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Evaluation of Toxicity in Cotton Production and Toxicity Impact Assessment Methods

Project Report

Prepared for:
Cotton Incorporated
World Headquarters
6399 Weston Parkway
Cary, North Carolina 27513
Final Project Report
Project 09-591

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March 4, 2010

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Abstract

Toxicity from cotton production is a major concern for cotton producers as retailers and consumers begin to incorporate environmental sustainability in their decision making process. There are numerous methods to assess the toxicity from pesticide use in cotton production. This study attempted to assess toxicity of cotton under multiple production practices and to compare several toxicity assessment methods currently in use. We selected five methods that provided index values for each pesticide, without requiring any other parameter input. Four of these methods (CML, Impact 2002 +, ReCiPe, and TRACI) were part of a more complete life cycle assessment methodology and accessible in SimaPro software. The fifth method, EIQ, available in Microsoft Excel, was a method used specifically for assessing toxicity from pesticides. These index methods provide a straightforward method to compare toxicity of individual pesticides as well as production practices. These methods can be useful as a screening tool. These methods showed that no till cotton appears to reduce the toxicity of conventional cotton production. Additionally, dryland cotton appears to have lower toxicity than irrigated cotton. It was not clear under the current study how seed type affected toxicity. While all five methods provide index values, only three were useful for our purposes, given that two, CML and TRACI, only had index values for roughly one third of the pesticides used on cotton. In addition those two methods did not have a method for comparing human toxicity with ecological toxicity. Of the three methods used for final comparison, the pesticide rankings were fairly consistent between Impact 2002+ and ReCiPe, however EIQ did not correlate nearly so well with Impact 2002+ and ReCiPe. However, when looking at rankings of production practices using combined scores for all pesticides applied for a given practice, the methods appeared more consistent. Impact 2002+ and ReCiPe are both European-centric models. Therefore, their weighting systems differ from what an American-centric model might apply. However, they are part of a complete LCA methodology, and therefore they may be more useful when undertaking a cradle-to-grave LCA analysis, looking at multiple environmental impacts along with toxicity. EIQ is a US-based model. Its assumptions and calculations are somewhat more straightforward and explicit. In addition, its impact categories (consumer, farmworker, fish, bees, etc) are more explicit. EIQ also has the most comprehensive list of index values for pesticides used on cotton. However, EIQ's methodology appears to have less capability of distinguishing between magnitude of toxicity of pesticides. It is unclear and beyond the scope of this study to understand how well these methods would perform when comparing cotton production with other agricultural products, or comparing cotton production with other textile production. Ultimately, each of the three methods has its strengths, and is a valuable tool in estimating toxicity from cotton, and all agricultural production. While the methods do correlate, they are not equal. Therefore method selection should depend on the needs of the analysis, such as which pesticides are under study, the type of toxicity being studied, and whether the study is specifically for toxicity from pesticides, or something more broad, including multiple environmental impacts.

Introduction

Toxicity from cotton production is a major concern for cotton producers as retailers and consumers begin to incorporate environmental sustainability in their decision making process. Pesticides are applied to cropland in order to decrease the populations of target pest organisms. However, excess chemicals are introduced into the surrounding terrestrial system directly through the initial application and to adjacent aquatic systems indirectly through runoff and leaching. Due to the toxic nature of these chemicals, the introduction of pesticides into ecological systems can have dramatic effects on biota as well as human populations.

A variety of methods for assessing the toxic potential of individual chemicals have been introduced. ReCiPe, Impact 2002+, TRACI, EIQ, and CML are all examples of toxicity metrics used in evaluating the human and ecological risks associated with agricultural inputs. SimaPro (PRé), a life cycle assessment (LCA) software, houses the impact assessment methods: ReCiPe; Impact 2002+; TRACI; and CML. These index values are also available in Microsoft Excel, but are less user friendly in Excel than EIQ, given the higher degree of complexity. These methods have much broader use covering many environmental impacts including Global Warming Potential and Eutrophication from all production practices, not solely agriculture. For this study, we used only those portions that pertained to toxicity. EIQ is a method specific to human and ecological toxicity from pesticides. While individual methods vary, these metrics generally evaluate the human risk, and the risk for each identified ecosystem receptor. This information is then combined to give a single impact score for each input. These metrics can be used to effectively evaluate the toxic contribution of different agricultural industries and their subsequent production practices.

Cotton production across the United States incorporates a wide variety of production practices that involve the application of chemical pesticides. These practices include conventional tillage and reduced tillage, dry land techniques and irrigated systems, and the use of seeds produced conventionally or through genetic modifications. The goal of this study was to determine the potential human and ecological risks associated with the use of chemicals in cotton production. Individual production practices and their chemical inputs were identified, and then ranked using different toxicity metrics.

Methodology

Toxicity Index Method Selection

There are numerous methods for assessing toxicity of pesticides. Toxicity can impact humans, and the environment. For humans, toxicity can be carcinogenic, or non-carcinogenic, and can have impacts on mortality and/or morbidity. With respect to environmental toxicity, pesticides can impact both aquatic and terrestrial organisms. Toxicity depends upon the levels of exposure of the receptor to the toxin. In addition, the impacts of exposure may not be linear. Often there are threshold values such that once a threshold is reached, adverse impacts may be irreparable.

Pesticides by design are created to treat pests through different mechanisms, whether broad spectrum, systemic, or very-targeted approaches. Pesticides and other agrochemicals are also designed to kill fungi, insects or other plants, or some other function that regulates plant function. The exposure mechanism and the impacts they cause on humans and the environment

will differ widely. In addition, the mechanism of application and treatment differ. Some are applied through aerial application, others are directly applied, while others may be applied to the soil and uptaken through the roots. Therefore the level of human and ecological exposure will differ between each method.

In addition to application methods, environmental factors will determine the fate, transport and exposure of these chemicals. Soil types will hold, release and degrade chemicals at different rates. Precipitation will impact runoff and leaching. Sunlight and temperature will impact photochemical degradation. And proximity to other human and environmental receptors will impact the exposure levels.

There are numerous toxicity models (e.g. SYNOPS_2, EYP, HD, etc. see Reus et al. 2002) that incorporate many of these human and environmental factors to give precise estimates of toxicity, given specific user inputs. However, these models are more useful for site level studies, or specific comparative approaches, where all of the many parameters are known, or can be reasonably specified. For a national level study, where these parameters are not known, these methods are less useful.

For our purposes, it was necessary to have indexes with specific values for toxicity for each chemical, where we did not need to have a highly parameterized model. These methods have parameters embedded within the models in order to estimate fate and exposure, but the parameters are constant, meaning that one cannot change pesticide fate based upon different environmental conditions. These methods are appropriate as screening tools, but may not be as useful when comparing two or several specific practices for which all model parameters are known.

Given this restriction on our model selection, we chose the 5 methods mentioned above. How each method weights each of these different characteristics plays an integral role in the results of the index, and its rankings. Given numerous weighting possibilities for all of the different characteristics, it is not possible to deliver an optimal index or ranking system that will be preferred by all stakeholders, with different weighting preferences (Arrow, 1950). However, it may be that for certain applications, certain weightings and therefore certain toxicity index methods may be more appropriate than other methods.

Pesticide Use Data

To determine inputs used for specific production practices in each state, we used cotton production budgets produced by University agricultural extension specialists. These production budgets provided a range of different inputs, including herbicides, insecticides, fungicides and other agrochemicals. Some states produce many different budgets per state. We used those budgets that were considered by the extension specialists to be predominant in a state. Budgets provided either a specific chemical, or a brand name product. Where brand names were used, we converted these values into their active ingredient (a.i.) of chemical compound.

Use in SimaPro

SimaPro was used for calculation of index values for ReCiPe, Impact 2002+, TRACI, and CML. Each pesticide was entered as an emission to agricultural soil. Each toxicity method in SimaPro allows for entry of data as emission to soil (agricultural, industrial or urban), emission to air, and emission to water. Emission to agricultural soil assumes that some portion of the pesticide will

be released to the air, in an agricultural setting, as well as to surface and groundwater. These methods also decrease exposure in soil, water and air based upon degradation half-life.

Categorization: Human- vs. Eco-Toxicity

Each toxicity method separates the impacts between human toxicity and ecological toxicity. Some methods separate these into categories within these two broader categories. Human toxicity may be characterized as carcinogenic, or non-carcinogenic (Impact 2002+ and TRACI), or by farm worker vs. consumer (EIQ). Ecological Toxicity may be categorized in terms of aquatic or terrestrial, or broken down further, into freshwater and marine, and separated into aquatic or sediment (CML). EIQ separates each impact by its impact on fish, birds, bees or beneficial (See Figure 1 for the categories).

Figure 1 Toxicity Method Indices and Indicators

EIQ	Impact 2002+	ReCiPe	CML	TRACI
		Human Toxicity		
Farmworker Applicator Picker Consumer Direct user of product Indirect consumer through drinking water *No Units*	Carcinogens Non-carcinogens *kg C2H3Cl eq / DALY*	Human Toxicity *kg 1,4-DB eq / DALY*	Human Toxicity *kg 1,4-DB eq*	Carcinogens Non-Carcinogens *kg benzen/ toluen eq*
		Ecological Toxicity		
Terrestrial Birds Bees Beneficials Aquatic Fish *No Units*	Aquatic Terrestrial *kg TEG eq/ PDF*m2*yr*	Freshwater Marine Terrestrial *kg 1,4-DB eq / species.yr*	Freshwater Aquatic Marine Aquatic Freshwater Sediment Marine Sediment Terrestrial *kg 1,4-DB eq*	Ecotoxicity *kg 2,4-D eq*

1,4-DB: Para-dichlorobenzene
2,4-Dichlorophenoxyacetic acid
C2H3Cl: Vinyl Chloride
TEG: Triethylene-glycol
DALY: Disability Adjusted Life Year
PDF*m2*yr: Potentially Disappeared Fraction

Equivalencies or Units of Toxicity

Toxicity can be measured in many ways, such as LD-50 (median lethal dose), LC-50 (median lethal concentration), No Observed Effect Level, or some combination of each. Each method uses these one or several of these toxicity metrics to come up with a single toxicity value for a given pesticide. The four LCA methods (CML, Impact 2002+, ReCiPe and TRACI) use equivalencies to represent toxicity. Each pesticide, based upon its toxic characteristics, is given an equivalency to a standard chemical with known toxic values.

For example, in looking at ecological toxicity, ReCiPe uses equivalencies of 1,4-DB (Para-dichlorobenzene). The terrestrial ecotoxicity of one kilogram of glyphosate applied would be the equivalent effect of .00107 kg of 1,4-DB. Using CML, which also uses 1,4-DB equivalencies, one kg of glyphosate would have a terrestrial ecotoxicity equivalent of 0.000241 kg 1,4-DB. TRACI, which uses 2,4-D equivalencies, would assess the ecological toxicity of 1 kg of

glyphosate applied equal to 0.000322kg of 2,4-D. Impact 2002+ uses triethylene-glycol (TEG) equivalencies (10.2 kg TEG-eq). EIQ however uses only an index value, which represents a calculation shown in Appendix B.

Midpoint vs. Endpoint Indicators

LCA typically uses two methods for assessing environmental impacts, midpoint and endpoint indicators. Midpoint indicators are used to compare all impacts that affect a certain category, for example ecological toxicity or human toxicity. Other impacts might include eutrophication, particulate formation and greenhouse gas emissions. Endpoint indicators are more broad categories of interest such as human health or ecosystem quality that may encompass numerous midpoint indicators.

Midpoint indicators are typically in terms of equivalencies (e.g. 2,4-D eq, 1,4-DB-eq for toxicity, kg P2O5-eq for eutrophication, or CO2e for greenhouse gas emissions). Midpoint indicators are useful because they are fairly robust calculations that are generally accepted by scientific consensus. Toxicity indicators, both ecological and human, however do not have the same level of certainty and consensus as other indicators (Humbert, et al., 2005).

