MODELING OF PESTICIDE EMISSIONS FOR LIFE CYCLE ASSESSMENT OF AGRICULTURAL PRODUCTS

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Abstract: Brazil is the fourth largest food producer in the world. The agricultural sector contributes significantly to the Bralizian economy, representing 23% of GDP in 2016. Government and private initiatives have encouraged the adoption of more sustainable production models. The potential benefits of these models can be better estimated by tools that consider the entire production chain, such as Life Cycle Assessment (LCA). One of the main challenges of LCA applied to agricultural systems is to estimate pesticide emissions to different environmental compartments. This study evaluates the influence on the environmental impacts of two approaches to estimating the pesticide emissions of a major Brazilian agricultural product, sugarcane: 1) 100% emissions to soil, according to Nemecek & Schnetzer (2011); 2) fractionated emissions to air, surface water and groundwater, according to the PestLCI v2.0.8 model, parameterized for three Brazilian regions. The environmental life cycle impact assessment was conducted using UseTox v2.0.2 for the categories of human toxicity (HT) and freshwater ecotoxicity (ETfw) impact categories. For both impact categories, environmental impacts of sugarcane production were influenced by the methodological approach, with significant differences for ETfw (about 20% higher when applying the PestLCI modelling). In general, the main contributors to the HT and ETfw categories were heavy metals and the insecticide fipronil, respectively. The results of this work highlights the importance of developing emission models that consider the complex dynamics of pesticides in agricultural production.

Keywords: sugarcane, life cycle inventory, pesticide emission model, PestLCI, agricultural systems.

Introduction

Consumer awareness of product sustainability has significantly increased in recent decades. As a result, government and private initiatives have encouraged the adoption of less-impactful production models. Methodologies capable of taking into account the entire production chain, such as Life Cycle Assessment (LCA), can efficiently estimate the potential benefits of processes considered more sustainable.

LCA plays a key role in the quantification of potential impacts related to agricultural systems (NOTARNICOLA et al., 2017). In Brazil, LCA has been used in several studies to evaluate the environmental performance of the agricultural products such as sugarcane, soybean, coffee, corn, and livestock, among others. Since the country is the fourth largest producer and the third largest exporter of agricultural products in the world, this tool can be applied for technological development as well as for meeting the standards demanded by the international market.

Brazil is also one of the largest consumers of pesticides in the world[9] (BRAZIL, 2018). The impact of the pesticide use is a matter of great concern, due the inherent high biological activity of this compound group and hence the potential to affect human's health and the environment. (ABRASCO, 2015; GOMES & BARIZON, 2014). Excessive application combined with inadequate agricultural practices can result in contamination of surface and groundwater, bee mortality, intoxication, and cancer in humans (ABRASCO, 2015; GOMES & BARIZON, 2014). However, due to the complexity of evaluating the fate of these compounds, most LCA studies of Brazilian agricultural products neglect the toxicological impacts of pesticide emissions (RIVERA et al., 2017; FANTIN et al., 2016; NORDBORG, CEDERBERG & BERNDES, 2014). Moreover, even when these impacts are considered, pesticide emission inventories are often obtained by simplified and non-regionalized models, and toxicological evaluation are not always performed according to standardized methods.

One of the main challenges of LCA applied to agricultural systems is to estimate pesticide emissions to the different environmental compartments (RIVERA et al, 2017; FANTIN et al., 2016; VAN ZELM et al., 2014). Two main approaches has been used in LCA studies that include pesticide emissions (RIVERA et al, 2017; GENTIÉ et al., 2015). The first approach, which is used in the main LCA international database - ecoinvent, assumes that pesticides are fully emitted to the soil (NEMECEK & SCHNETZER, 2011). A different approach is proposed in PestLCI, a model of pesticide

[9] In 2015, around 396 thousand tons of active ingredient were applied nationwide (4.6 kg of active principle ha-1) (FAO, 2017).

dispersion developed by Birkved & Hauschild (2006) and updated by Dijkman, Birkved & Hauschild (2012). This model estimates the pesticide fractions emitted to air, surface and groundwater based on information such as physicochemical properties of the molecule, method of application, crop, management practices and soil and climate properties. Emissions to the soil are not included because in this model the agricultural soil is considered a part of the technosphere.

As PestLCI is a model originally developed to meet production scenarios in Europe, PestLCI 2.0 does not take into account some specificities of the Brazilian agriculture, such as climate and soil attributes and specific active ingredients used in tropical crops, which are factors that influence pesticide emission patterns. The main objective of this study is to evaluate the influence on the environmental impacts of two main approaches to estimate the pesticide emissions of a major Brazilian agricultural product: 1) 100% emissions to soil, according to Nemecek & Schnetzer (2011); 2) fractionated emissions to air, surface water and groundwater, according to the PestLCI model, parameterized for three Brazilian regions.

