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1**Suitability of pesticide risk indicators for less developed countries: a comparison**

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12**Abstract**

13Pesticide risk indicators provide simple support in the assessment of environmental and health 14risks from pesticide use, and can therefore inform policies to foster a sustainable interaction of 15agriculture with the environment. For their relative simplicity, indicators may be particularly 16useful under conditions of limited data availability and resources, such as in Less Developed 17Countries (LDC). However, indicator complexity can vary significantly, in particular between 18those that rely on an exposure-toxicity ratio (ETR) and those that do not. In addition, pesticide 19risk indicators are usually developed for Western contexts, which might cause incorrect 20estimation in LDCs. This study investigated the appropriateness of seven pesticide risk 21indicators for use in LDCs, with reference to smallholding agriculture in Colombia. Seven 22farm-level indicators, among which 3 relied on an ETR (POCER, EPRIP, PIRI) and 4 on a 23non-ETR approach (EIQ, PestScreen, OHRI, Dosemeci et al., 2002), were calculated and then 24compared by means of the Spearman rank correlation test. Indicators were also compared 25with respect to key indicator characteristics, i.e. user friendliness and ability to represent the 26system under study. The comparison of the indicators in terms of the total environmental risk

1suggests that the indicators not relying on an ETR approach cannot be used as a reliable proxy

2for more complex, i.e. ETR, indicators. ETR indicators, when user-friendly, show a

3comparative advantage over non-ETR in best combining the need for a relatively simple tool

4to be used in contexts of limited data availability and resources, and for a reliable estimation

5of environmental risk. Non-ETR indicators remain useful and accessible tools to discriminate

6between different pesticides prior to application. Concerning the human health risk, simple

7algorithms seem more appropriate for assessing human health risk in LDCs. However, further

8research on health risk indicators and their validation under LDC conditions is needed.

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131. Introduction

14Pesticide risk indicators can support the assessment of environmental and health risks from

15pesticide use. They can be utilized by different kinds of users, such as farmers, extension

16agents, policy-makers, regulatory agencies and academia (Levitan, 2000). They serve as a

17basis for the evaluation of different pest management strategies (Levitan, 2000; Greitens and

18Day, 2007), and for the development, monitoring and assessment of environmental and health

19policies (Levitan, 2000; Maud et al., 2001; Falconer, 2002; Finizio and Villa, 2002). Thus,

20pesticide risk indicators can signal risky agricultural practices and inform interventions and

21policies to foster a sustainable interaction of agriculture with the environment on which

22agriculture itself relies. The contribution of pesticide risk indicators, and more in general of

23sustainability indicators, in helping minimising the impact of agriculture on the environment

24has been recognized not only in academia, but in the policy arena, which has often taken a

1proactive role in stimulating research on sustainability indicators in agriculture (e.g. CEC,

21999; OECD 1999 and 2001).

3Simplicity is a generally acknowledged feature of indicators. This often makes them

4acceptable, usable even with scarce data, quick to calculate and easy to communicate,

5although at the expense of a more realistic representation of pesticide impacts (van der Werf,

61996; Castoldi et al., 2007). In this regard, indicator-based assessment methods gain a

7comparative advantage over alternative assessment systems, such as direct measurements or

8simulation modelling, which instead require more qualified expertise, economic resources and

9data which might not always be available.

10However, the level of complexity of pesticide risk indicators can also vary significantly. Two

11broad typologies of indicators can be identified (Reus et al., 2002). The first includes user

12friendly assessment tools, usually with few input data requirements, and a scoring table based

13on rather simple algorithms which are often constructed on the basis of expert judgment.

14These indicators usually score pesticide properties first, which are then multiplied by the

15application rate. Finally, the scores are aggregated by summation. The second typology

16includes indicators using a risk-ratio, or exposure-toxicity ratio (ETR) approach, i.e. "the ratio

17between exposure (usually the concentration in a certain environmental compartment) and

18toxicity for relevant organisms" (Reus et al., 2002). These indicators are considered to better

19represent and quantify environmental risks from pesticide use, but have the drawbacks of

20requiring more detailed input data and the support of computer modelling (Reus et al., 2002;

21Castoldi et al., 2007). These indicators use the application rate to calculate pesticide

22concentrations, which are then scored by environmental compartment. The compartment

23scores can then be integrated by summation or by multiplication. Thus, from a mathematical

24perspective, the most significant difference between ETR and non-ETR indicators is how the

25application rate is included in the risk estimation.

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1The extent to which simple and complex pesticide risk indicators provide convergent
2assessment results is an open issue. Convergent results would allow for considering simple
3indicators as proxy to the more complex ones, and therefore allow them to be used as easy-to-
4use diagnostic tools. However, previous comparative studies highlighted a divergence rather
5than a convergence in assessment results (e.g. Maud et al., 2001; Reus et al., 2002).

6The quest for simple but reliable assessment methods is particularly relevant in Less
7Developed Countries (LDC). In effect, not only are LDCs often characterised by particularly
8serious pesticide-related externalities (e.g. Pimentel et al., 1992; Ecobichon, 2001), but also
9by a general limited ability in environmental and agricultural research and monitoring. The
10latter can be in broad terms related to two issues, i.e. lack of skilled human resources, with
11brain drain and de-qualification affecting many countries (UNESCO, 2009), and lack of
12infrastructure (e.g. information technology, laboratories) and financial resources to access and
13produce reliable data and information (Zhen and Routray, 2003; UNESCO, 2009).

14Furthermore, one open issue is that pesticide risk indicators are usually developed for
15productive and pedoclimatic conditions in Western countries, which might imply, especially
16for indicators relying on expert judgement, an incorrect assessment of pesticide risks in LDCs.
17Pesticide risk indicators have been used in LDCs, but usually with a preference for simple,
18non-ETR types (e.g. Muhammetoglu and Uslu, 2007; Pradel et al., 2009), an exception being
19a study of Kookana et al. (2007). However, while comparative evaluations of pesticide risk
20indicators exist (e.g. Maud et al., 2001; Reus et al., 2002; Stenrod et al., 2008), they do not
21refer to the conditions of resource availability usually encountered in LDCs. Moreover,
22comparative evaluations of indicators have neglected human health risk indicators. Analysing
23also this kind of indicators is of fundamental importance in LDCs, because pesticide
24application practices often differ significantly from those adopted in Western countries
25(Matthews, 2008). Such differences in contextual factors, in particular pesticide application

1techniques, suggest that the applicability of health risk indicators in LDCs might be limited,

2and call for the need for contextualizing pesticide risk, e.g. to understand the determinants of

3exposure more than to quantify levels of risk (Blanco et al., 2005).