Endpoint indicators are useful for comparing the overall impact of products or production methods. Endpoint indicators combine all of the midpoint indicators that impact the endpoint, such as human health, into one indicator, for example Disability-Adjusted Life Year (DALY). The DALY number is a weighted average of years of life lost and years of life disabled. By using DALY, one can compare all impacts that may affect human health, such as human toxicity, particulate formation and greenhouse gas emission into a single unit of measure. Likewise, one can use the same system to combine ecological impacts, such as eutrophication, ecotoxicity and climate change, into a single unit of measure, such as the potentially disappeared fraction species over an area over a given amount of time (PDF*m2*year in Impact 2002+ or Species*year in ReCiPe).

Endpoint indicators (also known as damage factors) are easier to interpret than midpoint categories. However, they are inherently more subjective with less certainty as compared with the midpoint indicators from which they derive. For our purposes, they are necessary when comparing human toxicity with ecological toxicity, as these may be measured with different equivalency factors and on different scales of measurement. While ReCiPe does use 1,4-DB as the equivalency factor for both human and ecological toxicity, most would not weight human and ecological toxicity equally. Therefore ReCiPe and Impact 2002+ normalize and weight each midpoint using specific characterization factors that convert midpoint indicators (e.g. kg 1,4 DB-eq) into endpoint indicators (e.g. DALY).

TRACI and CML do not use endpoint indicators, and so it was not possible to combine the human and ecological toxicity values into a single score. In addition, because they had toxicity values for only roughly one third of the pesticides used in cotton production, these methods were not used for further analysis and comparison.

Normalization and Weighting of Impacts

LCA methods use normalization factors as a way to convert endpoint categories into a scale that corresponds with a given population. Then they use a weighting system to convert endpoint categories into a single score. "A normalization factor represents the total impact of the specific category divided by the total European [sic] population. The total impact of the specific category is the sum of the products between all European emissions and the respective damage factors" (Humbert, et al. 2005). Normalization is an objective (although not perfect) method for weighting midpoint indicators in a weighted average endpoint indicator. Normalization uses the midpoint indicator value as a percent of the total impact in that midpoint category for a given region (typically either Europe or the World). It then combines all midpoint indicator percentages to come up with a total normalized value.

For example, in ReCiPe 1 kg of 1,4-DB in soil (for terrestrial ecotoxicity) is normalized to $1.3*10^{-7}$ species-yr, 1 kg of 1,4-DB in freshwater (freshwater ecotoxicity) is normalized to $2.6*10^{-10}$ species-yr whereas 1 kg CO2 (air) is normalized to $8.73*10^{-6}$ species-yr. In this manner, we can compare the impacts of terrestrial ecotoxicity, freshwater ecotoxicity and global warming potential or any other ecological impact all on the same scale. The use of non-ecotoxicity measures is for purposes of illustration here only. We did not use these numbers in our analysis. Likewise, human toxicity, which is also measured in terms of 1,4-DB-eq in urban air for ReCiPe, has a normalization factor of $7.0*10^{-7}$ DALYs.

Once these toxicity impacts have been normalized, they must be weighted in order to combine separate endpoint categories. This step is inherently subjective. Nevertheless, it is necessary in order to compare two separate impact categories. ReCiPe has several methods for normalization and weighting: Individualistic, Hierarchical, and Egalitarian. In general, Individual gives higher weighting to human health, and to living individuals. Hierarchical provides more balance in weighting, and Egalitarian gives more equal weighting between humans and the environment, as well as current and future generations. Impact 2002+ does not provide specific methods for weighting, but provides a default equal weight average, after normalization.

EIQ does not use the same methodology. Instead it uses an equal-weight average value of the consumer, farmer and ecosystem impacts. These categories are created using equations that have different weightings for each of the subcategories, such as farm picker vs. farm pesticide applicator.

Pesticide Index Values

Each chemical (49 in total) was given several toxicity values, one value for each toxicity index (See Appendix A.). No index had values for every chemical, although three, Impact 2002+, ReCiPe, and EIQ provided toxicity values for most chemicals. TRACI and CML lacked many of the chemicals used, therefore we did not use these methods for ranking chemicals and production practices.

Entering Index Values for Missing Data

For each pesticide that did not have a toxicity value for a given index, we used a proxy value. The proxy value was selected by using the value from the next closest pesticide using one of the other indices. First we sorted each pesticide by its ranking in EIQ. For any pesticide within either Impact 2002+ or ReCiPe, we used the ranking from EIQ to determine the closest related

pesticide. Then we chose the value from that closest pesticide, using the same value from the same index. If a value from EIQ was missing, we first ranked by Impact 2002+ and then used the EIQ value from next closest chemical based upon the Impact 2002+ ranking. If there was no value from Impact 2002+, we selected our EIQ value based upon a ReCiPe ranking. Only two pesticides, Envoke™ (trifloxysulfuron), and urea sulfate (used in combination with ethephon in First Pick™) were not in any of the toxicity methods. These two pesticides, because they had no index value and because they were not on the PAN Bad Actor Chemical list, were not given a toxicity value.

Calculation of Production Practice Score

For each production practice we multiplied the quantity of pesticide applied (in a.i.) by the toxicity value, and summed up the product for each pesticide, for a given toxicity index. This resulted in a toxicity value for each production practice for each of the three indices.

Overview of Toxicity Assessment Methods

The following is an overview of the methods by each metric in determining the toxicity impact score for each chemical. Each method is described in further detail in Appendix B.

EIQ:

The Environmental Impact Quotient (EIQ) metric focuses on the environmental impact assessment. EIQ is used to organize and quantify the extensive toxicological data from the various forms and uses of pesticides. The EIQ impact assessment is based on the three principal components of agricultural production systems: a farm worker component, a consumer component, and an ecological component. Each component in the equation is given equal weight in the final analysis, but within each component, individual factors are weighted differently. Individual factors include Applicator, Picker, Direct Consumer, Indirect Consumer, Birds, Bees, Beneficials and Fish. Coefficients used in the equation to give additional weight to individual factors.

TRACI:

This is a stand-alone computer program developed by the U.S. Environmental Protection Agency. TRACI stands for Tool for the Reduction and Assessment of Chemical and other environmental Impacts. This program facilitates the characterization of environmental stressors that have potential effects. The categories selected by the time that TRACI was created were the following: Ozone depletion, Global warming, Smog formation, Acidification, Eutrophication , Human health cancer, Human health non-cancer, Human health criteria pollutants, Eco-toxicity, Fossil fuel depletion, Land use, and Water use.

During the development of TRACI, consistency with previous modeling assumptions (especially of the U.S. EPA) was important for every impact category. The human health cancer and non-cancer categories were strongly based on the assumptions made for the U.S. EPA Risk Assessment Guidance for Superfund and the U.S. EPA's Exposure Factors Handbook. Many of the impact assessment methodologies within TRACI are based on “midpoints”.

CML:

CML 2001 utilizes the mid-point approach to quantify the human and environmental effects linked to the production and use of a certain substance. CML 2001 is an LCIA (Life Cycle Impact Assessment) that has eleven midpoint indicators including: primary energy, acidification, eutrophication, global warming, ozone depletion, photochemical ozone creation, human toxicity, terrestrial ecotoxicity, marine aquatic toxicity, freshwater aquatic ecotoxicity, and abiotic depletion. This assessment was drawn from similar techniques including IMPACT 2002+, EPS, and Eco-indicator 99.

Human toxicity: This category concerns effects of toxic substances on the human environment. Health risks of exposure in the working environment are not included. Characterization factors, Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission. The geographic scope of this indicator determines on the fate of a substance and can vary between local and global scale

Fresh-water aquatic eco-toxicity: This category indicator refers to the impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil. Eco-toxicity Potential (FAETP) is calculated with USES-LCA, describing fate, exposure and effects of toxic substances. The time horizon is infinite. Characterization factors are expressed as 1,4-dichlorobenzene equivalents/kg emission. The indicator applies at global/continental/ regional and local scale.

Marine eco-toxicity: Marine eco-toxicity refers to impacts of toxic substances on marine ecosystems (see description fresh water toxicity).

Terrestrial ecotoxicity: This category refers to impacts of toxic substances on terrestrial ecosystems (see description fresh water toxicity).

ReCiPe:

ReCiPe (named for its main contributors, RIVM and Radbound, CML and Pre) is a follow up of Eco-indicator 99 and CML 2001 methods. It integrates and harmonizes the midpoint and endpoint approaches in a consistent framework. Although initially the integration of the methods was intended, all impact categories have been redeveloped and updated. Midpoint and endpoint characterization factors are calculated on the basis of a consistent environmental cause-effect chain, except for land-use and resources.

The midpoint impacts covered by ReCiPe are several: Terrestrial acidification; freshwater eutrophication; marine eutrophication; human toxicity; photochemical oxidant formation; particulate matter formation; terrestrial ecotoxicity; freshwater ecotoxicity; marine ecotoxicity; ionizing radiation; agricultural land occupation; urban land occupation; natural land transformation; depletion of fossil fuel resources; depletion of mineral resources; and depletion of freshwater resources. The endpoint impacts covered are: Human health; Ecosystem Quality, and Resources.

This method has some unique features. It consistently uses midpoints and endpoints in the same environmental mechanism. Midpoints are chosen as close as possible to the LCI results (Lowest Uncertainty of the Indicator). It uses sub compartments rural air and urban air applied in fate and exposure model for human toxicity.

There are several impact categories than have been pre-selected for further evaluation such as: Non-linear marginal approach included in the calculation of human-toxicological and eco-toxicological effect factors. Midpoints and endpoints are available in the same mechanism.

IMPACT 2002+:

The IMPACT 2002+ life cycle impact assessment utilizes a combined midpoint/damage approach to quantify the environmental effects associated with the production of a certain substance. Life cycle inventory (LCI) results are linked to four damage categories, including human health, ecosystem quality, climate change, and resources, through fourteen midpoint categories, including human toxicity, respiratory effects, ionizing radiation, ozone layer depletion, photochemical oxidation, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification, land occupation, global warming, non-renewable energy, and mineral extraction. The assessment draws from other techniques, including CML 2001 and Eco-indicator 99, and also applies new techniques to describe midpoint and damage characterization factors (Jolliet et al., 2003).

All midpoint characterization factors are expressed in kg-equivalents of a substance to that of a reference substance. Damage characterization factors can then be obtained by multiplying the midpoint characterization factor by a damage characterization conversion factor that is associated with the reference substance. The following describes each midpoint characterization factor and its subsequent damage level characterization factor.

Human toxicity: The characterization factors are based on emissions into the air, water, soil and agricultural soil. General factors are calculated at a continental level for Western Europe. Human toxicity through emission into agricultural soil has been modified from an emission into European average soil based on a correction factor that takes into account the European agricultural land area. The midpoint reference substance is kg_{eq} chloroethylene emitted into the air. This midpoint category can be converted to the damage category of human health which is expressed in DALY.

Aquatic ecotoxicity: This midpoint factor only considers surface fresh water ecotoxicity and characterization factors are given for emissions into the air, water and soil. The midpoint reference substance is kg_{eq} triethylene glycol into water. Aquatic ecotoxicity relates to ecosystem quality and is expressed in $PDF*m^2*yr$ at the damage.

Terrestrial ecotoxicity: This midpoint only considers the ecotoxicity a substance has by exposition through the aqueous phase in soil. Characterization factors are given for emissions into air, water and soil. The reference substance is triethylene glycol into soil. Terrestrial ecotoxicity relates to ecosystem quality and is express in $PDF*m^2*yr$ at the damage (endpoint) level.

