**Use of Pesticide Risk Indicators to Measure How Changes in Crop Allocation Can Modify Welfare**

Geremia Gios, Stefano Farinelli, Flavia Kheiraoui, Fabrizio Martini, Jacopo Orlando

***Abstract***

**This study investigates how pesticide risk indicators (PRIs) can be applied to help develop sound economic policies. We modified one of the numerous PRIs proposed over the years, the Environmental Impact Quotient (EIQ), originally developed for the fruit industry, to take into account co-formulants and adjuvants. The new formula includes three components representing the externalities of farm worker risk, consumer risk, and ecological risk. It also takes into account the potential externalities of the use of pesticides on residents living near the farms where these products are used. We applied the modified EIQ to the Chiana Valley in Tuscany and the Tiber and Upper Tiber Valleys in Tuscany/Umbria, surveying a sample of farms to determine the quantity and types of pesticides used on five crops: durum wheat, soft wheat, corn, tobacco, and olives. After calculating the impact quotient, we used data from a survey conducted in a different Italian region regarding the willingness to pay (WTP) for a pesticide-free environment and determined the WTP for even minimal changes in that quotient. Using those results, we simulated the changes in welfare (calculated as changes in willingness to pay) that would result from modifying the amount of land used for each crop. Our findings indicate that the proposed WTP indicator may have broad utility and that its application may lead to enhanced awareness of the consequences of pesticide use in farming.**

***Key words:* Pesticides, impact indicators, TEIQ, pesticide externalities**

**Introduction**

The harmful effects of plant protection products[[1]](#footnote-1)(PPPs), like those of many pollutants, have not been fully established. There are generally significant obstacles to attempting to measure pesticide externalities[[2]](#footnote-2), which in many cases are compounded by the irreversibility of some of those effects (Turner *et al.*, 2003).

An accurate and realistic measurement of the environmental externalities caused by the use of PPPs would require the simultaneous assessment of all their potential harms with respect to human health and natural capital (Pretty et al., 2000). While there is abundant research into consumer health[[3]](#footnote-3) and the protection of farm workers,[[4]](#footnote-4) few studies have investigated the effects of pesticide use on people living near the land[[5]](#footnote-5) where such products are employed.[[6]](#footnote-6) However, the widespread urbanization of rural areas and the proximity of intensive farming to residential areas or other locations where people frequently visit have made this an increasingly important issue.

Because the most commonly used approach to ascertaining the consequences of pesticide use is to determine the relationship between a pollutant’s concentration in the environment and its effects, evaluating the risk entails an analysis of the “dose” (pollution level) and “response” (effect).[[7]](#footnote-7) In general, the three factors that must be considered when examining the environmental damage caused by PPPs are hazard (the potential harm caused), exposure,[[8]](#footnote-8) and risk, where risk is the likelihood that the hazardous effect will occur and depends on the interaction between the hazard and exposure.

Other factors important for assessing the externalities caused by PPPs are their characteristics of selectivity,[[9]](#footnote-9) spectrum of action,[[10]](#footnote-10) and penetration capacity and systemicity.[[11]](#footnote-11)

***Current legislation***

By law, plant protection products must be evaluated for potential hazards[[12]](#footnote-12) and, where necessary, classified for their toxicological,[[13]](#footnote-13) ecotoxicological, and physicochemical effects. PPPs are currently classified on the basis of acute and chronic toxicity. According to Directive (EC) 2009/128 of the European Parliament, a National Action Plan for the sustainable use of pesticides must include “indicators to monitor the use of plant protection products containing active substances of particular concern.” To ensure that this policy is successful in terms of reducing risk from the use of PPPs, the standard variable is the amount of pesticide per hectare of farmland. As observed by Devillers et al*.* (2005) and Ioriatti et al. (2011), it has become evident that simply measuring the quantity of PPPs used is not sufficient to estimate the risk and characteristics of exposure. To address this shortcoming, the scientific community has developed a wide range of tools to estimate the impact of PPPs more accurately. These tools are generally known as pesticide risk indicators (PRIs).[[14]](#footnote-14)

***Pesticide risk indicators***

Pesticide risk indicators (PRIs) have also been used to assess the environmental impact of certain plant disease control programs over time in different locations, to evaluate the impact of farming and plant protection policies (Gallivan et al., 2001; Greitens and Day, 2007), and to identify changes in environmental risks that require attention (Ioriatti, 2011).

The scientific community has developed numerous PRIs.[[15]](#footnote-15) As the output of a project launched by the French Ministry of Ecology in 1999, Deviller et al*.* (2005) presented an exhaustive list of dozens of PRIs and a grid describing each one’s components, formulation methods, advantages, and limitations.

The greatest challenge to developing meaningful risk indicators is determining how to incorporate the wide range of relevant environmental parameters. It is indeed challenging to find an acceptable balance between the benefits of a simplified system and a more elaborate model which can provide a greater wealth of information but is harder to use. Each of the available methods for devising PRIs has strengths and weaknesses that take on different degrees of importance depending on the intended purpose, whether helping a farmer choose among plant protection options, assisting in research purposes, providing support for laws and regulations, or for certification and ecolabelling. Regardless of the specified purpose, the methods for formulating PRIs can also simply identify changes in the environment or seek to quantify their extent and meaning (Ioriatti and Martini, 2011).

Pesticide risk indicators usually combine hazard and exposure information with data on the quantity of the pesticide used and under what conditions. To a large extent, hazard information can be found on the pesticide’s Safety Data Sheet (SDS). In this study, too, SDSs were used as a source of information for the assessment of health and environmental risks. Sections 2 and 3 of an SDS list all of a pesticide’s hazardous ingredients, along with their concentrations or ranges of concentration. These sections also contain the hazard statements that are assigned according to their physicochemical, health, and environmental risks. This approach follows the recommended methodology of, among others, Ioriatti et al*.* (2011).

For the purposes of this study, where Safety Data Sheets did not provide sufficient hazard information or a detailed breakdown of ingredients (as was sometimes the case for formulations that are no longer registered), the Pesticide Properties Database (PPDB) ([http://sitem.herts.ac.uk/aeru/ppdb/en/index.htm](http://sitem.herts.ac.uk/aeru/footprint)) or the safety data sheets of similar products were used as sources for toxicological information.

