UNIVERSIDADE FEDERAL DA GRANDE DOURADOS
FACULDADE DE ADMINISTRAÇÃO, CIÊNCIAS CONTÁBEIS E ECONOMIA
PROGRAMA DE PÓS-GRADUAÇÃO EM AGRONEGÓCIOS

PRECISION AGRICULTURE IN SOYBEAN PRODUCTION SYSTEM UNDER LCA APPROACH

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Dissertação apresentada à Universidade Federal da Grande Dourados – Faculdade de Administração, Ciências Contábeis e Economia, para obtenção do Título de Mestre em Agronegócios.

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PRECISION AGRICULTURE IN SOYBEAN PRODUCTION UNDER LCA APPROACH

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Resumo

A previsão de crescimento da população mundial tem elevado o interesse da sociedade por sustentabilidade e melhoramentos no uso eficiente de recursos nos sistemas agrícolas. O setor agrícola contribui com a emissão de gases de efeito estufa (GEE) como: CO_2 (25%), CH_4 (50%) e N_2O (70%) em nível global e aproximadamente 13,5% das emissões antropogênicas globais de GEE. Na busca por uma agricultura com menos impacto ambiental, a mecanização e tecnologia são vistas como vanguardas para um novo sistema produtivo. O desafio é aumentar uniformemente a adoção de tecnologia para grandes e pequenos produtores. O manejo de fertilidade através da Agricultura de Precisão (AP) pode reduzir significativamente o conteúdo de carbono atmosférico pela produção vegetal, pois trabalha para atender a variabilidade espacial e temporal das lavouras. Em relatório publicado pelo Laboratório de Agricultura de Precisão da Universidade de São Paulo, apenas 45% dos produtores de grãos no país tem adotado técnicas da AP e 38% possuem de fato algum equipamento. Mas um dos grandes obstáculos é a falta de informações sobre os benefícios do uso de tecnologias de AP que melhorariam o acesso homogêneo de produtores através de políticas de incentivo mais inclusivas. A Avaliação do Ciclo de Vida, termo em inglês Life Cycle Assessment (LCA) é uma importante ferramenta para avaliação ambiental e tem sido largamente utilizada por pesquisadores e técnicos. Baseada nas ISO 14040 e ISO 14044, esta ferramenta pode auxiliar fortemente na construção do conhecimento sobre os reais benefícios da AP. Por isso é importante identificar como a ferramenta LCA vem sendo utilizada, em forma e número de pesquisas para visualizar os gargalos da aplicação da AP no sistema produtivo. O Brasil é o segundo maior produtor mundial de soja com 117 milhões de toneladas produzidas e 33,347 milhões de hectares plantados. Por isso existe a necessidade de investigar os benefícios ambientais da AP na produção de soja em uma perspectiva de ciclo de vida, avaliando os impactos ambientais.

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LIST OF ABBREVIATIONS

PA = Precision Agriculture

LAP = Precision Agriculture Lab, in Portuguese initials

C = Carbon

CH_4 = Methane

CO_2 = Carbon dioxide

COP = Conference of the Parties

EF = Emission factor

EMBRAPA = Brazilian Agricultural Research Corporation

eq. = Equivalent

FU = Functional unit

GHG = Greenhouse gases

GWP = Global warm potential

ha = Hectare

IPCC = Intergovernmental Panel on Climate Change

ISO = International Standards Organization

LCA = Life Cycle Assessment

LCI = Life Cycle Inventory

LCIA = Life cycle impact assessment

MJ = Mega Joule

N_2O = Nitrous oxide

NH_3 = Ammonia

NO_3 = Nitrate

PO_4 = Phosphate

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CHAPTER I:

THEORETICAL REVIEW

1 GENERAL INTRODUCTION

Agricultural systems face considerably difficult challenges to meet global demands for sustainable food production. Specific consideration is related to climate change and food security (FAO, 2017a). The circumstances are quite alarming considering that the expectation of the global population in 2050 is around 10 billion people (FAO, 2009).

Soybeans are considered an important product in the production of by-products used in food and feed, which could contribute to the world's food supply nearly 10 billion people by 2050 (FAO, 2017a). Brazil is a crucial producer of this commodity with all conditions (climate, water and land) to surpassing other countries in food production and exports (Tollefson, 2010). Across the country, Brazilian soybean production reached the mark of 117 million of tons in 2018 (CONAB, 2018). At the second largest soybean producer in the world with a planted area of 33.347 million hectares, distributed in the Pampa, Atlantic Forest, Cerrado, and Amazon biomes (Lima et al., 2019).

Alternatives towards food production (sustainable management of natural resources, agricultural inputs and waste disposal) are pathways towards optimistic perspectives (FAO, 2009; Jussila, 2015). In this sense, a challenge is to develop and spread out innovation in rural areas with eco-adjusted technological options which may contrast with orthodox and conservative agricultural practices (FAO, 2017b).

Grain and beef production systems which lack of global positioning (GPS) and real-time reacting technology (variable-rate application) may be configured as conventional agricultural systems compared with an upcoming interface of smart-farming technologies (Bongiovanni and Lowenberg-Deboer, 2004; Kitchen et al., 2002).

It is assumed that new generation technologies are more eco-friendly. In this sense, conventional agricultural systems must adapt in order to meet global demands and expectations regarding sustainability (Kumar et al., 2018). For this purpose, environmental impact should be monitored throughout the entire life cycle of any food or agricultural product. In accordance with several agreements established during international agendas, traceability of carbon footprint should encompass all stages of the supply chain (Schieffer and Dillon, 2014).

Continuously, frameworks should be developed worldwide to tackle environmental impact and social distress which is associated to agriculture and livestock production (United Nations, 2014). More specifically, this is addressed to the preservation of water, air, soil and human health (Jensen et al., 2012).

Precision Agriculture (PA) is expected to improve crop yield and economic efficiency (LI et al., 2016; Van Evert et al., 2017). Likewise, it is expected to alleviate environmental and social impacts (FAO, 2016; Gebbers; Adamchuk, 2010). However, adoption of PA technology seems rather challenging in developed or developing countries (EIP-AGRI, 2015). Notably, government programs aiming to encourage the adoption of PA are rather discreet in several countries that lead exportation in global agribusiness (Gonzaga et al., 2019). Brazil is among the top three grain producers in the world. In this country, 55% of the grain systems lack of PA technology in any stage of production (MOLIN, 2017).

Precise quantification of environmental benefits (carbon footprint) is limited because of the heterogeneity in the circumstances in which PA is handled throughout production systems (Gebbers; Adamchuk, 2010). The LCA approach has enabled comparisons of the effect of specific PA technology in agriculture (Blagodatsky et al., 2016; Bright, 2015; Cerutti et al., 2014; Chagas et al., 2016; Engelbrecht et al., 2015; Engelbrecht et al., 2013; Gasso et al., 2014b; Li et al., 2016). In general, the results have revealed a hand full of benefits in the field level. Thus, PA can be a driver towards sustainable agricultural development, at least in terms of grain production (FAO, 2016).

In fact, the LCA approach provides an overview of various impacts related to the food supply chain (Axelsson et al., 2012; Gasso et al., 2014; Li et al., 2016; Ruviaro et al., 2012). This may be developed during any stage of the life cycle of products and services. Moreover, it covers a wide range of environmental features such as greenhouse gases (GHG) emissions, fossil depletion, acidification, toxicity, water and land use. Interestingly, LCA may consider all resources used and all emissions released to the air, soil, and water as a result of extraction of raw materials, manufacturing, logistics, scrapping and recycling (ISO 14040, 2006; Nemecek et al., 2015; Ruviaro et al., 2015).

Nevertheless, advances have been made under the assumption that interactions among people from different backgrounds are necessary (inter and multidisciplinary networking) to achieve new insights and perspectives for agricultural sustainable development (Jussila, 2015).

In this context, the following research question arises: “how does precision agriculture contribute to sustainable development throughout the soybean production life cycle?”. Thereby, the goal of this study will be to evaluate different environmental impacts of precision and non-precision soybean production systems.

To achieve the main goal of the study some targets are proposed:

- Accomplishing a Systematic Review to comprise the interaction level between PA and LCA;
- Ascertain the technological level in the cropping system of soybean production;
- Life Cycle Impact Assessment to compare both systems.

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CHAPTER II

HOW CAN LIFE CYCLE ASSESSMENT SUSTAIN THE ENVIRONMENTAL SUSTAINABILITY OF PRECISION AGRICULTURE TECHNOLOGIES?

Abstract

The forecast about world population and agricultural production has increased societal interest for sustainability and improvements in resource use efficiency in agricultural systems. The agricultural sector contributes to the production of 25% of CO_2, 50% of CH_4, and 70% of N_2O emissions in a global basis summing up to nearly 13.5% of the global anthropogenic GHG emissions. Precision Agriculture (PA) is a combination of technology and conservation practices that in their right combination could improve the sustainability in the agricultural production tackling climate change and food security gaps. Life Cycle Assessment (LCA) is an important tool for environmental evaluation of production chains and have been widely used by researches and technicians. PA technologies contributes to sustainable development affecting the environmental impacts, biodiversity conservation, land use, climate change, and productivity.