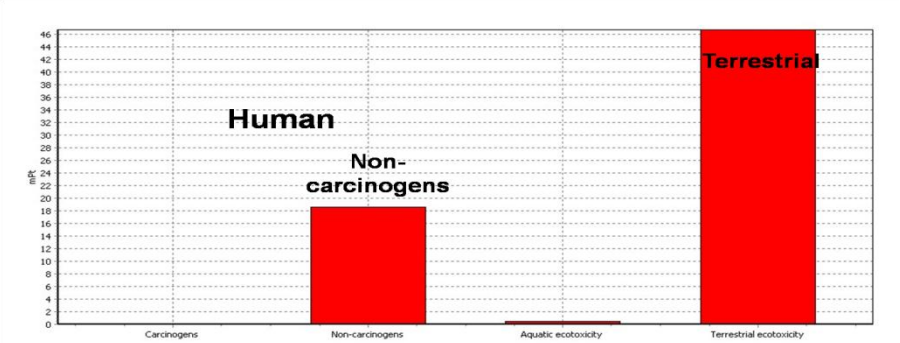
Once converted to a damage value, each of the damage categories can then be normalized to allow for single score to compare the overall effects a certain substance has to others. Using a normalization factor, each of the damage categories is converted to a point. The points can then be summed, giving the substance an overall single score.

Results

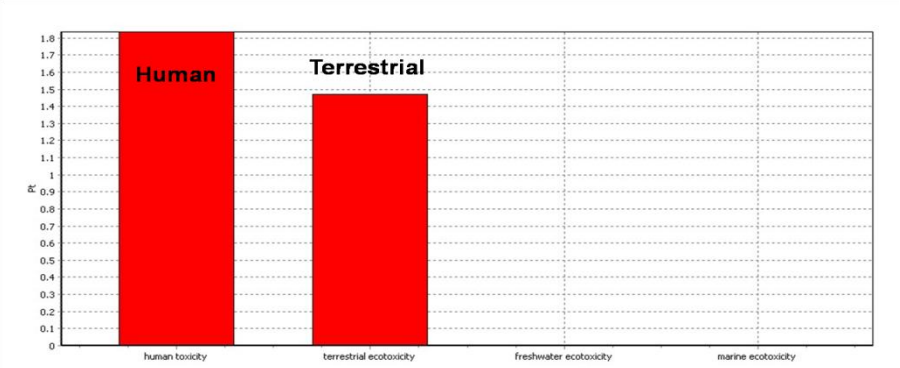
Using Human Toxicity, Ecotoxicity or Combination (Single Score)

We had no a priori reason to select a specific method of toxicity measure over another (e.g. human vs. ecological or terrestrial vs. aquatic). We made an initial screening of one production practice (Arkansas RR Flex) to see the impacts as assessed by Impact 2002+ and ReCiPe. We found that Impact 2002+ showed that pesticides had a much larger impact on terrestrial ecotoxicity than human toxicity. However, the ReCiPe method showed a larger impact to humans than to the terrestrial ecosystem (see Figure 2). Because it was not clear that one impact dominated all other impacts in all methods, we chose to look at the combined toxicity score (single score).

Figure 2 Toxicity Scores by Impact Category and by Toxicity Assessment Method for Arkansas Production



a. Impact 2002+



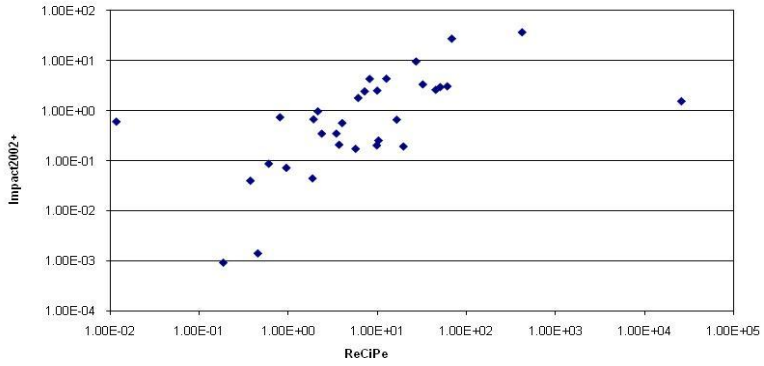
b. ReCiPe

Comparing Toxicity Impact Assessment Methods by Pesticide Scores and Rankings

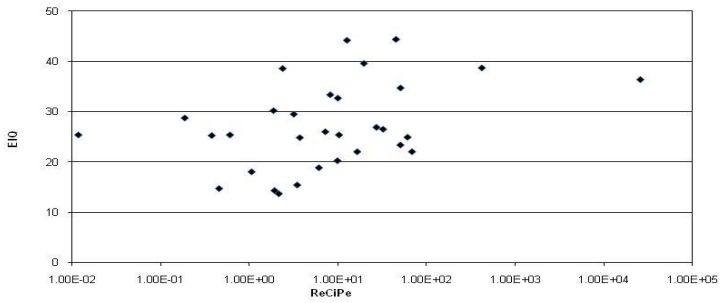
Comparing single scores for individual pesticide (per 1 kg a.i.) across the three final methods (Impact 2002+, ReCiPe, and EIQ), we found that Impact 2002+ and ReCiPe correlated fairly well with each other. There were a couple notable outliers, glyphosate (higher for Impact 2002+)

and cypermethrin (higher for ReCiPe), but in general, the methods were fairly close with respect to pesticide rankings. If these two pesticides were not used in production, the two methods may be expected to give somewhat similar relative results for different production practices. EIQ however did not correlate so well with ReCiPe or Impact 2002+ (see Figure 3). It is not clear why this is the case, however, EIQ does weight human toxicity more heavily as it takes two thirds of its score comes from humans (consumer and farmworker, as compared with ecosystems). See Appendix A. for individual pesticide scores.

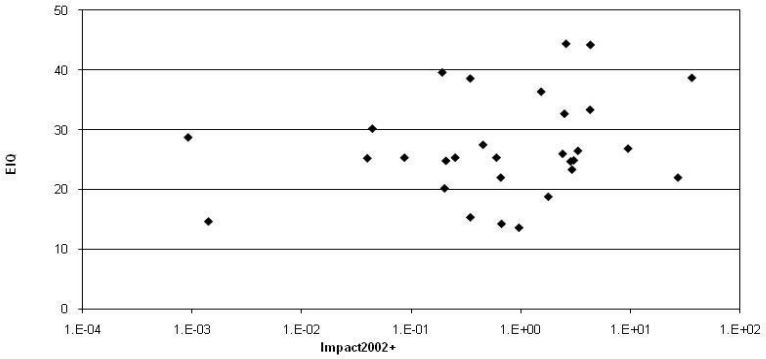
Figure 3 Comparing Single Score Values for Individual Pesticides by Toxicity Assessment Method



a. Impact 2002+ vs. ReCiPe



b. EIQ vs. ReCiPe



c. EIQ vs. Impact 2002+

Comparing Toxicity Impact Assessment Methods by Production Practice

While individual pesticide rankings do not correlate as well between EIQ and ReCiPe; and EIQ and Impact 2002+, production practices (using multiple pesticides at application rates) do show more correlation. This is presumably because some production practices use much greater quantities of pesticides than other production practices. When comparing ReCiPe with Impact

2002+ or EIQ, we see correlation and a general linear trend. ReCiPe however has an outlier value for cypermethrin, and so it pulls those production practices that use cypermethrin out of line with the general trend. If we were to assign a value that is more in line with all of the other pesticides (e.g. the median score from ReCiPe for all pesticides used on cotton), we would see much higher correlation between Impact 2002+ and ReCiPe, and a closer correlation with EIQ and ReCiPe (see Figure 4A-B). While we cannot change the value that is provided by ReCiPe for cypermethrin for further analyses, we can see that if cypermethrin is not used in a given production practice, EIQ, ReCiPe and Impact should provide relatively comparable results.

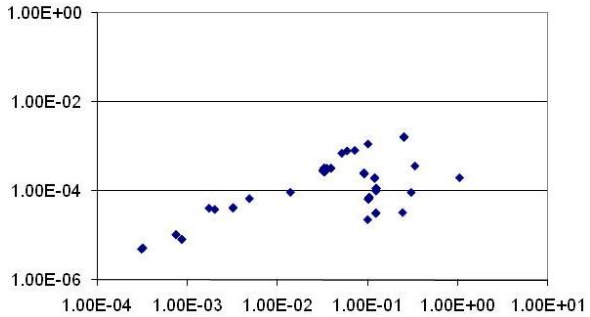
Production Practices

Cotton production practices in 16 states were assessed. In order to determine the range of practices and chemical inputs, cotton production budgets were produced by agricultural extension specialists. These budgets provided a production breakdown for each region. The types of production practices were identified in these budgets, i.e. conventional, Roundup Ready (RR), irrigated, etc., as well as the individual pesticide inputs. Once the chemicals were identified, they were evaluated in terms of toxic threat using the ReCiPe, Impact 2002+, and EIQ toxicity metrics.

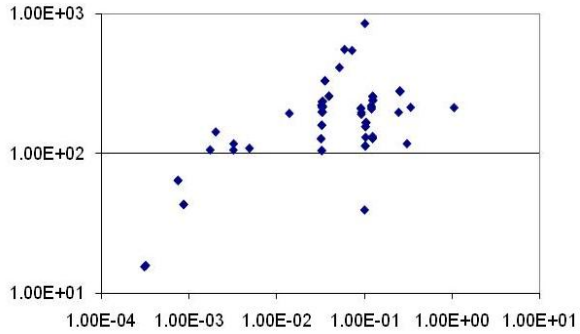
We categorized each production practice by three categories: tillage practice, irrigation, and seed type. For tillage we characterized each production practice as conventional-, low-, or no-till. For irrigation we characterized each practice as irrigated or dry. For seed type we characterized by Bollgard (BG), BG II/Flex, Roundup Ready (RR), BG/RR, RR Flex, Bt/RR, Liberty Link (LL), and Pima. We combined these values for each type of production practice by toxicity index, to create summary statistics for each type of production practice.

Table 1 shows the results of the impact analysis in ReCiPe, Impact 2002+, and EIQ for each tillage practice. Conventional tillage, low tillage, and no tillage scenarios are presented. Table 2 shows the results of the ReCiPe, Impact 2002+, and EIQ assessments for different irrigation practices. Dry and irrigated system scenarios are presented. Table 3 shows the results of the ReCiPe, Impact 2002+, and EIQ assessment for individual seed types.