**Materials and Methods**

Of the possible PRIs for this study, we chose to use a modified version of the Environmental Impact Quotient (EIQ), which was originally developed to help consultants, who were promoting integrated fruit production in New York State, select low-impact pest control methods (Ioriatti et al., 2011; Kovach et al.,1992).[[16]](#footnote-16)

Like most PRIs, the original EIQ does not consider co-formulants, for which information on identity, chemical properties, and health and environmental impact is rarely available. Surgan et al. (2010) raised some criticisms regarding PRI methodology, demonstrating that, with respect to farm workers’ health, the inert ingredients of a PPP can sometimes have a higher impact score, as determined from the EIQ, than its active ingredients. This means that relying solely on the active ingredient for measurement purposes may produce results that underestimate the potential adverse impact of a certain PPP formulation. In response to this criticism, we developed a modified EIQ for this study that considers all substances in a preparation that pose a risk to human health or the environment, as stated on safety data sheets (available at http://sds-agrofarma.imagelinenetwork.com) in accordance with Directive 91/155/EEC as amended by Directive 2001/58/EC.

The specific materials and methods used to conduct this study are described below.

As originally formulated, the EIQ is a rating system that evaluates all of a product’s active ingredients in relation to their potential adverse impact on farm workers, consumers, and terrestrial and aquatic organisms (Ioriatti et al*.,* 2011). The primary module of the EIQ is a simple algebraic equation that generates a composite index of environmental impacts for each pesticide. A second module produces a field rating by incorporating variables related to the use of the PPP in specific situations (dose per hectare and concentration of active ingredients). The third step of the EIQ method is to estimate the impact of different pest control strategies by combining the EIQ scores of each pesticide treatment deemed necessary for a working farm. The result is the **“EIQ field rating,”** which can be used to compare the environmental impact of alternative strategies for a given farm over a specified period of time.

Over the years, several authors have proposed modifications to the EIQ. Of the various possibilities, for this study, we chose a modified formula that takes into account the other substances in a product (co-formulants, adjuvants, etc.) in addition to its active ingredients (Ioriatti et al., 2011). In essence, the modified formula (newEIQ) is based on the same principles as the original EIQ (Kovach et al., 1992) but considers the overall impact of a commercial PPP as used in farming. It follows the rating system used in the original formula and is useful for determining the impact of all active ingredients hazardous to farm workers, consumers, and the environment.

The EIQ formula consists of three components. The first, X1, measures the risk to farm workers and is defined as the sum of exposure by workers who apply the PPP (**DT\*5**) and to workers who pick the produce (**DT\*P**), multiplied by the long-term health effect or chronic toxicity (**C**). Within the farm worker component, applicator exposure is determined by multiplying the acute toxicity score (**DT**) by a coefficient of 5, to account for the increased risk associated with handling concentrated PPPs. Picker exposure is defined as acute toxicity (**DT**) multiplied by the score representing the product’s half-life after application (Ioriatti et al., 2011).

The second component, X2, represents consumer risk and is defined as the sum of potential consumer exposure (**C\*P\*SY**) plus a score representing the risk of long-term adverse effects on aquatic organisms. The impact on aquatic organisms is included in consumer risk because it involves the stability of chemicals in the groundwater, which may affect human health (through drinking contaminated water) as well as wildlife (Ioriatti et al., 2011).

The third component, X3, represents the ecological element in the equation and refers to the impact on the water and terrestrial systems. The environmental impact on water systems is determined by multiplying the score for chemical toxicity to aquatic organisms (**F**) by the risk of long-term adverse effects on the aquatic environment (**L**). The impact on terrestrial systems is the sum of the chemical effects on bees (**Z\*P\*3**) and on other terrestrial organisms (**T\*P\*5**). Because terrestrial organisms are more likely than aquatic ones to come into contact with commercial farming systems, they are given greater weight by multiplying the risk rating for bees by three and the risk rating for other terrestrial organisms by five (Ioriatti et al,2011).

The components of the newEIQ can be written as follows:

**newEIQi = (X1 +X2 +X3)/3 (1)**

**with X1 = C[(DT\*5)+(DT\*P)] (2)**

**X2 = [(C\*P\*SY)+(L)] (3)**

**X3 = [(F\*P) +(T\*P\*5)+(Z\*P\*3)] (4)**

***Therefore:***

**[1] newEIQi={C[(DT\*5)+(DT\*P)]+[(C\*P\*SY)+(L)]+[(F\*P) +(T\*P\*5)+(Z\*P\*3)+]}/3 (5)**

where:

**i** = Each individual ingredient of the plant protection product;

**DT** = Acute toxicity: average individual rating for the risk of direct exposure to chemicals, considering the following DSD risk phrases:[[17]](#footnote-17) R20, 21, 22, 23, 24, 25, 26, 27, 28, 36, 37, 38, 41, 42, 43, 65, 66, 67;

**C** = Chronic toxicity: average individual rating for long-term fertility, and teratogenic, mutagenic, and oncogenic risks (DSD risk phrases[[18]](#footnote-18) R40, 45, 46, 12 48, 49, 60, 61, 62, 63, 64, 68);

**P** = Average score pertaining to: active ingredient persistence, based on the pre-harvest interval (PHI) for produce intended for human consumption; and to long-term environmental impact (DSD risk phrase R58);

**F** = Toxicity to aquatic organisms (DSD risk phrases R50, 51, 52);

**L** = Long-term risk to aquatic organisms (DSD risk phrase R53);

**Z** = Toxicity to bees (DSD risk phrase R57);

**T**= Toxicity to other terrestrial organisms (DSD risk phrase R54, 55, 56);

**SY**= Systemicity.

In order to examine the externalities of the use of pesticides on residents living near the farms where these products are used, a fourth component must be included. The premise used for quantifying this new component is that residents’ exposure is similar to that of farm workers, without the risk associated with handling concentrated PPPs, but with the added risk of not using personal protective equipment. In addition, exposure:

1. correlates with drift, or the distance of the residence and/or place of transit from the treated farmland. Based on the results of a study in the province of Bolzano (Clausing, 2016; Dallemule, 2014; Federazione protezionisti Sudtirolesi, 2017), we assumed that drift would affect areas within 500 m of pesticide-treated crops.[[19]](#footnote-19) Because the exposure dose declines as distance increases, a normalization factor of 0.2 (assuming logarithmic decline as a function of distance) was used to determine chronic toxicity (C) and acute toxicity (DT), taking persistence (P) into account;
2. depends on the number of individuals in the area affected by drift. Here, potentially exposed persons were placed into two categories: b1) workers at other local farms; and b2) residents. Ideally, tourists and hikers should also be included, but given the difficulty of finding reliable data for these categories, it was decided to omit them from this study. To normalize the X1 component, the number of individuals (workers at other farms and residents) was used as a denominator with respect to the acreage of the crop in question. The workers were then allocated to the various crops by tallying the total number of farm workers in the area and dividing that value on the basis of RICA-INEA data on each crop’s required hours of work per hectare;
3. depends on potential exposure time. This obviously differs for the two categories of individuals, farm workers and local residents. The potential exposure time of the farm workers other than sprayers was estimated to be half that of the sprayers, assuming that they spent six out of twelve hours outdoors. For residents, it was assumed that potential exposure time was one sixth that of the individuals who spray crops with PPPs, corresponding to the number of daylight hours they spent outdoors (two out of twelve).

Given all these factors, the relative likelihood that residents and bystanders, in comparison with farm workers, will be exposed to pesticides through drift can be estimated as:

**[2] C[(DT\*P)\*(Ha1/N1)\*0.2\*0.5]+C[(DT\*P)\*(Ha1/N2)\*0.2\*0.17]**

where

Ha1 = hectares occupied by the crop in question;

N1 = number of farm workers in the area affected by drift (excluding those working on the crop in question);

N2 = number of residents in the area affected by drift.

We can therefore define a new indicator, **TEIQ**, to take into account this fourth component. For a generic hazardous product (i), that indicator can be expressed as:

**[3] (X1+X2+X3+X4)/4;**

or, in extended form as:

**[4] TEIQi={C[(DT\*5)+(DT\*P)]+[(C\*P\*SY)+(L)]+[(F\*P)+(T\*P\*5)+(Z\*P\*3)+]+ C[(DT\*P)\*(N2/N1)\*0.05]+C[(DT\*P)\*(N3/N1)\*0.017]/4.**

This risk index accommodates all hazardous ingredients in a PPP and provides a classification system that may be fairly easy to implement using farmers’ mandatory logbooks of pesticide treatments. For this new index, too, the weight assigned to each kind of hazard depends on the rating system used to classify the risks that a given substance or formulation poses to humans and the environment. The rating system derives from Directive 67/548/EEC or Directive 1999/45/EC and is set by an official agency in accordance with the biological and physicochemical properties of the ingredients and the outcome of toxicological studies (Ioriatti et al.,2011).

The modified rating system (TEIQ) does not ameliorate all the accuracy limitations of PRIs for estimating the health and environmental hazards of pesticides (Greitens and Day, 2007; Levitan et al., 1995; Van Bol et al., 2003), but it is the first to consider all of a formulated product’s potentially dangerous ingredients, which can, in some cases, have a greater impact than the active ingredient alone (Surgan et al, 2010). If used widely, the newEIQ could help lead to changes in registration policies that would require the disclosure of all hazardous inert ingredients, even in countries where this is currently not mandatory (Ioriatti et al., 2011).

Once the T**EIQi** has been calculated for every hazardous ingredient (**i**), the overall score for a pesticide, T**EIQp,** is obtained by combining all of the single-ingredient T**EIQi** scores plus a T**EIQf** score for the entire product. The **TEIQf** is based on the hazard statements reported in Section 16 of the SDS with reference to the health, safety, and environmental labelling required by Directives 67/548/EEC and 1999/45/EC. Hazard statements currently differ according to whether the PPP was registered under the old standards (Directive 67/548/EEC, incorporated into Italian law by Legislative Decree 52/1997) (DSD classification with R-statements), or under the newer Regulation (EC) 1107/2009 (CLP Regulation with H-statements). Agrofarma (2014) has proposed a chart for converting from DSD to CLP classifications, which makes it possible to leave the scoring method as defined in Ioratti et al. (2011) more or less unchanged. The transition to the new safety sheet and labeling standards was completed in 2017.

To summarize:

**[5] TEIQp = TEIQi1 + TEIQi2 + ….TEIQin + TEIQf.**

This step constitutes the first module of the newEIQ. The second and third modules incorporate the dosage of formulated products actually used on crops throughout the season, to estimate a farm’s yearly newEIQ score [14].[[20]](#footnote-20)

**A Study in the Tiber Valley (Tuscany and Umbria) and Chiana Valley (Tuscany)**

This study evaluates the impact of pesticide use in two parts of central Italy: the Tiber Valley and Upper Tiber Valley in Tuscany and neighboring Umbria, and the Chiana Valley in the Tuscan province of Arezzo. Appendix 2 describes the agricultural features of the two areas.

Data was gathered from 16 farms in the Tiber Valley areas and 10 farms in the Chiana Valley on the quantity and type of pesticides used in the regions. The data was collected in person every two weeks from the logbooks compiled throughout the crop year.[[21]](#footnote-21)

We deliberately focused on arable land, in part, because it is better suited to replacing one crop with another than is land planted with permanent crops. We also included olives, because this crop is so prevalent in the area, albeit on small parcels of land at most of the farms studied. The farms specialized mostly in arable crops like tobacco, corn, and wheat (durum and soft), while some of them also grew olives or used land as meadows and pastures. Table 2 shows their overall crop allocation.

