Comparative agroenvironmental risks of pesticides in different cropping systems: application of the I-Phy indicator

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COMPARATIVE AGROENVIRONMENTAL RISKS OF PESTICIDES IN DIFFERENT CROPPING SYSTEMS: APPLICATION OF THE I-PHY INDICATOR

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Abstract:

Agricultural activities are responsible for causing impacts to the environment depending on the practices adopted during the production process. In order to access the risks of those practices, measurement tools are necessary. This paper concerns the empirical application of the environment assessment indicator I-Phy, an indicator measuring the risks of pesticide usage in agriculture. Five crops in two different climate regions were assessed, a tropical and a temperate, and three different cropping systems: no-tillage, minimal tillage and conventional tillage. No-tillage generally presented risks of environmental pollution slightly lower in both regions. High environmental vulnerability of the fields and the numerous applications of active substances with high risks exhibit high risks of general contamination. The I-Phy indicator can be useful as a support tool to farmers and research and extension institutions pursuing management practices with lower impact on the environment.

Key Words: pesticide indicator, environmental assessment, no tillage, I-Phy

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1. INTRODUCTION

Environmental assessment methods are needed to reconcile high performance of cropping systems with the demand for more sustainable farming practices (Thiollet-Scholtus and Bockstaller 2015). Impacts from agricultural activities are usually associated with pesticide use, both in tropical and temperate regions.

Pesticide use in a cropping system may result in surface- and groundwater contamination, air pollution, and accumulation in soils. Cropping system, soil type, relief, rainfall, and slope shape and length, all may affect prediction of transported particle size distribution (Flanagan and Nearing 2000). Tillage and other agricultural practices can determine runoff volume and subsurface drainage (Boyd et al. 2003); (Xie, Chen, and Shen 2015), and consequently affect the amount of nutrients and pesticides leached from agricultural fields, thus affecting their environmental risks and impacts.

Brazil has become the largest consumer of pesticides worldwide, with a great spectrum of active ingredients and chemical groups, gaps on the legislation regulating pesticide, lack of training and pressure of industry in many ways (Pedlowski et al., 2012). The impact of pesticides are well documented in Brazil, including cases of suicide (Krawczyk et al., 2014), changes in immune and endocrine markers (Raphael et al., 2011), fetal exposure in utero (Ferreira et al., 2013) and cutaneous melanoma (Segatto et al., 2015).

The large impact of pesticide use on agriculture has led to different studies using a range of phytosanitary indicators (Bockstaller et al. 2009). Phytosanitary treatments were compared in many different environmental situations and crop-specific conditions (Roussel, Cavelier, and van der Werf 2000), (Tixier et al. 2007), (Combret et al. 2007), (Hernández-Hernández et al. 2007), (Thiollet-Scholtus and Bockstaller 2015). In such studies, indicators consider differently the environment characteristics, and assign more or less importance to each of them in the impact evaluation.

The impact of an increasing number of pesticides is not simple to access and to express in a comprehensive base. The I-Phy index consider the active ingredient, the characteristics of the plot and the application to identify which practices are generating

the main environmental risks of phytosanitary treatments in different scenarios of crop production.

The I-Phy index has been used in different soil conditions, climates, crops, system arrangements and scales, moreover, the constant improvements is an determining factor to the robustness and applicability of models and indexes. Lindahl and Bockstaller (2012), as example, incorporating a mechanistic approach, that allows to consider preferential flow and calculate the risk to groundwater.

To address those issues, we assessed the environmental impacts of pesticide use in systems with soils managed in conventional system (CS), minimum tillage (MT) and no tillage (NT) in two different regions. The regions assessed were Is-sur-Tille in France, and Ituporanga in Brazil. Those are two important agricultural regions in their respective countries, and they have a long history of pesticide use in different crop systems and the associated environmental impacts. We adopt here the indicator I-Phy (van der Werf and Zimmer 1998) which has been designed for arable crops in France. Adaptations were made to use it in Ituporanga/SC. I-Phy is an indicator belonging to the environmental assessment method INDIGO® (aka IPest).

Our first objective is to apply the indicator I-Phy with modifications in a subtropical environment. Secondly we wish to compare three soil management systems, both having a long history of pesticide use, in two distinct regions.

In the first part of this paper, we give an overview on both regions and their environmental characteristics, and in the second part the methods are presented with a description of the I-Phy indicator. In sequence we present the Results and Discussion of our analysis followed by the conclusions.