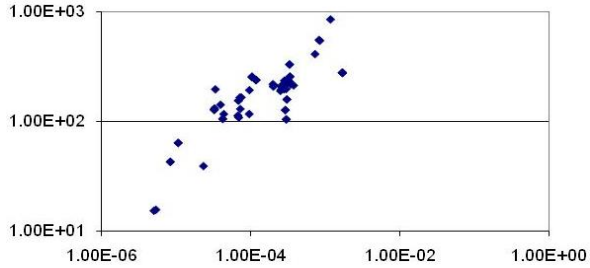
Figure 4A Comparing Single Score Values for Production Practices by Production Method



A1. Impact 2002+ vs. ReCiPe

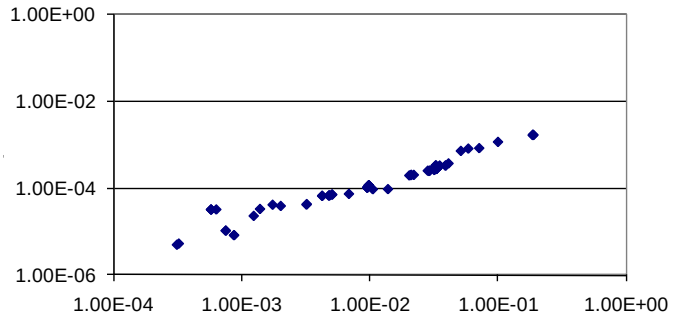


A2. EIQ vs. ReCiPe

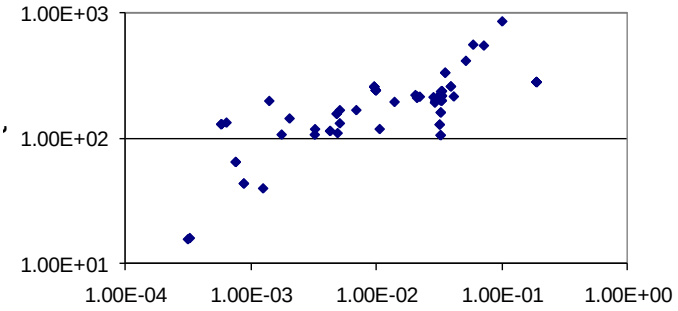


A3. EIQ vs. Impact 2002+

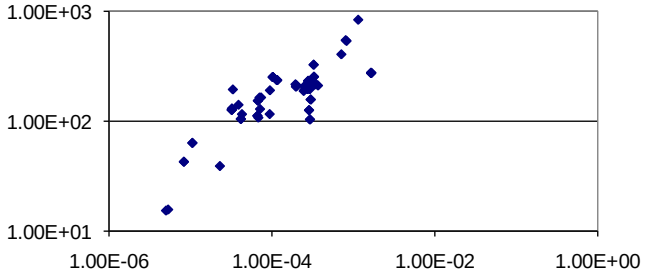
Figure 5B Comparing Single Score Values for Production Practices by Production Method, using a median value for cypermethrin in ReCiPe



B1. Impact 2002+ vs. ReCiPe



B2. EIQ vs. ReCiPe



B3. EIQ vs. Impact 2002+

Table 1 Toxicity impact scores from ReCiPe, Impact 2002+, and EIQ for each tillage practice

ReCiPe			
	Tillage Practice		
	Conventional Till	Low Till	No Till
Average of ReCiPe	1.40E-01	8.13E-02	5.26E-02
Max of ReCiPe	1.05E+00	2.54E-01	1.03E-01
Min of ReCiPe	3.22E-03	7.52E-04	2.03E-03
StdDev of ReCiPe	2.00E-01	8.49E-02	7.15E-02

Impact 2002+			
	Tillage Practice		
	Conventional Till	Low Till	No Till
Avg. of Impact 2002+	2.69E-04	4.05E-04	5.49E-05
Max of Impact 2002+	1.16E-03	1.67E-03	7.07E-05
Min of Impact 2002+	3.22E-05	8.30E-06	3.90E-05
StdDev of Impact2002+	2.92E-04	5.27E-04	2.24E-05

EIQ			
	Tillage Practice		
	Conventional Till	Low Till	No Till
Average of EIQ	248	198	154
Max of EIQ	852	331	166
Min of EIQ	105	43	143
StdDev of EIQ	171	72	17

Table 2 Toxicity impact scores from ReCiPe, Impact 2002+, and EIQ by irrigation practice

ReCiPe		
	Irrigation Practice	
	Dry	Irrigated
Average of ReCiPe	8.31E-02	1.14E-01
Max of ReCiPe	3.37E-01	1.05E+00
Min of ReCiPe	3.12E-04	3.23E-04
StdDev of ReCiPe	8.93E-02	1.66E-01

Impact 2002+		
	Irrigation Practice	
	Dry	Irrigated
Avg. of Impact2002+	3.01E-04	3.43E-04
Max of Impact2002+	1.67E-03	1.67E-03
Min of Impact2002+	5.00E-06	5.32E-06
StdDev of Impact2002+	4.44E-04	4.48E-04

EIQ		
	Irrigation Practice	
	Dry	Irrigated
Average of EIQ	1.86E+02	2.21E+02
Max of EIQ	3.31E+02	8.52E+02
Min of EIQ	1.55E+01	1.58E+01
StdDev of EIQ	7.87E+01	1.49E+02

Table 3 Toxicity impact scores from ReCiPe, Impact 2002+, and EIQ for each seed type

ReCiPe

	Seed Types							
	BG	BG II/Flex	BG/RR	BT/RR	LL	Pima	RR	RRFlex
Average of ReCiPe	1.25E-01	6.15E-02	1.14E-01	3.27E-02	1.05E-01	1.21E-01	1.09E-01	5.57E-02
Max of ReCiPe	1.25E-01	1.02E-01	1.25E-01	3.31E-02	1.05E-01	1.21E-01	1.05E+0	1.03E-01
Min of ReCiPe	1.25E-01	3.34E-02	9.25E-02	3.25E-02	1.05E-01	1.21E-01	3.12E-04	3.21E-02
StdDev of ReCiPe	1.63E-04	3.16E-02	1.40E-02	3.15E-04			1.67E-01	4.09E-02

Impact 2002+

	Seed Types							
	BG	BG II/Flex	BG/RR	BT/RR	LL	Pima	RR	RRFlex
Average of Impact2002	1.10E-04	2.58E-04	1.19E-04	3.15E-04	7.39E-05	2.03E-04	3.95E-04	2.14E-04
Max of Impact2002	1.16E-04	3.31E-04	2.53E-04	3.38E-04	7.39E-05	2.03E-04	1.67E-03	2.88E-04
Min of Impact2002	1.03E-04	6.66E-05	6.76E-05	3.00E-04	7.39E-05	2.03E-04	5.00E-06	6.76E-05
StdDev of Impact2002	7.62E-06	8.98E-05	6.25E-05	1.87E-05			5.36E-04	1.27E-04

EIQ

	Seed Type							
	BG	BG II/Flex	BG/RR	BT/RR	LL	Pima	RR	RRFlex
Average of EIQ	2.48E+02	2.17E+02	2.16E+02	2.24E+02	1.66E+02	2.14E+02	2.01E+02	1.37E+02
Max of EIQ	2.56E+02	2.57E+02	2.56E+02	2.34E+02	1.66E+02	2.14E+02	8.52E+02	1.56E+02
Min of EIQ	2.40E+02	1.13E+02	1.56E+02	2.18E+02	1.66E+02	2.14E+02	1.55E+01	1.27E+02
StdDev of EIQ	9.27E+00	4.97E+01	4.24E+01	7.08E+00			1.49E+02	1.62E+01

Note 1: BG: Bollgard; RR: Roundup Ready; BT: Bt; LL: Liberty Link.

Note2 : LL and Pima cotton do not have values for Std Deviation because they each only have one data point.

From the above results, one can see that no till cotton production appears to have lower toxicity than low till and conventional till based upon all three impact assessment methods. Low till production has lower toxicity than conventional till using ReCiPe and EIQ, but has a higher value using Impact 2002+. Dryland production practices had lower toxicity than irrigated cotton using all three methods. There was no clear difference when looking at seed type. This is primarily due to the high number of categories used. It is possible that more clear distinctions may be seen if the seeds were more broadly categorized; however, it is not clear how that categorization should be done, given stacked gene technologies that have overlapping categories.

Conclusion

There are numerous methods to assess the toxicity from pesticide use in cotton production. We selected five methods that provided index values for each pesticide, without requiring any other parameter input. Four of these methods (CML, Impact 2002 +, ReCiPe, and TRACI) were part of a more complete life cycle assessment methodology and accessible in SimaPro software. The fifth method, EIQ, was a method used specifically for assessing toxicity from pesticides.

These index methods provide a straightforward method to compare toxicity of individual pesticides as well as production practices. These methods can be useful as a screening tool. Other methods that incorporate many parameters, such as method and timing of application, and environmental factors may provide more accurate estimates of toxicity. However, those methods require too many parameter inputs to be used for a national comparison of production practices.

These methods showed that no till cotton appears to reduce the toxicity of conventional cotton production. Additionally, dryland cotton appears to have lower toxicity than irrigated cotton. It was not clear under the current study how seed type affected toxicity.

While all five methods provide index values, only three were useful for our purposes, given that two, CML and TRACI, only had index values for roughly one third of the pesticides used on cotton. In addition those two methods did not have a method for comparing human toxicity with ecological toxicity.

Our study used a single score for each pesticide, based on a weighted average of its impact to human and ecological toxicity. Each of the final three toxicity assessment methods had a different mechanism for weighting human, aquatic and terrestrial toxicity. This weighting matters, but appeared to have less effect on the final results than one would have hypothesized at the outset. Nevertheless, the decision of whether to focus solely on one component of the different toxicity metrics (human vs. ecological) might give vastly different results.

Of the three methods used for final comparison, the pesticide rankings were fairly consistent between Impact 2002+ and ReCiPe, however EIQ did not correlate nearly so well with Impact 2002+ and ReCiPe. However, when looking at rankings of production practices using combined scores for all pesticides applied for a given practice, the methods appeared more consistent. This was most likely due to the differences in raw quantities of pesticides applied. Nevertheless, differences did arise, and these show that method selection does matter.

Impact 2002+ and ReCiPe are both European-centric models. Therefore, their weighting systems differ from what an American-centric model might apply. However, they are part of a complete LCA methodology, and therefore they may be more useful when undertaking a cradle-to-grave LCA analysis, looking at multiple environmental impacts along with toxicity.

EIQ is an American model. Its assumptions and calculations are somewhat more straightforward and explicit. In addition, its impact categories (consumer, farmworker, fish, bees, etc) are more explicit. EIQ also has the most comprehensive list of index values for pesticides used on cotton. However, EIQ's methodology appears to have less capability of distinguishing between major and minor toxicity of pesticides. The difference in index value from the lowest to highest ranked pesticides in EIQ is a factor of 3, whereas in ReCiPe and Impact 2002+ is several orders of magnitude.

Interestingly, the rankings of different production practices for cotton appear to have relative consistency. Nevertheless, it is unclear and beyond the scope of this study to understand how well these methods would perform when comparing cotton production with other agricultural products, or comparing cotton production with other textile production.

Ultimately, each of the three methods has its strengths, and is a valuable tool in estimating toxicity from cotton, and all agricultural production. While the methods do correlate, they are not equal. Therefore method selection should depend on the needs of the analysis, such as which pesticides are under study, the type of toxicity being studied, and whether the study is specifically for toxicity from pesticides, or something more broad, including multiple environmental impacts.

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Appendix A.

