RESEARCH ARTICLE

Consequences of different pesticide emissions modelling: case study for soybean crop in Brazil

Consequências de diferentes modelagens de emissões de pesticidas: estudo de caso para a cultura da soja no Brasil

Consecuencias de diferentes modelos de emisiones de plaguicidas: estudio de caso para el cultivo de soja en Brasil

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Abstract

The impacts of pesticide use are one of the main environmental problems in agriculture and a threat to as much environment as human beings. Even Life Cycle Assessment (LCA) methodologies, one of the main ones to evaluate production systems, have encountered difficulties in determining the (eco)toxicity impacts of pesticides. The lack of understanding in the relationship between the production system and the environmental emission compartment is one of the problems. Thus, this study aimed to evaluate two modeling methods – and two definitions of environmental emission compartments, ecosphere and technosphere – for pesticides: 100% of emissions to soil and PestLCI. Two soybean production techniques were considered, integrated pest and disease management (IPM-IDM) and scheduled application. To assess the impacts, two methods were adopted: USEtox and ReCiPe. In the evaluation by USEtox, we observed the human toxicity category, which suffered few changes, different of the freshwater ecotoxicity category. For ReCiPe that most impact categories have undergone few changes, except for ecotoxicity categories, terrestrial and freshwater. Therefore, despite the difference in modeling and emission compartments, no consensus has been reached on the framing of compartments between ecosphere and technosphere. However, we observe that the combination of different models together with different impact assessment methods mainly influence the (eco)toxicity impact categories, of which the definition of emission compartments is more sensitive.
Keywords: Ecosphere. Technosphere. Ecoinvent. PestLCI.

Resumo

Os impactos provenientes do uso de pesticidas é um dos principais problemas ambientais na agricultura e oferece riscos tanto ao ambiente quanto aos seres humanos. Mesmo a metodologias de Avaliação do Ciclo de Vida (ACV), uma das principais para avaliar sistemas de produção, têm encontrado dificuldades para determinar os impactos de (eco)toxicidade de pesticidas. A falta de compreensão

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na relação entre sistema de produção e compartimento de emissão ambiental é um dos problemas. Assim, este estudo teve o intuito de avaliar dois métodos de modelagem – e duas definições de compartimentos de emissão ambiental, ecosfera e tecnosfera – para pesticidas: 100% das emissões para solo e PestLCI. Consideramos duas técnicas de cultivos de soja, manejo integrado de pragas e doenças (MIP-MID) e aplicação calendarizada. Para avaliar os impactos adotamos dois métodos: USEtox e ReCiPe. Observamos na avaliação pelo USEtox a categoria de toxicidade humana, sofreram poucas alterações, diferente da categoria de ecotoxicidade de água doce. Para o ReCiPe que a maioria das categorias de impactos sofreram poucas alterações, exceto as categorias de ecotoxicidade, terrestre e de água doce. Portanto, apesar da diferença de modelagem e compartimentos de emissão, nenhum consenso tem sido alcançado sobre o enquadramento dos compartimentos entre ecosfera e tecnosfera. Mas, observamos que a combinação das diferentes modelagem junto aos diferentes métodos de avaliação de impactos influenciam principalmente nas categorias de impactos de (eco)toxicidade, das quais é mais sensível a definição dos compartimentos de emissões.
Palavras-chave: Ecosfera. Tecnosfera. Ecoinvent. PestLCI.