2. MATERIALS AND METHODS

3.1   I-Phy

The I- Phy Indicator is based on *fuzzy* logic, which deals with variables that can have heterogeneous nature and limited accuracy associated in a rule-based decision system. This system can be summarized by a decision tree, in which the choice of a variable implies the choice of the next variable, until the last step leads to the final indicator (Bockstaller and Girardin 2008), as shown in Figure 1. This approach allows aggregation of quantitative and qualitative variables, such as characteristics of the active

62 substance, the environment and application conditions. It also considers qualitative loss

63 mechanisms crossed with toxicity. In the construction of the indicator I- Phy (van der

64 Werf and Zimmer 1998), four types of risks are considered: (I) the risk of leaching

65 toward groundwater (RESO), (II) the risk of surface water contamination (RESU), (III)

66 the airborne contamination risk (RAIR) and (IV) the risk of environmental presence

67 (DOSE). The risks are constructed with variables for which a favorable class (low risk)

68 and an unfavorable class (high risk) are defined.

69   3.2   Variables used

70   Each of these four types of risk is expressed on a scale from 0 (highest risk) and

71 10 (minimum risk). To calculate those risks the indicator uses physico-chemical

72 characteristics and toxicity of the molecule, environmental information (slope, soil

73 organic matter, distance from surface water bodies, crop species, etc.), and application

74 mode (date, dose, soil-incorporated or surface application, application on the entire field

75 or on bands, etc.) as summarized in table 2.

76   Table 1: Variables considered in risk calculation for each module of the I-Phy

77 indicator.

Variables	Units or modalities	Dose	Groundwater	Surface water	Air
Variables linked to the active substance					
Half-Life (HL 50)	days			x	x
GUS[1]	-		x		
Henry Constant K_H[2]	-				x
ADI[3]	mg.kg^{-1}		x	x	x
Aquatox[4]	mg.l^{-1}			x	
Variables linked to the environment (plot)					
Leaching potential	between 0 et 1		x		
Drift percentage[5]	%			x	
Runoff potential	between 0 et 1			x	
Variables linked to application conditions					
Application Dose	g ha^{-1}	x			
Application Position	Into or over the soil or over the soil cover (% soil cover)		x	x	x

78 * Adapted from (Werf & Zimmer, 1998). (1) Ground Water Ubiquity Score: index expressing the leaching potential
79 of the active substance. GUS = log 10 (TD50) * (4-log10) (Koc), where Koc is the coefficient of the division organic
80 carbon-water from the molecule. (2) Dimensionless variable determining the risk of volatilization the active
81 substance. (3) Acceptable Daily Intake (human toxicity). (4) Toxicity to wildlife (fish, etc.) and aquatic flora (algae).
82 It uses the highest toxicity for the three groups of aquatic organisms. (5) Expressed in % of active substance spread
83 depending on the distance of the river. It was considered that a risk of drift > 1% is totally acceptable.
84

85   Environment-related risks are measured by estimations related to risk potential of

86 some factors, e.g., soil organic matter content was used to estimate leaching potential.

87 Drift relates to the amount of product that can be found directly in a watercourse (ditch,

88 water well or other water source). Potential for surface runoff is based on slope

89   inclination, since a moderate slope may allow flow, unlike erosion itself, strongly linked

90   to steeper slopes. Soil cover is based on early crop establishment and treatment dates.

91   3.3   Method of calculation I-Phy (adapted from van der Werf and Zimmer

92   (1998) and Bockstaller and Girardin (2008)).

93   The calculation can be performed at different levels depending on the type of

94   information aimed, and done in the following order:

95
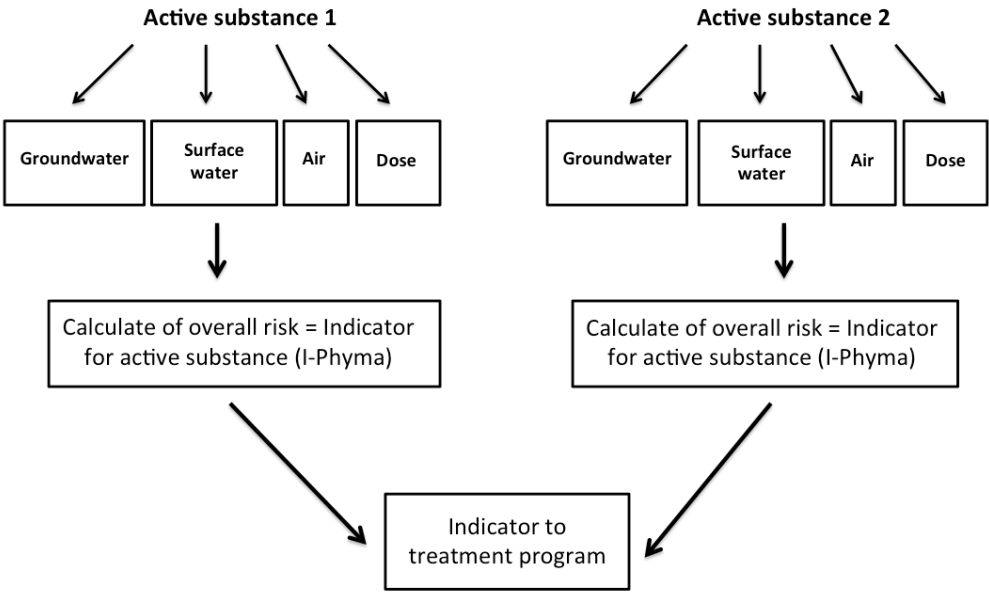
96   Figure 1: Steps of I-Phy indicator determination (adapted from van der Werf and