Methodology

The environmental impact assessment was performed using the LCA methodology, according to the technical requirements of ISO 14040: 2006 and ISO 14044: 2006 (ISO 2006a, 2006b). The agricultural product chosen for the analysis of this work was sugarcane, given its great importance for Brazilian agribusiness.

Product system, function and functional unit

The product systems assessed correspond to the typical sugarcane production systems of three important producing states: São Paulo (SP), Paraná (PR) and Mato Grosso do Sul (MS). The unit of analysis adopted was one kilogram of sugarcane during the first production cycle (cane-plant). The reference flow was established based on the agricultural productivity of each region.

Life cycle inventories

A cradle-to-gate approach was used for this LCA study. In addition to the sugarcane production process, the production processes of agricultural inputs and operations were included. The transportation processes of the inputs to the field and from the field to the sugarcane mills were not part of the system boundary.

The sugarcane production inventories of typical systems of the studied regions were elaborated by Embrapa Environment, within the framework of the "ACV Cana - Life Cycle Assessment of sugarcane and its products produced in the Center-South (FOLEGATTI-MATSUURA et al, 2013) and "ICVAgroBR - Inventories of the life cycle of Brazilian agricultural products: a contribution to the ecoinvent database" (FOLEGATTI- MATSUURA et al., 2017), with the exception of pesticide application data, which were obtained by specialist consultation[10], in order to represent the typical cultivation practices of each region. The production inventories for agricultural inputs (i.e. fertilizers, correctives and pesticides) were obtained in the ecoinvent v.3.3 database. The agricultural operations inventory was generated by the Brazilian Bioethanol Science and Technology Laboratory – CTBE (CAVALETT et al., 2016).

Pesticide emissions were calculated according to two approaches: 1) ecoinvent: 100% emissions to the soil (NEMECEK & SCHNETZER, 2011 and 2) PestLCI: fractionated emissions to air, surface water and groundwater, according to the PestLCI model v2.0.8 , parameterized for the three Brazilian regions.

Table 1 shows the main characteristics of sugarcane production considered in this study, including the list of pesticides assesed and the corresponding application rate.

Table 1 – Main characteristics of sugarcane production in the studied regions.

Parameter	Unit	SP	PR	MS
Productivity	t ha^{-1}	71.69	62.06	55.51

[10] André May, personal communication (2015).

Mechanized harvest	%	89	60	97
Agricultural inputs				
Urea	kg N ha^{-1}	77	66	62
Single superphosphate	kg P_2O_5 ha^{-1}	26	23	25
Potassium chloride	kg K_2O ha^{-1}	86	87	90
Limestone	kg ha^{-1}	125.24	130.70	119.90
Ametryn[1*]	kg a.i. ha^{-1}	3.25	3.25	---
Diuron[1]	kg a.i. ha^{-1}	1.17	0.10	---
Glyphosate[1]	kg a.i. ha^{-1}	2.40	1.75	---
Hexazinone[1*]	kg a.i. ha^{-1}	0.33	0.04	---
Sulfentrazone[1*]	kg a.i. ha^{-1}	0.60	---	0.84
Tebuthiuron[1*]	kg a.i. ha^{-1}	1.20	0.40	0.40
Azoxystrobin[2]	kg a.i. ha^{-1}	---	2.40	2.40
Cyproconazole[2*]	kg a.i. ha^{-1}	---	---	0.24
Pyraclostrobin[2*]	kg a.i. ha^{-1}	0.13	0.13	0.13
Carbofuran[3]	kg a.i. ha^{-1}	---	0.60	0.60
Fipronil[3*]	kg a.i. ha^{-1}	0.40	1.00	1.20
Trinexapac-ethyl[4]	kg a.i. ha^{-1}	---	0.30	0.30

[1]Herbicide; [2]Fungicide; [3]Inseticide; [4]Growth regulator.

[*] New active ingredients added to PestLCI 2.0.8.

Source: adapted from FOLEGATTI-MATSUURA et. al (2017) e May (2015).

Parameterization of PestLCI

In order to better describe the specificity of the Brazilian sugarcane production model, edaphoclimatic parameters from each of the three regions selected were added to the PestLCI database, as well as seven new active ingredients of pesticides.

