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Pesticides, crop choices and changes in well-being

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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 consider co-formulants and adjuvants. The new formula includes three components representing the externalities of farm worker risk, consumer risk, and ecological risk. It also considers 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 two areas located in central Italy (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.

Keywords: pesticides, impact indicators, TEIQ, pesticide externalities.
JEL Codes: Q10, Q15.

1. INTRODUCTION

The agri-food sector is nowadays asked to change approach towards production, taking into account the impact of its activities on the environment. In 2020, as part of the European Green Deal, the From Farm to Fork strategy highlighted the need to transform the European food system into a healthier, fairer and more sustainable system. Among its goals, the strategy aims to reduce by 50% the use of plant protection products. Previously, the Directive 128/2009 already raised the issue of a more sustainable use of plant protection products. However, the lack of knowledge about the overall effects of these products on health and the environment makes it more difficult to reach the goal.

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

Accurate and realistic measurement of the environmental externalities caused using PPPs would require the simultaneous assessment of all their potential harms concerning human health and natural capital (Pretty et al., 2000)[1]. While there is abundant research into consumer health and the protection of farm workers, few studies have investigated the effects of pesticide use on people living near the land where such products are employed. 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 (Targetti et al., 2020).

The most common 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). In general, the three factors that must be considered when examining the environmental damage caused by PPPs are hazard (the potential harm caused), exposure, 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, the spectrum of action, penetration capacity and systemic action.

By law, plant protection products must be evaluated for potential hazards and, where necessary, classified for their toxicological, ecotoxicological, and physicochemical effects. PPPs are currently classified based on 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." 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). 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 several PRIs.[2] For example, 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.

Generally, 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. Furthermore, each of the available methods for devising PRIs has strengths and weaknesses that take on different degrees of importance depending on the intended purpose. Finally, 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).

This article aims to study the possibility of assessing economically the consequences of PPPs reduction in a specific area. In this evaluation also the impact of co-formulants and adjuvants have been considered as well as drift effect for bystanders and locals.

For this purpose, an indicator has been integrated with few components in order to estimate the impact of PPPs used in an area located in the Tuscany Region. Data have been collected among a representative sample of farms. In this way the economic value of the externalities has been assessed. Finally, a simulation was conducted hypnotizing the substitution of high-impact crops with low-impact ones.

[1] Some definitions of technical terms have been provided in the glossary to Appendix 3 to avoid overburdening the paper.

[2] PRIs have been used in various parts of Italy, sometimes on an experimental basis, to evaluate environmental policies and plant protection practices. (Devillers et al., 2005) and the EIQ at the Centro Vitivinicolo Provinciale of Brescia (2008) the Piedmont Region's for rural development plan2000-2006 The EIQ has also been used in international research, (Leach and Mumford, 2008).

2. MATERIALS AND METHODS

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)[3]. 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 of all pesticide hazardous ingredients[4], 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. To provide consistent estimates, this work follows the methodology recommended, amongst others, by 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 of formulations that are no longer registered), the Pesticide Properties Database (PPDB)[5] or the safety data sheets of similar products were used as sources for toxicological information.

Among the possible PRIs which may be considered in 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).[6] 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, concerning 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 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.

As originally formulated, the EIQ is a rating system that evaluates product's active ingredients about 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.

In the last 15 years, several authors have proposed modifications to the EIQ. Of the various possibilities, for this study, we chose a modified formula that considers 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. By using the newEIQ it is, therefore, possible to determine the impact of all hazardous active ingredients on the agricultural workers, consumers, and the environment. More in detail, there are three components of the newEIQ. They can be written as follows:

$$newEIQi=(X1 +X2 +X3)/3 \tag{1}$$

with

$$X1=C[(DT*5)+(DT*P)] \tag{2}$$

$$X2=[(C*P*SY)+(L)] \tag{3}$$

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

Therefore:

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

[3] By the law, the safety data sheet that must be reported on the packaging of any pesticide shall include any health and safety information for the user.

[4] The hazard statements are described in Appendix 1.

[5] See (http://sitem.herts.ac.uk/aeru/ppdb/en/index.htm)) or the safety data sheets of similar products were used as sources for toxicological information.

[6] 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).

where: I = Each individual ingredient of the plant protection product; DT= Acute toxicity; C= Chronic toxicity; P = Average score related to the active ingredient persistence; F = Toxicity to aquatic organisms; L = Long-term risk to aquatic organisms; Z = Toxicity to bees; T = Toxicity to other terrestrial organisms;

It can be observed that the first component, 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).

