	3,000	240,000	0	0	0	0
Sulfuric acid	21	1,632,000	34,272,000	2,770,000	58,170,000	0	14,040
Total: Other Chemicals		2,653,000	199,412,000	2,796,000	60,068,000	51,000	70,200
Per Planted Acre		32	2,403	35.8	770	0.59	0.82
Herbicides, Insecticides, and Fungicides							
Total: H+I+F		1,277,166	197,594,120	1,158,000	144,344,000	1,163,068	159,422,640
Per Planted Acre		15.4	2,381	14.8	1,851	13.5	1,854
All Chemicals							
Total		3,930,166	397,006,120	3,954,000	204,412,000	1,214,068	159,492,840
Per Planted Acre		47.4	4,783	50.7	2,621	14.1	1,855

6

Table 6. Cost/benefit of reduced risk pest control. Coloma, WI 2000.

	Fungicide/Systemic Insecticide			
Program	Cost of Materials ($/A)	Yield (cwt)	Cost/Cwt (cents)	Toxicity Units
Conventional	$182	443 b	41.8	2494
Reduced Risk	$214	458 a	46.7	1242
Outcome of Reduced Risk	+ $32 / Acre	+ 15 cwt	+ 5.6/ cwt	-1252

Bottom line: Reduced risk costs 5.6 cents/cwt more, but the net financial gain from reduced risk programs (@$5.00/cwt) is $43 /A

Table 7. Cost/benefit of reduced risk pest control. Coloma, WI 2000.

	Fungicide/Foliar Insecticide			
Program	Cost of Materials ($/A)	Yield (cwt)	Cost/Cwt (cents)	Toxicity Units
Conventional	$136	444 b	30.6	2557
Reduced Risk	$190	464 a	40.9	1229
Outcome of Reduced Risk	+ $54 / Acre	+ 15 cwt	+ 10.3 / cwt	-1328

Bottom line: Reduced risk costs 10.3 cents/cwt more, but the net financial gain from reduced risk programs (@$5.00/cwt) is $21 / A

Additional Key Words: Toxicity, Biointensive IPM, Integrated Pest Management, Pesticide risk, Pesticide monitoring