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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 assess 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

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

33 The I-Phy index has been used in different soil conditions, climates, crops, system  
34 arrangements and scales, moreover, the constant improvements is an determining factor  
35 to the robustness and applicability of models and indexes. Lindahl and Bockstaller  
36 (2012), as example, incorporating a mechanistic approach, that allows to consider  
37 preferential flow and calculate the risk to groundwater.

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

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

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

## 54 **2. MATERIALS AND METHODS**

### 55 **3.1 I-Phy**

56 The I-Phy Indicator is based on *fuzzy* logic, which deals with variables that can  
57 have heterogeneous nature and limited accuracy associated in a rule-based decision  
58 system. This system can be summarized by a decision tree, in which the choice of a  
59 variable implies the choice of the next variable, until the last step leads to the final  
60 indicator (Bockstaller and Girardin 2008), as shown in Figure 1. This approach allows  
61 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 <sup>(1)</sup>	-		x		
Henry Constant K <sub>H</sub> <sup>(2)</sup>	-				x
ADI <sup>(3)</sup>	mg.kg <sup>-1</sup>		x	x	x
Aquatox <sup>(4)</sup>	mg.l <sup>-1</sup>			x	
Variables linked to the environment (plot)					
Leaching potential	between 0 et 1		x		
Drift percentage <sup>(5)</sup>	%			x	
Runoff potential	between 0 et 1			x	
Variables linked to application conditions					
Application Dose	g ha <sup>-1</sup>	x			
Application Position	Into or over the soil or over the soil cover (% soil cover)		x	x	x

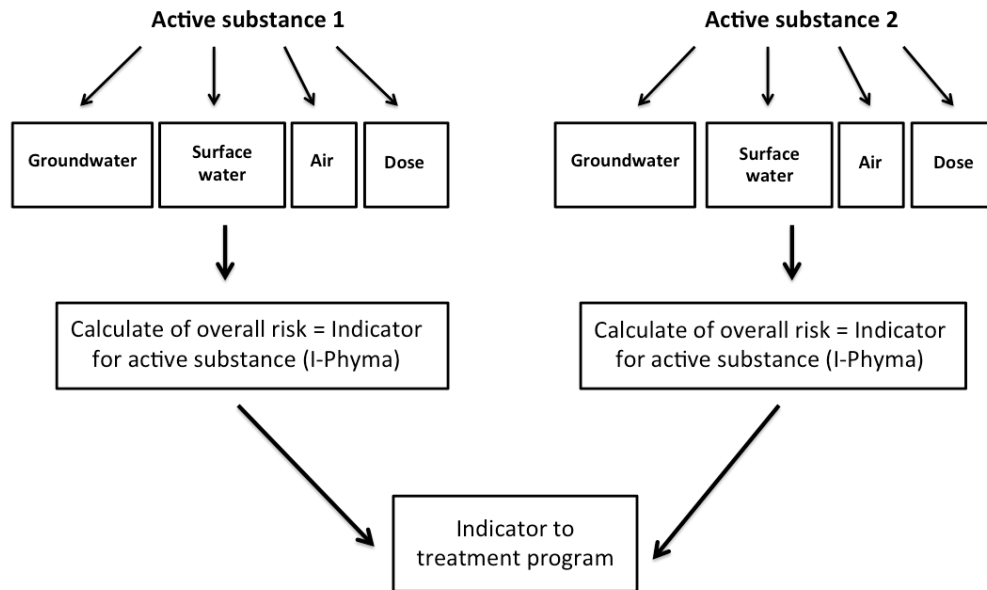
78 \* Adapted from (Werf & Zimmer, 1998). (1) Ground Water Ubiquity Score: index expressing the leaching potential  
 79 of the active substance.  $GUS = \log_{10}(TD50) * (4 - \log_{10}(Koc))$ , where Koc is the coefficient of the division organic  
 80 carbon-water from the molecule. (2) Dimensionless 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 ( $I_{physa}$ ), or to a  
110 program including a large number of low-risk treatments, according to equation 1.