Keywords: Technology food production, machinery, decision-making, supply chain, sustainable strategy

1 INTRODUCTION

The forecast about world population and agricultural production has increased societal interest for sustainability and improvements in resource use efficiency in agricultural systems (FAO, 2017a). In order to support the performance of resources use such as fertilizers, pesticides, irrigation water, land, and labor it’s found the precision agriculture technologies. Those technologies have presented a great efficiency on the reduction of impacts due to responding to spatial and temporal variability to improve economic returns and reduce environmental impacts (Balafoutis et al., 2017; Van Evert et al., 2017).

The agricultural sector contributes to greenhouse gases (GHG) emissions: CO_2 (25%), CH_4 (50%), and N_2O (70%) in a global basis summing up to nearly 13.5% of the global anthropogenic GHG emissions (Domingo et al., 2015). However, in Organization for Economic Co-operation and Development (OECD) member countries, agriculture produces 8% of the total GHG emissions with a decline between 2000 and 2010 by an average of 0.4% per annum with a simultaneous agricultural production increase of 1.6% per year (FAO, 2017b). Therefore, the developed countries members of OECD are trying to achieve synchronized GHG mitigation and productivity increase (Macleod et al., 2015).

In order to sustainable agriculture, mechanization and technology are key drivers to farming system change. The adoption of technology becomes crucial to enhance the production inputs, such as seed, fertilizer and water, and leading to improved productivity of both land and labor (FAO, 2017c). The challenge is increase technology adoption uniformly for both large and small farmers. To support that obstacle, further information about environmental benefits would help policy makers to improve the access for all farmers composing inclusive policies to financial incentives (FAO, 2017a).

Thereby, Precision Agriculture (PA) is a combination of technology and conservation practices classified in three categories (guidance, recording and reacting technologies) that in their right combination could improve the sustainability in the agricultural production tackling climate change and food security gaps (Balafoutis et al., 2017b; FAO, 2017b). Besides technical questions as efficient resources use, productivity and profitability (Kumar et al., 2018), PA could empowering smallholders, assurance gender equality, preserve the biodiversity and, be a great strategy in the battle against poverty, hunger and water scarcity in the world (FAO, 2017e).

The use of PA technologies in the world have been promoted in several countries (Hedayati et al., 2019; Michler et al., 2019), but most practitioners do not have a clear information of the benefits of PA technologies in agricultural production and do not consider the environmental return of payment that their use could provide due to a lack of technology transfer programs and support resources that are necessary to implementation (Balafoutis et al., 2017). To overcome this barriers to adoption is necessary to determine the real benefits of environmental impacts and investment risk to support policy makers to create inclusive incentives (EIP-Agri, 2015).

Withal, the United Nations Climate Change Conference, COP 23 (United Nations, 2018) has been the great influencer to the rising demand for reliable environmental criteria for food and feed products and have brought LCA methodologies to agribusiness as a tool to support the decision-making processes regarding agriculture and food production technologies (Ruviaro, 2012). In straight to build producers knowledge and develop their capacities, the Sustainable Development Goals (SDGs) come to revolutionize agriculture systems (Food and Agriculture Organization of the United Nations, 2018). A progressive replacing to multidisciplinary and pluralistic production system is becoming a trend in public sector, private agents, civil society organizations and non-governmental organizations in order to construct a modern agribusiness value chain (FAO, 2018).

Life Cycle Assessment (LCA) is an important tool for environmental evaluation of production chains and have been widely used by researches and technicians. Comprehensive systematization of the requirements and step of the LCA is contained in the standards ISO 14040:2009 (ISO 14040, 2006) and ISO 14044:2009 (ISO 14044, 2006). The relevance of LCA application to agricultural chains can be justified by: a) consumers demand environmentally friendly products and are willing to pay more for them, b) the producers are not demonstrating that their production is on the sustainable way, and c) environmental criteria are being gradually added by countries to their import requirements for agricultural products.

In this study, the aim was to investigate the LCA methodology is being used to support the evaluation of impacts of PA technologies applied in agricultural production. LCA approach is considered one of the most relevant methodology to estimate the impacts of products, processes and services supporting on the background of policy makers to formulate inclusive incentive policies for adoption of technologies in agricultural systems (Ruviaro et al., 2012; Saarinen et al., 2012).

2 MATERIALS AND METHODS

An intensive literature search into web databases (Scopus, Science Direct and Web of Science) for English-language scientific articles was carried out to compose a dataset of published Precision Agriculture LCAs. The execution planning was based on the systematic review methodology (Figure 1) using the software *StArt v. 3.3. beta* to support and improve the quality to the application of techniques (Fabbri et al., 2016).

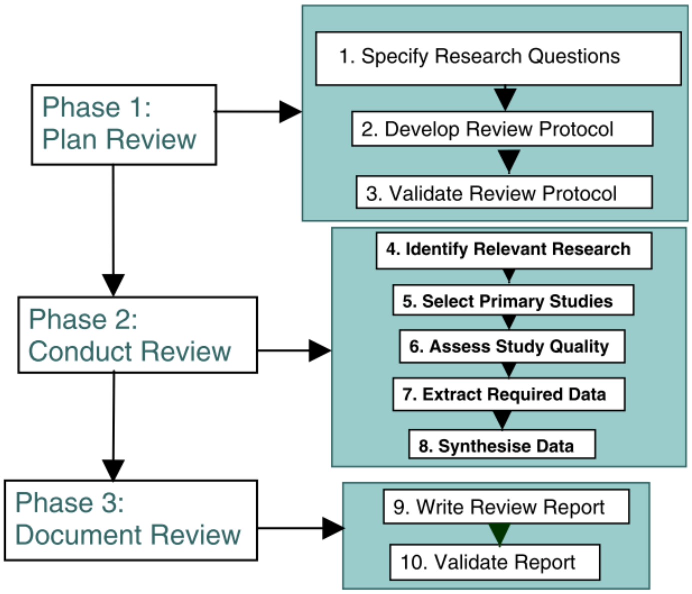


Figure 1: Systematic literature review process (Brereton et al., 2007).

The keywords used to search documents were based on the Precision Agriculture Technologies overview proposed by Balafoutis et al. (2017) and related words with LCA approach in several possible combinations as showed in Figure 2.

Figure 2: Word cloud showing the keywords used to browse and capture articles from scientific databases.

An important step in the Systematic Review approach is to stablish a guiding question that will guide all study. We considered the next research question: “Is LCA being used to measure PA impacts in agricultural systems?” and in order to screening the relevant researches, the following criteria was defined: just scientific article; published between 2008 and 2018; evaluated environmental impacts of any Precision Agriculture technology; applied LCA methods; written in English.

The database was structured to gather information of each accepted study. In general, any LCA study follows international standards, but every single study has peculiarities on the execution processes according to the products and origin of the publications. Therefore, the discussion was assembled in a general way based on main conclusions of the papers.

3 RESULTS

The use of LCA methods to estimate the impacts of precision agriculture technologies has been little studied in the last ten years, even the application of LCA methods to estimate environmental impacts reaching considerable numbers. After applying the criteria of selection we got 11 papers to analyze (Figure 3).

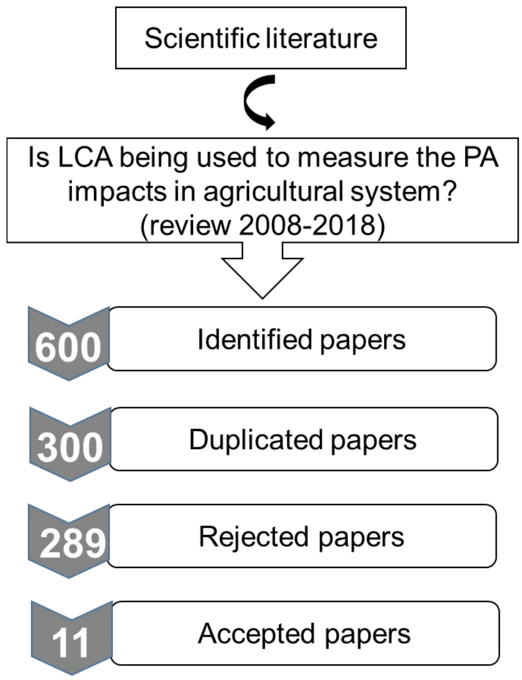


Figure 3: Flowchart of the screening.

The Table 1 list the papers that applied LCA to measure the impacts of PA technologies into the agricultural production according to the respective country of application, theme, authors, year of publication, agriculture products, functional unit, impact categories, and selected conclusions.