Resumen

Los impactos derivados del uso de plaguicidas son uno de los principales problemas ambientales en la agricultura y plantean riesgos tanto para el medio ambiente como para los seres humanos. Incluso la metodología de Análisis del Ciclo de Vida (ACV), una de las principales para evaluar sistemas de producción, han encontrado dificultades para determinar los impactos de (eco)toxicidad de los plaguicidas. La falta de comprensión en la relación entre el sistema de producción y el compartimento de emisión ambiental es uno de los problemas. Por lo tanto, este estudio tuvo como objetivo evaluar dos métodos de modelado - y dos definiciones de compartimentos de emisión ambiental, ecosfera y tecnosfera - para plaguicidas: 100% de emisiones al suelo y PestLCI. Consideramos dos técnicas de cultivo de soja, manejo integrado de plagas y enfermedades (MIP-MIE) y aplicación programada. Para evaluar los impactos, adoptamos dos métodos: USEtox y ReCiPe. En la evaluación de USEtox, observamos la que categoría de toxicidad humana sufrió pocos cambios, diferente a la categoría de ecotoxicidad de agua dulce. Para ReCiPe, la mayoría de las categorías de impacto han sufrido pocos cambios, a excepción de las categorías de ecotoxicidad, terrestres y de agua dulce. Por lo tanto, a pesar de la diferencia en el modelado y los compartimentos de emisión, no se ha llegado a un consenso sobre la estructura de los compartimentos entre la ecosfera y la tecnosfera. Sin embargo, observamos que la combinación de diferentes modelos junto con diferentes métodos de evaluación de impacto influyen principalmente en las categorías de impacto de (eco)toxicidad, de las cuales la definición de compartimentos de emisión es más sensible.
Palabras clave: Ecosfera. Tecnosfera. Ecoinvent. PestLCI.

1. INTRODUCTION

The impacts of use of pesticides are among the principal environmental problems of agriculture. Alternatives to reduce the use of these products, or even eliminating them, are always on the agenda of researchers and environmentalists.

Besides the problems caused by the use of pesticides, the assessment of their effects, as well as the risk that such products offer to environment and to human beings is one of key-issues in the search for the sustainability of agriculture.

However, many of the environmental assessment methodologies, including the Life Cycle Assessment (LCA), one of the most efficient in evaluating production systems, have found difficulties in assessments related to pesticides. The toxicity of these products has not been effectively assessed, due to the lack of knowledge on how pesticides are distributed in the environment compartments, in other words their destination modelling and their action in the environment (Bessou et al. 2013).

According to Dijkman (2013) while the third phase of an LCA study, the Life Cycle Impact Assessment (LCIA), includes methods that provide characterization factors to a great number of products (although it also has limitations), the previous phase of emission modelling of pesticides in the elaboration of inventories are still in unsure and disagree among the main methods available, mainly due to emission compartments.

Such disagree is so relevant that two of the main modelling methods are totally opposite in their readings of the environment. The 100% soil emissions (Nemecek, Schnetzer 2011) approach considers the soil as the single emission compartments, therefore it is inserted into the ecosphere. In opposition, PestLCI method (Djkman et al. 2012) considers as emission compartments for air, surface water and groundwater, and the soil to the production system, the technosphere. Due to such divergences, Dijkman (2013) states that only the development of one more accurate view of the amount of pesticides that end up in which compartment of the environment will allow for progress on the subject.

Thus, the goal of this study was to evaluate the combinations of two modeling methods (100% soil approach and PestLCI method) and two impact assessment methods (USEtox and ReCiPe), as well as emission compartments. We consider a case study in which the scheduled application of pesticides and the IPM-IDM (conceptual technique for reducing the use of pesticides) technique were compared on soybean crop production to identify which impact categories are most affected by the soybean production system based on the selection of methods (modeling and impact) and emission compartments.

2. MATERIALS AND METHODS

2.1. Definition of scope

The study was performed according to ISO 14044 standard (ISO 2006). For the case study two types of soybean production practices were considered, one adopted the integrated pests and diseases management (IPM-IDM), one other the scheduled management. The concepts of IPM-IDM include the selection of control measures, combined or isolated, that predict the economic benefits to farmers, taking into account the decision rules that guide the selection of the control action, the environmental benefits and damages to the species that they are not pests, but integrate agroecosystems. Such characteristics make the IPM-IDM one of the pillars of sustainable agriculture worldwide (Kogan 1998). In this study the IPM-IDM practices was define for Conte et al. (2017). Scheduled management is based on fixed pesticides applications dates, there is no technical concept for application decision, widely used in the evaluated area, for this inventory were consulted farmers from the region. Scope of the study is presented below:

a) Product system: corresponds to the processes of soybeans production and its inputs.
b) Function: to produce soybean grains.
c) Unit of reference: 1 kg of soybean grains.
d) Data sources: soybean production data were obtained through a direct interview with farmers in the region under study. The modal production system was defined by specialists, analyzing the results of the interviews, and by consulting the technical literature. The IPM-IDM inventory data were obtained from the state program of good agricultural practices Conte et al. (2017). Information on production of inputs and fuels are from Ecoinvent v. 3.3.
e) Geographic coverage: municipality of Rolândia, in the state of Paraná, Brazil.
f) Technological coverage: no-tillage system and integrated pest and disease management practices (IPM-IDM).
g) System boundaries: a cradle-to-gate approach was adopted. The processes covered were the soybean production and inputs and fuels production.
h) Impact assessment method: it was adopted the methods ReCiPe Midpoint (H) V1.13 / World ReCiPe H and USEtox, 2, v1.00 version. SimaPro version 8.4.0.0 was used as support software.

2.2. Life Cycle Inventory

In the inventories of soybean production, it was considered lime, fertilizers and pesticide. It was assumed that the nitrogen, phosphorus and potassium sources of the N-P-K formulations were anhydrous ammonia, with 83% N; phosphoric acid, with 62% P2O5; and potassium chloride, with 60% K2O. Regarding the seeds production and the fuels consumption in agricultural operations.

Table 1 shows the soybean production inventories by the scheduled management and IPM-IDM, generated by the study.

Table 1. Inputs o of scheduled management and integrated pest and disease management (IPM-IDM) inventories.

	Scheduled Practices	IPM-IDM
	kg ha^{-1}	
Yield grain	4.20E+03	4.20E+03
Sowing		
Seed	5.00E+01	5.00E+01
Fertilizers		
Lime	2.07E+03	2.07E+03
Phosphoric acid (H_3PO_4)	3.10E+01	3.10E+01
Anhydrous ammonia (NH_3)	4.15E+00	4.15E+00
Potassium chloride (K_2O)	2.61E+01	2.61E+01
Sulfur	1.25E+01	1.25E+01
Boron	5.00E-01	5.00E-01
Herbicides		
Glyphosate	3.08E+00	3.08E+00
2,4-D	6.69E-01	6.69E-01
Total	3.74E+00	3.74E+00
Insecticides		
Thiamethoxam	2.88E-01	5.64E-02
Lambda-cyhalothrin	8.48E-02	4,24E-02
Methoxyfenozide	1.44E-01	-
Total	5.17E-01	9,88E-02
Fungicides		
Cyproconazole	8.00E-02	3.00E-02
Trifloxystrobin	7.50E-02	6.00E-02
Azoxystrobin	6.00E-02	-
Total	2.75E-01	9.00E-02
Others		
Mineral oil	3.36E+00	1,92E+00
Inoculant	1,00E-01	1,00E-01
Total		
Total de pesticides[a]	4.54E+00	3,93E+00

[a] Sum of herbicides, insecticides e fungicides.

For pesticide modelling were considered the approach recommended by Ecoinvent (Nemecek, Schnetzer 2011), 100% of the substances emitted to the soil and PestLCI modeling (Djkman et al. 2012). In order to enable the use of PestLCI, it was adopted the parameterization made by Picoli et al. (2018), 2.2 1 topic.

2.2.1. Parameterization of scenarios in PestLCI

The parameterization of PestLCI was performed based on Picoli et al. (2018). Soil parameters (pH, organic carbon content, texture, and soil density) were obtained from the Embrapa-BD SOLOS database (Embrapa 2018). Climatic parameters such as temperature, precipitation, solar irradiation, and evapotranspiration were obtained from the agrometeorological IAPAR database (IAPAR 2018). The physicochemical properties of the pesticides were obtained from the PPDB database (University of Hertfordshire 2016). Field declivity of 6% and no-tillage assumptions were used. For the foliar interception of the crop at the time of application, the three soybean parameters already available in the PestLCI database were used.

2.3. Life Cycle Impacts

Although the purpose of this study was to assess compartments of environmental emissions in relation to (eco)toxicity of pesticides, complete inventories of soybean agricultural production systems were evaluated, therefore, we also assessed emissions from fertilizers.

Thereby, the emissions evaluated were: ammonia for air; leaching of nitrate to groundwater; phosphorus through erosion to surface water; N_2O for air; NO_x for air; Fossil CO_2 after the application of limestone; heavy metals for agricultural soils, surface water and groundwater; and, CO_2 to atmosphere, according to Nemecek and Schnetzer (2011), Canals (2003) and IPCC (2006).