Rankings of Pesticides by Toxicity Category and by Impact Assessment Method –

Rankings are based upon the percent of total impact of a given pesticide if applying 1 kg a.i. of all 49 pesticides:

Figure A.6 Individual Pesticide Human Ecotoxicity Rankings by Method (1 kg a.i. applied to agricultural soil)

EIQ	Human Avg	**Impact2002+**	DALY	**ReCiPe**	DALY	**CML**	kg 1,4-DB eq	**TRACI**	kg toluen eq
sodium chlorate	28.63	Chlorpyrifos	6.58652E-07	Cypermethrin	0.00000481	Cypermethrin	26.0	Aldicarb	10.3
methamidophos	24.75	Lambda-cyhalothrin	2.891E-07	Aldicarb	4.625E-07	Diuron	3.2	Cyanazine	2.1
aldicarb	20.50	Acephate	2.09245E-07	Acephate	0.000000165	Aldicarb	1.3	Cypermethrin	1.8
paraquat-dichloride	19.14	Bifenthrin	1.78452E-07	Chlorpyrifos	2.2875E-08	Trifluralin	0.3	Diuron	1.6
endosulfan	16.25	Parathion, methyl	1.36728E-07	Trifluralin	1.4775E-08	2,4-D	0.1	Tribufos	0.8
diuron	14.25	Aldicarb	1.28394E-07	Parathion, methyl	1.4575E-08	Methomyl	0.1	2,4-D	0.3
endothall	13.93	Trifluralin	1.24442E-07	Methamidophos	1.345E-08	Bifenthrin	0.1	Methomyl	0.1
acephate	13.75	Methamidophos	8.76828E-08	Methomyl	1.345E-08	Cyanazine	0.1	Trifluralin	0.1
ethephon	12.98	Dicrotophos	5.98897E-08	Ethephon	8.625E-09	Parathion, methyl	0.1	Metolachlor	0.1
thiamethoxam	12.19	Cypermethrin	5.94322E-08	Buprofezin	8.575E-09	Acephate	0.1	Endosulfan	0.0
thiodicarb	12.00	Methidathion	5.8987E-08	Bifenthrin	8.425E-09	Chlorpyrifos	0.0	Dicamba	0.0
lambda-cyhalothrin	11.58	Diuron	4.91962E-08	Glufosinate ammonium	8.325E-09	Metolachlor	0.0	Chlorpyrifos	0.0
flumioxazin	11.05	Thiobencarb	3.8175E-08	Thiobencarb	6.6E-09	Oxamyl	0.0	Bifenthrin	0.0
bifenthrin	10.85	Metolachlor	1.80645E-08	Cyfluthrin	5.725E-09	Endosulfan	0.0	Oxamyl	0.0
metolachlor	10.50	Methomyl	1.49287E-08	Methidathion	4.1E-09	Glyphosate	0.0	Acephate	0.0
glufosinate-ammonium	10.00	Fenpropathrin	1.47605E-08	Diuron	3.3E-09	Alpha-cypermethrin	#N/A	Glyphosate	0.0
cyanazine	9.65	Endosulfan	1.377E-08	Alpha-cypermethrin	2.95E-09	Buprofezin	#N/A	Alpha-cyperme	#N/A
cypermethrin	9.35	Tribufos	7.414E-09	Endosulfan	2.675E-09	Carfentrazone ethyl ester	#N/A	Buprofezin	#N/A
pendimethalin	8.75	Prometryn	4.48723E-09	Cyanazine	2.65E-09	Cyclanilide	#N/A	Carfentrazone	#N/A
methomyl	8.50	2,4-D	4.14965E-09	Thiodicarb	2.295E-09	Cyfluthrin	#N/A	Cyclanilide	#N/A
dicamba	7.50	Pendimethalin	2.85398E-09	Pendimethalin	1.85E-09	Dicamba	#N/A	Cyfluthrin	#N/A
trifluralin	7.25	Oxamyl	2.49888E-09	Fenpropathrin	1.2925E-09	Dicrotophos	#N/A	Dicrotophos	#N/A
imidacloprid	7.13	Cyfluthrin	2.46604E-09	Metolachlor	1.22E-09	Endothall	#N/A	Endothall	#N/A
fluazifop-P-butyl	6.98	Fluometuron	1.74304E-09	Dicamba	9.5E-10	Ethephon	#N/A	Ethephon	#N/A
oxamyl	6.68	Glufosinate ammonium	1.37773E-09	Prometryn	6.825E-10	Fenpropathrin	#N/A	Fenpropathrin	#N/A
buprofezin	6.50	Ethephon	9.52479E-10	2,4-D	6.7E-10	Fluazifop	#N/A	Fluazifop	#N/A
carfentrazone	6.50	Dicamba	8.20024E-10	Mepiquat chloride	4.95E-10	Flumioxazin	#N/A	Flumioxazin	#N/A
MSMA Methylarsonic acid	6.50	Paraquat	7.19616E-10	Oxamyl	4.8E-10	Fluometuron	#N/A	Fluometuron	#N/A
cyclanilide	6.49	Glyphosate	1.27365E-10	Fluometuron	4.275E-10	Glufosinate ammonium	#N/A	Glufosinate am	#N/A
prometryn	6.33	Endothall	2.4915E-11	Pyriproxyfen	2.65E-10	Imidacloprid	#N/A	Imidacloprid	#N/A
fluometuron	5.83	Mepiquat chloride	6.15E-12	Endothall	7.925E-11	Lambda-cyhalothrin	#N/A	Lambda-cyhalo	#N/A
glyphosate	5.50	Alpha-cypermethrin	#N/A	Glyphosate	1.29E-12	Mepiquat chloride	#N/A	Mepiquat chlor	#N/A
Methidathion	5.18	Buprofezin	#N/A	Carfentrazone ethyl est	#N/A	Methamidophos	#N/A	Methamidopho	#N/A
cyfluthrin	4.68	Carfentrazone ethyl este	#N/A	Cyclanilide	#N/A	Methidathion	#N/A	Methidathion	#N/A
Parathion, Methyl	4.18	Cyanazine	#N/A	Dicrotophos	#N/A	Monosodium acid methan	#N/A	Monosodium a	#N/A
2,4-DP, azin	4.00	Cyclanilide	#N/A	Fluazifop	#N/A	Paraquat	#N/A	Paraquat	#N/A
chlorpyrifos	4.00	Fluazifop	#N/A	Flumioxazin	#N/A	Pendimethalin	#N/A	Parathion, meth	#N/A
fenpropathrin	4.00	Flumioxazin	#N/A	Imidacloprid	#N/A	Prometryn	#N/A	Pendimethalin	#N/A
pyriproxyfen	4.00	Imidacloprid	#N/A	Lambda-cyhalothrin	#N/A	Pyriproxyfen	#N/A	Prometryn	#N/A
spinosad	4.00	Monosodium acid metha	#N/A	Monosodium acid meth	#N/A	Sodium chlorate	#N/A	Pyriproxyfen	#N/A
Alpha-cypermethrin	#N/A	Pyriproxyfen	#N/A	Paraquat	#N/A	Spinosad	#N/A	Sodium chlorat	#N/A
Dicrotophos	#N/A	Sodium chlorate	#N/A	Sodium chlorate	#N/A	Thiamethoxam	#N/A	Spinosad	#N/A
Mepiquat chloride	#N/A	Spinosad	#N/A	Spinosad	#N/A	Thidiazuron	#N/A	Thiamethoxam	#N/A
Thiobencarb	#N/A	Thiamethoxam	#N/A	Thiamethoxam	#N/A	Thiobencarb	#N/A	Thidiazuron	#N/A
Thiodicarb	#N/A	Thidiazuron	#N/A	Thidiazuron	#N/A	Thiodicarb	#N/A	Thiobencarb	#N/A
Tribufos	#N/A	Thiodicarb	#N/A	Tribufos	#N/A	Tribufos	#N/A	Thiodicarb	#N/A

Figure A.7 Individual Pesticide Terrestrial Ecotoxicity Rankings by Method (1 kg a.i. applied to agricultural soil)

	EIQ		Impact2002+		ReCiPe		CML		TRACI	
	Substance	EIQ Terrestrial	Substance	kg TEG soil	Substance	species.yr	Substance	kg 1,4-DB eq	Substance	kg toluen eq
1	Imidacloprid	89.88	Aldicarb	589	Cypermethrin	0.00000715	Cypermethrin	449	Aldicarb	10.3
2	Bifenthrin	86.35	Methomyl	448	Aldicarb	7.45E-08	Aldicarb	11	Cyanazine	2.1
3	Oxamyl	83.65	Oxamyl	73	Methomyl	1.89E-08	Methomyl	0.8	Cypermethrin	1.8
4	Cyfluthrin	83.35	Dicrotophos	69	Thiodicarb	1.4875E-08	Bifenthrin	0.2	Diuron	1.6
5	Lambda-cyhalothrin	83.35	Methamidophos	52	Bifenthrin	1.255E-08	Parathion, methyl	0.2	Tribufos	0.8
6	Thiamethoxam	72.52	Thiodicarb	50	Alpha-cypermethrin	1.2375E-08	Cyanazine	0.2	2,4-D	0.3
7	Methidathion	71.67	Paraquat	49	Diuron	9.275E-09	Trifluralin	0.1	Methomyl	0.1
8	Aldicarb	70.00	Diuron	44	Methamidophos	5.8E-09	Diuron	0.1	Trifluralin	0.1
9	Cypermethrin	64.35	Methidathion	28	Chlorpyrifos	5.575E-09	Parathion	0.0	Metolachlor	0.1
10	Cyclanilide	63.45	Cyanazine	16	Cyfluthrin	5.225E-09	Chlorpyrifos	0.0	Endosulfan	0.0
11	Dicamba	60.00	Mepiquat chloride	13	Metolachlor	4.775E-09	Oxamyl	0.0	Dicamba	0.0
12	Glyphosate	60.00	Cypermethrin	11	Lambda-cyhalothrin	3.775E-09	Endosulfan	0.0	Chlorpyrifos	0.0
13	Endosulfan	58.50	Fluometuron	11	Fenpropathrin	2.925E-09	Acephate	0.0	Bifenthrin	0.0
14	Parathion, Methyl	57.55	Metolachlor, (S)	11	Methidathion	2.525E-09	2,4-D	0.0	Oxamyl	0.0
15	Fluazifop-P-butyl	57.15	Parathion	10	Oxamyl	2.3925E-09	Metolachlor	0.0	Acephate	0.0
16	Methamidophos	55.00	Glyphosate	10	Glufosinate ammonium	2.0325E-09	Glyphosate	0.0	Parathion	0.0
17	Pendimethalin	48.00	Cyclanilide	8	Thidiazuron	1.7025E-09	2,4-D Butoxyethyl est	#N/A	Glyphosate	0.0
18	Chlorpyrifos	47.55	Parathion, methyl	8	Prometryn	9.575E-10	Alpha-cypermethrin	#N/A	2,4-D Butoxyethyl ester	#N/A
19	Acephate	46.15	Metolachlor	7	Parathion	9.55E-10	Buprofezin	#N/A	Alpha-cypermethrin	#N/A
20	Sodium chlorate	46.11	Ethephon	3	Parathion, methyl	5.425E-10	Carfentrazone ethyl e	#N/A	Buprofezin	#N/A
21	Methomyl	46.00	Prometryn	3	Fluometuron	5.275E-10	Cyclanilide	#N/A	Carfentrazone ethyl est	#N/A
22	Buprofezin	45.90	Glufosinate ammonium	3	Thiobencarb	4.725E-10	Cyfluthrin	#N/A	Cyclanilide	#N/A
23	Diuron	45.90	Thidiazuron	3	Endosulfan	4.1E-10	Dicamba	#N/A	Cyfluthrin	#N/A
24	Fenpropathrin	43.00	Cyfluthrin	3	Pendimethalin	3.55E-10	Dicrotophos	#N/A	Dicrotophos	#N/A
25	Endothall	42.82	Endosulfan	2	Cyanazine	3.5E-10	Endothall	#N/A	Endothall	#N/A
26	Ethephon	42.45	Lambda-cyhalothrin	2	MSMA Methylarsonic acid	3.175E-10	Ethephon	#N/A	Ethephon	#N/A
27	Flumioxazin	39.60	Chlorpyrifos	2	2,4-D	2.115E-10	Fenpropathrin	#N/A	Fenpropathrin	#N/A
28	Carfentrazone	38.55	Dicamba	1	Trifluralin	1.96E-10	Fluazifop	#N/A	Fluazifop	#N/A
29	Thiodicarb	37.00	Acephate	0.9	Mepiquat chloride	1.8725E-10	Flumioxazin	#N/A	Flumioxazin	#N/A
30	Metolachlor	36.00	Endothall	0.7	Ethephon	1.635E-10	Fluometuron	#N/A	Fluometuron	#N/A
31	MSMA Methylarsonic acid	36.00	Bifenthrin	0.6	Pyriproxyfen	1.07E-10	Glufosinate ammoniu	#N/A	Glufosinate ammonium	#N/A
32	Cyanazine	31.50	Fenpropathrin	0.5	Endothall	1.04E-10	Imidacloprid	#N/A	Imidacloprid	#N/A
33	Paraquat	30.95	Thiobencarb	0.3	Dicamba	7.6E-11	Lambda-cyhalothrin	#N/A	Lambda-cyhalothrin	#N/A
34	Spinosad	30.15	2,4-D	0.2	Acephate	6.375E-11	Mepiquat chloride	#N/A	Mepiquat chloride	#N/A
35	Fluometuron	28.17	Pendimethalin	0.1	Fluazifop-P-butyl	5.575E-11	Methamidophos	#N/A	Methamidophos	#N/A
36	Prometryn	24.45	Trifluralin	0.1	Glyphosate	3.375E-12	Methidathion	#N/A	Methidathion	#N/A
37	Trifluralin	17.00	Pyriproxyfen	0.0	Buprofezin	2.8E-12	Metolachlor, (S)	#N/A	Metolachlor, (S)	#N/A
38	Pyriproxyfen	11.00	Fluazifop-butyl	0.0	2,4-D Butoxyethyl ester	#N/A	MSMA Methylarsonic	#N/A	MSMA Methylarsonic a	#N/A
39	Alpha-cypermethrin	#N/A	Tribufos	0.0	Carfentrazone ethyl ester	#N/A	Paraquat	#N/A	Paraquat	#N/A
40	Dicrotophos	#N/A	2,4-D Butoxyethyl ester	0.0	Cyclanilide	#N/A	Pendimethalin	#N/A	Parathion, methyl	#N/A
41	Fluazifop	#N/A	Alpha-cypermethrin	#N/A	Dicrotophos	#N/A	Prometryn	#N/A	Pendimethalin	#N/A
42	Fluazifop-butyl	#N/A	Buprofezin	#N/A	Flumioxazin	#N/A	Pyriproxyfen	#N/A	Prometryn	#N/A
43	Glufosinate ammonium	#N/A	Carfentrazone ethyl ester	#N/A	Imidacloprid	#N/A	Sodium chlorate	#N/A	Pyriproxyfen	#N/A
44	Mepiquat chloride	#N/A	Flumioxazin	#N/A	Metolachlor, (S)	#N/A	Spinosad	#N/A	Sodium chlorate	#N/A
45	Metolachlor, (S)	#N/A	Imidacloprid	#N/A	Paraquat	#N/A	Thiamethoxam	#N/A	Spinosad	#N/A
46	Parathion	#N/A	MSMA Methylarsonic aci	#N/A	Sodium chlorate	#N/A	Thidiazuron	#N/A	Thiamethoxam	#N/A
47	Thidiazuron	#N/A	Sodium chlorate	#N/A	Spinosad	#N/A	Thiobencarb	#N/A	Thidiazuron	#N/A
48	Thiobencarb	#N/A	Spinosad	#N/A	Thiamethoxam	#N/A	Thiodicarb	#N/A	Thiobencarb	#N/A
49	Tribufos	#N/A	Thiamethoxam	#N/A	Tribufos	#N/A	Tribufos	#N/A	Thiodicarb	#N/A