Soil data such as pH, organic carbon content, texture, and soil bulk density were taken from the soil database - BD SOLOS (EMBRAPA, 2015). Climatic parameters such as temperature, precipitation, solar irradiation, and evapotranspiration were taken from the following agrometeorological database: IAPAR (2016), CIIAGRO (2016) and EMBRAPA (2016). Physicochemical properties of the pesticides were obtained from PPDB database (UNIVERSITY OF HERTFORDSHIRE, 2016). For the three regions, the following assumptions were used: ground application, field slope of 6%, and conventional tillage, since the study was limited only to the first crop year (plant cane). Crop foliar interception at the time of pesticide application is a process relevant to the emission modeling because it influences other important processes, such as pesticide degradation and leaching. However, this parameter is not available for sugarcane in the PestLCI database. Faced with this limitation and assuming that the maize has a plant architecture similar to that of sugarcane, maize foliar interception values from PestLCI database were used according to the growth stage at the time of pesticide application.

For PestLCI, pesticides applied to the agricultural system are considered emissions when they cross the borders between the technosphere and the ecosphere, i.e., when pesticides are transported from the production area and reach areas more than 1 m below and/or 100 m above the soil surface. Immediately after application, primary and secondary processes determine the degraded or emitted pesticide fractions into air, surface water and groundwater. According to Dijkman, Birkved & Hauschild (2012), emissions to soil compartments beyond the technosphere can only occur indirectly after the emission of pesticides to the air, surface water or groundwater and therefore they are not accounted for in the model (but will be accounted for by the characterization model, handling fate and exposure assessment beyond the technosphere).

Life cycle impacts assessment

USEtox 2 model (recommended + interim) v.1.00 was adopted along with the SimaPro® support software version 8.4.0.0 and the ecoinvent v3.3 database. The midpoint impact categories evaluated were: Carcinogenic Human Toxicity (HTc), Non-carcinogenic Human Toxicity (HTnc) and Freshwater Ecotoxicity (ETfw). The choice of the method of impact assessment was based on environmental studies addressed to the toxicological impacts assessment

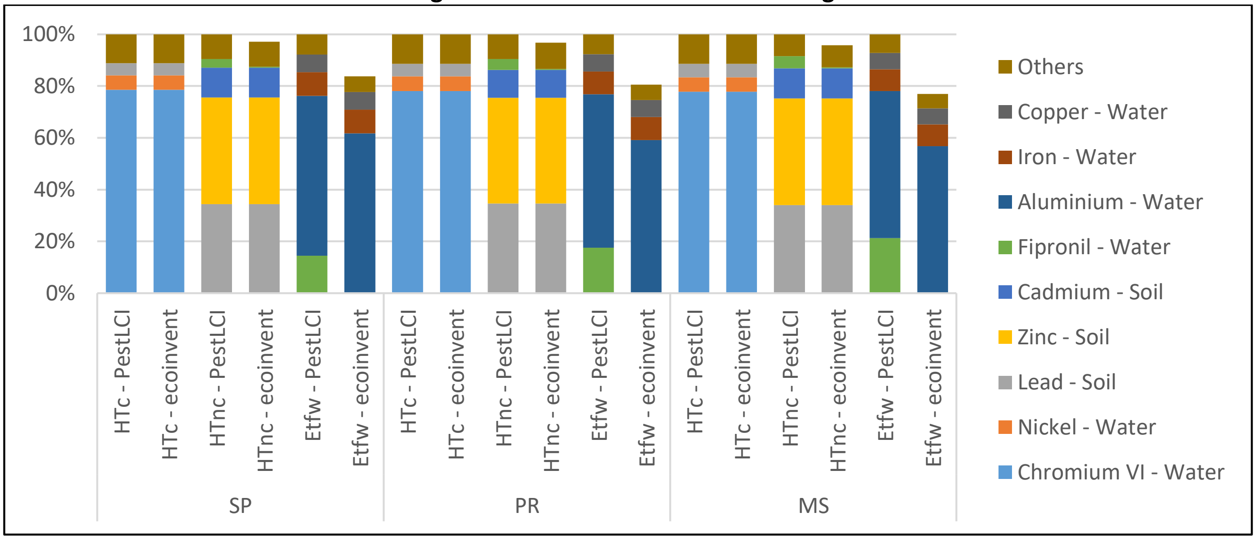
(NORDBORG et al., 2017; RIVEIRA et al., 2017; FANTIN et al., 2016; GENTIÉ et al., 2015; BERTHOUD et al., 2011 ROSENBAUM et al., 2008).

Results and discussion

Figure 1 and 2 present the contribution analyses of the main processes and substances involved in the sugarcane production chain. The analysis of the environmental profile obtained from the inventories of sugarcane production generated by the PestLCI, in comparison to the inventories calculated according to ecoinvent database, points out that application of PestLCI yields greater impacts for the categories HTnc (on average 3%) and ETfw (16% to 23%). For the HTc category, no significant differences were found between the approaches (Figure 1).

