



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

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## ABSTRACT

Pesticide risk indicators provide simple support in the assessment of environmental and health risks from pesticide use, and can therefore inform policies to foster a sustainable interaction of agriculture with the environment. For their relative simplicity, indicators may be particularly useful under conditions of limited data availability and resources, such as in Less Developed Countries (LDCs). However, indicator complexity can vary significantly, in particular between those that rely on an exposure–toxicity ratio (ETR) and those that do not. In addition, pesticide risk indicators are usually developed for Western contexts, which might cause incorrect estimation in LDCs. This study investigated the appropriateness of seven pesticide risk indicators for use in LDCs, with reference to smallholding agriculture in Colombia. Seven farm-level indicators, among which 3 relied on an ETR (POCER, EPRIP, PIRI) and 4 on a non-ETR approach (EIQ, PestScreen, OHRI, Dosemeci et al., 2002), were calculated and then compared by means of the Spearman rank correlation test. Indicators were also compared with respect to key indicator characteristics, i.e. user friendliness and ability to represent the system under study. The comparison of the indicators in terms of the total environmental risk suggests that the indicators not relying on an ETR approach cannot be used as a reliable proxy for more complex, i.e. ETR, indicators. ETR indicators, when user-friendly, 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, and for a reliable estimation of environmental risk. Non-ETR indicators remain useful and accessible tools to discriminate between different pesticides prior to application. Concerning the human health risk, simple algorithms seem more appropriate for assessing human health risk in LDCs. However, further research on health risk indicators and their validation under LDC conditions is needed.

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## 1. Introduction

Pesticide risk indicators can support the assessment of environmental and health risks from pesticide use. They can be utilized by different kinds of users, such as farmers, extension agents, policy-makers, regulatory agencies and academia (Levitan, 2000). They serve as a basis for the evaluation of different pest management strategies (Levitan, 2000; Greitens and Day, 2007), and for the development, monitoring and assessment of environmental and health policies (Levitan, 2000; Maud et al., 2001; Falconer, 2002; Finizio and Villa, 2002). Thus, pesticide risk indicators can signal risky agricultural practices and inform interventions and policies to foster a sustainable interaction of agriculture with the environment on which agriculture itself relies. The contribution of pesticide risk

indicators, and more in general of sustainability indicators, in helping minimising the impact of agriculture on the environment has been recognized not only in academia, but also in the policy arena, which has often taken a proactive role in stimulating research on sustainability indicators in agriculture (e.g. CEC, 1999; OECD, 1999, 2001).

Simplicity is a generally acknowledged feature of indicators. This often makes them acceptable, usable even with scarce data, quick to calculate and easy to communicate, although at the expense of a more realistic representation of pesticide impacts (Van der Werf, 1996; Castoldi et al., 2007). In this regard, indicator-based assessment methods gain a comparative advantage over alternative assessment systems, such as direct measurements or simulation modelling, which instead require more qualified expertise, economic resources and data which might not always be available.

However, the level of complexity of pesticide risk indicators can also vary significantly. Two broad typologies of indicators can be identified (Reus et al., 2002). The first includes user friendly assessment tools, usually with few input data requirements, and

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**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)						*				*

a scoring table based on rather simple algorithms which are often constructed on the basis of expert judgement. These indicators usually score pesticide properties first, which are then multiplied by the application rate. Finally, the scores are aggregated by summation. The second typology includes indicators using a risk-ratio, or exposure–toxicity ratio (ETR) approach, i.e. “the ratio between exposure (usually the concentration in a certain environmental compartment) and toxicity for relevant organisms” (Reus et al., 2002). These indicators are considered to better represent and quantify environmental risks from pesticide use, but have the drawbacks of requiring more detailed input data and the support of computer modelling (Reus et al., 2002; Castoldi et al., 2007). These indicators use the application rate to calculate pesticide concentrations, which are then scored by environmental compartment. The compartment scores can then be integrated by summation or by multiplication. Thus, from a mathematical perspective, the most significant difference between ETR and non-ETR indicators is how the application rate is included in the risk estimation.

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

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

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

that the applicability of health risk indicators in LDCs might be limited, and call for the need for contextualizing pesticide risk, e.g. to understand the determinants of exposure more than to quantify levels of risk (Blanco et al., 2005).