Figure A.8 Individual Pesticide Aquatic Ecotoxicity Rankings by Method (1 kg a.i. applied to agricultural soil)

EIQ	Aquatic Value	**Impact2002+**	TEG water	**ReCiPe**	species.yr	**CML2001**	kg 1,4-DB eq	**TRACI**	kg toluen eq
bifenthrin	25.0	Methomyl	1990.0	Cypermethrin	6.80E-09	Cypermethrin	9.95E+02	Aldicarb	10.3
buprofezin	25.0	Prometryn	271.8	Aldicarb	7.33E-11	Aldicarb	2.40E+02	Cyanazine	2.1
chlorpyrifos	25.0	Aldicarb	260.1	Methomyl	5.55E-11	Methomyl	3.53E+01	Cypermethrin	1.8
cyfluthrin	25.0	Lambda-cyhalothrin	120.0	Diuron	2.26E-11	Metolachlor	4.73E+00	Diuron	1.6
cypermethrin	25.0	Diuron	88.3	Alpha-cypermethrin	2.16E-11	Parathion, methyl	2.80E+00	Tribufos	0.8
endosulfan	25.0	Cyanazine	81.5	Chlorpyrifos	1.91E-11	Cyanazine	2.02E+00	2,4-D	0.3
fenpropathrin	25.0	Cypermethrin	48.0	Metolachlor	1.83E-11	Chlorpyrifos	8.90E-01	Methomyl	0.1
lambda-cyhalothrin	25.0	Thiodicarb	47.3	Thiodicarb	1.20E-11	Diuron	8.63E-01	Trifluralin	0.1
pendimethalin	25.0	Metolachlor	44.7	Cyfluthrin	9.68E-12	Bifenthrin	2.58E-01	Metolachlor	0.1
pyriproxyfen	25.0	Fenpropathrin	25.9	Methamidophos	8.75E-12	Acephate	1.27E-01	Endosulfan	0.0
trifluralin	25.0	Chlorpyrifos	22.7	Fenpropathrin	7.60E-12	Trifluralin	9.95E-02	Dicamba	0.0
2,4-DP, azin	15.0	Cyfluthrin	21.8	Bifenthrin	6.18E-12	2,4-D	7.38E-02	Chlorpyrifos	0.0
fluazifop-P-butyl	15.0	Parathion, methyl	20.2	Lambda-cyhalothrin	3.95E-12	Oxamyl	7.38E-02	Bifenthrin	0.0
flumioxazin	10.2	Oxamyl	15.5	Prometryn	3.55E-12	Endosulfan	5.53E-03	Oxamyl	0.0
carfentrazone	9.0	Paraquat	15.1	Methidathion	2.55E-12	Glyphosate	2.31E-03	Acephate	0.0
metolachlor	9.0	Fluometuron	14.3	Oxamyl	1.85E-12	Alpha-cypermethrin	#N/A	Parathion, methyl	0.0
Parathion, Methyl	9.0	Methidathion	10.7	Pendimethalin	1.52E-12	Buprofezin	#N/A	Glyphosate	0.0
prometryn	9.0	Dicrotophos	8.8	Thiobencarb	1.49E-12	Carfentrazone	#N/A	Alpha-cypermethrin	#N/A
thiodicarb	9.0	Endosulfan	8.5	Parathion, methyl	1.47E-12	Cyclanilide	#N/A	Buprofezin	#N/A
cyanazine	6.3	Dicamba	8.2	Endosulfan	1.46E-12	Cyfluthrin	#N/A	Carfentrazone	#N/A
aldicarb	5.0	Cyclanilide	6.7	Thidiazuron	1.45E-12	Dicamba	#N/A	Cyclanilide	#N/A
diuron	5.0	Methamidophos	6.2	Cyanazine	1.23E-12	Dicrotophos	#N/A	Cyfluthrin	#N/A
endothall	5.0	Trifluralin	4.8	Fluometuron	9.75E-13	Endothall	#N/A	Dicrotophos	#N/A
ethephon	5.0	Glyphosate	3.1	Glufosinate ammonium	5.20E-13	Ethephon	#N/A	Endothall	#N/A
glyphosate	5.0	Acephate	1.6	Dicamba	3.73E-13	Fenpropathrin	#N/A	Ethephon	#N/A
Methidathion	5.0	Mepiquat chloride	1.5	Acephate	2.78E-13	Fluazifop	#N/A	Fenpropathrin	#N/A
MSMA	5.0	Tribufos	1.5	Pyriproxyfen	2.65E-13	Flumioxazin	#N/A	Fluazifop	#N/A
paraquat-dichloride	5.0	Bifenthrin	1.1	Fluazifop-P-butyl	1.98E-13	Fluometuron	#N/A	Flumioxazin	#N/A
cyclanilide	3.0	Thidiazuron	0.9	Trifluralin	1.19E-13	Glufosinate ammonium	#N/A	Fluometuron	#N/A
fluometuron	3.0	Pendimethalin	0.8	MSMA	8.10E-14	Imidacloprid	#N/A	Glufosinate ammonium	#N/A
imidacloprid	3.0	Endothall	0.7	Endothall	6.05E-14	Lambda-cyhalothrin	#N/A	Imidacloprid	#N/A
methomyl	3.0	2,4-D	0.5	2,4-D	5.73E-14	Mepiquat chloride	#N/A	Lambda-cyhalothrin	#N/A
oxamyl	3.0	Ethephon	0.4	Mepiquat chloride	4.78E-14	Methamidophos	#N/A	Mepiquat chloride	#N/A
thiamethoxam	3.0	Glufosinate ammonium	0.4	Ethephon	4.40E-14	Methidathion	#N/A	Methamidophos	#N/A
acephate	1.0	Thiobencarb	0.2	Glyphosate	1.72E-14	MSMA	#N/A	Methidathion	#N/A
dicamba	1.0	Fluazifop-butyl	0.0	Buprofezin	8.75E-15	Paraquat	#N/A	MSMA	#N/A
glufosinate-ammonium	1.0	Pyriproxyfen	0.0	Carfentrazone	#N/A	Pendimethalin	#N/A	Paraquat	#N/A
methamidophos	1.0	Alpha-cypermethrin	#N/A	Cyclanilide	#N/A	Prometryn	#N/A	Pendimethalin	#N/A
Alpha-cypermethrin	#N/A	Buprofezin	#N/A	Dicrotophos	#N/A	Pyriproxyfen	#N/A	Prometryn	#N/A
Dicrotophos	#N/A	Carfentrazone	#N/A	Flumioxazin	#N/A	Thiamethoxam	#N/A	Pyriproxyfen	#N/A
Mepiquat chloride	#N/A	Flumioxazin	#N/A	Imidacloprid	#N/A	Thidiazuron	#N/A	Thiamethoxam	#N/A
Thidiazuron	#N/A	Imidacloprid	#N/A	Paraquat	#N/A	Thiobencarb	#N/A	Thidiazuron	#N/A
Thiobencarb	#N/A	MSMA	#N/A	Thiamethoxam	#N/A	Thiodicarb	#N/A	Thiobencarb	#N/A
Tribufos	#N/A	Thiamethoxam	#N/A	Tribufos	#N/A	Tribufos	#N/A	Thiodicarb	#N/A

Appendix B.

Toxicity Impact Assessment Methods

EIQ:

The Environmental Impact Quotient (EIQ) metric focuses on the environmental impact assessment. EIQ is used to organize and quantify the extensive toxicological data from the various forms and uses of pesticides. The EIQ impact assessment is based on the three principal components of agricultural production systems: a farm worker component, a consumer component, and an ecological component. Each component in the equation is given equal weight in the final analysis, but within each component, individual factors are weighted differently. Coefficients used in the equation to give additional weight to individual factors.

EIQ Field Use Rating was developed. This rating is calculated by multiplying the EIQ value for the specific chemical obtained in the tables by the percent active ingredient in the formulation by the rate per acre used (usually in pints or pounds of formulated product).

(EIQ Field Use Rating = EIQ x % active ingredient x Rate)

With this method, comparisons of environmental impact between pesticides and different pest management programs can be made. A consistent rule throughout the model is that the impact potential of a specific pesticide on an individual environmental factor is equal to the toxicity of the chemical times the potential for exposure. Stated simply, environmental impact is equal to toxicity times exposure. For example, fish toxicity is calculated by determining the inherent toxicity of the compound to fish times the likelihood of the fish encountering the pesticide. In this manner, compounds that are toxic to fish but short-lived have lower impact values than compounds that are toxic and long-lived.