97   Zimmer, 1998).

98   Step 1: Calculation of a risk per module for each application of a given active

99   substance. It is based on four modules: the environmental compartments of

100   groundwater, surface water, air, and dose-associated risk.

101   Step 2: Calculation of an indicator (Iphysa) for each application of an active

102   substance.

103   The four risks are combined with the same method using *fuzzy* logic (it is neither

104   an addition nor a calculation of the mean) for a global risk rated from 0 (highest risk) to

105   10 (zero risk), depending on the active substance dose.

106   Step 3: Calculation of a global indicator on a program of treatments applied over a

107   crop.

108   The risk linked to a treatment program is due to either a treatment with high risk

109   (estimated by the minimum values of the indicators for each treatment (Iphysa), or to a

110   program including a large number of low-risk treatments, according to equation 1.

111   Equation 1:

$$I - Phy = \min(Iphysa_i) \times \sum Ki \times (10 - Iphysa_i) \div 10 + k_i \times (10 - \min(Iphysa_i) \div 10)$$

112   Where:

113        $Iphysa_i$: indicator for the application of active substance i;

114   k_i weighting coefficient empirically obtained by regression (k = 0,1 to Iphysa =

115   10, k = 0.2 to Iphysa = 7 and k = 1 to Iphysa = 2). It is obtained from equations 2 and 3.

116   Equation 2:

117        $k = 1{,}7175 \times e^{(-0{,}2913 \times Iphysa)}$

118   Equation 3:

119        $\sum ki \times (10 - \min Iphysa_i) \div 10)$, that represents the sum of the weighted risks

120   less the minimum value Iphysa.

121   Figure 2 shows the decision rules for calculation of overall risk.

122   For each figure, the white boxes represent the cases in which the variable is

123   favorable and dark boxes represent cases in which the variable is unfavorable.
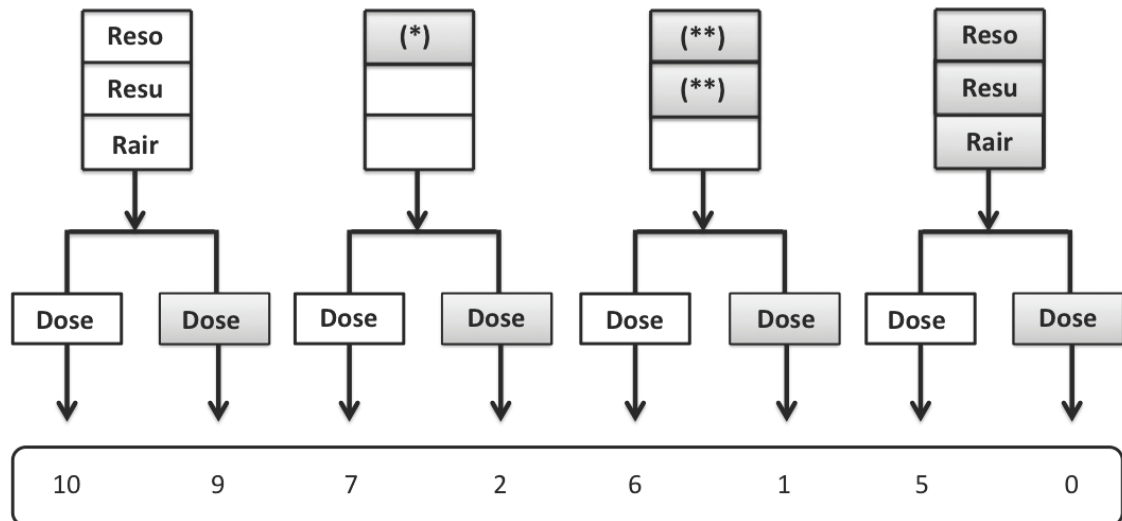
(*) - One of the three modules Reso, Resu, Rair takes an unfavorable value (= 0)

(**) - Two of the three modules Reso Resu, Rair takes an unfavorable value (= 0)

124
125 Figure 2: Rules of decision tree for the calculation of the overall risk per active
126 substance of the I-Phy (adapted from Bockstaller et al. 2008).