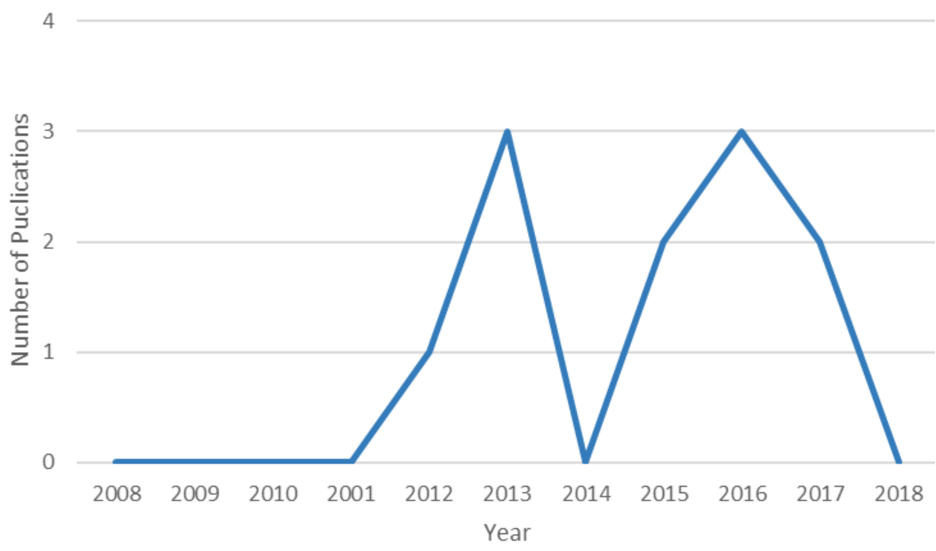
Table 1: Aplication of LCA on use of PA technologies in worldwide agriculture.

Country	Theme	Authors	Year	Agriculture products	Functional unit	Impact categories	Selected conclusions
Greece	Life Cycle Assessment of Two Vineyards after the Application of Precision Viticulture Techniques: A Case Study	Balafoutis et al.	2017	Grape	1 tonne of grapes	Carbon footprint	Precision viticulture practices can significantly reduce GHG emission derived by wine grape production.
Zambia	Life Cycle Assessment to Evaluate the Environmental Impact of Biochar Implementation in Conservation Agriculture in Zambia	Sparrevik et al.	2013	Maize	1 ton of maize per year	Acidification, eutrophication, toxic effects and resource depletion.	When introducing these biochar generation technologies, social and economic aspects have to be evaluated in addition to life cycle impacts.
Denmark	An environmental life cycle assessment of controlled traffic farming	Gasso et al.	2013	Wheat	1 tonne of winter wheat grain with 84% of dry matter content after harvest	Aquatic and terrestrial eutrophication, climate change, acidification, human- toxicity, ecotoxicity, and land use.	Controlled Traffic Farm had lower environmental impacts than Random Traffic Farm in all impact categories analyzed.
Brazil	Environmental and economic impacts of different sugarcane production systems in the ethanol biorefinery	Chagas et al.	2012	Sugarcane	1 litre of ethanol	Abiotic depletion, acidification, eutrophication, global warming, ozone layer depletion, human toxicity, photochemical oxidation.	Management options such as controlled traffic farming that allow an increased number of sugarcane harvests per crop cycle demonstrated highly positive outcomes regarding the economic and environmental impacts of sugarcane production system. Reduced tillage in sugarcane has a small positive effect on decreasing production cost and environmental impact.
Australia	Mapping agriculture's impact by combining farm management handbooks, life-cycle assessment and	Navarro et al.	2016		1 ha.	GHG (Mtonnes CO2-eq)	The availability of high resolution farm practice data remains an issue because statistical collections do not yet exist for them. The use of farm management handbooks was identified

	search engine science						as an avenue to help reduce those demands to manageable levels. A novel method to mine knowledge from a large number of farm management handbooks has been presented.
Italy	Boosting the use of spectral heterogeneity in the impact assessment of agricultural land use on biodiversity	Rugani and Rocchini.	2017	Vineyards and other crops.		Land use change	The detection of spectral heterogeneity (SH) patterns can provide with actual state references on the conditions of biodiversity at multiple time and spatial scales.
German y	Carbon balance of rubber (Hevea brasiliensis) plantations: A review of uncertainties at plot, landscape and production level	Blagodatsky et al.	2016	Rubber plantations		Land use change	Enhanced remote sensing techniques can greatly improve C stock estimates at the regional level, allowing for an accounting of the variability caused by terrain and plantation properties. A partial life cycle assessment of rubber production revealed greenhouse gas emissions as a minor contribution when compared to land use change effects on plant and soil C stocks and C accumulation in latex, wood products and seed oil.
Australia	Integrated spatial technology to mitigate greenhouse gas emissions in grain production	Engelbrecht et al.	2015		1 tonne of grain	Carbon footprint	Various options exist for the use of the IST in the agricultural cycle and this article highlighted the use and acquisition of chemicals (including fertilizers) and how these contribute to GHG emissions through production, dosage control, the substitution of one chemical with another and the transportation of the chemicals. Further factors highlighted in this study were the GHG emissions from the use of farm machinery due to production costs and the combustion of fuel, the GHG emissions from animal husbandry and stubble burning and how these could be reduced or eliminated by altering or adapting other farm management practices.
USA	Metrics for Biogeophysical Climate Forcings from Land Use and Land Cover Changes and Their Inclusion in	Bright, Ryan M.	2015	Grassland.	CO2-eq/ Time Horizon	Global warming	Land use processes in LCI databases would either need to be adapted to accommodate all of the relevant surface energy balance terms needed to compute biogeophysical

	Life Cycle Assessment: A Critical Review						climate impacts (with methods or metrics that would need to be standardized in LCIA)-or, alternatively- amend or augment land-based process inventories with geographic information (coordinates) so that precomputed metrics in the form of look-up maps can be applied in LCIA.
Australia	An evaluation of integrated spatial technology framework for greenhouse gas mitigation in grain production in Western Australia	Engelbrecht et al.	2013	Maize	1 tonne of grain	Climate change	The key feature of the proposed framework is its ability to be applied on a micro scale (paddock and/or farm level). This enables individual property holders to make a strategic decision to evaluate their farming activities thereby facilitating with the alteration of farming practices to reduce GHG emissions.
USA	A Case Study of Environmental Benefits of Sensor-Based Nitrogen Application in Corn	Li et al.	2016	Corn	1 tonne of corn grain	Fossil energy use, global warming potential, acidification potential and eutrophication potential.	Our analysis, incorporating direct measurements, model simulation, and a LCA, suggest that, relative to a uniform rate of fertilizer application, corn production using a sensor-based, variable-rate N application system can significantly decrease both gaseous and aqueous N losses.

As shown in Figure 4, the number of published papers with LCA applied to measure environmental impacts of PA technologies from the year 2008 was modest and still had not publication in 2018. We can see that purpose to identify the impacts of PA its still immature.



Some countries have focused on use of LCA to assess the PA as showed in figure 5. The number of publication it is not expressive but on the other hand, could be the fuel to meet worldwide perspectives for environmental data about application of PA technologies.

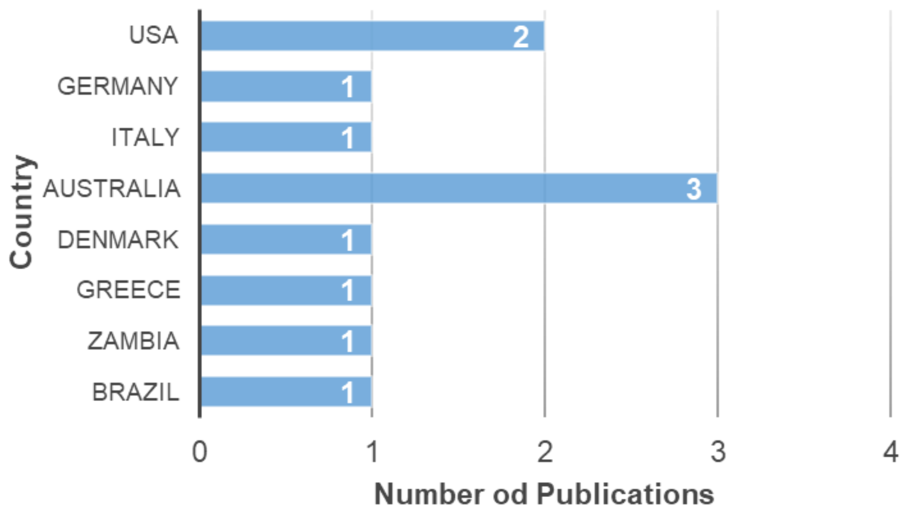


Figure 5: Geographic distribuition of LCA used to measure PA environmental impacts in the world for the period 2008-2018. (until March 2018)

4 DISCUSSION

In this topic will be presented different perspectives about the adoption of PA technologies in the food production systems. The first topic is the use of technology as a strategy to achieve the SDG's and multidisciplinary approach as a way to boost the engagement of the stakeholders. Not less important, the linking of PA and sustainability is the second that shows the perspectives of the adoption of PA can be a way to ensure food security under climate change. The third topic is about contributions from LCA to PA technologies and the benefits of the use these method to measure the PA impacts.