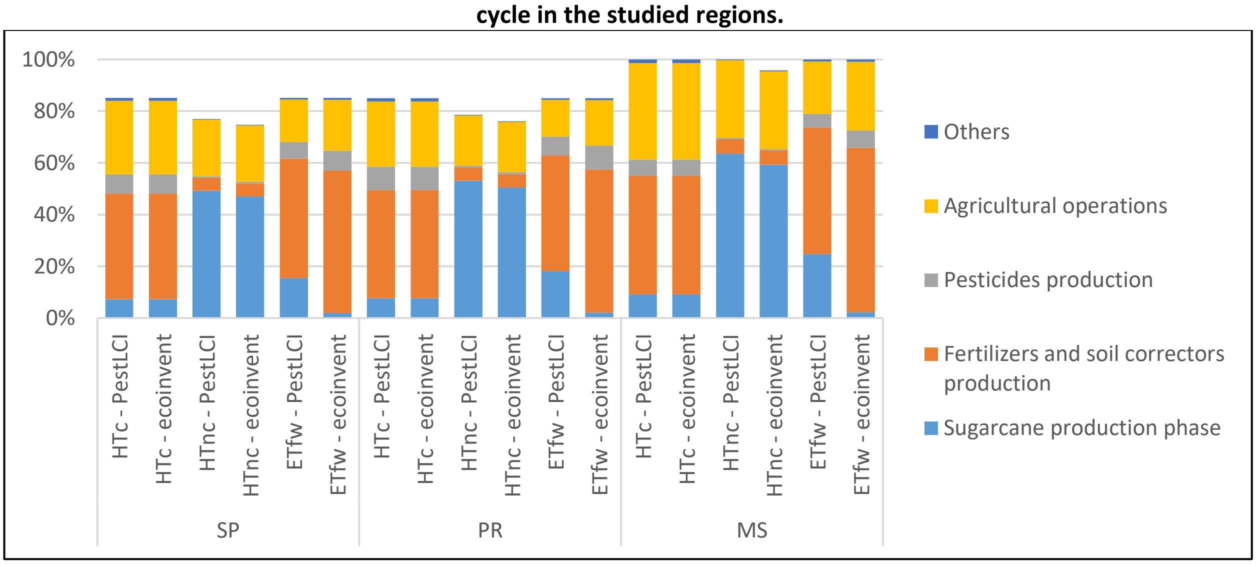
In general, emissions from the production and use of urea and diesel were primarily responsible for the toxicological impacts of all categories evaluated (Figure 2). In addition, the insecticide fipronil emitted to water was another important impact factor to the HTnc and ETfw categories. This emission was only accounted for in the PestLCI inventories, which explains the greater impacts observed in this approach (Figure 1).

Figure 1 – Contribution analysis for the environmental impacts of the substances emitted during the life cycle of sugarcane cultivated in the studied regions.



Note: HTc: Human toxicity, cancer; HTnc: Human toxicity, non cancer; ETfw: Freshwater ecotoxicity.

Figure 2 – Contribution analysis for the environmental impacts of the sugarcane production processes of the life cycle in the studied regions.



Note: HTc: Human toxicity, cancer; HTnc: Human toxicity, non cancer; ETfw: Freshwater ecotoxicity.

For the HTc impact category, the main contaminant was the heavy metal Chromium VI emitted to the water in the urea production process, in addition to the manufacturing of agricultural machinery, focused mainly on mechanized harvesting and transshipment operations. Heavy metals nickel and lead also contributed to this impact by the agricultural use of fertilizers (Figures 1 and 2).

For HTnc category, the agricultural production phase accounted for more than 50% of the impact, mainly due to the emission of lead, zinc and cadmium to the soil, by the use of fertilizers and limestone. Fipronil emission to water was also highlighted in the PestLCI approach. For PestLCI, this insecticide was responsible for about 20% of the ETfw impact. Emissions of the heavy metals aluminum, iron and copper also contributed to this impact (Figure 1). The main processes involved were the production of urea and single superphosphate fertilizers, as well as the fertilizers and limestone use in the sugarcane production (Figure 2).

Among the studied regions, MS state presented the worst environmental performance, followed by PR state. The main factors that influenced this result were lower productivity and higher percentage of mechanized harvest, due to the heavy metals emission in the manufacturing process (Figure 2). Finally, it is important to highlight that, as demonstrated in the present study, the application of simplified approaches, such as the one proposed by Nemecek & Schnetzer (2011), may imply the underestimation of toxicological impacts in the aquatic and aerial environments.

Conclusion

The results of this work highlighted the importance of developing emission models that address the complex dynamics of pesticides in the agricultural production. The use of simplified approaches, such as that proposed by Nemecek & Schnetzer (2011), although low data demanding, may lead to the underestimation of toxicological impacts. Parameterization of the PestLCI - the most advanced pesticide emissions inventory model currently available - has been confirmed to be of great effect for the assessment of sugarcane life cycle impacts.

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