127   A decision tree is constructed with the following hypotheses:

128 a)   No weighing is made among the modules of risk to groundwater, surface
129   water, and air.
130 b)   A low dose significantly minimizes risk. If, in the case of a totally
131   unfavorable value in one of the compartments, dose is very low and
132   favorable, the indicator score is set at the limit of 7, expressing the
133   minimum acceptable in INDIGO® method.

134   The general structure of the I-Phy highlights the architecture of interactions
135 between input data, which describe farming practices, climate, field characteristics and
136 the active substance used, as well as the calculation processes and the ultimate indicator.

137   3.4   Field characteristics and Data collection

138   The data was collected in 26 farms from the two regions totaling 43 fields, 12 in
139 No Tillage, 17 in Minimal Tillage and 14 in Conventional. The description and the
140 insertion in the local context are as follows.

141   The main crops in the Is-sur-Tille (Burgundy/France) region are wheat, barley and
142 rapeseed, with cropping systems heavily dependent on agrochemicals. The area is
143 crossed by the Ignon River, which at certain times of the year has contamination

144 problems, caused mainly by nitrates, phosphates, herbicides, and others chemical. This

145 has affected aquatic communities and curtailed water consumption (Poquet M. E. 2007).

146 Rainfall is around 744 mm/year, and the region is composed by two natural zones: in

147 the western part there is a heavily forested limestone plateau with shallow soils having

148 high infiltration potential, and in the eastern part there is a more humid clayey plain,

149 with deeper soils on a slight slope. In the entire region, tillage is limited by shallow

150 soils, with depth rarely exceeding 30 cm. Those farmers who remain tilling their soils

151 have fields on medium-depth to deep soils, located mainly on the clay plain.

152 In the Ituporanga (SC / Brazil) region, tillage practices are marked by intense

153 plowing and disk harrowing, especially in areas grown with onions, the region's main

154 crop. The intense plowing leads to soil compaction, and intense rainfalls in some

155 periods of the year cause important erosion events. The Itajaí-Açú River crosses the

156 municipality, and the annual average rainfall is around 1400mm. Soils in that region are

157 predominantly Cambisol and Gleysol (WRB/FAO 2014), distributed in various types of

158 relief, most of them subject to high runoff potential. Table 1 summarizes the most

159 common practices in the three different cropping systems found in both regions.

160 Table 2: Characteristics of the conventional soil tillage, minimal tillage and no-

161 tillage systems.

Characteristics of crops	Farming/cropping System		
	Conventional	Minimal tillage	No-tillage
Tillage	Deep	Reduced	Only in the crop row, 2 to 10 cm depth
Plowing	Twice a year, 10 to 20 cm depth	Absent	Absent
Harrowing	Twice a year, 5 to 10 cm depth	Once or twice a year, 5 to 10 cm depth	Absent
Subsoiler	Absent	Once or twice a year, 8 to 15 cm depth	Absent
Crop residues	Incorporated into the soil	Incorporated into the soil	Over the soil

162

163 The study was carried out from April to July 2009 in the French region, and from

164 August to December 2010 in the Brazilian region. Indicator calculations were then

165 performed for each field and each farm.

166 Indicator analyses were performed individually for each region. The results were

167 linked to the farming systems, in order to better understand the differences between

168 practices, and their effects on treatments and on the environment.

169   In Is-sur-Tille (N47°31'00" E05°06'00") the study was carried out with ten
170   farmers belonging to the Group of Studies and Agricultural Development (GSAD),
171   which comprises 35 farmers totaling 7.000 ha, of which 2.000 ha are under no tillage
172   (NT) since 2009. Three of the ten participants used conventional tillage with plowing,
173   four adopted minimum tillage (MT), two used no tillage (NT) system, and one used MT
174   and NT. The fields studied, ranging from 4,3 to 52,0 hectares, were located on smooth
175   slopes (3 to 20 %), generally near watercourses. The crops present in this region were
176   winter wheat, winter barley and rapeseed.

177   In Ituporanga (S27º24'52" W49°36'9"), 13 farmers participated in the study; five
178   of them used conventional tillage with plowing, four used MT, three used NT, and one
179   used MT and NT. The fields, ranging from 2 to 12 ha, in general 1.0 km far from
180   watercourses, had slopes with medium to high inclination (20 to 45 %). The crops
181   present in this region were tobacco, onion and corn.