Consequently, it is not clear what indicators might be more appropriate to assess environmental and health risks from pesticide use, and thus properly inform agricultural management, under pesticide application practices typical of LDCs. The objective of this study was to investigate the appropriateness of seven pesticide risk indicators for use at farm level in LDCs, with particular reference to smallholding agriculture in the Colombian Andean region. With reference to this area, two research questions drove the study:

- Can simple pesticide risk indicators be used as proxies for more complex ones, thus facilitating the task of risk assessment?
- What is the most appropriate indicator to assess pesticide risk to human health and the environment?

The paper is structured as follows. Firstly, a short description of the indicators selected, study area, data used and comparative procedure adopted are provided. Secondly, the results are presented separately for environmental and human health risk indicators. Finally, results are discussed with reference to the two research questions, and conclusions on the use of pesticide risk indicators in the context of LDCs are drawn.

## 2. Method

### 2.1. Indicators

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

#### 2.1.1. Coverage of environmental and health compartments

Three indicators, i.e. PestScreen (Juraskie et al., 2007), EPRIP (Padovani et al., 2004; Trevisan et al., 2009), and PIRI (Kookana et al., 2005), focus exclusively on environmental risks, whereby risk to consumer health is implicitly and partly included, since drinking water contamination and ingestion of contaminated food are part of the environmental risk assessment. Two indicators, i.e. OHRI (Bergkvist, 2004) and the indicator developed by Dosemeci et al. (2002), focus solely on occupational health risk, whereby only the pesticide operator is considered. The remaining two indicators, i.e. EIQ (Kovach et al., 1992) and POCER (Vercruysse and Steurbaut, 2002), include an environmental risk component and an occupational health risk component, whereby both assess the risk to agricultural workers in addition to pesticide operators and

POCER also considers bystanders' risk to pesticide exposure (a short description of the indicators is given in [Supplementary data](#)).

### 2.1.2. Representation of ETR and non-ETR indicators

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

### 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, 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.

## 2.2. Data

### 2.2.1. Data and study area

The data necessary to calculate the indicator rankings were mainly derived from an existing georeferenced dataset produced in a previous study in the *vereda* (community) called La Hoya, located in the Department of Boyacá, in the eastern chain of the Colombian Andes ([Feola, 2010a](#)). For many aspects such as pesticide application technique or socio-demographic structure, this study area may be considered typical of the broader Andean region ([Feola, 2010a](#)) and very similar to other rural areas in LDCs ([Matthews, 2008](#)).

Vereda La Hoya ranges from 2700 to 3250 masl over an area of 8.4 km<sup>2</sup> (840 ha), and has a population of about 750 inhabitants. It is a rural region mainly dedicated to the cultivation of potato ([MADR, 2006](#)). The production of potato in Vereda La Hoya relies mainly on smallholders, who cultivate an average of 3 hectares subdivided into different plots. The land is cultivated in two cycles a year (September–February and March–August). Average productivity rates range between 15 and 17 ton/ha ([MADR, 2006](#)). Potato crops in this region are vulnerable to three major pests: the soil-dwelling larvae of the Andean weevil (*Premnotrypes vorax*), the late blight fungus (*Phytophthora infestans*) and the Guatemalan potato moth (*Tecia solanivora*). To protect the crop from these pests, the use of chemical pesticides, in particular insecticides and fungicides, is widespread among smallholders ([Feola and Binder, 2010b](#)). The most common way of applying pesticide is by means of a lever-operated knapsack sprayer (20–25 L), which is filled from a bigger tank, usually of about 200 L, where the pesticide mix is prepared.

Also as a result of the misuse of personal protective equipment (PPE), high levels of pesticide-related health risk have been

observed in the region ([Cardenas et al., 2005](#); [Ospina et al., 2008](#); [Feola, 2010b](#)). Regarding adverse environmental effects, both [Schoell and Binder \(2009\)](#) and [Feola and Binder \(2010b\)](#) reported that farmers in Vereda La Hoya observed a pesticide-related reduction of soil biodiversity in recent years. Finally, pesticide overuse has attracted the concern of governmental agencies because of its economic drawbacks ([MADR, 2004](#)). In this respect, [Feola and Binder \(2010b\)](#), showed that some of the farmers tend to use pesticides ineffectively, with a persistent overuse.