4Consequently, it is not clear what indicators might be more appropriate to assess

5environmental and health risks from pesticide use, and thus properly inform agricultural

6management, under pesticide application practices typical of LDCs. The objective of this

7study was to investigate the appropriateness of seven pesticide risk indicators for use at farm

8level in LDCs, with particular reference to smallholding agriculture in the Colombian Andean

9region. With reference to this area, two research questions drove the study:

10   i)   Can simple pesticide risk indicators be used as proxies for more complex ones,

11   thus facilitating the task of risk assessment?

12   ii)   What is the most appropriate indicator to assess pesticide risk to human health and

13   the environment?

14The paper is structured as follows. Firstly, a short description of the indicators selected, study

15area, data used and comparative procedure adopted are provided. Secondly, the results are

16presented separately for environmental and human health risk indicators. Finally, results are

17discussed with reference to the two research questions, and conclusions on the use of pesticide

18risk indicators in the context of LDCs are drawn.

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23**2. Method**

24**2.1. Indicators**

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1Seven farm-level indicators (i.e. EIQ, PestScreen, EPRIP, PIRI, POCER, OHRI and the
2indicator proposed by Dosemeci et al., 2002) were selected so that i) every environmental and
3health compartment was considered by at least two of the selected indicators and ii) both
4simple, i.e. non-ETR, and complex, i.e. ETR, indicators were represented (Table 1).

52.1.1. Coverage of environmental and health compartments

6Three indicators, i.e. PestScreen (Juraske et al., 2007), EPRIP (Padovani et al., 2004; Trevisan
7et al., 2009), and PIRI (Kookana et al., 2005), focus exclusively on environmental risks,
8whereby risk to consumer health is implicitly and partly included, since drinking water
9contamination and ingestion of contaminated food are part of the environmental risk
10assessment. Two indicators, i.e. OHRI (Bergkvist, 2004) and the indicator developed by
11Dosemeci et al. (2002), focus solely on occupational health risk, whereby only the pesticide
12operator is considered. The remaining two indicators, i.e. EIQ (Kovach et al., 1992) and
13POCER (Vercruysse and Steurbaut, 2002), include an environmental risk component and an
14occupational health risk component, whereby both assess the risk to agricultural workers in
15addition to pesticide operators and POCER also considers bystanders' risk to pesticide
16exposure (a short description of the indicators is given in the supplementary data files).

172.1.2. Representation of ETR and non-ETR indicators

18Four indicators were chosen that do not rely on an ETR approach, i.e. they transform
19variables into scores which, in turn, are aggregated empirically (EIQ, PestScreen, OHRI and
20the indicator from Dosemeci et al., 2002), and three indicators were chosen which rely on the
21ETR approach (POCER, EPRIP, PIRI). The first four indicators are considered simple
22indicators because they do not make use of site specific data (e.g. pedoclimatic conditions)
23and because pre-calculated hazard scores are multiplied with application rates by the end-user,
24which results in low data requirements. The latter three indicators take into account site
25specific data, make use of the ETR approach and are more data demanding.

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2.1.3. Further indicator characteristics

PestScreen, POCER, EPRIP and PIRI all implement at least some of the suggestions made in earlier studies for the development of more accurate pesticide risk indicators (Levitan, 1997 and 2000; Maud et al., 2001; Reus et al., 2002). Among these suggestions were: to be analogous to the technical concept of risk, to have large potential ranges to allow for differentiation between pesticides, to include application rate, application factors and environmental conditions, to give separate rankings for different compartments (including human health). On the other hand, EIQ is one of the most dated, but also one of the most widely used indicators, with numerous applications in LDCs (e.g. Muhammetoglu and Uslu, 2007; Pradel et al., 2009).

Finally, all indicators chosen present a relative outcome. That is, instead of providing an absolute value, the assessment provides a qualitative statement on the relative risks a pesticide application or control strategy might have in comparison to the application of another pesticide or to a control strategy based on different pesticides.

Table 1. Risk indicators considered in this study by environmental and health compartments

Indicator	Environment					Health			Calculation methodology	
	Soil	Air	Surface water	Groundwater	Beneficial arthropods	Pesticide operator	Farm worker	Consumer	ETR	Non-ETR
EIQ			*	*	*	*	*	*		*
PestScreen	*	*	*	*				*		*
POCER	*		*	*	*	*	*	*	*	
EPRIP	*	*	*	*				*	*	
PIRI			*	*				*	*	
OHRI						*				*
Dosemeci et al. (2002)						*				*

2.2. Data

2.2.1. Data and study area

1The data necessary to calculate the indicator rankings were mainly derived from an existing

2georeferenced dataset produced in a previous study in the *vereda* (community) called La

3Hoya, located in the Department of Boyacá, in the eastern chain of the Colombian Andes

4(Feola, 2010a). For many aspects such as pesticide application technique or socio-

5demographic structure, this study area may be considered typical of the broader Andean

6region (Feola, 2010a) and very similar to other rural areas in LDCs (Matthews, 2008).

7Vereda La Hoya ranges from 2,700 to 3,250 masl over an area of 8.4 km^2 (840 ha), and has a

8population of about 750 inhabitants. It is a rural region mainly dedicated to the cultivation of

9potato (MADR, 2006). The production of potato in Vereda La Hoya relies mainly on

10smallholders, who cultivate an average of 3 hectares subdivided into different plots. The land

11is cultivated in two cycles a year (September to February and March to August). Average

12productivity rates range between 15 and 17 ton/ha (MADR, 2006). Potato crops in this region

13are vulnerable to three major pests: the soil-dwelling larvae of the Andean weevil

14(*Premnotrypes vorax*), the late blight fungus (*Phytophthora infestans*) and the Guatemalan

15potato moth (*Tecia solanivora*) . To protect the crop from these pests, the use of chemical

16pesticides, in particular insecticides and fungicides, is widespread among smallholders (Feola

17and Binder, 2010b). The most common way of applying pesticide is by means of a lever-

18operated knapsack sprayer (20-25 litres), which is filled from a bigger tank, usually of about

19200 litres, where the pesticide mix is prepared.