If we 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 like that of one 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:

a. 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.[7] This is a conservative value as recent investigations in Val di Sole (Tn) have shown the possibility of drifts up to 10 Km (Favaro et al., 2019). 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;

b. 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 based on RICA-INEA[8] data on each crop's required hours of work per hectare;

c. depends on potential exposure time. This obviously differs for the two categories of individuals, farm workers and 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 daylight 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:

$$C[(DT*P)*(Ha1/N1)*0.2*0.5]+C[(DT*P)*(Ha1/N2)*0.2*0.17] \quad (6)$$

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);

[7] 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.

[8] Italian farm accountancy data network. It is based on a sample of Italian farms and represents the only source of microeconomic data harmonised at agricultural level.

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

We can therefore define a new indicator, TEIQ, to consider this fourth component. Therefore, the indicator [1] newEIQi becomes:

TEIQi=(X1+X2+X3+X4); (7)

or, in extended form as:

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)*(N2/N1)*0.017].[9] (8)

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 overcome 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 any potentially dangerous ingredients of a formulated product, which can, in some cases, have a greater impact than the active ingredient alone (Surgan et al., 2010).

Once the TEIQi has been calculated for every hazardous ingredient (**i**), the overall score for a pesticide, TEIQp**,** is obtained by combining all the single-ingredient TEIQi scores plus a TEIQf 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 more or less unchanged as it is defined in Ioratti et al. (2011). The transition to the new safety sheet and labeling standards was completed in 2017.

To summarize:

TEIQp = TEIQi1 + TEIQi2 + … TEIQin + TEIQf. (9)

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 .[10]

3. 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: on one side the Tiber Valley and Upper Tiber Valley, located in the Tuscany Region neighboring the Umbria Region, and on the other the Chiana Valley, located in the Tuscany Region in the 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.[11]

We focused on annual crops, being more easily changeable compared to tree crops (such as vines and olive trees). 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 the land as meadows and pastures. Table 2 shows their overall crop allocation.

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 indica-

[9] To compare the impacts measured by using the new EIQ indicator with those assessed through the TEIQ, the former new EIQ should be multiplied by 3.

[10] 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).

[11] 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.

Table 1. 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.

tor was not limited to the active ingredient but accommodated all dangerous ingredients and their corresponding hazard statements. For the evaluation of co-formulant products, the new indicator considers the hazard statements included on the label.

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

Regarding the first component of the TEIQp as per equation [7] (risk to farm workers), the values obtained were compared (where possible) with the values obtained by Ioriatti et al. (2011). The comparison showed remarkable similarities between the two values compared.

To calculate the second and third components of equation [7] (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 [7] (risk to residents) was calculated in agreement with the corresponding component of equation [8] using populations of 86,895 and 168,044 for the studied areas of the Tiber Valley and the Chiana Valley, respectively.[12] As noted in the geostatistical information presented in Appendix 2, in both regions studied, residential areas (except for 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).

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 of 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.

[12] Because crop data is from 2010, population data from the 2011 census was used.

Table 2. 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	2,372.8	2,372.8
Soft wheat	66.6	66.6
Corn	316.1	316.1
Olives	193.2	193.2
Tobacco	6,923.8	7,006.8
Average for all five crops	1,974.5	1,990.6

Unfortunately, the results obtained cannot be compared with those obtained from other studies as no surveys like the one presented here are known.

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 69,204,800.8. If durum wheat and tobacco were replaced with soft wheat, that score would decrease substantially, to 3,429,371.7.

4. RESULTS: AN ATTEMPT TO QUANTIFY THE ECONOMIC EXTERNALITIES OF THE USE OF PESTICIDES

To identify the externalities resulting from the use of plant protection products, it is theoretically possible to use two different approaches. The first one is a direct assessment of the costs (in terms of health, environment, etc.) of using a given quality and quantity of plant protection products. 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

Table 3. Calculation of total TEIQp scores.

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	2,372,8	4,901.06	11,629,235.2	2,372,8	9,416.72	22,343,993.2	33,973,228.4
Soft wheat	66.6	1,385.28	92,259,6	66.6	2,139.63	142,499.4	234,759,0
Corn	316.1	770.87	243,672,0	316.1	1,088.62	344,112.8	587.784.8
Tobacco	6,923.8	4,073.41	28,203,476,2	**7,006.8**	695.02	4,869,866.1	33,073,342.3
Olives	193.2	865.86	167,284,2	193.2	6,047.63	1,168,402.1	1,335,686.3
Total	----------------	11,996.48	40,335,927.2	-----------	19,387.62	28,868,873.6	69,204,800.8

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.