Technology as a strategy to achieve the Sustainable Development Goals

The adoption of technologies is one of the most important strategies to affect the sustainability framework of the production value chain in connection with natural resources (FAO, 2017e), promoting synergistic thinking among governments and private sector, small and large producers (Gonzaga et al., 2019), all kind of consumers and genders (Brown et al., 2019), developed and developing countries (Jiang et al., 2018) in order of a clean production that assure the environmental protection (Bongiovanni and Lowenberg-Deboer, 2004), increasing profit (Korsaeth and Riley, 2006; Wang et al., 2003), income distribution and empowerment of the minority classes (Jensen et al., 2012) in a world perspective.

A multidisciplinary approach is a way to transforming and strengthen the engagement of the stakeholders (Fullen et al., 2011; Lockeretz, 1991) in the challenge to blend high productivity, environmental protection and a healthy society (Sarandon and Marasas, 2017). The adoption of technologies can be a key to gather information of all different value-chain sectors and their peculiarities into a large and only smart package (Adjei-Bamfo et al., 2019; Holden et al., 2018). This type of interaction could change the perspective of the use of technologies shifting the debate from “all farmers need technology” to a more nuanced understanding of what is the farmers’ need and how to help them.

The use of technologies in agriculture is essential to achieve the SDG’s and support current and future human needs (Moyer and Bohl, 2018). The PA technologies are able to get higher productivities, quality of employment and value addition in food systems, beyond to protect and enhance natural resources while improving livelihoods and foster inclusive economic growth (Kumar et al., 2018). The adoption of PA technologies can enhance the resilience of people and communities changing their awareness about themselves and their true role in sustainable development looking ahead (Sonetti et al., 2019).

Precision Agriculture and sustainability

For a long time the agricultural production was seen as a necessary evil, due to the uncontrolled use of resources and your weight on the climate change (FAO, 2017a). The society is becoming more aware of the level of technological in the agriculture and its current contributions to environmental impacts (FAO, 2017c; Makate et al., 2019). The PA technologies have been contributing to give a new face to agriculture and linking to sustainability theme (EIP-AGRI, 2015; EU Commission, 2017).

Guidance technologies focusing on precise machinery movement reducing overlapping causing lower input use (seeds, fertilizers, pesticides, and fuel) (Van Evert et al., 2017b). Recording technologies are used in order to receive information before, during and after crop period, and after processing can provide useful data for any kind of PA application (Korsaeth and Riley, 2006). Reacting technologies use the data produced by the recording systems and supplies the optimum quantity required by the crop to grow (Adeyemi et al., 2017; Balafoutis et al., 2017a).

The adoption of the PA technologies in agriculture systems is considered a way to ensure food security under climate change (Dovie, 2019; Makate et al., 2019). Several benefits about PA have been discussed in the world but the level of technology adoption it’s still a problem because involve significant capital costs (Bongiovanni and Lowenberg-Deboer, 2004). A way to enhance the incentive policies and increase the use for farmers could be more researches in order to show the connection of PA technologies to the capacity to minimize impacts with a recognized tool (European Commission, 2017).

Life Cycle Assessment contributions to PA technologies

Whatsoever the tool or processes need to be measured in order to identify problems and opportunities to get improved management practices and boost the production system (Xu et al., 2019). The technologies has the potential to reduce the vulnerability to the climate change and the LCA can collaborate for a wider development ensuring the adoption for farmers by presentation of solid results (Wollenberg et al., 2016). The productivity and profitability in agricultural systems can be enhanced while reducing the use of water in irrigation, fertilizer application, fuel consumption, greenhouse gases (GHG) emissions, human labor and pesticides through the adoption of technologies and conservation practices (Kumar et al., 2018).

There is some evidences which shows that PA technologies contributes to reduce costs, social and environmental impacts (Bongiovanni and Lowenberg-Deboer, 2004). However, this article shows that the research applying LCA approach to investigate the improvements from PA technologies are quickly discrete (Table 1). The relevance to apply LCA methods to identify the impacts of those technologies in agriculture systems allow us an interpretation for a life cycle view of the effects and provide necessary and useful information for decision making (Liang et al., 2018; Xu et al., 2019). Ingrao et al. (2018) revealed that LCA can find important numbers to contribute to quality, energy efficiency and sustainability, by operating at different system levels (i.e., materials, components, structures, portions, or the whole building) and a large of numbers of other applications are expected in the future that could contribute in the life of humans, in terms of quality, health and safety.

The ability of timely and accurate application of N fertilization, water and pesticides from PA, reduces the most significant activity producing GHG emissions in the agricultural sector (Balafoutis et al., 2017b; Liang et al., 2019). These farm-level advances meets to the international requirement for emissions reduction, and the use of LCA to understand the relative contributions of PA technologies as a good strategy of on-farm mitigation (Hedayati et al., 2019).

PA technologies contribute to sustainable development affecting the environmental impacts (Chagas et al., 2016; Gasso et al., 2014a), biodiversity conservation (Rugani; Rocchini, 2017; Sparrevik et al., 2013), land use (Bright, 2015; Engelbrecht et al., 2015; Navarro et al., 2016), climate change (Blagodatsky et al., 2016; Engelbrecht et al., 2015; Reijnders et al., 2008), and productivity (Balafoutis et al., 2017c; Li et al., 2016). The application of LCA it is possible to evaluate the optimal solution that are becoming the process of agricultural production more efficient and leave to be seen as a bad boy on the value chain.

The source of environmental impacts throughout the entire supply chain of food production have become a real concerning in the last years due to the data about climate change (Matthews; Hendrickson; Weber, 2008). The choice for LCA methods is relevant by the occurrence of multidisciplinarity, teleological features, the presence of large and complex system, and the existence of case studies and their iterative nature that can enable the analysis of alternative actions (Tillman, 2000). In any product chain the focus is meeting the sustainability to our society by strong legislation or sustainable awareness but one point is becoming indisputable: LCA is a powerful method to get gaps in sustainable development.

5 CONCLUSIONS

The LCA approaches are being largely used but the cooperation to PA technologies it is still awakening. Precision agriculture is a great package of sustainable technologies but with a considerable high cost being a barrier to the adoption. The need for relative information about their effects on entire value chain it is opening a way to the application of LCA methodologies.

The use of LCA to measure the benefits of PA technologies could support the lack of information that would stimulate the designing of financial incentives more inclusive to achieve higher levels of quality and sustainability in the agricultural systems. Important questions about the use of PA can be enhanced with the adoption in production system like equality gender, healthy, connection from small farmer to global markets, etc.

This work should be considered as an attempt of providing information upon LCA development in PA technologies in order to show the relevance of those technologies in whole product chain, to be of interest and support for researchers, policy-makers and producers.

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CHAPTER III

ENVIRONMENTAL BENEFITS OF SOIL FERTILITY MANAGEMENT USING PRECISION AGRICULTURE (PA) IN SOYBEAN PRODUCTION

ENVIRONMENTAL IMPACTS OF SOIL FERTILITY MANAGEMENT USING PRECISION AGRICULTURE IN A SOYBEAN PRODUCTION SYSTEM IN BRAZIL

Abstract

Brazil is a crucial soybean producer with all conditions (climate, water and land) to surpassing other countries in food production and exports. With 117 million of tons and 33.347 million hectares of soybean across the country. Just 45% of growers have adopted Precision Agriculture (PA) techniques and 38% have any equipment. Through the fertility management by PA its possible reducing 10-28% of environmental impacts in vegetal production compared to conventional system. The Life Cycle Assessment (LCA) have been viewed as an efficient tool to measure the environmental impacts on farm-level and development of best management practices of low-impact. The Life Cycle Assessment of soybean with PA practices over the period 2014-2018 reached a difference of 31.79% (AP), 60.84% (EP), 28.65% (GWP) and 19.54% (HTP).

Keywords: sustainability, supply chain, decision-making, sustainable food production, variable-rate

1 INTRODUCTION

The expected population by 2050 is around 10 billion people (FAO, 2017a). This is an alarming issue in terms of global food security and is related to the demands for greater production of grains. Brazil is a key player in terms of yield and exportation of soya and maize. This is favored by the great extension of agricultural land and the tropical climate (Tollefson, 2010).

In 2018, the production of soybean in Brazil reached the mark of 117 million tons (CONAB, 2018). The South American country is currently the second largest soybean producer in the world. The planted area is estimated around 33.347 million hectares, encompassing several biomes such as the Atlantic and the Amazon Forest, the Pampa ecosystem and the Brazilian Savanah (Lima et al., 2019).

Systematically, discussions have been focused on the environmental impacts related to food production. Increasing yield has become a promising pathway to achieve greater food production, decoupled from environmental impact (deforestation) (Tollefson, 2010).