**Table 2. Breakdown of UAA (ha) at Surveyed Farms in the Tiber and Upper Tiber Valleys and the Chiana Valley**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Area** | **Total UAA** | **Soft wheat** | **Durum wheat** | **Corn** | **Tobacco** | **Forage, set-aside land, other** | **Olive and other trees** |
| ***Tiber and Upper Tiber Valley*** | 625.37 | 20.89 | 110.12 | 103.52 | 44.58 | 330.82 | 15.44 |
| ***Chiana Valley*** | 283.06 | 66.72 | 4.26 | 76.54 | 29.63 | 102.36 | 3.55 |

*ISTAT data, 2010*

To calculate the impact quotient, we began with safety data sheets (SDSs), specifically Sections 2 and 3, that list all hazardous ingredients along with their concentrations or concentration range, together with the hazard statements assigned as a function of physicochemical, health, and environmental risks. Pre-harvest intervals were taken from the registered labels of each pesticide. Unlike the original EIQ, the modified indicator was not limited to the active ingredient, but accommodated all dangerous ingredients and their corresponding hazard statements. For the evaluation of formulated products, the new indicator did not consider the R-statements in Section 16 of the SDS, but, rather, the hazard statements included on the label.

A score from 1 to 5 was assigned for each of the phrases for hazard referring to acute and chronic toxicity and environmental risks, as shown in Appendix 1.

Regarding the first component of the TEIQp as per equation [1] (risk to farm workers), the newEIQ scores of some products rated earlier by Ioratti et al. (2011) were used as benchmarks for validating the new calculations carried out for previously unscored PPPs.

To calculate the second and third components of equation [2,3] (consumer risk and environmental risk), the dose per hectare of the various crops obtained from our survey of the 26 farms in Tuscany and Umbria was used.

The fourth component of equation [4] (risk to residents) was calculated using the second part of equation [2], using populations of 86,895 and 168,044 and for the studied areas of the Tiber Valley and the Chiana Valley, respectively.[[22]](#footnote-22) As noted in the geostatistical information[[23]](#footnote-23) presented in Appendix 2, in both regions studied, residential areas (with the exception of a few scattered homes in mountainous areas) fell within a 500 m radius of mapped farmland.

Following the method described by Leach and Mumford (2008), the individual TEIQ scores per hectare-application of pesticide were combined to obtain each crop’s TEIQp per hectare (Table 3). The total scores for the areas studied are shown in Table 4.

***Table 3. TEIQ per Hectare in the Two Areas Studied***

|  |  |  |
| --- | --- | --- |
| **Crop** | **Sum of EIQ field scores per hectare in the Tiber and Upper Tiber Valleys** | **Sum of EIQ field scores per hectare in the Chiana Valley** |
| **Durum wheat** | 593.2093253 | 593.2093253 |
| **Soft wheat** | 16.66028395 | 16.66028395 |
| **Corn** | 79.02905077 | 79.02905077 |
| **Olives** | 48.30632308 | 47.67589038 |
| **Tobacco** | 1730.959449 | 1751.700847 |
| **Average for all five crops** | **493.6328864** | **497.6550796** |

It is important to note that the wide gap in TEIQ scores between durum wheat and soft wheat reflects the different treatments used for the two crops, as gleaned from the logbooks used to calculate field score: durum wheat was subject to more products and more sprayings than was soft wheat. More specifically, at the farms under study, soft wheat was not treated with glyphosate-based herbicides (Roundup or Ouragan), copper compounds, Axial Pronto 60, or Granstar 50SX. This explains the greater impact on one variety of wheat compared with the other. Obviously, the data from this sample is not necessarily representative of all or most crops in the area. Nonetheless, this data has been used as it is indicative of a different, but possible, method of farming.

***Table 4. Calculation of Total TEIQp*** S***cores***

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Crop** | **TEIQ**  ***Tiber and Upper Tiber Valleys (per ha)*** | ***Tiber and Upper Tiber Valleys (no. ha)*** | ***TEIQpTiber and Upper Tiber Valleys*** | **TEIQ**  ***Chiana Valley (per ha)*** | ***Chiana Valley (no. ha)*** | ***TEIQp***  ***Chiana Valley*** | ***Total TEIQp*** |
| **Durum wheat** | 593.2093253 | 4,901.06 | 2,907,354.50 | 593.2093253 | 9,416.72 | 5,586,086.12 | 8,493,440.61 |
| **Soft wheat** | 16.6602840 | 1,385.28 | 23,079.16 | 16.6602840 | 2,139.63 | 35,646.84 | 58,726.00 |
| **Corn** | 79.0290508 | 770.87 | 60,921.12 | 79.0290508 | 1,088.62 | 86,032.61 | 146,953.73 |
| **Tobacco** | 1,730.9594489 | 4,073.41 | 7,050,907.53 | 1,751.7008472 | 695.02 | 1,217,467.12 | 8,268,374.65 |
| **Olives** | 48.3063231 | 865.86 | 41,826.51 | 47.6758904 | 6,047.63 | 288,326.14 | 330,152.66 |
| **Total** | **2,468.16** | **11,996.48** | **10,084,088.82** | **2,488.28** | **19,387.62** | **7,213,558.83** | **17,297,647.65** |

Therefore, the impact score for all hectares planted with soft wheat, durum wheat, tobacco, olives, and corn in the Chiana Valley and the Tiber and Upper Tiber Valleys amounts to 17,297,647.65. If durum wheat and tobacco were replaced with soft wheat, that score would decrease substantially, to 853,814.06.

**V. Results: An Attempt to Quantify the Economic Externalities of the Use of Pesticides**

Many studies have investigated the direct adverse effects of pesticides. Far fewer have sought to quantify the negative externalities associated with their use. The great number of substances to be considered, the time needed to determine the adverse consequences of direct and/or indirect exposure, our incomplete knowledge of metabolites and food chains, the problem of identifying means of contact, and a poor understanding of the relationships between different molecules and the environment make it challenging not only to identify potential harms, but also to put an economic price on them.

In an effort to quantify the economic variables at play, we referred to a meta-analysis conducted by Boatto et al. (2008) that determined the willingness to pay (WTP) of households in the Veneto in 2006. On the basis of the equations reported in that analysis, and using the average income in Tuscany,[[24]](#footnote-24) we obtained the following WTP per household/year for the reported goals:

- having water free of pesticide residues (taking the low end of the range): €18.7

- protecting biodiversity (taking the low end of the range): €23.6

- being free of acute and chronic health issues caused by pesticides: €126.4

Therefore, in total, the willingness to pay for a pesticide-free environment amounted to €168.7 per household per year.