182   To obtain the data, we studied a field of each crop from the crop-succession
183   adopted in each farm. Each farmer defined the field with the largest representativeness
184   of the respective crop.

185   3.5   Active Substances
186   The impact of each active substance was evaluated to determine their
187   environmental risk, according to some characteristics of the compound, as example, the
188   risk in assessing the aquatic environment, the leaching potential, the volatilization
189   potential and the persistence.

190   **3. RESULTS AND DISCUSSION**

191   I-phyma values were variable in three farming systems (Table 4). Index variability
192   were strongly linked to three factors that affects I-phyma, environment characteristics,
193   as fields near rivers and soil type, active substances (AS) used and their doses, and
194   agricultures techniques used by farmers.

195   Soils are a key component that rule many processes on Earth and soil texture is an
196   important characteristic to water fluxes. The region of Is-sur-Tille has high pesticide
197   leaching potential, due to clayey texture, low content of organic matter and shallow
198   soils, environment-linked characteristics that reduce RESO indexes. The texture has a
199   dominant effect for water infiltration capacity, and the increment of organic matter

200 generally increases water holding capacity and conductivity (Saxton and Rawls, 2006).
201 Moreover, shallow soils are strong influenced by bedrocks and presents high spatial
202 variability of hydraulic conductivity and water infiltration (Pedron et al., 2011). The
203 water flow in these soils is complex and the groundwater module of I-Phy relies on
204 GUS-index, neglecting preferential flow and, consequently, can underestimate pesticide
205 leaching (Lindhal et al., 2012).

206 The results also varied significantly due to phytosanitary control techniques, as
207 shown by Combret et al. (2007), who observed that sprays carried by airplanes and
208 tractor led to differences in 4.0 points in their final I-Phyma index, due to the impact on
209 AS's drift by technique employed.

210 Active substances also had an important role in environmental impact, as is the
211 case of *isoproturon, 2,4-D - MCPA, trifluralin, metazachlor, quinmerac, chlormequat*
212 *and alphamethrin* (Table 3), even then presents distinct aspects regarding environmental
213 patterns and human health impacts. Isoproturon, as example, shows a dose-dependent
214 increase in its persistence and low affinity for soil adsorption (Papadopoulou et al,
215 2016) leading to high leaching potential. Whilst, the exposure to *2,4-D - MCPA* are
216 linked to some cancers and other diseases (Mills, et al., 2005; Hartge et al., 2005),
217 although the studies are not conclusive in some aspects like the effects of association of
218 *2,4-D* and *MCPA* (Stackelberg, 2013).

219 Farmers applied high doses of these substances, which have toxicity to humans
220 and the environment, besides a high risk of volatilization, leaching, and persistence in
221 environment.

222 Those factors reduce scores when they are present in phytosanitary treatments.
223 Tixier et al. (2007) found significant differences in environmental contamination
224 indicators due to the characteristics of specific AS. However, glyphosate® was applied
225 at high doses in all NT fields. Environmental contamination risks of this molecule are
226 considered low in I-Phy environmental modules (Table 3).

227 Therefore, it is not possible to infer, per the I- Phy indicator, that high doses of
228 glyphosate® in NT induce strong impacts on the environment. Despite the indicator is
229 sensitive to high doses, glyphosate presents low environmental toxicity because its
230 values of some parameters, e.g., GUS, half-life, aquatox.

231   Table 4: The descriptive Statistics of I-phyma results for crops in the three

232   different systems

System	Crop	Mean of fields	Std. Dev.	Min	Max	System Mean	System Std.Dev.
No Tillage	Tobacco	7,40	2,26	5,8	9		
	Onion	9,05	0,21	8,9	9,2		
	Rapeseed	8,10	1,13	7,3	8,9	7,5	1,49
	Winter wheat	7,33	0,67	6,6	7,9		
	Winter barley	6,30	1,91	5,2	8,5		
Minimal Tillage	Tobacco	8,20	0,85	7,6	8,8		
	Onion	8,00	0,71	7,5	8,5		
	Rapeseed	6,30	2,01	2,8	7,9	6,37	1,88
	Winter wheat	6,35	1,29	5	8,1		
	Winter barley	4,75	1,97	2,1	6,8		
Conventional	Tobacco	8,20	0,14	8,1	8,3		
	Onion	6,60	2,13	4,3	8,5		
	Rapeseed	6,60	0,79	5,7	7,2	6,69	1,87
	Winter wheat	6,47	2,10	4,4	8,6		
	Winter barley	6,07	3,20	2,4	8,3		