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

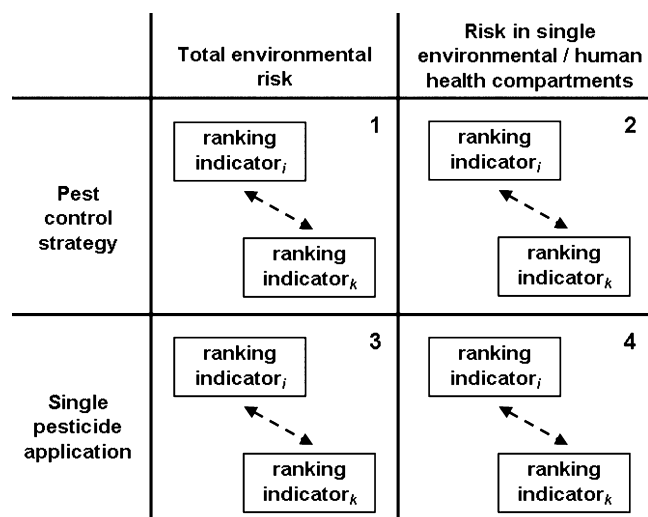
### 2.2.2. Additional data

Additional data necessary to calculate the indicators was gathered from various sources. Pesticide properties were obtained through the Pesticide Properties Database (PPDB, 2009). Climatic data, such as precipitation and temperature (for the years 1994–2003), were obtained from the Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia. For the reference period the temperature was between an average minimum of 5.7 °C and an average maximum of 20 °C. Total annual precipitation in the reference period was 343.5 mm. For soil parameters, the classification of "clay loam" was used ([Binder and Patzel, 2001](#)). According to [Leuenberger \(2005\)](#) average organic carbon content in the study area was 6.4%. Mean bulk density was assumed to be 0.9 tons per m<sup>3</sup> according to [Binder and Patzel \(2001\)](#). Soil loss was adapted from [Binder and Patzel \(2001\)](#) and assumed to be 9.6 tons per hectare and year. The distance of the plot to water bodies was calculated with the software ESRI ArcGIS 9.3. An overview of the data used to calculate the indicators is available in [Supplementary data](#).

## 2.3. Procedure

The study consisted of three phases. First, the indicator values were calculated for the pest control strategy and for single pesticide applications. A pest control strategy is defined for each of the 72 farmers as the total amount of pesticide applied by active ingredient (examples of pesticide application patterns and strategies can be found in [Feola and Binder, 2010b](#), and [Juraske et al., 2011](#)). For EIQ and EPRIP, the number, frequency and sequence of applications also contributes in differentiating among pest control strategies, since they propose how to calculate the cumulative risk which occurs when several applications of different active ingredients are used within the same pest control strategy. Concerning the single pesticide applications, the 72 farmers applied pesticides a total of 1772 times to their fields during the agricultural cycle considered. These applications were aggregated by summing up all applications of a particular pesticide during each of the five production phases (i.e. sowing of the potato, emergence of the shoot, weeding, earthing up, and maintenance). For example, if a farmer applied carbofuran four times with varying application rates during the emergence of the potato shoot, the indicator values were calculated for all four applications taken together. Accordingly, the amount of applications analysed decreased to 581. In sum, 72 pest control strategies, i.e. each strategy consisting of all applications for each single farmer, and 581 pesticide applications, were considered.

Second, the indicator rankings were compared by means of the Spearman rank correlation test, in accordance with [Maud et al. \(2001\)](#) and [Reus et al. \(2002\)](#), and using the software PASW Statistics 18.0. Not only were the indicators compared with respect to



**Fig. 1.** Comparative analysis of the indicator rankings. The subscripts *i* and *k* indicate indicators among the ones compared in the study.

their overall outcome (Fig. 1, quadrant 1), but also every individual environmental and health risk component that the indicators have in common (Table 1) was compared separately (Fig. 1, quadrant 2). Furthermore, the indicators were compared with regard to both the 518 pesticide applications and the 72 control strategies (Fig. 1, quadrants 3 and 4). Since only EIQ and EPRIP propose how to calculate the cumulative risk accruing when several applications of different active ingredients are used within the same pest control strategy, the other indicator's values for the pest control strategies were simply summed up from those of the single applications, as proposed by Kovach et al. (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 (Fig. 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 cov-

**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				
	<i>1.00</i>				
PestScreen	0.96**	1.00			
	<i>0.99**</i>	<i>1.00</i>			
POCER	−0.08*	−0.18**	1.00		
	<i>0.18</i>	<i>0.20</i>	<i>1.00</i>		
EPRIP	0.12**	0.02	0.74**	1.00	
	<i>0.05</i>	<i>0.07</i>	<i>0.34**</i>	<i>1.00</i>	
Application rate	0.96**	0.98**	−0.27**	−0.03	1.00
	<i>0.98**</i>		<i>0.12</i>	<i>1.00</i>	<i>1.00</i>

\*  $p > 0.01$ .