20Also as a result of the misuse of personal protective equipment (PPE), high levels of

21pesticide-related health risk have been observed in the region (Cardenas et al., 2005; Ospina

22et al., 2008; Feola, 2010b). Regarding adverse environmental effects, both Schoell and

23Binder (2009) and Feola and Binder (2010b) reported that farmers in Vereda La Hoya

24observed a pesticide-related reduction of soil biodiversity in recent years. Finally, pesticide

25overuse has attracted the concern of governmental agencies because of its economic

1drawbacks (MADR, 2004). In this respect, Feola and Binder (2010b), showed that some of
2the farmers tend to use pesticides ineffectively, with a persistent overuse.

3The data used in this study to calculate the indicator values were gathered through a survey
4carried out in La Hoya in 2007 (Feola and Binder, 2010c). The data consisted of detailed
5information on 72 farmers' safety practices (e.g. hygiene and use of personal protective
6equipment) and pesticide applications on one selected plot. The reference period for the data
7was one entire agricultural cycle (March to August 2007).

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9*2.2.2. Additional data*

10Additional data necessary to calculate the indicators was gathered from various sources.
11Pesticide properties were obtained through the Pesticide Properties Database (PPDB, 2009).
12Climatic data, such as precipitation and temperature (for the years 1994-2003), were obtained
13from the Instituto de Hidrologia, Meteorologia y Estudios Ambientales de Colombia. For the
14reference period the temperature was between an average minimum of 5.7 °C and an average
15maximum of 20 °C. Total annual precipitation in the reference period was 343.5 mm. For soil
16parameters, the classification of "clay loam" was used (Binder and Patzel, 2001). According
17to Leuenberger (2005) average organic carbon content in the study area was 6.4%. Mean bulk
18density was assumed to be 0.9 tons per m^3 according to Binder and Patzel (2001). Soil loss
19was adapted from Binder and Patzel (2001) and assumed to be 9.6 tons per hectare and year.
20The distance of the plot to water bodies was calculated with the software ESRI ArcGIS 9.3.
21An overview of the data used to calculate the indicators is available in the supplementary data
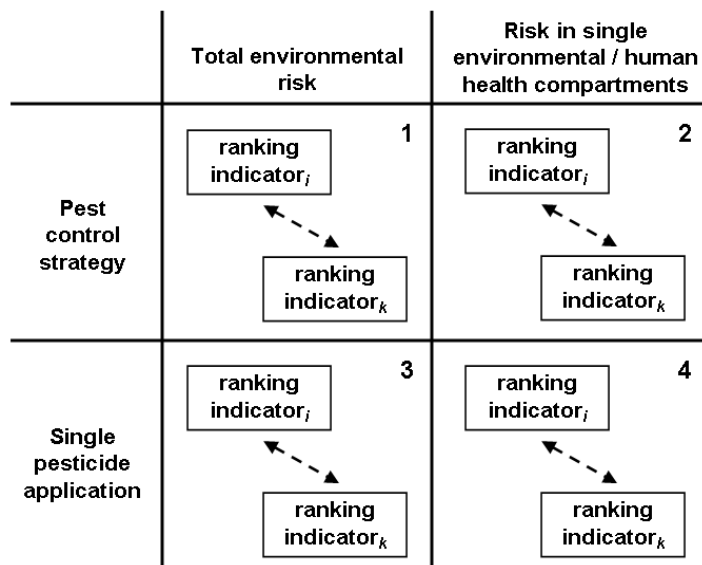22files.

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24**2.3. Procedure**

1The study consisted of three phases. First, the indicator values were calculated for the pest

2control strategy and for single pesticide applications. A pest control strategy is defined for

3each of the 72 farmers as the total amount of pesticide applied by active ingredient (examples

4of pesticide application patterns and strategies can be found in Feola and Binder, 2010b, and

5Juraske et al., 2011). For EIQ and EPRIP, the number, frequency and sequence of applications

6also contributes in differentiating among pest control strategies, since they propose how to

7calculate the cumulative risk which occurs when several applications of different active

8ingredients are used within the same pest control strategy. Concerning the single pesticide

9applications, the 72 farmers applied pesticides a total of 1772 times to their fields during the

10agricultural cycle considered. These applications were aggregated by summing up all

11applications of a particular pesticide during each of the five production phases (i.e. sowing of

12the potato, emergence of the shoot, weeding, earthing up, and maintenance). For example, if a

13farmer applied carbofuran four times with varying application rates during the emergence of

14the potato shoot, the indicator values were calculated for all four applications taken together.

15Accordingly, the amount of applications analysed decreased to 581. In sum, 72 pest control

16strategies, i.e. each strategy consisting of all applications for each single farmer, and 581

17pesticide applications, were considered.

18Second, the indicator rankings were compared by means of the Spearman rank correlation

19test, in accordance with Maud et al. (2001) and Reus et al. (2002), and using the software

20PASW Statistics 18.0. Not only were the indicators compared with respect to their overall

21outcome (Figure 1, quadrant 1), but also every individual environmental and health risk

22component that the indicators have in common (Table 1) was compared separately (Figure 1,

23quadrant 2). Furthermore, the indicators were compared with regard to both the 518 pesticide

24applications and the 72 control strategies (Figure 1, quadrants 3 and 4). Since only EIQ and

25EPRIP propose how to calculate the cumulative risk accruing when several applications of

26different active ingredients are used within the same pest control strategy, the other indicator's

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values for the pest control strategies were simply summed up from those of the single applications, as proposed by Kovach (1992). Due to the lack of daily meteorological data, the groundwater module of POCER was not calculated through the suggested PESTLA model, but through the groundwater module of the PIRI indicator. PestScreen, which does not propose rankings for single environmental compartments, was compared to other indicators only with respect to the total environmental risk. In addition, the comparison was carried out separately for environmental and occupational health indicators (Figure 1).