111 Equation 1:

$$I - Phy = \min(I_{physa_i}) \times \sum K_i \times (10 - I_{physa_i}) \div 10 + k_i \times (10 - \min(I_{physa_i}) \div 10)$$

112 Where:

113  $I_{physa_i}$ : indicator for the application of active substance  $i$ ;

114  $k_i$  weighting coefficient empirically obtained by regression ( $k = 0,1$  to  $I_{physa} =$   
115  $10$ ,  $k = 0,2$  to  $I_{physa} = 7$  and  $k = 1$  to  $I_{physa} = 2$ ). It is obtained from equations 2 and 3.

116 Equation 2:

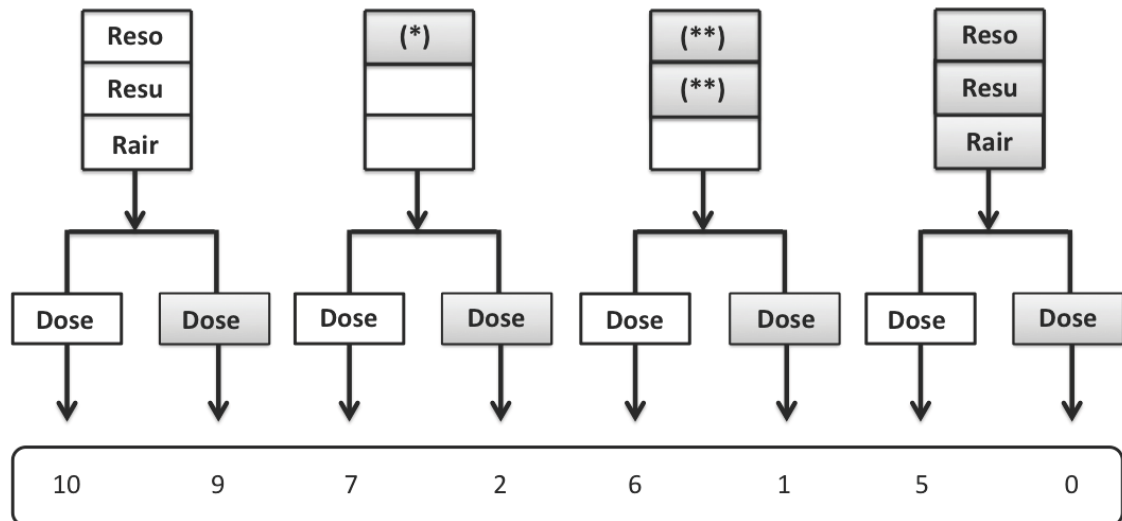
$$117 \quad k = 1,7175 \times e^{(-0,2913 \times I_{physa})}$$

118 Equation 3:

119  $\sum k_i \times (10 - \min I_{physa_i}) \div 10$ , that represents the sum of the weighted risks  
120 less the minimum value  $I_{physa}$ .

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-Açu 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 (S27°24'52" 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 strongly influenced by bedrocks and present 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-Phy 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 alphas-methrin* (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).

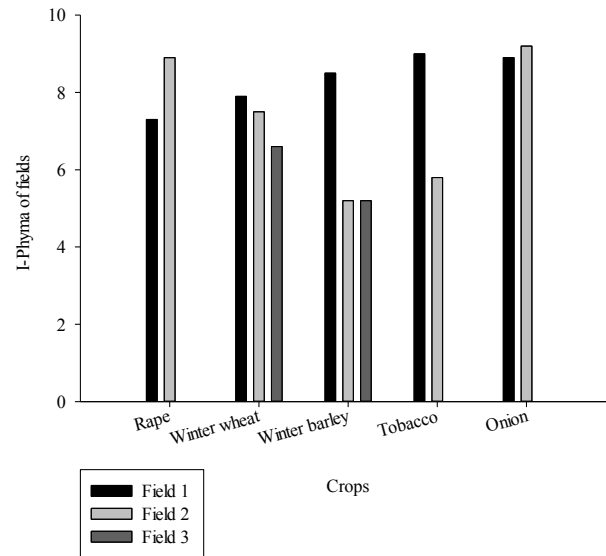
227 Therefore, it is not possible to infer, per the I-Phy indicator, that high doses of  
228 glyphosate® in NT induce strong impacts on the environment. Despite the indicator is  
229 sensitive to high doses, glyphosate presents low environmental toxicity because its  
230 values of some parameters, 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	7,5	1,49
	Onion	9,05	0,21	8,9	9,2		
	Rapeseed	8,10	1,13	7,3	8,9		
	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	6,37	1,88
	Onion	8,00	0,71	7,5	8,5		
	Rapeseed	6,30	2,01	2,8	7,9		
	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	6,69	1,87
	Onion	6,60	2,13	4,3	8,5		
	Rapeseed	6,60	0,79	5,7	7,2		
	Winter wheat	6,47	2,10	4,4	8,6		
	Winter barley	6,07	3,20	2,4	8,3		