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234   Excessive doses, lack of care in applications, number of applications above the
235   necessary or done in inappropriate periods, all contribute to high environment
236   contamination risk in those systems and conditions. Among the most common farming
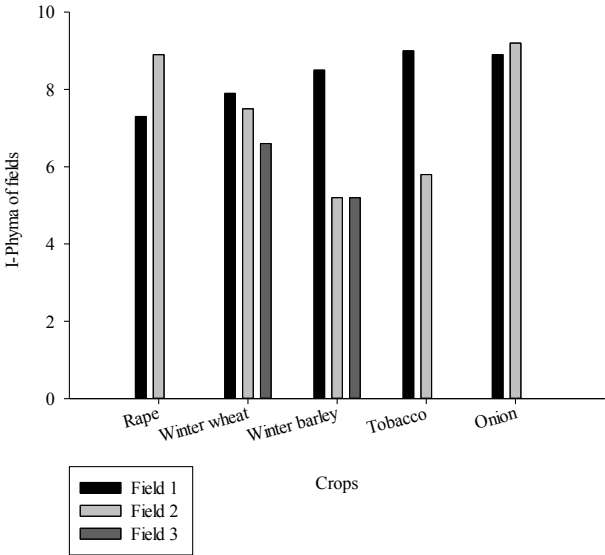
237   systems in Is-sur-Tille, difficulties in phytosanitary control during cultivation of winter
238   barley stands out in all cropping system. Figures 3, 4 and 5 present the I-phyma results
239   of all fields accessed in No Tillage, Minimal Tillage and Conventional system
240   respectively. Winter Wheat and Rapeseed also had problems in the MT system (figure
241   4), and in CS, only tobacco had good scores (above 7) (Figure 5).

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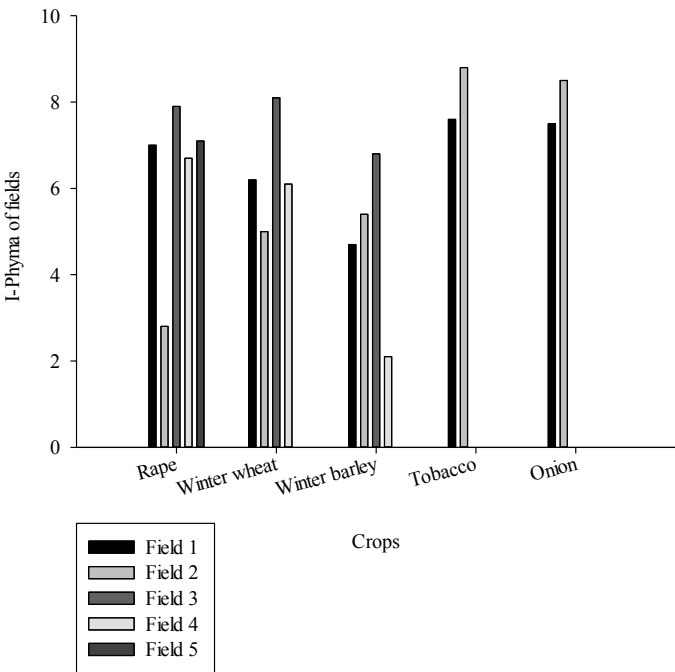243   Figure 3: I-phyma results for the different fields in No Tillage system
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Figure 4: I-phyma results for the different fields in Minimal Tillage system

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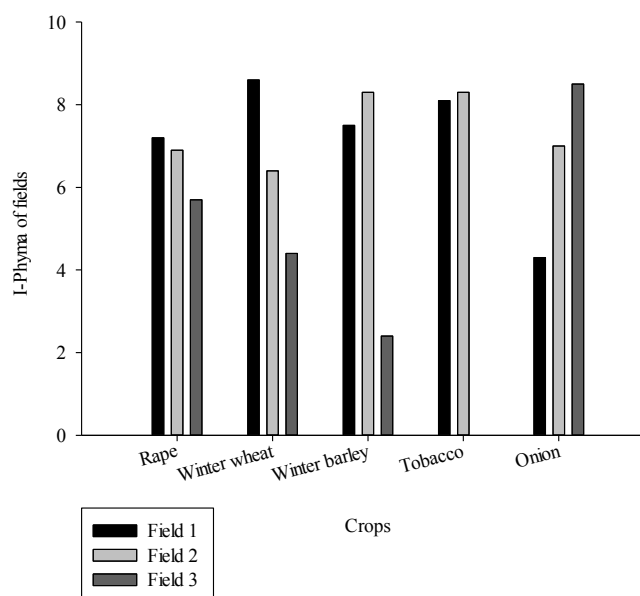259

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Figure 5: I-phyma results for the different fields in Conventional system

The small differences between different systems (1,13 points) do not suffice to state that plowing induces reduction of certain risks associated with pesticide use. The NT system also showed greater uniformity in results, indicating a standardization of phytosanitary controls and the possibility pesticides uses without an adequate technical support. The perception of farmers the richest and most diverse weed community in NT system could be a factor to increase the use of pesticides, even the tillage system had no effect for cereal production (Mas et al., 2003). In that system, no plot showed extremely high contamination risks (Figure 3), i.e., I-phyma scores under 5.0 points, which indicate high contamination, a condition in which the phytosanitary control program must be reformulated, to reduce contamination levels.