Third, a comparison based on key indicator characteristics was made, taking into account each indicator's user friendliness (i.e. data availability, calculation procedure, and interpretation of ranking) and ability to represent the specific system under study (i.e. compartments considered, use of site specific data). The former refers to the procedural dimension of sustainability assessment (Binder et al., 2010), and concerns the indicator best suited to practical use in LDCs. The latter refers to the systemic dimension of sustainability assessment (Binder et al., 2010), and entails the coverage of all relevant ecosystem and human system (i.e. health) compartments. This also entails the use of site specific information, which might significantly alter the estimated level of risk associated with a given application of pesticide due to, for instance, the influence of environmental characteristics such as soil composition on the persistence of active components in the ecosystem under study (the details of the criteria used for this comparison are given in the supplementary data files).

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2**Figure 1**. **Comparative analysis of the indicator rankings. The subscripts *i* and *k* indicate indicators**

3**among the ones compared in the study.**

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5**3. Results**

6**3.1. Comparison of indicators based on rankings: environmental risk**

7*3.1.1. Total environmental risk*

8Four indicators aggregate the risk to the different environmental compartments into an overall

9risk value, namely EIQ, PestScreen, POCER and EPRIP. The highest and significant

10correlations between rankings were those between EIQ and PestScreen (both non-ETR) and

11between POCER and EPRIP (both ETR). The latter decreased when control strategy instead

12of single applications was considered, while all other correlations increased. EIQ and

13PestScreen showed a high correlation with the application rate (Table 2).

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Table 2. Correlation between rankings of the 581 pesticide applications, and between rankings of the 72 control strategies (in *italics*) for total environmental risk (Spearman correlation test)

	EIQ	PestScreen	POCER	EPRIP	Application rate
EIQ	1.00				
PestScreen	0.96 **	1.00			
POCER	-0.08 *	-0.18 **	1.00		
EPRIP	0.12 **	0.02	0.74 **	1.00	
Application rate	0.96 **	0.98 **	-0.27 **	-0.03	1.00

3.1.2. Risk to surface water and groundwater

Four indicators rank the risk to surface water, namely EIQ, POCER, EPRIP and PIRI, while three of these, i.e. EIQ, EPRIP and PIRI, also rank the risk to groundwater. The rankings for all indicators correlated with each other, albeit with differing strength. Regarding the risk to surface water, EPRIP was the only indicator for which the correlation with the other indicators was smaller when the control strategy rather than the single applications was considered, while, for the risk to groundwater, this also occurred for PIRI. EIQ, POCER and PIRI had significant correlations with the application rate. In general, correlations between rankings of the latter (i.e. POCER, EPRIP, PIRI) tended to be higher than those between rankings of ETR and non-ETR indicators (i.e. EIQ) (Tables 3 and 4).

Table 3. Correlation between rankings of the 581 pesticide applications, and between rankings of the 72 control strategies (in *italics*), for risk to surface water (Spearman correlation test)

	EIQ	PestScreen	POCER	EPRIP	Application rate
EIQ	1.00				
PestScreen	0.99 **	1.00			
POCER	0.18	0.18	1.00		
EPRIP	0.05	0.05	0.34 **	1.00	
Application rate	0.98 **	0.98 **	0.12	0.01	1.00

1Table 4. Correlation between rankings of the 581 pesticide applications, and between rankings of the 72
2control strategies (in *italics*), for risk to groundwater (Spearman correlation test)

	EIQ	POCER	EPRIP	PIRI	Application rate
EIQ	1.00				
POCER	0.45 **	1.00			
EPRIP	0.18 **	0.74 **	1.00		
PIRI	0.40 **	0.64 **	0.43 **	1.00	
Application rate	0.86 **	0.34 **	0.04	0.33 **	1.00

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53.1.3. Risk to soil and beneficial arthropods, birds and bees

6Two indicators, namely POCER and EPRIP (both ETR), rank the risk to soil. They correlated
7significantly at 0.01 level (Spearman correlation test 0.82); POCER also correlated
8significantly with the application rate (Spearman correlation test 0.42).

9The risks to beneficial arthropods, birds and bees are each ranked by EIQ and POCER.
10Significant correlations (at 0.01 level) between the two rankings were observed for the risk to
11birds, both when single applications and control strategy are considered (Spearman
12correlation test 0.43 and 0.35 respectively). Regarding the risk to bees, the two rankings
13correlated significantly (at 0.01 level) only when the control strategy was considered
14(Spearman correlation test 0.43). Concerning risk to beneficial arthropods, the two rankings
15were significantly, but negatively, correlated (Spearman correlation test -0.5) when single
16applications were considered. Finally, for all three compartments, and for both control
17strategy and single applications, EIQ always correlated significantly at 0.01 level and very
18strongly (Spearman correlation tests > 0.94) with the application rate (Tables showing the
19correlations for these three compartments are given in the supplementary data files).

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3.2. Comparison of indicators based on rankings: health risk

Four indicators rank the risk to the pesticide operator, namely EIQ, POCER, OHRI and the indicator from Dosemeci et al. (2002). The latter only provides an assessment of the control strategy. When single applications were considered, all rankings correlated with each other significantly (Table 5). Both EIQ and POCER also correlated significantly with the application rate, while OHRI does not include the application rate in its algorithm. However, the rankings correlated less strongly, and in some cases not significantly, when the control strategy was considered (Table 5). The highest correlations were observed between EIQ and POCER, both of which also significantly and strongly correlate with the application rate (Table 5).

Table 5. Correlation between rankings of the 581 pesticide applications, and between rankings of the 72 control strategies (in *italics*), for risk to pesticide operator (Spearman correlation test)

	EIQ	POCER	EPRIP	PIRI	Application rate
EIQ	1.00				
POCER	0.51 **	1.00			
EPRIP	0.13	0.61 **	1.00		
PIRI	0.58 **	0.70 **	0.31 **	1.00	
Application rate	0.94 **	0.38 **	0.30	0.49 **	1.00

Two indicators rank the risk for farm workers, namely EIQ and POCER. The two rankings correlated significantly at the 0.01 level and rather strongly, considering both single applications and control strategies (Spearman correlation tests 0.56 and 0.49 respectively). Both indicators correlated significantly with the application rate (Table given in the supplementary data).