233

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).

242

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

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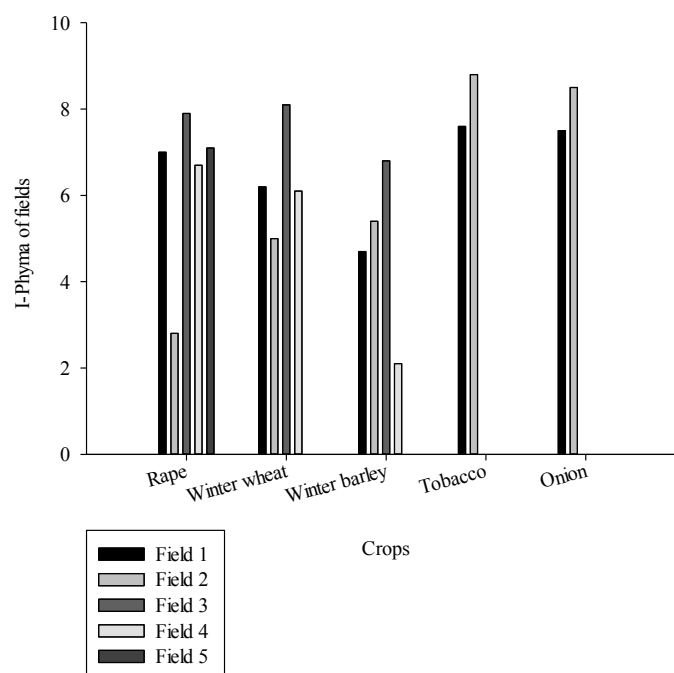
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Figure 4: I-phyma results for the different fields in Minimal Tillage system

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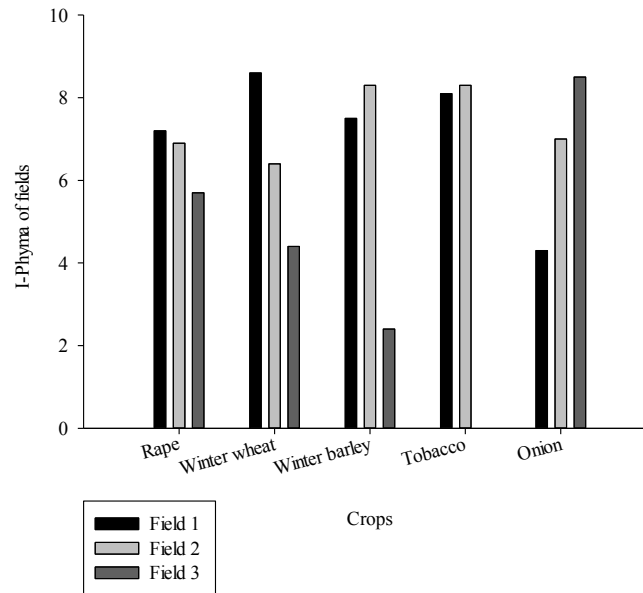
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Figure 5: I-phyma results for the different fields in Conventional system

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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.

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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<sup>-1</sup>)  
338 <sup>1</sup>). 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 *ioxynil*, 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). *Mancozeb* 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 *bifenthrin*, 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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