By using the EIQ Field Use Rating, IPM practitioners and growers can incorporate environmental effects along with efficacy and cost into the pesticide decision-making process. IPM programs can also use the EIQ model as another method to measure the environmental impact of different pest management and pesticide programs. As newer biorational pesticides are marketed with lower EIQ values and more emphasis is placed on biologically based IPM practices, the EIQ field use ratings will continue to decrease. Eventually these ratings may approach zero, resulting in an environmentally neutral or benign agricultural production system.

The formula for determining the EIQ value of individual pesticides is listed below and is the average of the farm worker, consumer, and ecological components

$$EIQ=\{C[(DT*5)+(DT*P)]+[(C*((S+P)/2)*SY)+(L)]+[(F*R)+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]\}/3$$

DT = dermal toxicity
C = chronic toxicity
SY = systemicity
F = fish toxicity
L = leaching potential
R = surface loss potential
D = bird toxicity
S = soil half-life

Z = bee toxicity
B = beneficial arthropod toxicity
P = plant surface half-life

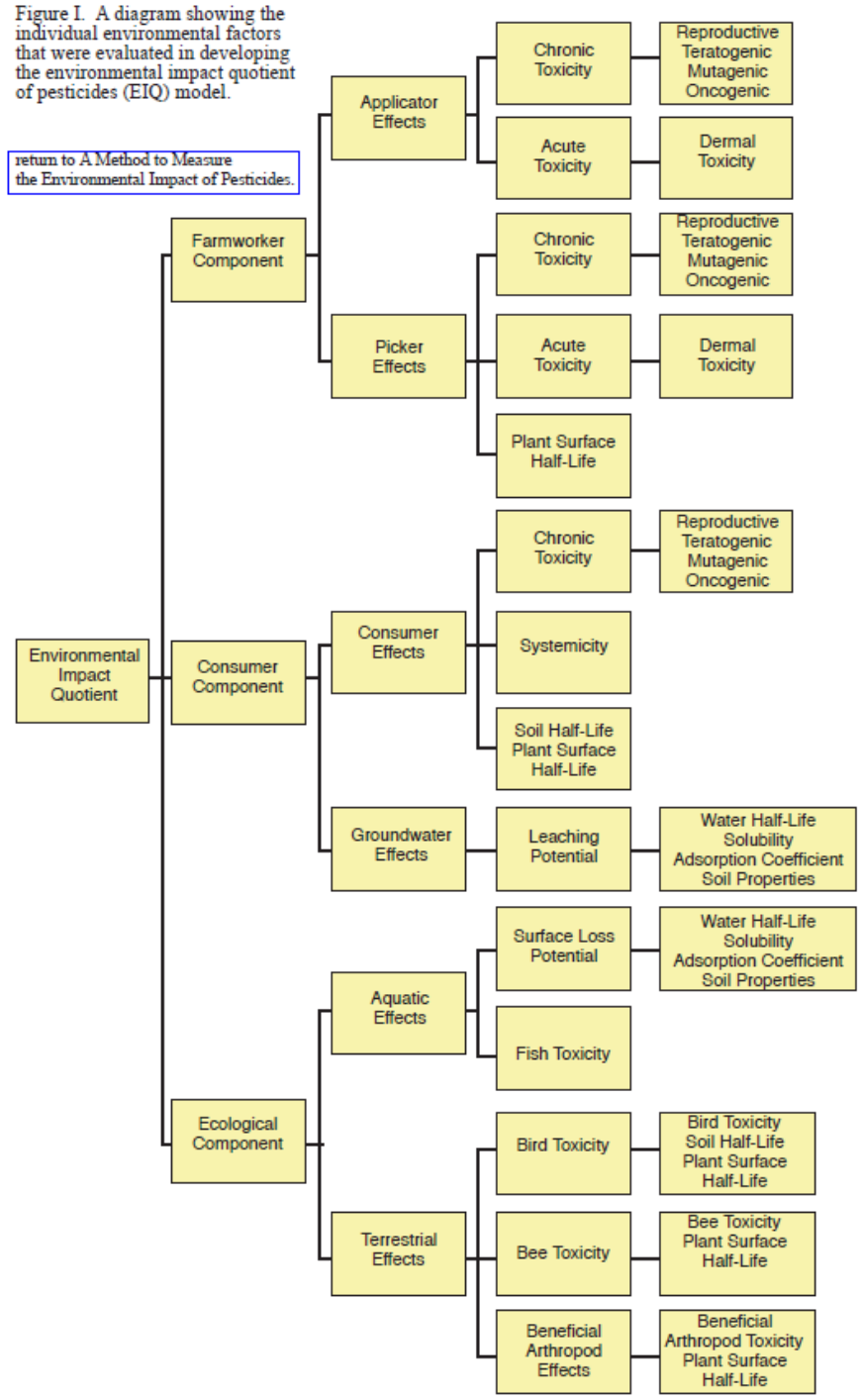
Farm worker risk: the sum of applicator exposure (DT*5) plus picker exposure (DT*P) times the long-term health effect or chronic toxicity (C). Chronic toxicity of a specific pesticide is calculated as the average of the ratings from various long-term laboratory tests conducted on small mammals. These tests are designed to determine potential reproductive effects (ability to produce offspring), teratogenic effects (deformities in unborn offspring), mutagenic effects (permanent changes in hereditary material such as genes and chromosomes), and oncogenic effects (tumor growth). Within the farmworker component, applicator exposure is determined by multiplying the dermal toxicity (DT) rating to small laboratory mammals (rabbits or rats) times a coefficient of five to account for the increased risk associated with handling concentrated pesticides. Picker exposure is equal to dermal toxicity (DT) times the rating for plant surface residue half-life potential (the time required for one-half of the chemical to break down). This residue factor takes into account the weathering of pesticides that occurs in agricultural systems and the days to harvest restrictions that may be placed on certain pesticides.

Consumer component: is the sum of consumer exposure potential (C*((S+P)/2)*SY) plus the potential groundwater effects (L). Groundwater effects are placed in the consumer component because they are more of a human health issue (drinking well contamination) than a wildlife issue. Consumer exposure is calculated as chronic toxicity (C) times the average for residue potential in soil and plant surfaces (because roots and other plant parts are eaten) times the systemic potential rating of the pesticide (the pesticide's ability to be absorbed by plants).

Ecological component: is composed of aquatic and terrestrial effects and is the sum of the effects of the chemicals on fish (F*R), birds (D*((S+P)/2)*3), bees (Z*P*3), and beneficial arthropods (B*P*5). The environmental impact of pesticides on aquatic systems is determined by multiplying the chemical toxicity to fish rating times the surface runoff potential of the specific pesticide (the runoff potential takes into account the half-life of the chemical in surface water). The impact of pesticides on terrestrial systems is determined by summing the toxicities of the chemicals to birds, bees, and beneficial arthropods. Because terrestrial organisms are more likely to occur in commercial agricultural settings than fish, more weight is given to the pesticidal effects on these terrestrial organisms. Impact on birds is measured by multiplying the rating of toxicity to birds by the average half-life on plant and soil surfaces times three. Impact on bees is measured by taking the pesticide toxicity ratings to bees times the half-life on plant surfaces times three. The effect on beneficial arthropods is determined by taking the pesticide toxicity rating to beneficial natural enemies times the half-life on plant surfaces times five. Because arthropod natural enemies spend almost all of their life in agroecosystem communities (while birds and bees are somewhat transient), their exposure to the pesticides, in theory, is greater. t To adjust for this increased exposure, the pesticide impact on beneficial arthropods is multiplied by five. Mammalian wildlife toxicity is not included in the terrestrial component of the equation because mammalian exposure (farm worker and consumer) is already included in the equation, and these health effects are the results of tests conducted on small mammals such as rats, mice, rabbits, and dogs. After the data on individual factors were collected, pesticides were grouped by classes (fungicides, insecticides/miticides, and herbicides), and calculations were conducted for each pesticide. When toxicological data were missing, the average for each environmental factor

within a class was determined, and this average value was substituted for the missing values. Thus, missing data did not affect the relative ranking of a pesticide within a class.

Figure 9 EIQ Methodology



IMPACT 2002+:

The IMPACT 2002+ life cycle impact assessment utilizes a combined midpoint/damage approach to quantify the environmental effects associated with the production of a certain substance. The model was co-created by the Industrial Ecology & Life Cycle Systems Group, GECOS, and the Swiss Federal Institute of Technology Lausanne (EPFL). Life cycle inventory (LCI) results are linked to four damage categories, including human health, ecosystem quality, climate change, and resources, through fourteen midpoint categories, including human toxicity, respiratory effects, ionizing radiation, ozone layer depletion, photochemical oxidation, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification/nitrification, land occupation, global warming, non-renewable energy, and mineral extraction. The assessment draws from other techniques, including CML 2001 and Eco-indicator 99, and also applies new techniques to describe midpoint and damage characterization factors (Jolliet 2003).

All midpoint characterization factors are expressed in kg-equivalents of a substance to that of a reference substance. Damage characterization factors can then be obtained by multiplying the midpoint characterization factor by a damage characterization conversion factor that is associated with the reference substance. The following describes each midpoint characterization factor and its subsequent damage level characterization factor.

Human toxicity: The characterization factors are based on emissions into the air, water, soil and agricultural soil; however, no factors are yet available for emissions into the ocean, underground water and stratosphere. General factors are calculated at a continental level for Western Europe nested in a World box. Human toxicity through emission into agricultural soil has been modified from an emission into European average soil based on a correction factor that takes into account the European agricultural land area. The midpoint reference substance is kg_{eq} chloroethylene emitted into the air. Human toxicity characterization factor for heavy metals only apply for metal emitted as dissolved ions. This midpoint category can be converted to the damage category of human health which is expressed in DALY (Disability Adjusted Life Years) (Humbert et al. 2005).

Aquatic ecotoxicity: This midpoint factor only considers surface fresh water ecotoxicity and characterization factors are given for emissions into the air, water and soil. The midpoint reference substance is kg_{eq} triethylene glycol into water. Relates to ecosystem quality and is express in PDF*m^2*yr at the damage level (Potentially Disappeared Fraction of species per m^2 per year). The conversion from the midpoint substance to PDF*m^2*yr was determined with the IMPACT 2002+ model (Humbert et al. 2005).

Terrestrial ecotoxicity: This midpoint only considers the ecotoxicity a substance has by exposition through the aqueous phase in soil. Characterization factors are given for emissions into air, water and soil. The reference substance is triethylene glycol into soil. Characterization factors for heavy metals only apply for metals emitted as dissolved ions. Relates to ecosystem quality and is express in PDF*m^2*yr at the damage level. The conversion from the midpoint substance to PDF*m^2*yr was determined with the IMPACT 2002+ model (Humbert et al. 2005).

Once converted to a damage value, each of the damage categories can then be normalized to allow for single score to compare the overall effects a certain substance has to others. Using a

normalization factor, each of the damage categories is converted to a point. The points can then be summed, giving the substance an overall single score.