However, sustainable agricultural development will depend on the diffusion and adoption of conservation practices and innovative technologies. These alternatives must enable greater productivity, food processing, with lower impact on biodiversity (FAO, 2017b). Curiously, a report from the Precision Agriculture Lab from the University of Sao Paulo, Brazil, revealed that only 45% of grain producers in Brazil have adopted some technique that resemble Precision Agriculture (PA) (Molin, 2017). Surprisingly, only 38% of the grain growers declared to own any equipment related to PA (Molin, 2017). The levels of PA adoption are rather discrete and may be a consequence of little information regarding the economic and environmental benefits related to PA (EIP-AGRI, 2015) and financial incentives aiming towards greater inclusion of farmers in modernization strategies (Gonzaga et al., 2019).

Conservative techniques of soil management, i.e. adoption of PA, have been associated to the reduction of carbon footprint in vegetable production by 10-28% (Balafoutis et al., 2017; Li et al., 2016). More sustainable performance has been associated to the adoption of smart technologies that optimize the efficiency and properly deal with the spatial and temporal variability (i.e. variable-rate, GPS, sensors, interactive software, auto-guidance, etc). In contrast, this is not accounted for in the conventional management of grain production systems (Colaço and Molin, 2015; Van Evert et al., 2017).

Some challenges in the 21st century are related to improvements on the population dynamics (sustainable usage and management of natural resources, technological change, transformation of farmers and consumers behavior, climate change and optimal responses in development policies) (FAO, 2017a). Clearly, PA may enhance productivity and profit (Kumar et al., 2018). Still, PA may also play a crucial role on the empowerment of family farmers, driving gender equality, poverty and hunger alleviation, biodiversity and water preservation (FAO, 2017c; Makate et al., 2019).

Notably, the Life Cycle Assessment (LCA) tool has been efficient to measure the environmental impacts. It has enabled the identification of better management practices related to lower impact (Hedayati et al., 2019; Xu et al., 2019). This is made possible by accounting for all inputs and all emissions released to the air, soil, and water “from the cradle to grave” (ISO 14040, 2006). All inputs and emissions are properly addressed to processes (extraction of primary materials, manufacturing, logistics, consumers, disposal and recycling) that occur at the farm level or any other subsequent stage in the supply chain (ISO 14040, 2006; Nemecek et al., 2015; Ruviaro et al., 2015).

In this sense, the aim of this study was to develop the life cycle impact assessment of the production of soya under two different perspectives of soil fertility management: conventional versus precision agriculture (PA). In both perspectives, we evaluated the contribution of different stages of soya production (tillage, sowing, cultivation and harvesting) on global warming potential (GWP), acidification potential (AP), eutrophication potential (EP) and human toxicity potential (HTP).

2 MATERIALS AND METHODS

This study is designed to perform analysis on the environmental impact potential of a soybean production system. For this purpose, a farm system managed with precision agriculture (PA) was inventoried. To contrast the environmental performance of modern versus conventional practices of soil fertility management, pre-existing data from literature was adapted to build datasets which enabled the comparison of both situations.

Subsequently, a Life Cycle Impact Assessment (LCIA) was assessed following the stages of ISOs 14040 and 14044 in order to obtain potential impact estimates. Six steps were followed in order to report the data which was measured by means of LCIA, according to item 4.3 of ISO14044. Roughly, the procedures consisted of building a flowchart diagram to describe all processes (unitary processes to be modeled, including their interrelationships) (*i*), to describe each unit process (in relation to factors that influence all inputs and outputs) (*ii*) and to list the flows and data pertaining to the operation associated with each unit process (*iii*). Also, all units were listed and properly specified (*iv*), with description of data collection and calculation techniques (*v*), which provided insight on limitations and irregularities regarding the data (*vi*).

2.1 Characterization of farm system

The selected farm is representative to the predominant fashion of alternating crops throughout the seasons, aiming to alleviate the practice of tillage, indiscriminant usage of fertilizers and intensity of parasitism. This has become mainstream in several agricultural frontiers in South America, subject to Precision Agriculture (PA). More specifically, it consisted of a non-irrigation soybean/winter-maize cropping-system, similar to descriptions found in (Embrapa et al). The farm is located in a commercial area, with great relevance to grain production in Brazil (Table 1). With exception to nitrogen, soil is managed under synthetic fertilizer. For nitrogen, the system relies on biological fixation with rizobacteria (Puente et al., 2019). The application of lime and gypsum are calculated once a year, every year. The application of other fertilizers varies, depending on the nutritional demands of each crop. This is done to optimize the operations and cost (Broch and Ranno, 2012).

Table 1: Farm characteristics.

Issues	Description
Crop type	Transgenic soybean
Country	Brazil
State	Mato Grosso do Sul
City	Caarapó
Gegraphic coordinates	22°44'1.14"S, 54°47'52.26"O
Field size	218.02 ha
Soil class and texture	Oxisol - 60% of clay
Average annual precipitation	1547 mm
In-field operations	Tillage, sowing, cultivation and harvesting
Precision agriculture technologies	Auto-guidance, variable rate fertilizer, sensors.
Period practicing PA	5 years (2014 - 2018)
Tillage type	No-tillage

Crop rotation	Soybean/winter-maize

2.2 Description of PA in the case study

PA consisted of variable-rate fertilizer, auto-guidance and sensors and was adopted to manage soil fertility in two areas of the farm, side-by-side to each other (T01; T02) (Figure 1).

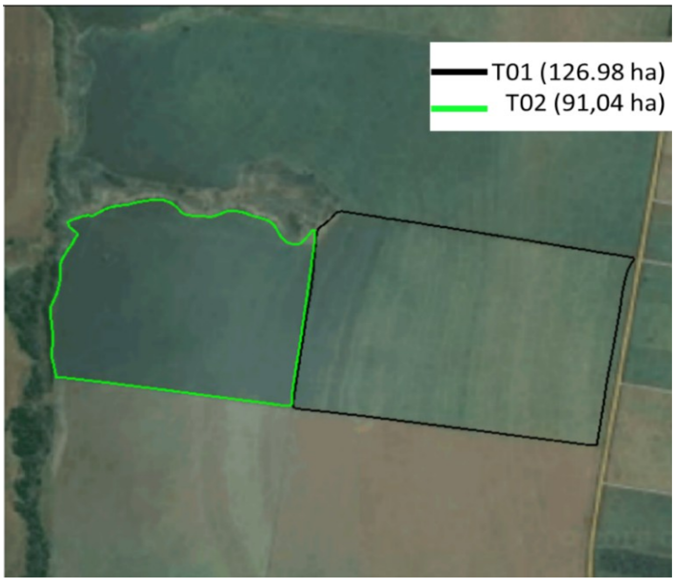


Figure 6: Delimitation of two areas subject to a soybean/winter-maize crop system and PA. Satellite image showing field boundaries. Source: courtesy of *Agges Integrated solution Company*

In the first area (T01), PA techniques were adopted since 2014 in an extension of 126.98 ha. In the second (T02), PA were adopted since 2015, in 91.04 ha (Figure 1). At the farm level, geo-referenced grid points of 5 ha (24 (T01) and 20 (T02) grid points) (Figure 2) supported management of soil fertility requirement by means of annual analysis of the level of nutrients.

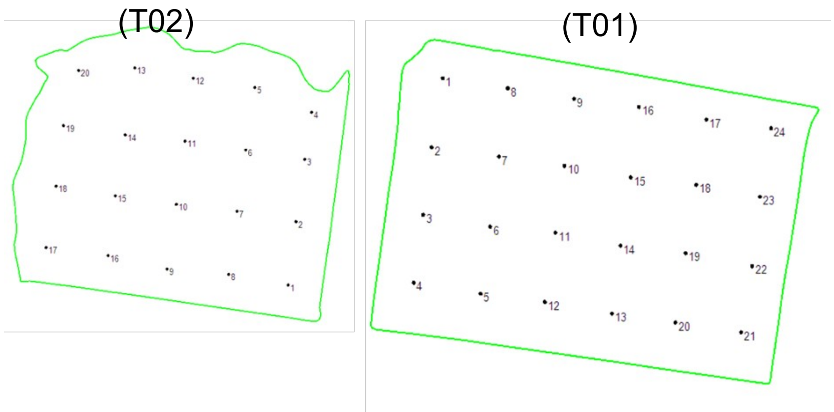


Figure 7: Geo-referenced grid points used for soil sampling and management of fertility requirements.

As shown in Figure 7, each grid point was subject to soil fertility analysis (P, K, Ca, Al, B, Cu, Fe, Mn, Zn, Co, Mo). Every year, over five years, PA assisted the definition of the nutrient requirements, accounting for spatial and temporal variability of soil. In practice, after soil analysis, recommendations for fertilization were facilitated using maps, explicitly revealing the spatial variation of requirements, for each soil attribute (Trevisan and Molin, 2008).

As shown in Figure 3, clay content were presented between 40% and 60%. An important aspect in fertility management is the clay content, the greater productivities are expected in soils with more than 15% of clay (Embrapa, 2013).