We adopted two impact assessment methods, USEtox, a specialized method indicated for (eco)toxicity assessments, and ReCiPe, for being one of the most applied impact assessment method in LCA studies and, therefore, of interest in the results of emissions in environmental compartments. The table 2 shows the impact categories adopted in the study by the two methods of impact assessment.

Table 2. Impact categories adopted according to the impact assessment methods.

Impact Categories					
USEtox	Units	Initials	ReCiPe	Units	Initials
Human toxicity, cancer	Cases	HTC	Climate change	kg CO_2 eq.	CC
Human toxicity, non-cancer	Cases	HT	Ozone depletion	kg CFC-11 eq.	OD
Freshwater ecotoxicity	PAF.m^3.day	FEW	Terrestrial acidification	kg SO_2 eq.	TA
			Freshwater eutrophication	kg P eq.	FE
			Human toxicity	kg 1,4-DB eq.	HT
			Photochemical oxidant formation	kg NMVOC	POF
			Particulate matter formation	kg PM10 eq.	PMF
			Terrestrial ecotoxicity	kg 1,4-DB eq.	TE
			Freshwater ecotoxicity	kg 1,4-DB eq.	FWE
			Agricultural land occupation	m^2a	ALO
			Natural land transformation	m^2	NLT
			Water depletion	m^3	FWD
			Metal depletion	kg Fe eq.	MD
			Fossil depletion	kg oil eq.	FD

3. RESULTS

3.1. USEtox

Figure 1 shows that the human toxicity categories, cancer and non-cancer suffered little alteration according to the different modelling methods and emission compartments. Differently, for freshwater ecotoxicity category in which higher alterations were observed.

We consider the complete system of soybean production, the (eco)toxicity impacts come mainly from the use and production of inputs in general (pesticides and fertilizers) and the occurrence of heavy metals in the system. Therefore, although the IPM-IDM is a technique for reducing pesticides, and hence (eco)toxicity, other inputs and managements should be given attention, so that (eco)toxicity impacts on agricultural production systems are more broadly reduced.

Figure 1. Impactassessment by USEtox method using two different modelling methods of pesticide emission.

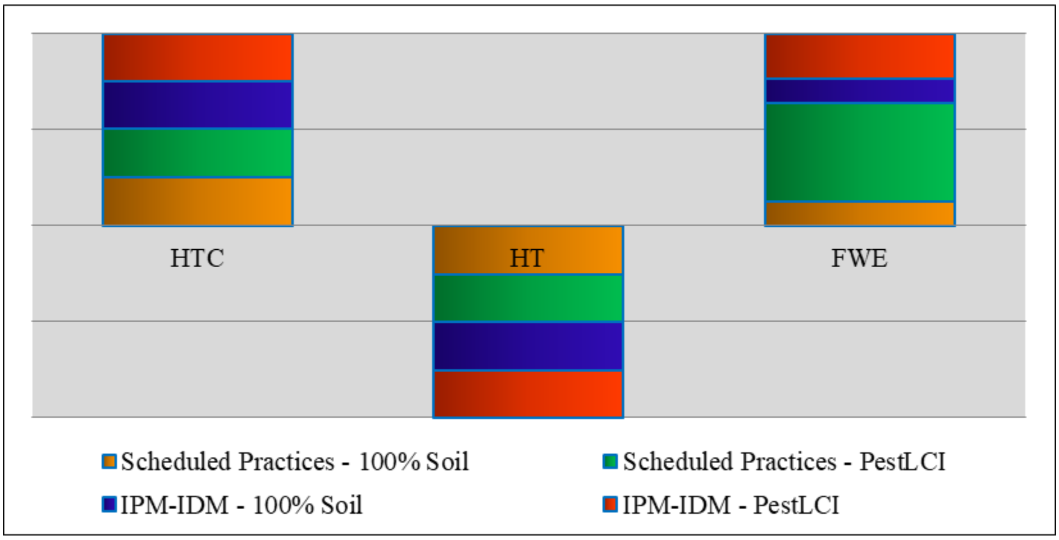
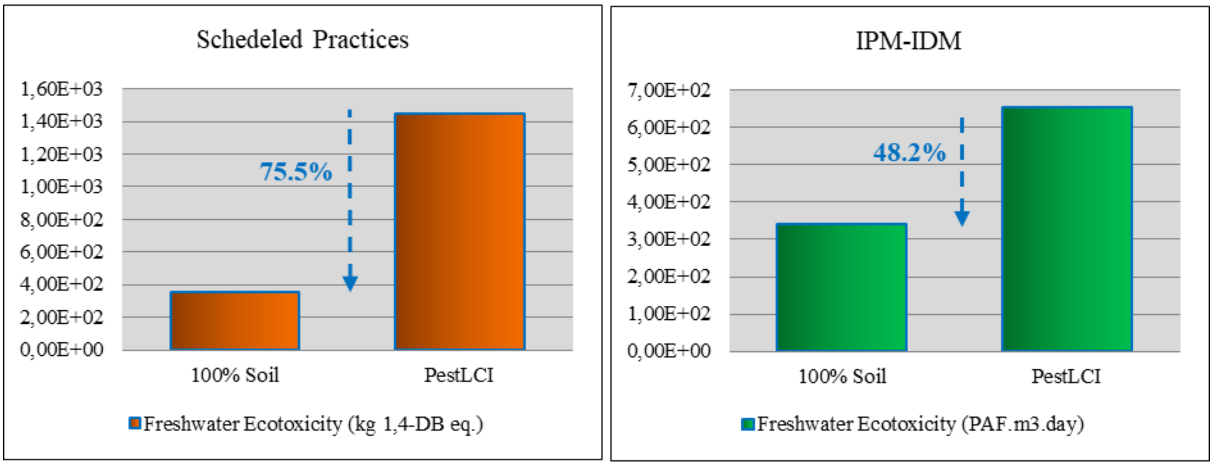