**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	POCER	EPRIP	PIRI	Application rate
EIQ	1.00				
	<i>1.00</i>				
POCER	0.45**	1.00			
	<i>0.51**</i>	<i>1.00</i>			
EPRIP	0.18**	0.74**	1.00		
	<i>0.13</i>	<i>0.61**</i>	<i>1.00</i>		
PIRI	0.40**	0.64**	0.43**	1.00	
	<i>0.58**</i>	<i>0.70**</i>	<i>0.31**</i>	<i>1.00</i>	
Application rate	0.86**	0.34**	0.04	0.33**	1.00
	<i>0.94**</i>	<i>0.38**</i>	<i>0.30</i>	<i>0.49**</i>	<i>1.00</i>

\*  $p > 0.05$ .

\*\*  $p > 0.01$ .

erage 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 Supplementary data).

### 3. Results

#### 3.1. Comparison of indicators based on rankings: environmental risk

##### 3.1.1. Total environmental risk

Four indicators aggregate the risk to the different environmental compartments into an overall risk value, namely EIQ, PestScreen, POCER and EPRIP. The highest and significant correlations between rankings were those between EIQ and PestScreen (both non-ETR) and between POCER and EPRIP (both ETR). The latter decreased when control strategy instead of single applications was considered, while all other correlations increased. EIQ and PestScreen showed a high correlation with the application rate (Table 2).

##### 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).

##### 3.1.3. Risk to soil and beneficial arthropods, birds and bees

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

The risks to beneficial arthropods, birds and bees are each ranked by EIQ and POCER. Significant correlations (at 0.01 level) between the two rankings were observed for the risk to birds, both when single applications and control strategy are considered (Spearman correlation test 0.43 and 0.35 respectively). Regarding the risk to bees, the two rankings correlated significantly (at



**Table 4**

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

	EQ	EPRIP	PIRI	Application rate
EQ	1.00			
	<i>1.00</i>			
EPRIP	0.10 <sup>*</sup>	1.00		
	<i>0.13</i>	<i>1.00</i>		
PIRI	0.50 <sup>**</sup>	0.79 <sup>**</sup>	1.00	
	<i>0.27<sup>*</sup></i>	<i>0.32<sup>*</sup></i>	<i>1.00</i>	
Application rate	0.94 <sup>**</sup>	−0.08 <sup>*</sup>	0.34 <sup>**</sup>	1.00
	<i>0.98<sup>**</sup></i>	<i>0.07</i>	<i>0.25<sup>*</sup></i>	<i>1.00</i>

<sup>\*</sup>  $p > 0.05$ .

<sup>\*\*</sup>  $p > 0.01$ .

0.01 level) only when the control strategy was considered (Spearman correlation test 0.43). Concerning risk to beneficial arthropods, the two rankings were significantly, but negatively, correlated (Spearman correlation test −0.5) when single applications were considered. Finally, for all three compartments, and for both control strategy and single applications, EQ always correlated significantly at 0.01 level and very strongly (Spearman correlation tests  $> 0.94$ ) with the application rate (tables showing the correlations for these three compartments are given in [Supplementary data](#)).

### 3.2. Comparison of indicators based on rankings: health risk

Four indicators rank the risk to the pesticide operator, namely EQ, 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 EQ 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 EQ and POCER, both of which also significantly and strongly correlate with the application rate ([Table 5](#)).

Two indicators rank the risk for farm workers, namely EQ 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 [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 [Supplementary data](#)).