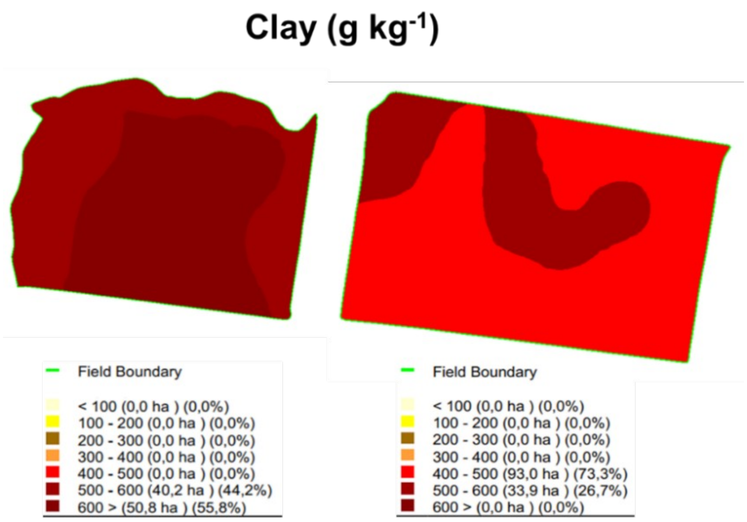
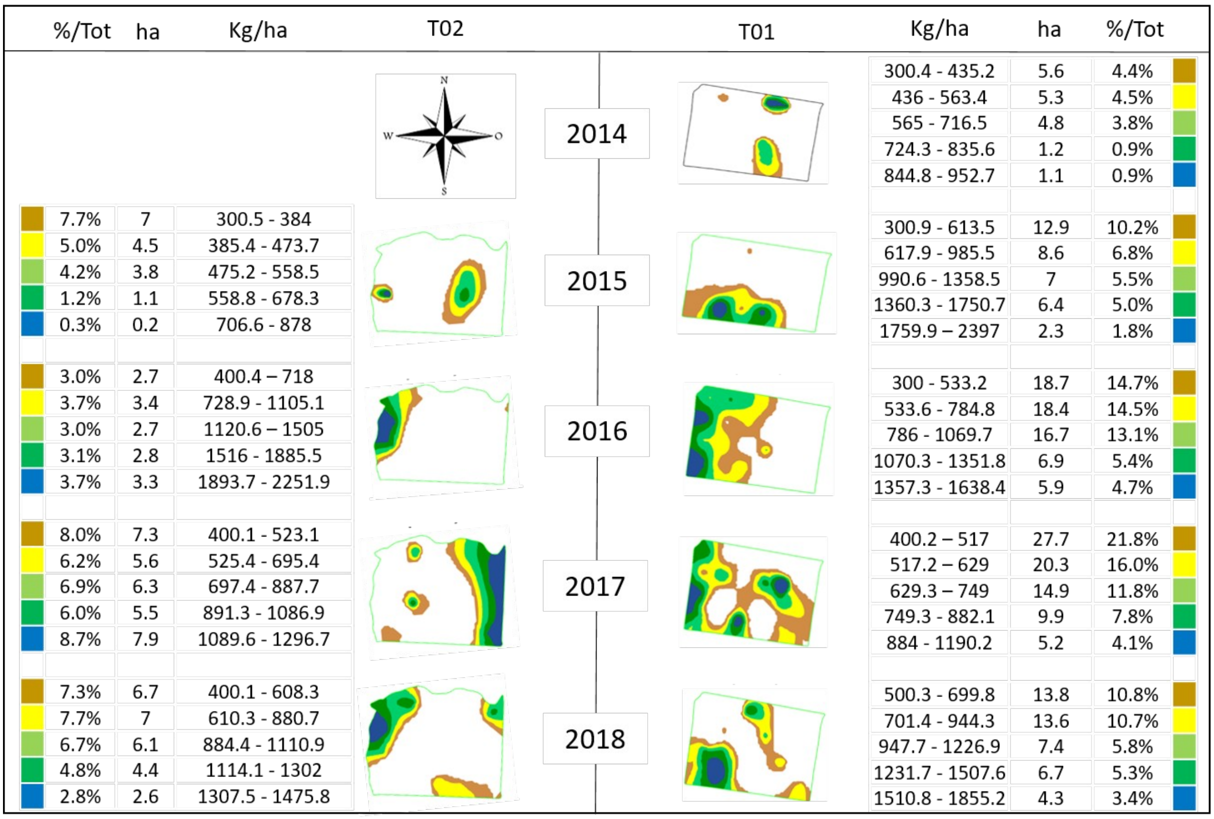


Figure 8: Variability of clay content.

The lime recommendation can change year by year over the spatial and temporal variability in the soil fertility (Bottega et al., 2017). We can see over the years (Figure 4) the soil fertility behavior changing by lime recommendation maps due to land-use and environmental effects (Benedito et al., 2018; Goenster-Jordan et al., 2018). The adoption of localized nutrition has positive effects on soil quality supporting the stability of the whole agro-ecosystem (Mininni et al., 2018).



T02:

Year	%/Tot	ha	Kg/ha
2015	7.7%	7	300.5 - 384
2015	5.0%	4.5	385.4 - 473.7
2015	4.2%	3.8	475.2 - 558.5
2015	1.2%	1.1	558.8 - 678.3
2015	0.3%	0.2	706.6 - 878
2016	3.0%	2.7	400.4 – 718
2016	3.7%	3.4	728.9 - 1105.1
2016	3.0%	2.7	1120.6 – 1505
2016	3.1%	2.8	1516 - 1885.5
2016	3.7%	3.3	1893.7 - 2251.9
2017	8.0%	7.3	400.1 - 523.1
2017	6.2%	5.6	525.4 - 695.4
2017	6.9%	6.3	697.4 - 887.7
2017	6.0%	5.5	891.3 - 1086.9
2017	8.7%	7.9	1089.6 - 1296.7
2018	7.3%	6.7	400.1 - 608.3
2018	7.7%	7	610.3 - 880.7
2018	6.7%	6.1	884.4 - 1110.9
2018	4.8%	4.4	1114.1 - 1302
2018	2.8%	2.6	1307.5 - 1475.8

T01:

Year	Kg/ha	ha	%/Tot
2014	300.4 - 435.2	5.6	4.4%
2014	436 - 563.4	5.3	4.5%
2014	565 - 716.5	4.8	3.8%
2014	724.3 - 835.6	1.2	0.9%
2014	844.8 - 952.7	1.1	0.9%
2015	300.9 - 613.5	12.9	10.2%
2015	617.9 - 985.5	8.6	6.8%
2015	990.6 - 1358.5	7	5.5%
2015	1360.3 - 1750.7	6.4	5.0%
2015	1759.9 – 2397	2.3	1.8%
2016	300 - 533.2	18.7	14.7%
2016	533.6 - 784.8	18.4	14.5%
2016	786 - 1069.7	16.7	13.1%
2016	1070.3 - 1351.8	6.9	5.4%
2016	1357.3 - 1638.4	5.9	4.7%
2017	400.2 – 517	27.7	21.8%
2017	517.2 – 629	20.3	16.0%
2017	629.3 – 749	14.9	11.8%
2017	749.3 - 882.1	9.9	7.8%
2017	884 - 1190.2	5.2	4.1%
2018	500.3 - 699.8	13.8	10.8%
2018	701.4 - 944.3	13.6	10.7%
2018	947.7 - 1226.9	7.4	5.8%
2018	1231.7 - 1507.6	6.7	5.3%
2018	1510.8 - 1855.2	4.3	3.4%

Figure 9: Spatial and temporal variability of nutrient requirement (lime) in two commercial cropping systems (T02; T01) (soybean/winter-maize) in Central Brazil.

The same procedure was made for all nutrient requirements and recommendations following the step by step of precision agriculture in fertility management in order to attend the guidance and technical reports from main researcher in PA technologies in Brazil, the LAP - *Precision Agriculture Lab of São Paulo University* (Colaço and Molin, 2015), EMBRAPA - *Brazilian Agricultural Research Corporation* (Broch and Ranno, 2012) and the MAPA - *Ministry of Agriculture, Livestock, and Food Supply* (MAPA, 2013).

The mapping of fertility can present effects in the amount of fertilizers and fuel consumption in the whole production system (Balafoutis et al., 2017). We analyzed the contribution of each operational stage (Figure 7) in order to identify the behavior of PA technologies in both systems.

2.3 Conventional practices

Conventional practices was based on the study developed by EMBRAPA (Folegatti-Matsuura et al., 2018) in Mato Grosso do Sul state of Brazil over the period 2012-2016 that they did not consider the use of PA technologies. That dataset includes the yield of 3 Mg ha^{-1}, the inputs of seeds, mineral fertilizers and pesticides. We adapted the inventory to get the equivalency in both system.

2.4 Scope

The system boundaries (Figure 4) were based on the “cradle to farm gate” inventory, accounting indirect emissions associated with the farm inputs (i.e. fertilizers, pesticides, seeds, machinery, fuel and infrastructure), which consisted material extraction, manufacture, infrastructure, transport and disposal. Grain drying operations were not included.