Figure 2 shows in percentage the alteration in the results in the category of freshwater ecotoxicity, which altered 75.5% in the scheduled practice and 48.2% in the IPM-IDM.

Figure 2. Difference, in percentage, of result of freshwater ecotoxicity category using two modelling methods of pesticides emission.



3.2. ReCiPe

Figure 3 shows that most of impact categories presented little alterations in their results according to different modelling methods. Except in the ecotoxicity categories, high differentiations for both the terrestrial and freshwater were observed.

Thus, considering the results produced by using ReCiPe, even though it is not a specialized assessment method for (eco)toxicity impacts, indicated that the assessment of different management techniques in the use of pesticides can be noted and measured by this method as well.

Figure 3. Impact assessment by ReCiPe method, using two different modelling methods of pesticide emission.

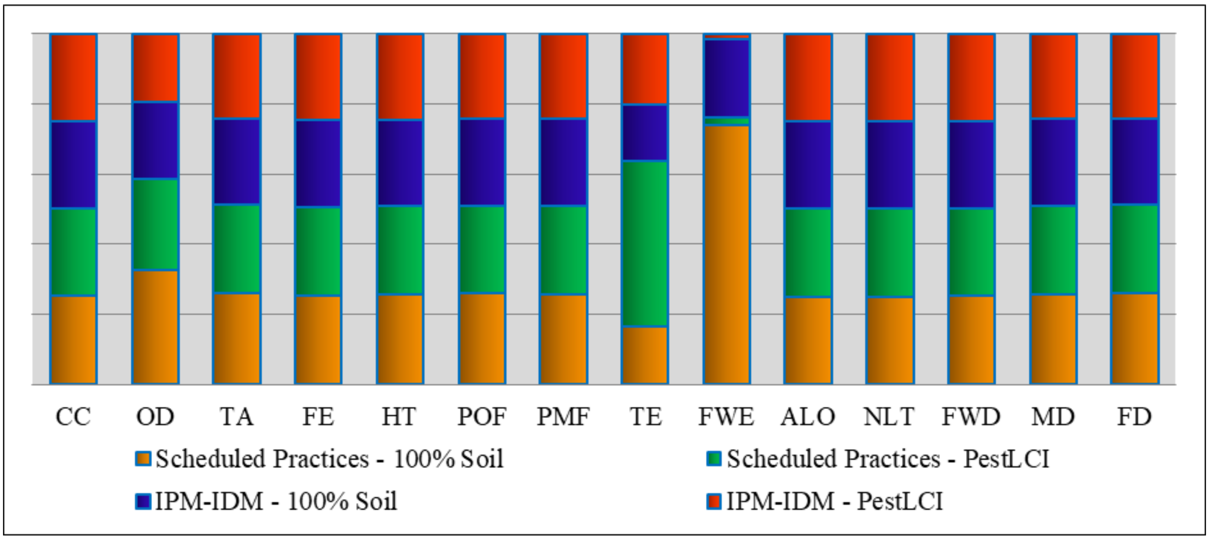
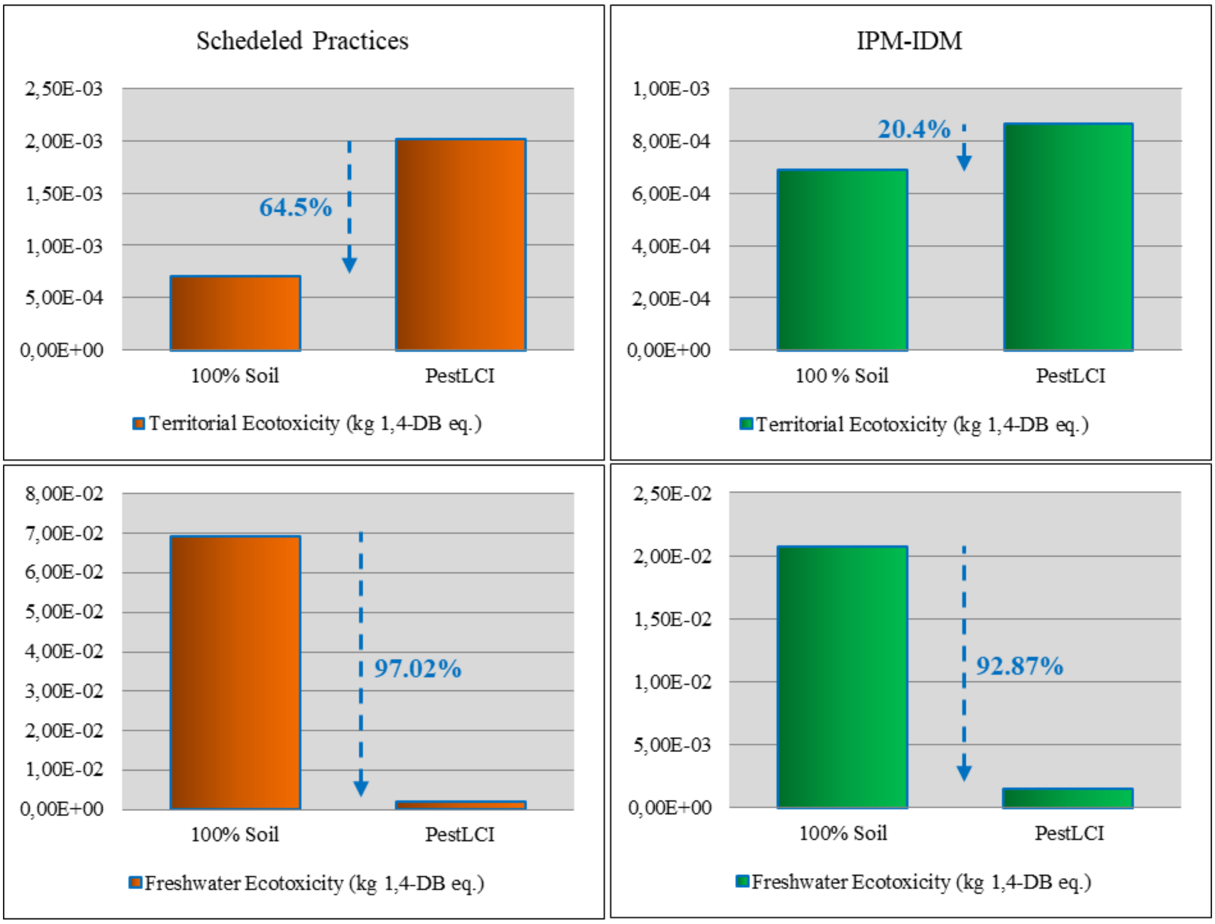


Figure 4 shows, in percentage, how expressive were the alterations in results in terrestrial ecotoxicity and freshwater ecotoxicity category. The alterations for terrestrial ecotoxicity category were of 64.5% in the scheduled practices, and 20.4% in the IPM-IDM; and for in freshwater ecotoxicity category, the alterations were of 97.2% in scheduled practices and 92.87 in IPM-IDM.