The second approach is based on the assessment of the willingness to pay (WTP) of a given population in order not to be exposed to the consequences of pesticide use in a given area. In our study, this approach seems to be the only one that could be pursued. A survey carried out in Veneto in 2009, offered some information useful for our study.

In the 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 region in 2006[13]. Socio-economic conditions in Veneto are like those in Tuscany. More specifically, in the two regions, the incomes of families are very similar (Banca d'Italia, different years)[14] Similarities are also found in social capital and attitudes towards the environment. (Carocci,2009; Sabatini, 2009; Istat, 2021).

On the basis of the equations reported in that analysis, and using the average income in the Tuscany Region,[15] 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)[16]: €18.70;
- protecting biodiversity (taking the low end of the range): €23.60;
- being free of acute and chronic health issues caused by pesticides: €126.40.

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.[17] Assuming that the WTP rises in a straight line from 0 (no use of pesticides) to the TEIQp total impact score of more than

[13] Concerning the work made in the Veneto region, the WTP was obtained by a meta-analysis complemented by other assessments used according to the technique of value transfer, whose primary studies used both direct and indirect assessment methods. This has led (in Veneto) to the estimation of meta-functions which shows a satisfying statistical significance, and which differ for type and number of the explanatory variables featuring socio-economical, environmental and methodological factors. The WTP thus estimated, has made it possible to compare organic agriculture and conventional agriculture. The WTP concerning the non-use of pesticides in the conventional agriculture was estimated, in our case, by pairing it with the WTP estimated for obtaining the organic agriculture.

[14] In 2018, while the national average income per household was € 31,641, in Veneto region it was € 35,673 and in Tuscany € 33,792 (similar observations can also be made for previous years). At the same time, there is also considerable homogeneity in the distribution of family income. In fact, the Gini index has a value of 0.252 in Veneto and 0.277 in Tuscany (ISTAT).

[15] This statistic was used in place of the average income in the Veneto region, deflated by the ISTAT cost of living index to update the original 2006 figures to 2017. For the meta-analysis made in Veneto, among all the explanatory variables used, exclusively the income was considered since it has better explanatory qualities. Furthermore, the rest of the variables considered in Veneto, show similar values to those available in Tuscany in the same year.

[16] In Veneto Region, the WTP was reported as being a range between a minimum value and a maximum value. These values are connected with the different value attributed to the explanatory variables. In this work, as a precautionary measure, the minimum value of such rage was chosen.

[17] In this study, the municipality of Arezzo (98,144 inhabitants) was considered as if it were formally falling within the Chiana Valley area. The municipality of Arezzo was counted in this article because of its proximity to agricultural areas, as also shown in Figure A2.2 "Urbanization of rural areas in the Chiana Valley". If we exclude the municipality of Arezzo from the calculation, the total potential willingness to pay for a pesticide-free environment would amount to 14,825,154.23 euros per year.

Table 4 Changes in WTP, GSP, gross margin and operating margin, compared to baseline (scenario A).

	WTP Gain	Change in GSP		Change in Gross margin		Change in operating margin	
		Absolute values	Variation from scenario A=100	Absolute values	Variation from scenario A=100	Absolute values	Variation from scenario A=100
Scenario A (cultivations of tobacco)	baseline	51.833.950	100	39.850.087	100	-18.050.906	100
Scenario B (with soft wheat instead of tobacco)	8.436.983	23.481.044	45,3	20.885.942	52,4	-8.433.043	46.7
Scenario C (with corn instead of tobacco)	8.369.472	25.402.709	49,0	23.251.287	58,3	-8.170.781	45.3

17 million euros estimated for 2016. In this scenario, a reduction of one percentage point in the TEIQp index is equivalent to a WTP of EUR 25.68. It goes without saying that the value of the TEIQp index calculated in this way, can vary greatly from one year to the next one, depending on the crop growth, the climate variability and the cultivation techniques adopted. Consequently, the value of a percentage decrease (or increase) of the index itself will also vary. To get to define results useful for the economic policy purposes, it would therefore be necessary to calculate the index shown here in relation to average or standard values per crop, or per area. This calculation is possible but goes beyond the objectives of this paper.

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).