Rapeseed in NT was less pollutant (Figure 3) than in other systems, since it does not receive high pesticide doses, except for glyphosate®. In this case, there may be an interaction between crop and cropping system. That is not the case for winter barley in CS, in which scores have high variance (Table 4). This high variance in winter barley is due to treatment management practices, since plot characteristics are similar and did

282   influence I-phyma variance. High doses and high toxicity risks of substances such as

283   *trifluralin, metazachlor, alphamethrin and quinmerac,* were responsible for indicator

284   decrease in rapeseed grown in MT and CS systems.

285   Environmental characteristics may either enhance or reduce contamination

286   chances, as observed in the work by Combret et al. (2007), in which environmental

287   factors changed results in up to 2,4 I-phyma points. The interaction of soil

288   characteristics and the landscape are important to determine the behavior of pesticides

289   on the environment, e.g., the transference of chemicals from soil to water is fewer from

290   a deep and clayey profile on a flat relief, under a system which maintain plants on the

291   surface than a sandy soil or even a clayey one located in a steeper region. Rossa et al.

292   (2017), shows that river contamination increases when it drains areas with contaminated

293   plots, highlighting the importance of consider the watershed scale to a more integrative

294   approach management.

295   Winter wheat received high doses of pollutant AS (*2,4- MCPA, mécoprop-P,*

296   *chlortoluron*) in CS. However, it showed no noticeable global changes, having a

297   reasonable control in most fields and, at the same time, more uniform environmental

298   impact. This crop demonstrates to perform better in NT where RESO and RESU scores

299   remains at higher levels due to soil cover. Correia et al. (2007) compared atrazine

300   contamination potential in soil under different cropping systems, and found that NT had

301   a greater potential to reduce leaching and groundwater contamination. The role of

302   enhancing the storage of organic matter, especially at the surface layers of long-term

303   areas under NT system must be considered as a factor to improve the biological

304   properties and control the processes of degradation and transference of molecules to the

305   watercourses (Melero et al., 2009).

306   Spatial isolation (distance from water sources, hedges) of winter wheat fields in

307   CS reduced environmental impact risk. At the same time, there are situations in which

308   environment was unfavorable to the indicators, such as the second plot of winter wheat

309   in MT, which exhibited low I-phyma (Figure 4). In this plot the treatments are

310   considered acceptable, but the plot is vulnerable to environmental contamination,

311   particularly RESO risks. This result corroborates those obtained by Roussel, Cavelier,

312   and van der Werf (2000) in winter wheat fields, where the high risks of runoff and

313   "drift" percentage led to lower scores, indicating higher risk of environmental

314   contamination.

315   In the Ituporanga region, indicators of environmental contamination show no

316   strong overall risk. The context must be concerned to this case because in the time data

317   collection took place, corn crop was predominantly from genetically modified (GM)

318   seeds, and, according to the farmers, pesticides were not used due to the absence or low

319   incidence of pests. Therefore, there are no I-Phy indicators of environmental pollution,

320   and it appears that environmental pollution by pesticides in GM corn is void, since

321   farmers grow it in CS, and therefore do not apply any glyphosate® nor any other

322   herbicide. However, according to the farmers, there are already records of progressive

323   incidence of some pests in the crop to which GM corn is supposedly resistant, and

324   pesticides are being reintroduced just can be observed on the fields.

325   Regarding both places, there were few differences between farming systems, and

326   the results were, in general, satisfactory (Figures 3, 4 and 5), with only a few fields

327   indicating high risks. There are fields in NT system with high performance, and, as

328   noted by Combret et al. (2007), that happens because I-Phy analyses consider soil cover

329   percentage at the time of pesticide application. Due to better soil cover in NT, the direct

330   impact of pesticides on soil are reduced, with higher adsorption rates to crop residues

331   and/or cover crop dry mass, consequently, erosion and runoff will be reduced.