Figure 4. Difference, in percentage, of the results of terrestrial and freshwater ecotoxicity impact categories using two different modelling methods of pesticide emissions.



4. DISCUSSION

In the evaluation using the ReCiPe impact assessment method we observed damage mainly in the freshwater ecotoxicity and territorial ecotoxicity categories. In the 100% soil approach, the highest impacts were observed in the freshwater ecotoxicity, while for the PestLCI method they were in the territorial ecotoxicity. In the assessment using the USEtox impact assessment method, we observed significant variations just for the freshwater ecotoxicity category. Similar results regarding the different modeling methods were found in the study by Picoli et al. (2018), which evaluated sugarcane cultivation emissions. The two impact assessment methods applied here are not comparable, as they are composed of different characterization factors (Owsianiak et al 2014).

The differences observed in the use of the two modeling methods are due to the fact that by assuming that 100% of the applied pesticides are emitted to the soil, the other compartments are totally neglected. While adopting the PestLCI method, there is a distribution of substances between the different emission compartments, in addition to considering the degradation and absorption of substances by crop (Dijkman 2012). Thus, the 100% soil approach covers a single emission compartment: the 100% soil approach refers only to the soil and defines it as the ecosphere; in PestLCI the soil is part of the technosphere and air, surface and underground water are part of the ecosphere. According to Renaud-Gentiéa et al. (2015) when agricultural soil is included in the technosphere, a fraction of the products will be considered as emitted to water via groundwater, surface runoff or leaching. Then, if the soil is defined as an ecosphere, the fraction of pesticides emitted to the soil will be higher.

Dijkman (2012) evaluated three pesticide models, the 100% soil approach and the PestLCI method in the conventional mode and in a version considering the soil as part of the econosphere. The author observed differences just between the conventional PestLCI and the other two. Between the evaluations of the 100% soil approach and the PestLCI considering the soil in the econosphere, just small variations were observed. Thus, for impact assessments the definition of emission compartments is the most important aspect to be considered, even more than the assessment method. The question remains whether or not the soil compartment should be considered part of the technosphere, as it is not possible to determine exactly where the boundary between the econosphere and the technosphere is in agricultural assessments.

As for limitations in the use of different methods, we found only for the PestLCI method, whose climate and soil parameters that integrate the method were elaborated for the context of the northern hemisphere. Therefore, it was only possible to apply it in this study due to the parameterization elaborated by Picoli et al. (2018) (2.2.1 topic). However, the version of the PestLCI method applied in this study is not the most recent, a new version with relevant development was recently released, the PestLCI Consensus v. 1.0 (Frantke et al. 2017), and should be considered in further studies.

5. CONCLUSIONS

The LCA methodology suggests that the environmental impacts of soybean production, when adopting the IPM-IDM technique, occur mainly in the impact categories of terrestrial ecotoxicity and freshwater ecotoxicity. This information can be important for the development of management actions that aim to reduce the impacts on soybean production. Due to the adoption of different modeling methods and assessment methods, some differences in the magnitude of damage were noted, but overall, the same impacts were characterized by the different methods.

The question regarding environmental compartments and their framing in the ecosphere and technosphere remains open. The 100% soil approach is currently the most viable for modeling pesticides in agricultural production systems in Brazil, as it does not havelimitations. As for the PestLCI method, it has a better set of environmental characterization and parameterization factors, but with limitations in its adoption to assess certain scenarios under Brazilian conditions.

For future studies, we recommend the use of the PestLCI version (PestLCI Consensus v. 1.0), already adjusted for evaluations in the southern hemisphere and with a great advance in the structural part of the composition of characterization factors and distribution parameters of substances in the environment.