Table 4 shows that while the welfare gain (measured as WTP) resulting from the elimination of the tobacco crop is lower than the loss in terms of GSP and gross margin, it does lead to a reduction in net operating margin losses. Table 4 demonstrates that while the welfare gain (measured as WTP) resulting from the elimination of the tobacco crop is lower than the loss in GSP and gross margin, it does lead to a reduction in net operating margin losses. To interpret Table 4 correctly, it should be noted that both the GSP and gross margin indicator refer to day-to-day operations, while the operating margin also includes other elements that are not included in ordinary operations[25]. For reasons of space, in this paper, we present an example in which the land used to grow tobacco (scenario A) is planted instead with soft wheat (scenario B), or with corn (scenario C).

5. CONCLUSIONS

Quantification of the negative externalities associated with cultivation methods can have interesting operational implications both in terms of land-use planning and in defining economic policies for the industry (Maietta et al., 2019). This is particularly true when defining support measures for agricultural activities under the RDPs (Rural Development Programmes).

It is not easy to evaluate the value of externalities linked to agricultural production activity. In most cases, positive externalities are considered, but also negative ones should also be considered. Among the latter, those connected with the use of plant protection products are particularly important. In fact, Italian agriculture can be considered 'urban agriculture', i.e., agriculture in which cultivated areas are intertwined with residential areas (Filippini et al. 2021). This situation makes it difficult, in many cases, to reconcile the needs of producers to protect their crops and those of citizens to have an unpolluted environment.

From this point of view, this work is characterised by at least two limitations. Firstly, the use of meta-analyses to evaluate the WTP for a pesticide-free environment approximates the real WTP of the inhabitants of the area considered. Secondly, the farms taken into consideration are not a probabilistic sample of the farms in the area considered, and the surveys of the pesticides used relate to a single agricultural year. Therefore, the TEIQp index values obtained, following more in-depth investigations, could lead to different values.

Finally, since 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 to reach results at the operational level. Despite these limitations, the results obtained lead us to believe that the application of tools like the one used in this case may have general validity.

Firstly, it should be noted that it is necessary to try to identify indicators that consider all possible externalities. Specifically, we believe that the TEIQ indicator proposed in these notes can be of help in all cases where intensive agricultural activities and residential and recreational activities take place in very close areas.

Secondly, 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.

Thirdly, 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.

Fourthly, the exercise conducted in this study confirms once again that the economic policy objective pursued must be assessed very carefully. In the present case, in addition to the obvious difference between profit maximization and social benefit, there is a difference also between gross marketable output and operating margin (Mack et al., 2019).

Finally, being able to rely on an indicator such as the one shown in the present study, make it possible to appropriately modulate the objectives of reducing the environmental impact of agricultural activity. Consequently, it would be possible to overcome the contrast between conventional farming and organic farming, coming to define the maximum levels of environmental impact that can be tolerated in a given area. These levels depend not only on the characteristics of the agricultural sector but also on the environmental and socio-economic context in which ~~it~~ the area is located.

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DATA AVAILABILITY

All data, associated metadata, and calculation tools are available through supplemental files upon request.

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APPENDIX 1

Table A1.1. 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

The different components considered are assessed by considering the following risk phrases:
DT = Acute toxicity defines the average individual rating for the risk of direct exposure to chemicals, considering the following DSD risk phrases: R20, 21, 22, 23, 24, 25, 26, 27, 28, 36, 37, 38, 41, 42, 43, 65, 66, 67.
C= Chronic toxicity defines the average individual rating for long-term fertility, and teratogenic, mutagenic, and oncogenic risks (DSD risk phrases R40, 45, 46, 12 48, 49, 60, 61, 62, 63, 64, 68).
P= Average score related to the active ingredient persistence based on the pre-harvest interval (PHI) of the agricultural 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.

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).[18] 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 its municipalities[19] 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 A2.1 shows the total crop acreage of the two areas studied. Figures A2.1 and A2.2 come from the ISTAT database and refer to the latest agriculture census available, for 2010, as intercensal data only provides aggregate figures by province.

The two areas are characterized by a widespread urbanization of rural areas and by a significant proximity of intensive farming to residential areas where people frequently visit. Figures A2.1 and A2.2 present some buffer zones 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 inter-distanced according to the density and distribution of the farms included in the study. The result was then superimposed on the colour orthophoto map of the Region of Tuscany.

Table A2.1. 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.