According to ISTAT data for 2011, in the areas studied, the Tiber and Chiana Valleys, there were a total of 254,939 residents in 105,352 households. Applying the WTP per household from the Veneto study, the total potential willingness to pay for a pesticide-free environment would amount to €17,772,882 per year. Assuming that the WTP rises in a straight line from 0 (no use of pesticides) to the TEIQp total impact score of more than 17 million euros estimated for 2016, a WTP of €1.03 is obtained for every one-point reduction in that score.

On that basis, alternative scenarios were investigated in which one crop was hypothetically replaced with another to gauge variations in terms of WTP (here representing a replacement for welfare) as well as gross saleable production (GSP), gross margin, and operating margin (which is more representative than other variables of the actual difference between one crop and another in a farm’s gross income). For reasons of space, in this paper, we present an example in which land used to grow tobacco (scenario A) is planted instead with soft wheat, treated as explained below in Table 3 (scenario B), or with corn (scenario C). Table 5 shows how the gain in welfare (measured as WTP) from eliminating the tobacco crop is not only less than the loss in terms of GSP and gross margin, but actually leads to an increase in net operating margin.

***Table 5. Changes in WTP, GSP, Gross Margin and Operating Margin***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | WTP gain | GSP decrease | Gross margin decrease | Change in operating margin |
| Scenario A | 0 | 0 | 0 | 0 |
| Scenario B | 8,436,983 | -28,353,085 | -20,547,164 | 8,216,005 |
| Scenario C | 8,369,472 | -26,431,408 | -20,060,790 | 8,263,269 |

**VI. Conclusions**

Despite the many limitations arising from the data currently available to us, we believe the above study may produce information that is useful beyond the specific case at hand. It certainly indicates that the choice of one economic variable over another depends on the economic policy objective being pursued. That objective will make it more sensible, for example, to refer to gross saleable production rather than operating margin. This study also demonstrates that for the purpose of deciding how best to allocate farmland, the inclusion of potential externalities, such as the results of pesticide use, leads to significantly different results than can be obtained without considering such factors.

In a heavily subsidized industry like agriculture, modulating subsidies to reflect the extent of environmental externalities may be essential, given the goal of maximizing social welfare. When attempting to quantify the externalities of pesticide use, indicators such as those described in this study can make a valuable contribution.

As this is an initial study, the methodology and the definition of indicators for specific regions will have to be refined. Specifically, field experiments to determine the actual range and persistence of pesticide drift will need to be conducted in order to reach results at the operational level.

REFERENCES

Agnello, A.M., Atanassov, A., Bergh, J.C., Biddinger, D.J., Gut, L.J., Haas, M.J., Harper, J.K., Hogmire, H.W., Hull, L.A., Kime, L.F., Krawczyk, G., McGhee, P.S., Nyrop, J.P., Reissig, W.H., Shearer, P.W., Straub, R.W., Villanueva, R.T. and Walgenbach, J.F. (2009). Reduced-risk pest management programs for eastern U.S. apple and peach orchards: a 4-year regional project. *American Entomologist* 55: 184–197.

Agrofarma (2014). La classificazione e l’etichettatura degli agrofarmaci. Le nuove regole. Federchimica, May 2014.

Boatto, V., Menguzzato, A. and Rossetto, L. (2008). Valutazione monetaria dei benefici esterni dell’agricoltura biologica. Working Paper — Sabio no. 6. Rome: Inea.

Clausing, P. (2016). Bewertung von Pestizidrückständen in Pflanzenmaterial (Grasproben vom 28.5.2016) aus Südtirol. http://www.pangermany.org/download/Bewertung\_Grasproben\_Final\_160716.pdf

Cross, P. and Edwards-Jones, G. (2006). Variation in pesticide hazard from arable crop production in Great Britain from 1992 to 2002: pesticide risk indices and policy analysis. *Crop Protection* 25: 1101–1108.

Dallemule, C. (2014). Versuche zur Effizienz abdriftmindernder Maßnahmen unter Freilandbedingungen im Obervinschgau. Agrarwissenschaften und Agrartechnologie Fakultät für Naturwissenschaften und Technik, academic year 2013–2014, 46.

Devillers, J., Farret, R., Girardin, P., Rivière, J.P. and Soulas, G. (2005). *Indicateurs pour Évaluer les Risques Liés à l’Utilisation des Pesticides.* Paris: Lavoisier.

Gallivan, G.J., Surgeoner, G.A. and Kovach, J. (2001). Pesticide risk reduction on crops in the province of Ontario. *Journal of Environmental Quality* 30: 798–813.

Greitens, T.J. and Day, E. (2007). An alternative way to evaluate the environmental effects of Integrated Pest Management: Pesticide Risk Indicators. *Renewable Agriculture and Food Systems* 22(3): 213–222.

Ioriatti, C., Agnello, A.M., Martini, F. and Kovach, J. (2011). Evaluation of the environmental impact of apple pest control strategies using pesticide risk indicators. *Integrated Environmental Assessment and Management* 7(4): 542–549. doi 10.1002/ieam.185

Ioriatti, C. and Martini, F. (2011). La protezione integrata del melo. Valutazione dell’impatto ambientale generato dall’uso dei fitofarmaci in Val di Non. *Economia Trentina* 60 (2-3): 64–67.

Kovach, J., Petzoldt, C., Degni, J. and Tette, J. (1992). A method to measure the environmental impact of pesticides. *New York’s Food and Life Sciences Bulletin* 139: 1–8.

Leach, A.W. and Mumford, J.D. (2008). Pesticide Environmental Accounting: A method for assessing the external costs of individual pesticide applications. *Environmental Pollution* 151: 139–147.

Levitan, L., Mervin, I. and Kovach, J. (1995). Assessing the relative environmental impacts of agricultural pesticides: the quest for a holistic method. *Agriculture, Ecosystems & Environment* 55: 153–168.

OECD (2002). Glossary of statistical terms. Consulted at https://stats.oecd.org/glossary/detail.asp?ID=3215.

Pretty, J.N., Brett, C., Gee, D., Hine, R.E., Mason, C.F., Morison, J.I.L., Raven, H., Rayment, M.D. and van der Bijl, G. (2000). An assessment of the total external costs of UK agriculture. *Agricultural Systems* 65(2): 113–136.