3.3. Comparison of indicators based on key indicator characteristics

The results of the comparison based on key indicator characteristics are shown in Table 6 (the details of the criteria used for this comparison are given in the supplementary data files).

Table 6. Comparison based on key indicator characteristics of the selected indicators.

	EIQ	EPRIP	PIRI	Application rate
EIQ	1.00			
EPRIP	0.10 *	1.00		
PIRI	0.50 **	0.79 **	1.00	
Application rate	0.94 **	-0.08 *	0.34 **	1.00

3.3.1. User friendliness

Data for calculating the majority of the indicators are easily available. Data availability in this analysis does not concern data about the pesticides used by farmers, which are assumed to be available and relatively easy to collect e.g. through a survey, but instead other inputs such as parameters related to their physical and chemical properties, or toxicity.

Data for some pesticides are missing in the indicators' internal databases, and in this study were substituted with the values (for EIQ and PestScreen) or property parameters (for POCER, EPRIP, and PIRI) of pesticide belonging to the same chemical classes. Regarding the health risk component of POCER, the low score in Table 6 depends on the actual, but probably temporary impossibility of accessing the EUROPOEM database, on which this indicator relies. The indicator proposed by Dosemeci et al. (2002) only requires information on pesticide use practices, although rather detailed, and not on pesticide properties.

EIQ and PestScreen can be calculated without a highly specialist knowledge of pesticides and have a simple calculation algorithm. POCER, in particular regarding the groundwater and

1health modules, needs a higher level understanding of the model used and tends to require a

2significant amount of time for the calculations.

3All indicators except EIQ provide thresholds on which basis pesticide risk classes can be

4identified, but only EPRIP and PIRI provide such thresholds for both the risk associated with

5single pesticide applications and for the control strategies. However, PIRI is less transparent

6than EPRIP on the value at which such thresholds are set.

7*3.3.2. Ability to represent the system*

8EIQ and PestScreen do not make use of site specific information, while POCER, EPRIP and

9PIRI do, thus providing a more appropriate representation of the specific system under

10analysis. The indicators also differ in terms of environmental compartments considered, and

11therefore on their ability to produce a comprehensive overview of risk in the environmental

12system, with PestScreen, POCER and EPRIP covering the most compartments. Concerning

13health risk, OHRI and the indicator proposed by Dosemeci et al. (2002) are limited to the

14occupational health of the farm worker.

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16**4. Discussion**

17*4.1. Simple versus complex indicators*

18Comparison of the indicators with regard to the total environmental risk suggests that simple

19indicators not relying on an ETR approach cannot be used as a reliable proxy for more

20complex indicators, i.e. those relying on an ETR approach. In effect, the values of the former

21(i.e. EIQ, PestScreen) tended to correlate weakly with those of the latter (i.e. EPRIP, POCER

22and PIRI) when the total environmental risk was considered (Table 2). When single

23compartments were considered, the correlation between the indicator rankings was stronger,

24which confirms the results of other studies (Maud et al., 2001; Reus et al., 2002). However,

the correlations between non-ETR and ETR indicator values for single compartments were rather weak in the majority of cases (Tables 3 and 4 and supplementary material; Spearman correlation test < 0.6). This confirms the key role played by the calculation method, and in particular by the way the pesticide dose data are mathematically included in the formulas, and by the way compartment scores are aggregated into a total score, in determining the rankings.

Moreover, for both the total environmental risk and the risk in selected compartments, the correlations among all indicators were weaker or not significant when the pest control strategy instead of the single applications was considered (Tables 2 to 4 and supplementary material). This underlines the importance of the aggregation procedure, i.e. from single pesticide applications to pest control strategy, adopted for the different indicators. For EIQ, PestScreen and POCER the individual values of each pesticide applications were summed up. In this procedure, the number of treatments may have a greater impact on the final risk ranking than the impacts of single pesticides, because less and more risky pesticides are equally weighted. At the other extreme, EPRIP is the only indicator among those analysed in this study, which i) gives more weight when high risk occurs in an environmental compartment, ii) relies on a probability function in order to account for a possible cumulative effect of exceeding two thresholds of risk, and iii) accounts for the degradation occurring between single pesticide applications. While some aspects of the aggregation procedure and scoring system are still undergoing validation (Balderacchi and Trevisan, 2010), these are clear strengths of EPRIP in comparison with other indicators.

As also found by Maud et al. (2001), simple indicators tended to be driven by the application rate, which instead was less dominant in determining the values of ETR indicators, since these accord more weight to pesticide properties and environmental conditions such as distance to water body or slope. This difference between the two types of indicators was also tested by calculating ETR indicators using average values for the site specific parameters (not shown in

the present paper). This significantly improved the correlations, proving the essential difference marked by using site specific parameters, and also confirmed the good correlation between PestScreen and EPRIP found by Juraske et al. (2007) using constant site specific data for EPRIP.

An additional contribution to the difference in risk rankings between non-ETR and ETR indicators might come from the fact that EIQ and PestScreen adopt low ranges of values, which are likely to distort the differences in risk between pesticides with different properties, as pointed out by other studies (e.g. Dushoff et al., 1994).

Finally, concerning the human health risk the results show a more complex picture, especially when the pest control strategy is considered. Correlations between rankings of different indicators, both ETR and non-ETR, tended to be weak and to change significantly when the control strategies instead of the single applications were considered. These differences were very likely to depend not on the calculation procedure (ETR vs. non-ETR), but on the radically different attribution of risk potential to different factors in the indicators, i.e. misuse of protective equipment and highly toxic pesticides in POCER, powder formulations and large plot areas in OHRI, misuse of personal protective equipment and hygiene habits in Dosemeci et al (2002). Since no other similar comparison of health pesticide risk indicators exists in the literature, it was not possible to compare these results with those of other studies. Further research in this direction is recommended.

4.2. Use of risk indicators in developing countries

LDCs are often characterized by particularly serious pesticide-related externalities but also by a general lack of resources, i.e. data, and expertise dedicated to environmental (Zhen and Routray, 2003; UNESCO, 2009) and health protection (Feola, 2010b), and the promotion of

sustainable agricultural production. In this context, the availability of a simple but reliable pesticide risk indicator would be particularly relevant.