The functional unit (FU) to which the system inputs and outputs were related was one kilogram of soybean grain with 13% of moisture content after harvest.

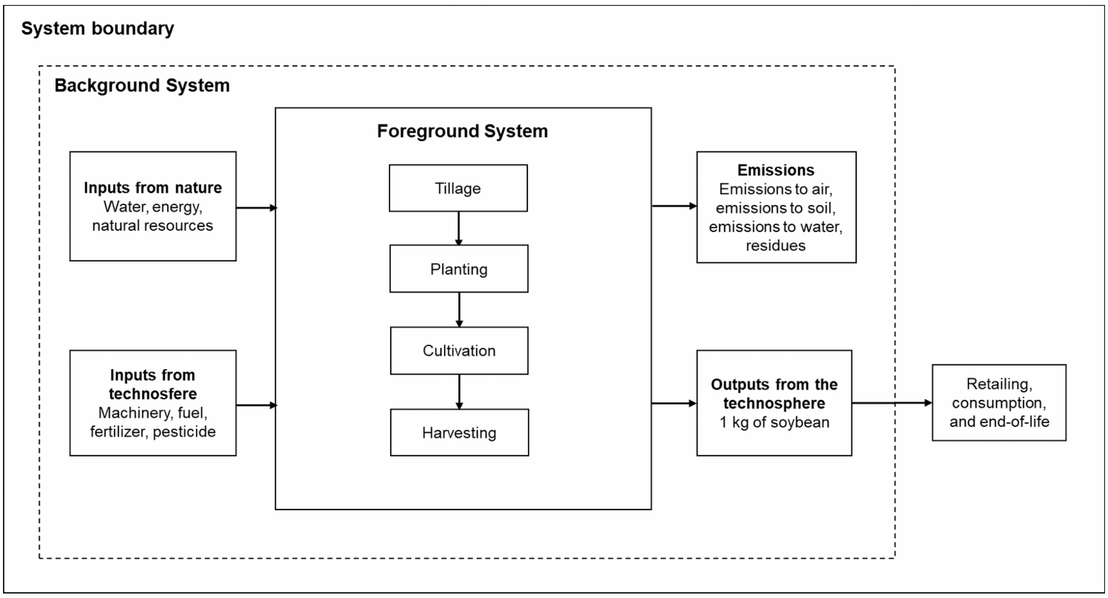


Figure 10: System boundaries of soybean production.

2.5 Life Cycle Inventory

The PA system data were gathered by farmer’s data cooperation (nutrient inputs in field) and EMBRAPA research (chemicals). The life cycle inventory of PA system is an accounting of all inputs and outputs, as foreground data, and were not calculated the direct emissions. The background data to complement the analysis were obtained from the Ecoinvent 3.0 database (Nemecek et al., 2015).

The conventional system were based on the LCI available in Ecoinvent database developed for a team of Brazilian researchers (Folegatti-Matsuura et al., 2018) that calculated the environmental exchanges of chemicals applied in the soybean production following the Agroscope guides (Nemecek et al., 2015; Nemecek and Schnetzer, 2012).

The pesticide data were used the same in both system production supporting the focus on fertility management. The lime and gypsum amount were based on crop period per year (Nemecek et al., 2015). The P (monoammonium phosphate) and K (potassium chloride) fertilizer were based on the recommendation of crop requirement. The average of seed and micronutrients in PA system were larger than conventional per hectare, but when is calculated for reference flow got a lower number.

Table 3: Farm input and output data per hectare.

Parameter	Input/Output ha^{-1}	Unit	PA	Conventional	Source (PA)
Tillage	Lime ($CaCO_3$)	kg	84,67	130,00	measured
	Gypsum ($CaSO_4$)		100,00	130,00	measured
	2,4 D	kg a.i.	0,90	0,00	measured
	Glyphosate		0,80	0,80	Folegatti-Matsuura et al., 2018
	Paraquat		0,40	0,40	Folegatti-Matsuura et al., 2018
	Fuel	l	3,15	-	measured
Planting	P_2O_5	kg	51,88	70,00	measured
	Seed		55,00	50,00	measured
	Fuel	l	5,89	-	measured
Cultivation	K_2O	kg	51,88	70,00	measured
	Molybdenum		0,025	0,020	measured
	Cobalt		0,0050	0,0025	measured
	Copper		0,03	0,02	measured
	Carbendazim	kg a.i.	0,501	0,501	Folegatti-Matsuura et al., 2018
	Azoxystrobin		0,12	0,12	Folegatti-Matsuura et al., 2018
	Thiamethoxam		0,0333	0,0333	Folegatti-Matsuura et al., 2018
	Lambda-cyhalothrin		0,0125	0,0125	Folegatti-Matsuura et al., 2018
	Cyproconazole		0,048	0,048	Folegatti-Matsuura et

					al., 2018
	Mineral oil		0,642	0,642	Folegatti-Matsuura et al., 2018
	Fipronil		0,03	0,03	Folegatti-Matsuura et al., 2018
	Pyraclostrobin (prop)		0,003	0,003	Folegatti-Matsuura et al., 2018
	Thiophanat-methyl		0,027	0,027	Folegatti-Matsuura et al., 2018
	Thiodicarb		0,096	0,096	Folegatti-Matsuura et al., 2018
	Chlorimuron-ethyl		0,025	0,025	Folegatti-Matsuura et al., 2018
	Bifenthrin		0,020	0,020	Folegatti-Matsuura et al., 2018
	Imidacloprid		0,0999	0,0999	Folegatti-Matsuura et al., 2018
	Glyphosate		2,16	2,16	Folegatti-Matsuura et al., 2018
	Paraquat		0,30	0,30	Folegatti-Matsuura et al., 2018
	Fuel	l	3,25	-	measured
Harvesting	Grain production	kg	3780,00	3000,00	measured
	Fuel	l	3,00	-	measured

Apparently, the fuel consumption per hectare was lower in PA than conventional system due to auto-guidance effect reducing the overlapping and linear traffic in the field. The conventional system have not this issue by operational stage, but it is a concrete fact from farmer's opinion and literature (Balafoutis et al., 2017; Gasso et al., 2014b; Li et al., 2016; Chagas et al, 2012).

2.6 Life Cycle Impact Assessment

Impact assessment was based on method of *CML-IA baseline 2000* in the *3.2* version (Nemecek et al., 2016) and the software *SimaPro – pre consultants 8.1* was used to perform calculations. The impact categories analyzed were: eutrophication potential (EP), global warming potential (GWP), human toxicity potential (HTP) and acidification potential (AP). The categorization of impacts was calculated for 1 kg of soybean grain after harvesting with 13% moisture content.

3 RESULTS AND DISCUSSION

The important inputs of system were reduced with PA in comparison to conventional practice (table 2) and this fact reflect to decreasing in all impact categories analyzed (Table 3). These results demonstrate the potential of PA technologies in agricultural systems through the effect of optimizing the number of fertilizers in the field by fertility management.

Table 4: Life Cycle Assessment between conventional and precision agriculture systems (per 1 kg of soybean).

Environment impact category	Unit	Conventional	PA
Acidification (AP)	kg SO_2 eq	0,00151	0,00103
Eutrophication (EP)	kg PO_4 eq	0,00549	0,00215
Global warming (GWP 100a)	kg CO_2 eq	0,185	0,132
Human Toxicity (HTP)	kg 1,4-DB eq	0,0783	0,0630

The Life Cycle Assessment of soybean with PA practices over the period 2014-2018 reached a difference of 31.79% (AP), 60.84% (EP), 28.65% (GWP) and 19.54% (HTP). A decrease in all impact categories even disregarding the direct emissions in-field, the results tends significantly to positive effect by PA technologies in the fertility management. The optimization of fertilizer distribution is able to tackle to environmental harmful and contribute to sustainable agriculture (Jensen et al., 2012).