Surgan, M., Condon, M. and Coc, C. (2010). Pesticide risk indicators: Unidentified inert ingredients compromise their integrity and utility. *Environmental Management* 45: 834–841.

Turner, R.K., Pearce, D.W. and Bateman, I. (2003). *Economia Ambientale*. Bologna: Il Mulino.

Van Bol, V., Claeys, S., Debongnie, P., Godfriaux, J., Pussemier, L., Steurbaut, W. and Maraite, H. (2003). Pesticide indicators. *Pesticide Outlook* 14: 159–163.

**Appendix 1**

**Table 6**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Scoring system used to develop the new environmental impact quotient for pesticides (newEIQ) | | | | |
| Scores range from 1 (no hazard statement) | | | | |
| to 5 (hazard statements include high potential risk of acute or chronic toxicity or harm to the environment). | | | | |
| Hazard | | R-phrases (DSD classification) | H-statements (CLP classification) (not all can be converted directly) | Score |
| Acute Toxicity = DT | harmful (by inhalation, contact with skin, ingestion) | R20, R21, R22 | H300, H301, H310, H311, H330, H331 | 3 |
| toxic (by inhalation, contact with skin, ingestion) | R23, R24, R25 | 4 |
| very toxic (by inhalation, contact with skin, ingestion) | R26, R27, R28 | 5 |
| irritating (by inhalation, contact with skin, ingestion) | R36, R37, R38 | H319, H335, H315 | 2 |
| may cause sensitization by inhalation or skin contact | R42, R43 | H334, H317 | 5 |
| risk of serious damage to eyes | R41 | H314, H318 | 3 |
| harmful: may cause lung damage if swallowed | R65 | H304 | 2 |
| repeated exposure may cause skin dryness or cracking | R66 | - | 3 |
| vapors may cause drowsiness and dizziness | R67 | H336 | 3 |
| Chronic Toxicity = C | possible risk of impaired fertility | R62 | H361 | 3 |
| may impair fertility | R60 | H360 | 5 |
| teratogenic (possible risk of harm to the unborn child) | R63 | H361D | 3 |
| teratogenic (may cause harm to the unborn child) | R61 | H360D | 5 |
| mutagenic (possible risk of irreversible effects) | R68 | H341 | 3 |
| mutagenic (may cause inheritable genetic damage ) | R46 | H340 | 5 |
| cancerogenic (limited evidence of a carcinogenic effect) | R40 | H351 | 3 |
| cancerogenic (may cause cancer) | R45, R48, R49 | H350 (H372, H373) | 5 |
| Aquatic Organisms = F | very toxic | R50 | H400, H410 | 5 |
| toxic | R51 | H411 | 4 |
| harmful | R52 | - | 3 |
| Long-term adverse  effects in the aquatic environment = L | may cause long-term adverse effects in the aquatic environment | R53 | H410, H411, H412, H413 | 5 |
| Bees = Z | toxic | R57 | - | 5 |
| Other terrestrial organisms = T | toxic to flora, fauna, soil organisms | R54, R55, R56 | - | 5 |
| Persistence = P | may cause long-term adverse effects in the environment | R58 | - | 5 |
| Pre-harvest interval < 2 days |  |  | 1 |
| Pre-harvest interval > 2 < 15 days |  |  | 3 |
| Pre-harvest interval > 14 days |  |  | 5 |
| Systematicity (SY) | Systemic |  |  | 3 |

**Appendix 2**

***Farming in the Tiber Valley (Tuscany) and the Upper Tiber Valley (Umbria)***

The Tiber Valley and Upper Tiber Valley form a geographical area in the Central-Northern Apennines. The area consists of 11 municipalities in two Italian regions: Umbria (province of Perugia) and Tuscany (province of Arezzo).[[25]](#footnote-25) It falls mainly on the flood plain of the Tiber River, with the exception of some mountain communities (e.g. Caprese Michelangelo, Badia Tedalda, Sestino, and Monte Santa Maria Tiberina) adjacent to the plain. In the valley there are numerous residential districts and scattered homes, while in the mountain communities, anthropization is more limited to the village centers. The area covers a total of 75,285 ha, with UAA of 35,644 ha or 47% of the total. More specifically, arable crops take up 70% of the cultivated land, meadows and pastures 23%, and permanent (woody) crops 7%. Of the arable crops, the most prevalent are cereals (36%), fodder (27%), and industrial crops (22%). The latter consist almost exclusively of tobacco.

***Farming in the Chiana Valley***

The Chiana Valley is a geographical area in Central Italy that was reclaimed as farmland during the 1900s.

All of its municipalities[[26]](#footnote-26) are in the province of Arezzo; they cover 74,258 ha with UAA of 46,714 ha (63% of the total). Arable crops take up 72% of the cultivated land, meadows and pastures 3%, and permanent (woody) crops 25%. Of the arable crops, the most prevalent are cereals (45%), fodder (13%), and industrial crops (15%). The permanent cropland is planted primarily with olive trees (6,047 ha), grapevines (3,618 ha), and orchards (1,512 ha).

Table 1 shows the total crop acreage of the two areas studied. The figures come from the ISTAT database and refer to the latest agriculture census available, for 2010, as intercensal data only provides aggregate figures by province.

***Table 1. Total crop acreage in the municipalities of the Chiana Valley and Tiber/Upper Tiber Valley included in the study***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Area | **Soft wheat** | **Durum wheat** | **Corn** | **Tobacco** | **Olives** |
| ***Chiana Valley (Tuscany)*** | 9,416.72 | 2,139.63 | 1,088.62 | 695.02 | 6,047.63 |
| ***Tiber Valley (Tuscany) and Upper Tiber Valley (Umbria)*** | 4,901.06 | 1,385.28 | 770.87 | 4,073.41 | 865.86 |