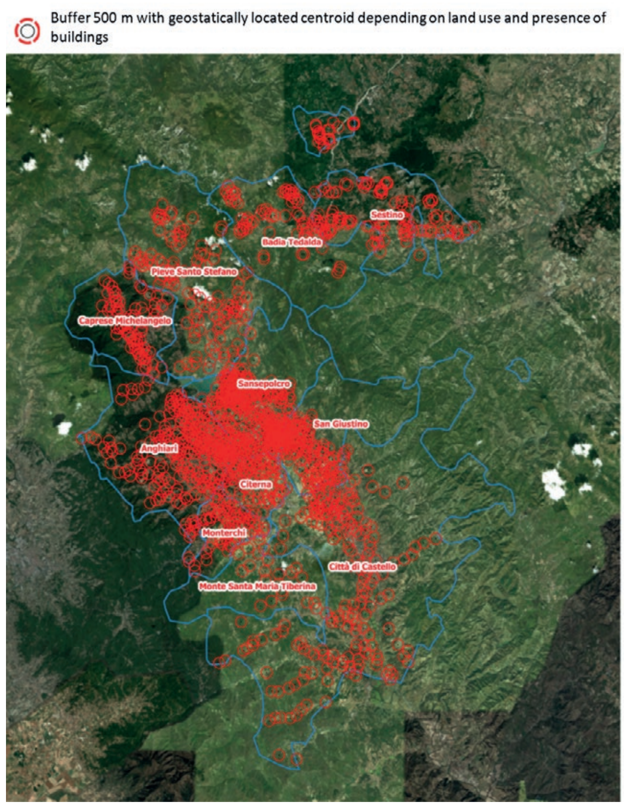

Figure A2.1. Urbanization of rural areas in Tiber Valley.

[18] 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).

[19] Arezzo, Castiglion Fiorentino, Cortona, Civitella in Val di Chiana, Monte San Savino, Foiano della Chiana, Lucignano, and Marciano della Chiana.

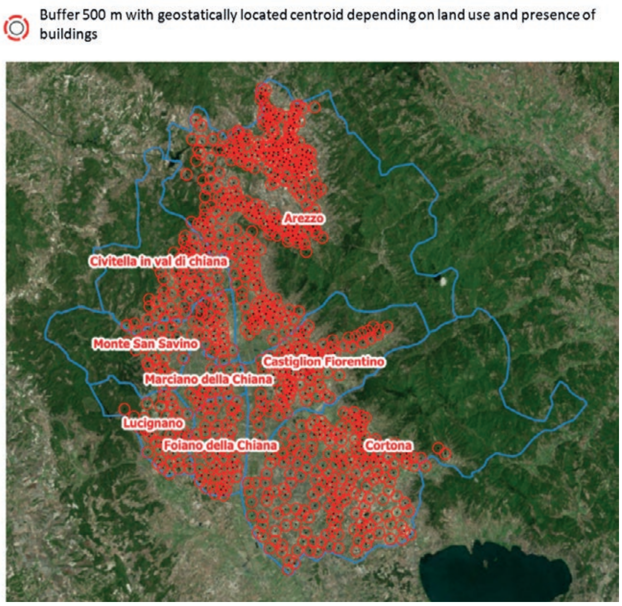

Figure A2.2. Urbanization of rural areas in the Chiana Valley.

APPENDIX 3

Glossary

"**Consumer protection**" 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.

"**Exposure**" This term 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).

"**Gross margin and operating margin** " As known, this balance sheet partially deviates the traditional financial statements and from the annual consolidated financial statements (Barbieri et al., 2004). Specifically, the gross margin represents a value of the profitability of the company's production activities (crops and livestock), obtained as the difference between the total value of production (main product plus any secondary products) and the costs incurred in the production processes. At the same time, operating income is the economic result of the characteristic management of the agricultural enterprise, which includes all costs and revenues generated by the production processes and by active and passive services related to agricultural activities. It is calculated as the difference between the farm net product and the income distributed (wages and social security contributions, rents payable).In this specific balance sheet, since the operating margin considers both revenue and expenses different from those typical of the ordinary operations, there may be some cases where the operating margin is higher than the gross one. In the case under consideration, the considered RICA-INEA data report such situation for the olive growing in Tuscany.

"**Hazard-based classification criteria**" These 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.

"**Plant protection products**" (PPPs) In this paper include all active ingredients, as well as 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.

"**Selectivity**" PPPs selectivity can be physiological or ecological. It is physiological if it derives from the characteristics of the PPPs itself.

"**Spectrum of action**" This term 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.

"**Systemic action**" indicates 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).

"**Toxicological classification**" 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 PPPs.

"**Worker protection**" 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).