With regard to total environmental risk, the result seems to exclude the possibility of using simple, i.e. non-ETR, indicators as proxies for more complex, i.e. ETR, indicators in the assessment of farm-level pesticide-related risk (see also section 4.1). However, recent developments of EPRIP (Trevisan et al., 2009), and in particular the provision of a freely accessible user-friendly software with an internal database, have reduced the complexity of this indicator and made its use relatively simple, even with a data requirement comparable to that of EIQ and PestScreen (Table 6). Moreover, EPRIP is also the indicator that more strictly complies with the other requirements identified by previous studies for the development of more accurate pesticide risk indicators (i.e. Levitan, 1997 and 2000; Maud et al., 2001; Reus et al., 2002). Nevertheless, non-ETR indicators remain very useful and accessible tools for discriminating between different potentially risky pesticides prior to application. In this regard, PestScreen is probably to be preferred to EIQ for it not only includes half life values for single media but makes use of the overall environmental persistence.

Concerning risk in single environmental compartments, the use of single components of different indicators might be considered. For example, PIRI proposes a convincing calculation approach for risk to surface water organisms, with the inclusion of the main transport routes, and accounting for possible site specific mitigation measures, which can be useful for monitoring purposes. The choice of the indicator to be used for a single environmental compartment is likely to depend on the specific research, management or policy needs, on the availability of data and other necessary resources, and on an accurate analysis of the characteristics of the different indicators.

With regard to human health risk indicators, the results do not give strong support for one specific indicator among those analysed. Because uncertainties still exist in the literature on

1human exposure to pesticide during pesticide application and other operations, it might be

2preferable to avoid using indicators based on exposure models. In addition, these models are

3usually developed under European conditions, while it has been shown that in developing

4countries such as the study area, pesticide application techniques and chemicals used might

5differ extensively from those conditions (Feola and Binder 2010a and 2010b). In fact,

6following Blanco et al. (2005), it might be less important to accurately quantify the exposure

7of farmers to pesticides than to understand the determinants of exposure, both in terms of risk

8factors (e.g. misuse of personal protective equipment, hygiene habits) and of determinants of

9risky behaviour (e.g. cost of protective equipment, social norm) (Feola and Binder, 2010a).

10Consequently, algorithms such as the OHRI or the indicator proposed by Dosemeci et al.

11(2002) would seem more appropriate in assessing human health risk in developing countries

12than POCER. They provide a simple algorithm with limited data requirements and can

13support the identification of the most risky practices in pesticide handling and application.

14However, these indicators might also suffer from a bias towards North American or European

15application techniques, since in OHRI parameter values are partly drawn from UKPOEM

16(UKPOEM, 1992) and in Dosemeci et al. (2002) are mainly drawn from studies in North

17America and Europe. Further research on the validation of such parameter values in these

18algorithms under the pesticide application conditions found in many developing countries is

19needed.

20

21**5. Summary of conclusions**

22This study investigated the appropriateness of seven pesticide risk indicators for use at farm

23level in Less Developed Countries, with particular reference to smallholding agriculture in the

24Colombian Andean region. The comparison of the indicators with regard to the total

25environmental risk suggests that simple indicators not relying on an exposure-toxicity ratio

approach cannot be used as reliable proxies for more complex ones, i.e. indicators based on an exposure-toxicity ratio approach. The choice of the indicator to be used for a single environmental compartment is likely to depend on specific research, management or policy needs, on the availability of data and other necessary resources, and on an accurate analysis of the characteristics of the various indicators. ETR indicators, such as EPRIP show a comparative advantage over non-ETR in best combining the need for a relatively simple tool to be used in contexts of limited data availability and resources, such as those usually characterizing Less Developed Countries, and that of a reliable estimation of environmental risk. Indicators not based on an exposure-toxicity ratio approach such as PestScreen remain useful and accessible tools for discriminating between different pesticides prior to application. Concerning the human health risk, simple algorithms such as the OHRI or that proposed by Dosemeci et al. (2002) seem more appropriate than complex ones in assessing human health risk in Less Developed Countries. This study also pointed out the need for further research on health risk indicators and their validation under the conditions encountered in Less Developed Countries.

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Suitability of pesticide risk indicators for Less Developed Countries: A comparison

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Supplementary data

A - Short description of the indicators

EIQ

The Environmental Impact Quotient (EIQ) (Kovach et al., 1992) estimates the environmental impact of a pesticide by aggregating the hazard posed to farm workers, consumers and the local environment in one score. Each of these three components in the equation is given equal weight, but within each component, factors are given a different weighting (1, 3 or 5) in order to represent their importance. Similarly, toxicological data, which are drawn from different sources and databases, are normalized into a three level scale depending on their danger, i.e. 1 for low, 3 for medium and 5 for high toxicity.

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

Where: DT = dermal toxicity; C = chronic toxicity; SY= systemicity; F = fish toxicity; L = leaching potential; R = surface loss potential; D = bird toxicity; S = soil half-life; Z = bee toxicity; B = beneficial arthropod toxicity; P = plant surface half-life.

An EIQ field use rating (FUR) allows the EIQ to be calculated for pest control strategies (equation 2).

$$EIQ (FUR) = EIQ \times (\% \text{ active ingredient}) \times \text{rate}$$

PestScreen

1PestScreen was developed as a screening tool to provide a relative assessment of pesticide
2hazards to human health and the environment (Juraske et al., 2007). The indicator provides a
3ranking approach, which not only includes data on toxic effects and bioaccumulation, but also
4on persistence and mobility of pesticides in the environmental compartments. The indicator
5provides a simple categorical distinction between pesticides as a function of application dose,
6and three hazard categories, i.e. fate, exposure and toxicity.

7

8        $PestScore = D* [(\sum F_{i=2} /2) + E_{i=1} + (\sum T_{i=4} /4)]$

9

10Where: D = application dose; $\sum F_{i=2}$ is the sum of overall persistence and long-range transport
11potential; E is the intake fraction; $\sum T_{i=4}$ is the sum of toxicity for rats, bees, fish and humans.