*ISTAT data, 2010*

1. While in both routine and technical language, the Italian terms *agrofarmaci, presidi sanitari, fitofarmaci, antiparassitari,* and *pesticidi* are used interchangeably, under Italian law (Presidential Decree 290/01) only the term *prodotti fitosanitari* is correct. This term is translated in this paper as “plant protection products” (PPPs). PPPs are all active ingredients and commercial preparations containing one or more active ingredients, used in farming for the purposes of: protecting plants or produce from harmful organisms or preventing the effects thereof; assisting or regulating plant metabolism (except for fertilizers); preserving produce (except for preservatives governed by specific regulations); clearing the crop of weeds or other undesired plants; and removing parts of plants or halting or preventing their undesired growth. For this and other basic information on pesticides and pesticide use in Italy, we have relied on the Veneto Region’s *Guida ai prodotti fitosanitari* available at http://www.venetoagricoltura.org/upload/ pubblicazioni/Guida\_prodotti\_fito/1\_capitolo\_br.pdf. [↑](#footnote-ref-1)
2. The OECD defines externalities as “situations when the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided” (OECD, 2002). In economic analysis, the main challenge is how to determine the value of non-market goods, whose characteristics of non- (or partial) excludability and non- (or partial) competitiveness mean that they have no market. [↑](#footnote-ref-2)
3. Consumer health is protected by determining the maximum permitted residue of an active ingredient in foods meant for final consumption. In case of residue, the law defines the tolerance limit or Maximum Residue Limit (MRL) as the maximum amount of PPP active ingredients tolerated in food products, consistent with the amount that is safe for consumers. The limit is set for each crop by Regulation (EC) 396/2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin. It is worth specifying here that in accordance with EU legislation, plant protection products must be used in compliance with parameters and limitations that prevent, to the best of available knowledge, all risks to consumer health. Specifically, Directive 91/414/EEC (since replaced by Regulation [EC] 1107/2009) restricted permitted substances to those whose potential risks to consumers have been assessed through a range of short- and long-term toxicological studies. Based on these studies, a determination is made of an Admissible Daily Intake (ADI) expressed in milligrams or mg/kg bw: that is, of a level of prolonged (in theory, lifelong) intake that does not pose a risk to health. Generally, the ADI is derived from the lowest no-observed-effect level (NOEL) determined from the range of toxicology tests; the NOEL is then divided by a safety factor to account for the difficulty of extrapolating to humans the results found in small, homogeneous groups of lab animals. Finally, evaluation of the ADI and other studies and data on the transformation and persistence of the molecule in the target organisms and in the environment leads to the definition of the Maximum Residue Limit essential for the proper management of the risk. Compliance with MRLs ensures that the overall dietary intake of residue does not exceed the ADI, even considering potential “peak” exposures due to over-consumption. Importantly, the ADI adequately protects not only a hypothetical average individual, but also population subgroups that may be more susceptible to the specific molecule (children, for example, are particularly susceptible to various molecules that affect the immune system, hormone levels, the nervous system, etc.) For this footnote, Coldiretti’s article “Come avviene il controllo dei residui di fitofarmaci negli alimenti?”, available at https://www.ambienteterritorio.coldiretti.it/ tematiche/Agrofarmaci /Pagine/ Comeavvieneilcontrollodeiresiduidifitofarmacineglialimenti.aspx was consulted. [↑](#footnote-ref-3)
4. While the pre-harvest interval protects consumers by affecting the amount of residue remaining on foodstuffs, the restricted entry interval is the amount of time that must elapse between pesticide treatment and workers’ access to the treated area for pruning, thinning, picking, etc. without personal protective equipment (PPE). For most formulations, the restricted entry interval is not yet stated on the label, but new legislation does call for this, and PPP labels will gradually be required to include it. As a precaution for farm workers, manufacturers usually recommend waiting at least 48 hours before re-entering the field. Where necessary, PPP labels must also indicate how long livestock should be kept away from treated pastures and so forth. [↑](#footnote-ref-4)
5. The effect on people living near the land is also not considered when a pesticide is registered. [↑](#footnote-ref-5)
6. In recent years, the formation of health committees by residents living near farmland has become another factor in the discussion of pesticide use. In many cases, farmers believe the concerns are excessive, given the extensive medical and scientific literature on the subject, as well as the very stringent EU legislation that governs today’s farming industry. However, at the same time, they find it worthwhile to invest in increasingly safe and conservative methods of pesticide use. [↑](#footnote-ref-6)
7. This type of analysis reveals how the risk measurement process transforms a context of uncertainty into a context of risk. Once the risk is assessed, the next phase is to manage it, through a two-step decision-making process: first determining the amount of acceptable risk, and then deciding by what means unacceptable risks can be reduced (Turner et al., 2003). This tends to reduce uncertainty. [↑](#footnote-ref-7)
8. Exposure refers to the likelihood of coming into contact with the substance, based on the quantity of substance to which the living organism or the environment is exposed and the length of time of the exposure. Exposure may have different origins, such as: direct human interaction while working with the substance (mixing, spraying, etc.); contaminated rain and volatilization; drift during spraying; or soil and groundwater contamination after spraying (runoff, leaching, drainage). [↑](#footnote-ref-8)
9. PPP selectivity can be physiological or ecological. It is physiological if it derives from the characteristics of the PPP itself. Pesticides based on Bacillus thuringiensis (Bt), for example, are microbiological products that release proteins that are highly toxic to certain insects. The conditions that allow the toxin to develop are present only in the gut of Lepidoptera larvae (leafroller moths, etc.), so PPPs containing Bt are nontoxic to all other insects. PPP selectivity is ecological if it depends on the PPP’s usage and not on its characteristics. For example, an insecticide sprayed when a beneficial insect is safe in its chrysalis within the folds of bark is selective, not because of the formulation of the PPP, which might even be a broad-spectrum agent, but because at that moment, the beneficial insect is protected and the PPP cannot reach it. There is therefore a period of ecological selectivity that ends when the insect is no longer protected. A PPP can be selective at that moment and not at a future time. In the case of insecticides, the mode of action (contact, ingestion, or asphyxia) also makes a PPP more or less selective. [↑](#footnote-ref-9)