#### 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 EQ 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

**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).

	EQ	POCER	OHRI	Dosemeci et al. (2002)	Application rate
EQ	1.00				
	<i>1.00</i>				
POCER	0.56 <sup>**</sup>	1.00			
	<i>0.44<sup>**</sup></i>	<i>1.00</i>			
OHRI	0.52 <sup>**</sup>	0.17 <sup>**</sup>	1.00		
	<i>0.18</i>	<i>0.24<sup>**</sup></i>	<i>1.00</i>		
Dosemeci et al. (2002)	–	–	–	–	
	<i>0.02</i>	<i>0.24<sup>*</sup></i>	<i>0.04</i>	<i>1.00</i>	
Application rate	0.91 <sup>**</sup>	0.51 <sup>**</sup>	–	–	1.00
	<i>0.97<sup>**</sup></i>	<i>0.43<sup>**</sup></i>	–	–	<i>1.00</i>

<sup>\*</sup>  $p > 0.05$ .

<sup>\*\*</sup>  $p > 0.01$ .

**Table 6**

Comparison based on key indicator characteristics of the selected indicators.

	User friendliness			Ability to represent the system under study	
	Data availability	Calculation procedure	Score interpretation	Site specific data	Compartments considered
Environment					
EQ	**	***	*	*	**
PestScreen	**	***	**	*	***
POCER	**	*	**	***	***
EPRIP	**	**	***	***	***
PIRI	**	**	***	***	*
Health					
EQ	**	***	*	–	***
POCER	*	*	**	–	***
OHRI	**	***	*	–	*
Dosemeci et al. (2002)	***	***	*	–	*

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.

EQ 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 health modules, needs a higher level understanding of the model used and tends to require a significant amount of time for the calculations.

All indicators except EQ provide thresholds on which basis pesticide risk classes can be identified, but only EPRIP and PIRI provide such thresholds for both the risk associated with single pesticide applications and for the control strategies. However, PIRI is less transparent than EPRIP on the value at which such thresholds are set.

### 3.3.2. Ability to represent the system

EQ and PestScreen do not make use of site specific information, while POCER, EPRIP and PIRI do, thus providing a more appropriate representation of the specific system under analysis. The indicators also differ in terms of environmental compartments considered, and therefore on their ability to produce a comprehensive overview of risk in the environmental system, with PestScreen, POCER and EPRIP covering the most compartments. Concerning health risk, OHRI and the indicator proposed by Dosemeci et al. (2002) are limited to the occupational health of the farm worker.

## 4. Discussion

### 4.1. Simple versus complex indicators

Comparison of the indicators with regard to the total environmental risk suggests that simple indicators not relying on an ETR approach cannot be used as a reliable proxy for more complex indicators, i.e., those relying on an ETR approach. In effect, the values of the former (i.e. EQ, PestScreen) tended to correlate weakly with those of the latter (i.e. EPRIP, POCER and PIRI) when the total environmental risk was considered (Table 2). When single compartments were considered, the correlation between the indicator rankings was stronger, which 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 2–4 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 EQ, 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 (data not shown). 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 Juraskie 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 EQ 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 EQ 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, 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 EQ 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 human exposure to pesticide during pesticide application and other operations, it might be preferable to avoid using indicators based on exposure models. In addition, these models are usually developed under European conditions, while it has been shown that in developing countries such as the study area, pesticide application techniques and chemicals used might differ extensively from those conditions (Feola and Binder, 2010a,b). In fact, following Blanco et al. (2005), it might be less important to accurately quantify the exposure of farmers to pesticides than to understand the determinants of exposure, both in terms of risk factors (e.g. misuse of personal protective equipment, hygiene habits) and of determinants of risky behaviour (e.g. cost of protective equipment, social norm) (Feola and Binder, 2010a). Consequently, algorithms such as the OHRI or the indicator proposed by Dosemeci et al. (2002) would seem more appropriate in assessing human health risk in developing countries than POCER. They provide a simple algorithm with limited data requirements and can support the identification of the most risky practices in pesticide handling and application. However, these indicators might also suffer from a bias towards North American or European application techniques, since in OHRI parameter values are partly drawn from UKPOEM (1992) and in Dosemeci et al. (2002) are mainly drawn from studies in North America and Europe. Further research on the validation of such parameter values in these algorithms under the pesticide application conditions found in many developing countries is needed.

## 5. Summary of conclusions

This study investigated the appropriateness of seven pesticide risk indicators for use at farm level in Less Developed Countries, with particular reference to smallholding agriculture in the Colombian Andean region. The comparison of the indicators with regard to the total environmental 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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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.agee.2011.05.014.

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