12Each hazard category is given the same weight, and is scored on a 1 to 4 scale, i.e, low to very
13high concern. The hazard category's sub-scores are calculated using physical and chemical
14properties and cut-off criteria.

15

16POCER

17The pesticide occupational and environmental risk indicator (POCER) was developed by
18Vercruysse and Steurbaut (2002). It consists of ten modules covering both human health and
19environmental risk, which are based on the modules of Directive 91/414/EC (CEC, 1994) for
20the evaluation and acceptance of plant protection products in the European Union. A risk
21index is calculated for each module as the quotient of the estimated human exposure of the
22predicted environmental concentration and a toxicological reference value. The latter are
23endpoints defined by the Annex VI of the Directive 91/414/EC (CEC, 1994). For example, the
24risk index for the worker is calculated as

25

26        $RI_{worker} = DE \times Ab_{DE}/ AOEL$

27

28Where DE is the dermal exposure (mg/person/day), Ab_{DE} is the dermal absorption factor
29(fraction), and the AOEL is the Acceptable Operator Exposure Limit (mg/kg body
30weight/day).

31The ten risk indices are aggregated into a total risk indicator by transforming each index into a
32value ranging from 0 to 1. In order to do that, a lower and an upper limit have to be
33established for the ten risk indices. The risk of a pesticide to the different components
34depends on the extent to which the lower limit is exceeded. Finally, the total risk of a
35pesticide is calculated by summing the values of the ten components (i.e. assuming equal
36weight).

37

38

39

40EPRIP

41The Environmental Potential Risk Indicator for Pesticide (EPRIP) was first developed by
42Padovani et al. (2004) and then updated by Trevisan et al. (2009) to improve the indicator,

1and in particular its applicability to different weather conditions. EPRIP is based on an ETR
2approach, by using the predicted environmental concentration estimated at local scale divided
3by short-term toxicological parameters (i.e. LD_{50}, NOEL). The ETR values are then
4normalized into risk points (RP) using a scale ranging from 1 to 5, where 1 represents no risk
5and 5 represents very large risk. Finally, to obtain the overall EPRIP score, the RP values for
6the different compartments are multiplied as follows:

7

8        $EPRIP = RP_{gw} \times RP_{sw} \times RP_s \times RP_a + 25 \times N4 + 50 \times N5$

9

10Where RP_{gw} is the risk point for groundwater, RP_{sw} is the highest risk point among six different
11values for surface water, RP_s is the risk point for soil, RP_a is the risk point for air, N4 is the
12number of RP values equal to 4 and N5 is the number of RP values equal to 5.

13

14**PIRI**

15The Pesticide Impact Rating Index (PIRI) (Kookana et al., 2005) assesses the off-site
16migration potential of pesticides and risk of surface and groundwater contamination. PIRI
17makes use of an exposure-toxicity ratio approach and is based on an ad hoc developed
18software package. The risk assessment is based on pesticide use; the pathway through which
19the pesticides are released to the water resources (drift, runoff, erosion, leaching) and the
20value of the water resources threatened. Each component is quantified using pesticide
21characteristics (e.g. toxicity to organisms at different trophic levels, i.e. fish, daphnia, algae),
22environmental and site conditions (e.g. organic carbon content of soil, water input, slope of
23land, soil loss, recharge rate, depth of water table).
24

25**OHRI**

26The Operator Health Risk Indicator (OHRI) (Bergkvist, 2004) provides a measure of risk to
27the pesticide operator. It combines data on hazard and exposure and combines them with data
28on intensity of pesticide use. The toxicity values were drawn from the EU risk phrases defined
29in Annex II of the EU Directive 67/548/EEC as amended by the EU Directive 2001/59/EC
30and scored by the authors. The protective factors of different pieces of personal protective
31equipment, used to calculate the indicator's value, are drawn mainly from the UKPOEM
32(1992).

33

34   OHRI = AT x OT x FT x AMO x PMO

35

36Where: AT = area treated; OT = operator toxicity; FT = formulation type; AMO = application
37method; PMO = use of personal protective equipment.

38

39**Dosemeci et al. (2002)**

40Dosemeci et al. (2002) developed a quantitative method for estimating the intensity of
41exposure to pesticides in the agricultural sector. The algorithms developed, i.e. a detailed and
42a general one, consider different factors which contribute to the exposure of the operator to

1

1pesticides. The exposure scores assigned to each factor are mainly derived from empirical
2studies in the scientific literature.

3

4   Intensity level = [(*Mix* x *Enclosed*) + (*Appl* x *Cab*) + *Repair* + *Wash*] x *PPE* x
5   *Repl* x *Hyg* x *Spill*

7Where: *Mix* is a score for the method of pesticide mixing; *Enclosed* is a score for whether or
8not an enclosed mixing system is used; *Appl* is a score related to the application method; *Cab*
9refers to whether or not a tractor with enclosed cab and/or charcoal filter is used; Repair is a
10score for the status of maintenance of the equipment; *Wash* is a score for the practice of
11washing the equipment after pesticide application; *Repl* is a score for the rate of replacement
12of old protective gloves; *Hyg* is a score for the practices of personal hygiene; *Spill* is a score
13for whether or not clothes are changed after a spill.

14

15

1
1B- Overview of data requirements

2
3Table 7. Data used to calculate the indicators

Data	Indicators*						
	EIQ	Pest Screen	POCER	EPRIP	PIRI	OHRI	Dosemeci et al. (2002)
PESTICIDE APPLICATION							
Application method			*			*	*
Application rate	*	*	*	*	*		
Duration of re-entry			*				
Exposure area for bystanders			*				
Frequency of application	*	*	*	*	*		
Inhalation exposure for the applicator			*				
Minimum number of days from application of pesticides to first rainfall/irrigation					*		
Parcel area			*	*	*	*	
Parcel perimeter				*			
Safety practices (washing, changing clothes, etc.)							*
Use of personal protective equipment			*			*	*
Transfer factor for re-entry			*				
Width of buffer zone					*		
Work rate (ha/h)			*				
PESTICIDE PROPERTIES							
Henry constant				*			
k_{oc}				*	*		
Long range transport potential		*					
Mode of action	*						
Molecular weight				*			
Overall persistence		*					
Pesticide composition (active ingredients)	*	*	*	*	*		
Pesticide formulation (liquid/powder)			*			*	
Pesticide half-life in soil	*		*	*	*		
Pesticide solubility in water				*			
Plant surface residue half-life	*						
Vapour pressure				*			
TOXICITY							
Acceptable daily intake (ADI)		*					
Acceptable operator exposure limit (AOEL)			*				
EC_{50} algae			*	*	*		
EC_{50} daphnia			*	*	*		
LC_{50} earthworms			*	*			
LC_{50} fish	*	*	*	*	*		
LC_{50} rabbit/rat	*						
LD_{50} bees		*	*				
LD_{50} birds			*				
LD_{50} rat		*		*			
Long-term health effects	*						
Operator toxicity						*	
Toxicity to bees	*						
Toxicity to beneficial arthropods	*		*				
Toxicity to birds	*						