Figure 10 General Methodology Used by Impact 2002+

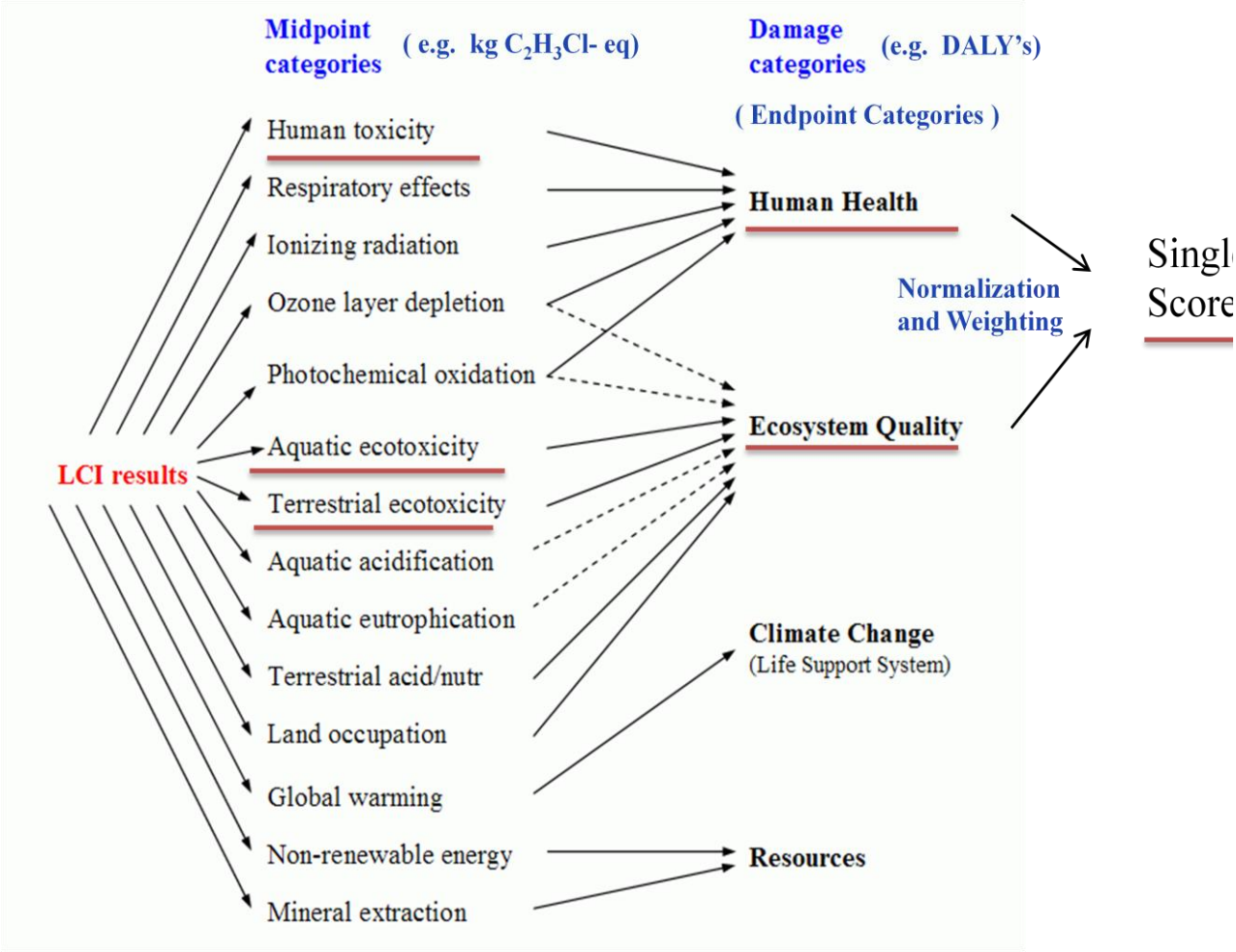
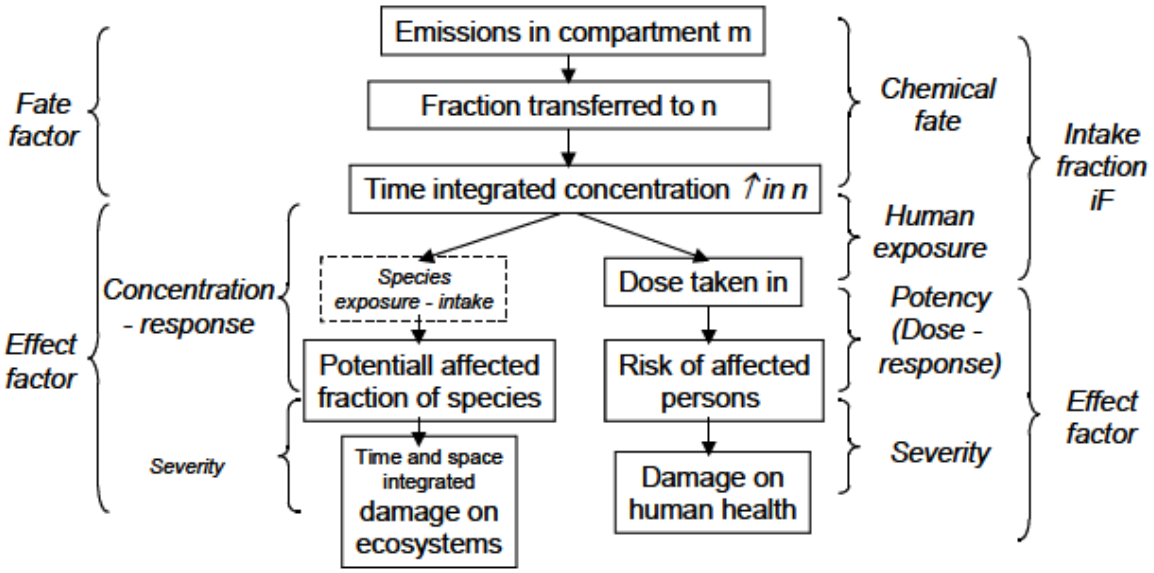


Figure 11 Impact 2002+ Toxicity Framework



CML:

CML 2001 utilizes the mid-point approach to quantify the human and environmental effects linked to the production and use of a certain substance. CML 2001 is an LCIA (Life Cycle Impact Assessment) that has eleven midpoint indicators including: primary energy, acidification, eutrophication, global warming, ozone depletion, photochemical ozone creation, human toxicity, terrestrial ecotoxicity, marine aquatic toxicity, freshwater aquatic ecotoxicity, and abiotic depletion. This assessment was drawn from similar techniques including IMPACT 2002+, EPS, and Eco-indicator 99.

In 2001 a group of scientists under the lead of CML (Center of Environmental Science of Leiden University) proposed a set of impact categories and characterization methods for the impact assessment step. A "problem oriented approach" and a "damage approach" are differentiated. Since the damage approaches chosen are the Eco-indicator 99 and the EPS method, the impact assessment method implemented in ecoinvent as CML 01 methodology is the set of impact categories defined for the midpoint approach.

Depletion of abiotic resources: This impact category is concerned with protection of human welfare, human health and ecosystem health. This impact category indictor is related to extraction of minerals and fossil fuels due to inputs in the system. The Abiotic Depletion Factor (ADF) is determined for each extraction of minerals and fossil fuels (kg antimony equivalents/kg extraction) based on concentration reserves and rate of deaccumulation. The geographic scope of this indicator is at global scale.

Human toxicity: This category concerns effects of toxic substances on the human environment. Health risks of exposure in the working environment are not included. Characterisation factors, Human Toxicity Potentials (HTP), are calculated with USES-LCA, describing fate, exposure and effects of toxic substances for an infinite time horizon. For each toxic substance HTP's are expressed as 1,4-dichlorobenzene equivalents/ kg emission. The geographic scope of this indicator determines on the fate of a substance and can vary between local and global scale

Fresh-water aquatic eco-toxicity: This category indicator refers to the impact on fresh water ecosystems, as a result of emissions of toxic substances to air, water and soil. Eco-toxicity Potential (FAETP) are calculated with USES-LCA, describing fate, exposure and effects of toxic substances. The time horizon is infinite Characterisation factors are expressed as 1,4-dichlorobenzene equivalents/kg emission. The indicator applies at global/continental/ regional and local scale.

Marine eco-toxicity: Marine eco-toxicity refers to impacts of toxic substances on marine ecosystems (see description fresh water toxicity).

Terrestrial ecotoxicity: This category refers to impacts of toxic substances on terrestrial ecosystems (see description fresh water toxicity).

TRACI:

This is a stand-alone computer program developed by the U.S. Environmental Protection Agency. TRACI stands for Tool for the Reduction and Assessment of Chemical and other environmental Impacts. This program facilitates the characterization of environmental stressors that have potential effects. The categories selected by the time that TRACI was created were the following:

- Ozone depletion; Global warming; Smog formation; Acidification; Eutrophication; Human health cancer; Human health noncancer; Human health criteria pollutants; Eco-toxicity; Fossil fuel depletion; Land use; Water use.

It should be noted, however, that the impact categories selected for inclusion within TRACI are considered a minimal set that may be expanded in future versions. This method is supported by the US EPA, and is very important for emissions occurring as parts of product life cycles in the USA.

TRACI was created in 1995. The U.S. Environmental Protection Agency was conducting several LCA (Life Cycle Assessment) case studies and they were trying to find the best impact assessment tool for LCIA (Life Cycle Impact Assessment), pollution prevention, and sustainability metrics for the United States. Because it was apparent that no tool existed that would allow the sophistication, comprehensiveness, and applicability to the United States that was desired, the U.S. EPA decided to begin development of software to conduct impact assessment with the best applicable methodologies within each category. The result was the tool for the reduction and assessment of chemical and other environmental impacts (TRACI).

During the development of TRACI, consistency with previous modeling assumptions (especially of the U.S. EPA) was important for every impact category. The human health cancer and non-cancer categories were strongly based on the assumptions made for the U.S. EPA Risk Assessment Guidance for Superfund and the U.S. EPA's Exposure Factors Handbook. For areas such as acidification and smog formation, US empirical models allowed the inclusion of the more sophisticated location specific approaches and location specific characterization factors. When there was no EPA precedent, assumptions and value choices were simplified by the use of midpoints

Many of the impact assessment methodologies within TRACI are based on "midpoints". Analysis at a midpoint minimizes the amount of forecasting and effect modeling incorporated into the LCIA, making the modeling less complex and often enhancing simplicity of communication. Another factor supporting the use of midpoint modeling is the incompleteness of model coverage for endpoint estimation. Models and data exist to allow a prediction of potential endpoint effects. These endpoints and their expected effects remain

important but are not often captured in certain endpoint analyses. A good example of this would be to consider the ozone depletion potential as a midpoint and skin cancer, crop damage, immune system suppression, damage to materials like plastics, marine life damage, as endpoints.

TRACI tries to provide the most up-to-date scientifically defensible impact assessment methodologies for the US by providing a modular set of LCIA methods. TRACI can also be used in LCA, to set corporate environmental goals, to plan a path to meet those goals, and the to measure environmental progress.

ReCiPe:

This is is a follow up of Eco-indicator 99 and CML 2001 methods. It integrates and harmonizes midpoint and endpoint approach in a consistent framework. Although initially integration of the methods was intended, all impact categories have been redeveloped and updated. The method is still to be published as a whole, but most impact categories have been described in peer reviewed magazines. Midpoint and endpoint characterization factors are calculated on the basis of a consistent environmental cause-effect chain, except for land-use and resources. This method had regional validity in Europe, Global for Climate Change, Ozone layer depletions and resources.

The midpoint impact covered by ReCiPe are several: Terrestrial acidification; freshwater eutrophication; marine eutrophication; human toxicity; photochemical oxidant formation; particulate matter formation; terrestrial ecotoxicity; freshwater ecotoxicity; marine ecotoxicity; ionizing radiation; agricultural land occupation; urban land occupation; natural land transformation; depletion of fossil fuel resources; depletion of mineral resources; depletion of freshwater resources. The end point impacts covered are: Human health; Ecosystem Quality, Resources (surplus cost).

This method has some unique features. It consistently uses midpoints and endpoints in the same environmental mechanism. Midpoints are chosen as close as possible to the LCI results (Lowest Uncertainty of the Indicator). It uses sub compartments rural air and urban air applied in fate and

exposure model for human toxicity. Most impacts of ReCiPe have been described in peer reviewed papers (some still in press).

There are several impact categories than have been pre-selected for further evaluation such as:

- Non-linear marginal approach included in the calculation of human-toxicological and ecotoxicological effect factors. Midpoints and endpoints are available in the same mechanism

Figure 12 ReCiPe Methodolgy