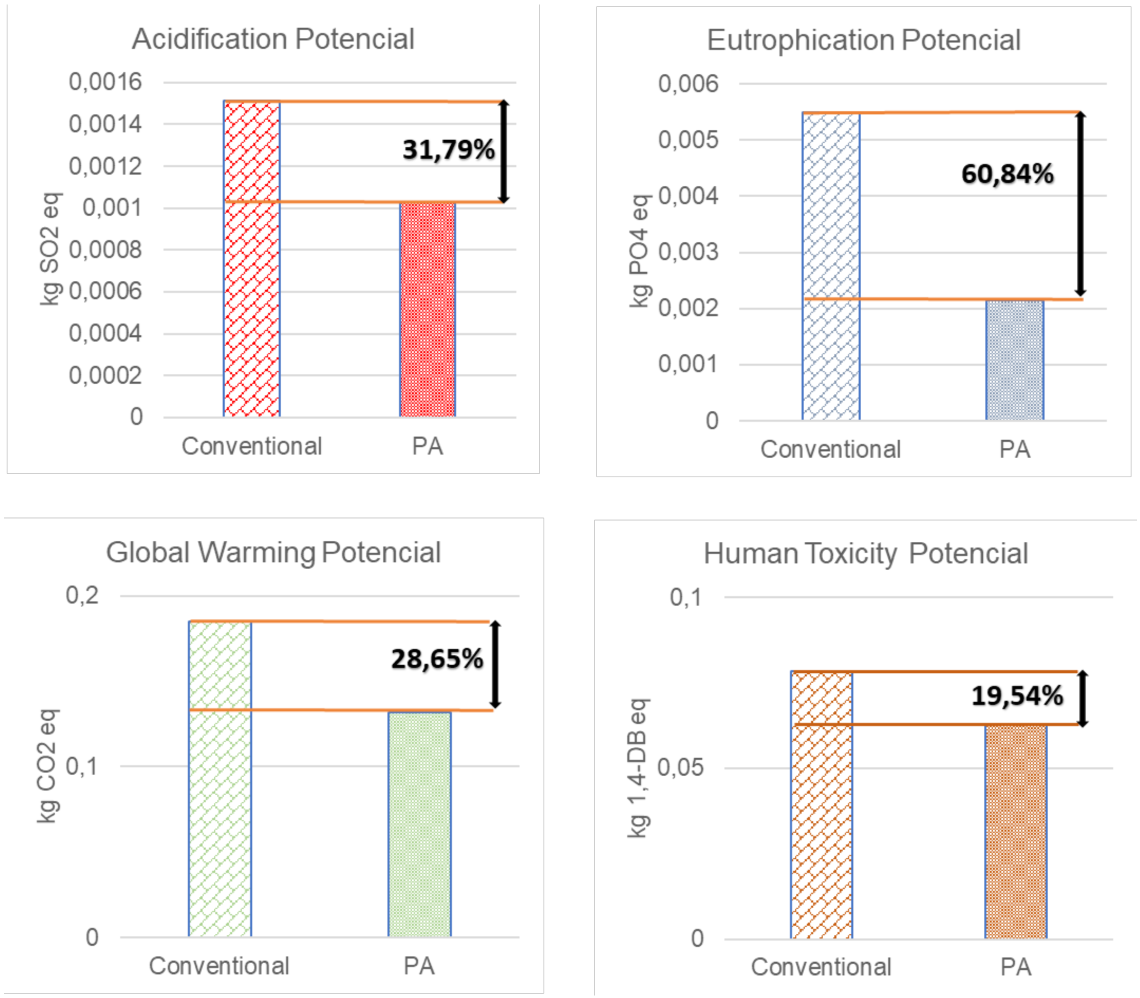


Figure 11: Difference in percentage by impact assessment categories between conventional and precision agriculture (per 1kg of soybean).

The analysis of impact assessment of this study follow the trend of other studies that used LCA methods to measure the environmental impacts of the use of PA technologies in different crops. Gasso et al. (2014) got a significantly reduction of 50% in GWP, 33% in AP, 29% in EP and 3-15% in HTP just analyzing the effects from controlled traffic farming in wheat production. The use of controlled traffic farming in sugarcane production promoted one cycle else compared to other scenario without that technology and reduced GWP and HTP in 0.86% and 8.99%, respectively (Chagas et al., 2012).The nitrogen application in corn production by canopy sensors and variable-rate declined 10% in GWP, 22% in AP and 16% in EP (Li et al., 2016). Precision viticulture techniques (fertility management, N application by remote sensing and variable-rate irrigation) achieved a decreasing of 25-28% in GWP between vineyards, reducing the carbon footprint in grape production (Balafoutis et al., 2017).

If we compare system by system, PA technologies present lower environmental impacts (Table 3), but in the LCA perspective we have a deeper observation and when the operational stages are separated to understand the individual contribution in the system, interesting observations can be highlighted (Figure 12).

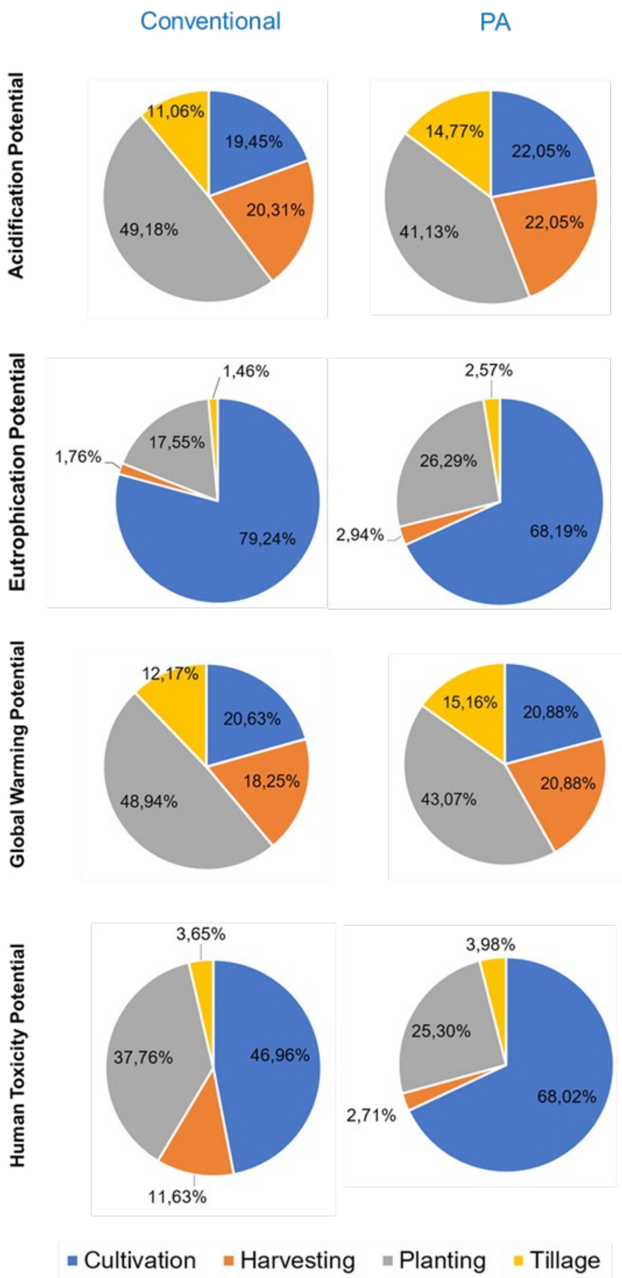


Figure 12: Impact contribution by practices in conventional and precision agriculture systems in soybean production.

In the Acidification Potential (AP) and Global Warming Potential (GWP) the planting operation got a larger slice in the cake in both systems of 41.13% and

49.18%, PA and conventional, respectively. It can be explained for the seed contribution to those environmental impacts. Into the soybean seed process is found another life cycle of soybean production and all process and emissions aggregated adding up the environmental impacts. Despite the higher number of seed between systems (Table 2) the PA system also have a higher productivity (26%). This issue can attenuate the contribution of planting operation in PA system and increasing the contribution of the others stages (Figure 6). Analyzing the planting operation, we observed less approximately 13% in the PA system compared to conventional production.

Cultivation and harvesting operation have a substantial contribution in AP and GWP categories due to mainly building machine process and the use of fossil fuel but the use of fertility management by PA technologies it is possible to reach from 10% to 20% of reduction in the environmental impacts, approximately.

With no-tillage practice in the soybean production the tillage operation have not been a bottleneck in environmental impacts in grain production (Telles et al., 2018). In both systems, the main process that contribute to all impact categories in tillage stage are the *application of plant protection product by field sprayer* (20-50%), and *fertilizing by broadcaster* (2-5%). And PA technologies reduced nearly 20% in these unit process.

The cultivation operation has a relevant piece in the Eutrophication and Human Toxicity impact categories. But this event is explainable in the LCA perspective. In PA system we got a reduction of 10-20% on the main process unit, in other words in a life cycle thinking we can get a systemic view and the understanding that a breakdown in a field stage can develop a chain reaction in whole value chain (Plouffe et al., 2011). The concentration of fertilizer and pesticides is on the cultivation stage. Therefore, there is a great interaction from nutrients, heavy metals and chemicals to the soil and water (Balafoutis et al., 2017; Nemecek et al., 2015).

4 CONCLUSIONS

Although the performance with the best available information, the limitations exist: different period analyzed between systems; local conditions such as weather, soils, and management practices; in-field direct emissions were not considered. On the other hand, structuring the analysis as a comparison reduces the importance of uncertainties focusing on the potential contribution of fertility management by precision agriculture to environmental impacts.

The successfully in all impact categories expose the importance of PA technologies adoption by farmers to contribute to agenda of the Sustainable Development Goals. This study meets the lack of information about benefits of technologies application in field that would support financial incentives policy more inclusive.

It is clear that the fertility management efficiency and environmental performance can be improved if PA technologies are applied on the soybean production system. But PA technologies and practices are part of a vast portfolio of equipment and techniques, and there is a need for environmental performance information in order to boost the adoption of powerful tools to reach sustainable agriculture.

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