4
5
6
7

1

Table 7 (continued). Data used to calculate the indicators

Data	Indicators*						
	EIQ	PestScreen	POCER	EPRIP	PIRI	OHRI	Dosemeci et al. (2002)
SOIL							
Bulk density of soil			*	*			
Estimated average soil loss during period of interest					*		
Slope of land to water body				*	*		
Soil depth			*				
Soil moisture					*		
Soil organic carbon content				*	*		
Soil type				*	*		
WATER BODIES							
Annual recharge rate				*			
Depth of nearest water body			*	*			
Depth of water table				*	*		
Diameter of nearest water body					*		
Distance from edge of crop to water body				*	*		
Groundwater and runoff potential	*						
Recharge rate during period of interest					*		
Water table thickness				*			
Width of nearest water body			*	*			
METEOROLOGICAL CONDITIONS							
Average maximum air temperature during period of interest					*		
Maximum daily rain				*			
Mean annual precipitation				*			
Mean annual temperature				*			
Total rainfall during period of interest					*		
OTHER DATA							
Body weight of birds			*				
Body weight of bystanders			*				
Crop interception factor			*	*			
Daily food intake by birds			*				
Dermal absorption factor			*				
Drift			*				
Drinking water standard				*			
Intake fraction		*					
Leaf area index			*				
Total irrigation during period of interest					*		

* An asterisk indicates that the data was used in calculating the respective indicator.

The specific values used to calculate the indicators, as well as sources and assumptions made, are to be found in Rahn, E., 2010. Environmental and health risk indicators to assess pesticide use. A comparison of different indicators for the case of potato production in La Hoya, Colombia. Master thesis, Department of Geography, University of Zurich, Switzerland.

C – Criteria for the comparison based on key indicator characteristics

Table 8. Criteria for the comparison based on key indicator characteristics and corresponding scores.

Criteria	Scores	*	**	***
User friendliness	Data availability	Not available (additional assumptions needed)	Available for some pesticides	Easily available
	Calculation procedure	Calculation procedure knowledge-intensive and time-consuming	Calculation procedure either knowledge intensive or time-consuming	Calculation procedure neither knowledge intensive nor time-consuming
	Score interpretation	Relative comparison (ranking)	Risk classes given when single applications are considered	Risk classes given both when single applications and control strategy are considered
Ability to represent the specific system under study	Site specific data	No site specific data used	-	Site specific data used
	Compartments considered (environment)	One-two compartments	Three compartments	Four-Five compartments
	Compartments considered (health)	One compartment	Two compartments	Three compartments

D - Additional tables

Table 9. Correlation between rankings of the 581 pesticide applications for risk to soil (Spearman correlation test)

	EPRIP	POCER	Application rate
EPRIP	1.00		
POCER	0.82 **	1.00	
Application rate	0.07	0.42 **	1.00

* p > 0.05; ** p > 0.01

Table 10. Correlation between rankings of the 72 control strategies for risk to soil (Spearman correlation test)

	EPRIP	POCER	Application rate
EPRIP	1.00		
POCER	0.38 **	1.00	
Application rate	0.14	0.32 **	1.00

* p > 0.05; ** p > 0.01

Table 11. Correlation between rankings of the 581 pesticide applications for risk to beneficial arthropods (Spearman correlation test)

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	-0.50 **	1.00	
Application rate	0.98 **	-	1.00

1 * p > 0.05; ** p > 0.01

2

3 **Table 12. Correlation between rankings of the 72 control strategies for risk to beneficial arthropods**
4 **(Spearman correlation test)**

	EIQ	POCER	Application rate
EIQ	1,00		
POCER	0,09	1,00	
Application rate	0,99 **	0,09	1,00

5 * p > 0.05; ** p > 0.01

6

7 **Table 13. Correlation between rankings of the 581 pesticide applications for risk to birds (Spearman**
8 **correlation test)**

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.43 **	1.00	
Application rate	0.94 **	0.25 **	1.00

9 * p > 0.05; ** p > 0.01

10

11 **Table 14. Correlation between rankings of the 72 control strategies for risk to birds (Spearman**
12 **correlation test)**

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.35 **	1.00	
Application rate	0.96 **	0.28 *	1.00

13 * p > 0.05; ** p > 0.01

14

15 **Table 15. Correlation between rankings of the 581 pesticide applications for risk to bees (Spearman**
16 **correlation test)**

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.05	1.00	
Application rate	0.96 **	0.90 *	1.00

17 * p > 0.05; ** p > 0.01

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23 **Table 16. Correlation between rankings of the 72 control strategies for risk to bees (Spearman correlation**
24 **test)**

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	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.43 **	1.00	
Application rate	0.97 **	0.34 **	1.00

1 * $p > 0.05$; ** $p > 0.01$

2

3 **Table 17. Correlation between rankings of the 581 pesticide applications for risk to farm worker**
4 **(Spearman correlation test)**

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.56 **	1.00	
Application rate	0.91 **	0.51 **	1.00

5 * $p > 0.05$; ** $p > 0.01$

6

7 **Table 18. Correlation between rankings of the 72 control strategies for risk to farm worker (Spearman**
8 **correlation test)**

	EIQ	POCER	Application rate
EIQ	1.00		
POCER	0.49 **	1.00	
Application rate	0.97 **	0.46 **	1.00

9 * $p > 0.05$; ** $p > 0.01$

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