332   Fields in NT (15 years under NT) have higher contents of organic matter (OM), as

333   compared to systems without crop residues on the soil. RESO risks of NT are also

334   reduced, since I-Phy considers that OM lowers leaching potential. Lower weed

335   incidence, due to the presence of cover crops, also reduces the need for numerous

336   applications of herbicides.

337   Onion crop yield was generally similar in all three farming systems (25 to 35 t ha^{-}

338   ^{1}). There was a reduction in pesticide applications in onion under NT because planting

339   is carried out with seedlings, 70 days after sowing. At that time, seedlings show

340   pseudostem diameter of 0.5 cm and 15-30 cm high, unlike other systems, in which

341   sowing is done directly in the field. In some cases, this planting practice (with 70 days)

342   does not require initial pesticide treatments in fields under NT. The plot 1 of onion in

343   CS showed low I-phyma (Figure 5), due to application of *pendiméthaline*, a very

344   volatile AS, which increases RAIR impacts at high doses.

345   In CS, the high doses of *ioxynyl , and mancozeb* also contribute to increased risks

346   on onion crop. *Ioxynil* has a high risk of human toxicity measured through the ADI,

347   therefore impacting all three modules RESO, RESU, and AIR (table 2). M*ancozeb* has a

348   high risk of toxicity for aquatic life, leading to a strong impact on RESU.

349   MT system did not have any plot with less than 7,0 points I-phyma, and it also

350   showed the lowest variance (table 4). It was the system with greater standardization of

351   controls in both tobacco and onion crops.

352   In the NT system, only tobacco showed scores under 7,0 on plot 2, due to use of

353   high doses of substances such as *chlorpyrifos-ethyl, mancozeb, acephate, iprodione and*

354   *bifentrine,* which may cause greater contamination. Therefore, more effective

355   management of applications, anticipation of treatments, appropriate choice of species

356   for soil cover, and decrease in number of treatments, could reduce contamination risk.

357   Comparing three maize fields under similar environmental conditions and even

358   cropping system, Roussel et al. Roussel, Cavelier, and van der Werf (2000) found

359   different results, which highlights the importance of pest control practice. Farmers can

360   choose doses, number of applications and the AS (more or less toxic), and those choices

361   are determinant of differences in environmental impacts.

362

363   *REGIONAL DIFFERENCES & PRACTICAL USE OF THE I-Phy INDICATOR*

364   The I-Phy was developed and calibrated under temperate climates and soils,

365   nevertheless was possible to apply the indicator under subtropical conditions

366   satisfactorily, showing robustness and adaptability. Once the climatic, farm and

367   production characteristics influence on-farm pesticide use (Andert et al., 2015), the

368   demonstration of sensitivity to Brazilian soil and climate open a wide field of

369   possibilities to application to another areas, crops and management conditions.

370   In Ituporanga, there was not high risk associated with the vulnerability of fields

371   (proximity to rivers or watercourses, shallow soils, surface sealing, etc). For that reason,

372   RESU and RESO scores did not have major reductions, even when doses were high.

373   This fact kept the I-phyma of fields in environmental contamination levels considered

374   tolerable in all systems, with few variations between fields from the same system.

375   However, the indicator does not consider the specific conditions of subtropical climate,

376   where rainfall is higher, with average annual precipitation around 1,400 mm. Therefore,

377   rates of leaching, runoff, and drift are different from those normally included in I-Phy.

378   On the other hand, in the French region of Is-sur-Tille, the fields are extremely
379   vulnerable to environmental contamination, since pesticides quickly reach waterways
380   and/or groundwater, which are close to the surface and have little protection to prevent
381   rapid contact with pesticides from fields.

382   The I-Phy indicator can be useful as a support tool to farmers and research and
383   extension institutions pursuing management practices with lower impact on the
384   environment. However, I-Phy has some limitations that should be reviewed in order to
385   increase the reliability and accuracy of its results. Some proposals are: to include the
386   risks to the operator and to soil macro and microfauna; to have an online platform with
387   constant updating of the database; to include a tropical agriculture platform which
388   considers half-lives of active substances in tropical weather conditions.

389   **4. CONCLUSIONS**

390   The I-Phy indicator was able to access the characteristics of systems tested,
391   including under a subtropical condition.

392   The assessment of environmental impact of pesticide use in conventional tillage
393   system, minimal tillage and no-tillage showed that no-tillage generally presented risks
394   of environmental pollution slightly lower in both regions.

395   The phytosanitary controls in the region Is-sur-Tille exhibit higher risk of
396   contamination due to high environmental vulnerability of the fields and the numerous
397   applications of active substances with high risks.

398   The phytosanitary controls in the region Ituporanga exhibit low overall risk of
399   environmental contamination, mainly due to low vulnerability of fields and some good
400   management practices.

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