REFERENCES

BESSOU, C., LEHUGER, S., GABRIELLE, B., MARY, B. 2013. Using a crop model to account for the effects of local factors on the LCA of sugar beet ethanol in Picardy region, France. The International Journal of Life Cycle Assessment. vol.18, p. 24-36. https://doi: 10.1007/s11367-012-0457-0

CANALS, L.M., 2003. Contributions to LCA methodology for agricultural systems. Tese (Doutorado em Ciència i Tecnologia Ambientals). Barcelona, CAT: Universitat Autònoma de Barcelona, Faculdade de Ciències.

CONTE, O., OLIVEIRA F.T, HARGER, N., CORRÊA-FERREIRA, B.S., ROGGIA, S., PRANDO, A.M., SERATTO, C.D. 2017. Resultados do manejo integrado de praga da soja na safra 20016/17 no Paraná. Documento 394. Embrapa Soja. Londrina, PR. pp 75

DIJKMAN, T.J., 2013. Modelling of pesticide emissions for Life Cycle Inventory analysis: Model development, applications and implications. Tese (Doutorado em Management Engineering). Lyngby, Dinamarca: Techinical University of Denmark, Faculdade de Management Engineering.

DIJKMAN, T.J., BIRKVED, M., HAUSCHILD, M.Z., 2012. PestLCI 2.0: a second generation model for estimating emissions of pesticides from arable land in LCA. The International Journal of Life Cycle Assessment. vol. 17, p. 973-986. https://doi:org/10.1007/s11367-012-0439-2

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA. 2018. Sistema de Informação de Solos Brasileiros. https://www.bdsolos.cnptia.embrapa.br/consulta_publica.html. Accessed 10 September 2019

FANTKE, P., ANTÓN, A., GRANT, T., HAYASHI, K., 2017. Pesticide emission quantification for life cycle assessment: a global consensus building process. J. Life Cycle Assess. vol. 13(3), p. 245-251. https://doi.org/10.3370/lca.13.245

INSTITUTO AGRONÔMICO DO PARANÁ – IAPAR. Historical averages. http://www.iapar.br/modules/conteudo/conteudo.php?conteudo=1070 Accessed 25 July 2019

IPCC, 2006. N2O emissions from managed soils, and CO2 emissions from lime and urea application. In: IPCC. Guidelines for national greenhouse gas inventories: Agriculture, forestry and other land use. Japan: IPCC.

ISO 14044, 2006, ISO 14044: Environmental Management d Life Cycle Assessment Requirements and Guidelines. International Standards Organization.

KOGAN, M. 1998. Integrated pest management: historical perspectives and contemporary developments. Annual review of entomology. vol. 43(1), p. 243-270. https://doi.org/10.1146/annurev.ento.43.1.243

NEMECEK, T., SCHNETZER, J., 2011. Methods of assessment of direct field emissions for LCIs of agricultural productions systems. data v3.0. Zürich: ART. p. 34. (Ecoinvent Report, 15).

OWSIANIAK, M., LAURENT, A., BJORN, A., HAUSCHILD, M.Z. 2014. IMPACT 2002+, ReCiPe 2008 and ILCD's recommended practice for characterization modeling in life cycle impact assessment: a case study-based comparison. The International Journal of Life Cycle Assessment. vol. 19, p. 1007–1021. https://doi.org/10.1007/s11367-014-0708-3

PICOLI, J.F., BARIZON, R.R.M., BIRKVED, M., FOLEGATTI-MATSUURA, M.S. 2018. Modeling of pesticide emissions for life cycle assessment of agricultural products. In IV Congresso Brasileiro de Gestão do Ciclo de Vida – GCV 2018, p. 193-198. Brasília, DF: Ibict.

RENAUD-GENTIÉ, C., DIJKMAN, T.J., BJORN, A., BIRKVED, M., 2015. Pesticide emission modelling and freshwater ecotoxicity assessment for Grapevine LCA: adaptation of PestLCI 2.0 to viticulture. The International Journal of Life Cycle Assessment, vol. 20, p. 1578-1543. https://doi.org/10.1007/s11367-015-0949-9

UNIVERSITY OF HERTFORDSHIRE PPDB: Pesticide Properties DataBase. 2016. https://sitem.herts.ac.uk/aeru/ppdb/en/ Accessed 10 September 2019