10. Spectrum of action means the range of pests a PPP is meant to control. For example, an insecticide that simultaneously acts against aphids, moth larvae, and fruit flies has a broad spectrum of action. In such a case, the PPP will be effective against many pests, but will probably have little or no selectivity for beneficial insects. Conversely, an insecticide that controls aphids only will most likely be more selective for beneficial insects. PPPs work in a variety of ways and can target a greater or lesser number of parasites. Broad-spectrum products act on many parasite species; organophosphates, for example, are effective against a very wide range of insects from different families. Narrow-spectrum pesticides are more specific (selective) because they act on only a few parasite species. Of the broad-spectrum PPPs, some are effective against very different parasites, such as polysulfides, which affect both insects and fungi. [↑](#footnote-ref-10)
11. These terms indicate the PPP’s ability to penetrate the plant and fight infections within organs that cannot be reached directly by substances that work through contact action (surface-active ingredients). Translaminar PPPs are able to pass from one side of a leaf to the other; cytotropic products penetrate just below the surface; and systemic products move through the plant's vascular system. In general, systemic PPPs are more effective, last longer, and kill parasites even in parts of the plant not directly reached by spraying. Systemic, cytotropic, and translaminar products are generally absorbed by the green parts of the plant. Absorption takes a certain amount of time, usually a few hours, and requires temperatures of approximately above 12–15°C. Once absorbed, the products cannot be washed away by rain. [↑](#footnote-ref-11)
12. Hazard-based classification criteria are based on: a) the median lethal dose (LD50), defined as the dose of active ingredient expressed in mg/kg body weight (ppm) that causes death in 50% of the lab animals exposed to the ingredient orally or through the skin; and b) the median lethal concentration (LC50), or the concentration in air or water of an active ingredient that acts in the gas or vapor state and leads to the same outcome as the median lethal dose. The LC50 thus expresses the same standard as the LD50, but refers to lab animals that are exposed to the active ingredient in the form of a gas or vapor. [↑](#footnote-ref-12)
13. PPPs are currently classified on the basis of: a) acute toxicity, expressed as LD50 for solid and liquid preparations and as LC50 for gases, fumigants, and aerosols; b) chronic toxicity, which depends on the product’s hazardousness, indicated as risk to the farm worker, the consumer, and the environment as a function of exposure to the PPP. The appropriate risk statement is printed on the label along with the hazard symbol. Depending on their acute toxicity, PPPs are classified as: a) very toxic, with an orange label with a skull and crossbones and the symbol T+ (formerly Toxicity Class I), and which may be fatal to humans through any route of exposure; b) toxic, with an orange label with a skull and crossbones and the letter T (formerly Toxicity Class I); and c) harmful, with an orange label with a black cross and the letters Xn (formerly Toxicity Class II). These are PPPs that may cause serious contamination to humans through any route of exposure. Unclassified products may be: a) irritants, with an orange label with a black cross and the letters Xi (formerly Toxicity Class III e IV); or b) none of the above and not labeled with hazard symbols, though the label often states “Warning: handle with care” (formerly Toxicity Class III and IV). [↑](#footnote-ref-13)
14. In this context, an indicator can be defined as a unit of information produced from one or more data points that becomes meaningful when compared to a threshold (Devillers *et al.*, 2005). [↑](#footnote-ref-14)
15. PRIs have been used in various parts of Italy, sometimes on an experimental basis, to evaluate environmental policies and plant protection practices. Some examples are the use of the Environmental Potential Risk Indicator for Pesticides (EPRIP) (Devillers et al, 2005) and the aforementioned EIQ at the Centro Vitivinicolo Provinciale of Brescia, or the use of the EIQ to assess the Piedmont Region's 2000–2006 rural development plan and estimate the reduction of pesticide inputs as a result of agro-environmental regulations. The EIQ has also been used in international research, including Leach and Mumford's important study (2008) on the externalities of individual pesticide applications in the United Kingdom, the United States, Germany, and Mediterranean countries. [↑](#footnote-ref-15)
16. This type of approach is used not only to compare the impact of different plant production strategies, but also to assess the environmental benefits of integrated fruit production (Agnello et al., 2009), to evaluate the overall impact of plant protection methods on different crops in a certain territory (Ioriatti and Martini, 2011), and to monitor the success of specific plant protection regulations (Cross and Edward-Jones, 2006; Gallivan et al., 2001). [↑](#footnote-ref-16)
17. These phrases are required by the Dangerous Substances Directive (Directive 67/548/EEC), incorporated into Italian law with Legislative Decree 52/1997. They were modified with Regulation (EC) 1272/2008 of the European Parliament. A conversion table between the old and new terminology, based on Agrifarma’s recommendations, is provided in Appendix 1. [↑](#footnote-ref-17)
18. See note 17 for all references to DSD. [↑](#footnote-ref-18)
19. Clearly, this distance is purely indicative and should be quantified, where possible, on the basis of measurements taken from different areas with respect to topography and wind patterns. [↑](#footnote-ref-19)
20. Various authors have described how to combine the EIQ rating system in its original formula (Kovach et al., 1992) with an environmental cost estimate for every pesticide application. For example, Leach and Mumford (2008) propose a system of Pesticide Environmental Accounting that estimates the environmental and health impacts per hectare application of pesticide. [↑](#footnote-ref-20)
21. While this laborious data collection method prevented us from surveying a greater number of farms, it provided greater accuracy than would different methods applied to a larger sample size. [↑](#footnote-ref-21)
22. Because crop data is from 2010, population data from the 2011 census was used. [↑](#footnote-ref-22)
23. Buffer zones were mapped within a 500 m radius of farmland. The centroids of the circular buffer zones (2 km radius) were selected using the geostatistical method with a semi-regular grid. The centroids were interdistanced according to the density and distribution of the farms included in the study. The result was then superimposed on the color orthophoto map of the Region of Tuscany. [↑](#footnote-ref-23)
24. This statistic was used in place of the average income, reduced by the ISTAT cost-of-living index to update the original 2006 figures to 2017. [↑](#footnote-ref-24)
25. The 11 municipalities are Sansepolcro (AR), Anghiari (AR), Pieve Santo Stefano (AR), Caprese Michelangelo (AR), Badia Tedalda (AR), Sestino (AR), Monterchi (AR), San Giustino (PG), Citerna (PG), Monte Santa Mara Tiberina (PG), and Città di Castello (PG). [↑](#footnote-ref-25)
26. Arezzo, Castiglion Fiorentino, Cortona, Civitella in Val di Chiana, Monte San Savino, Foiano della Chiana, Lucignano, and Marciano della Chiana. [↑](#footnote-ref-26)