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SUSTAINABILITY

ENVIRONMENTAL PROGRESS & SUSTAINABLE ENERGY

Greenhouse gas emissions associated with four types of fertilization for corn crops in a Mediterranean basin

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Abstract

The environmental impacts associated with the intensification of agricultural practices have become an emerging issue, and new techniques are being developed to satisfy public demands. The application of fertilizers is a crucial step for agriculture practices. Building upon previous studies at a Mediterranean basin, the objective of the research presented herein was to quantify the greenhouse gas emissions associated with four different types of fertilization in the production of corn: traditional (NPK 8–15-15 and urea), controlled-release (NPK 8–15-15, and a combination of urea and encapsulated urea), and two types of fertilization with pig slurry (NPK 8–15-15, pig slurry and different amounts of urea). The Life Cycle Assessment methodology was employed, with the Ecoinvent database and the IPCC 2013 GWP 100y impact assessment method. The results revealed that traditional fertilization emitted 3251 kg CO_2-eq/ha·year, against 2191 kg CO_2-eq/ha·year for controlled-release fertilization. Pig slurry fertilization emitted 2160 kg CO_2-eq/ha·year, and its alternative with less urea, only 1030 kg CO_2-eq/ha·year. The utilization of pig slurry solves the issue of its disposal and entails lower costs (commercial fertilizer prices follow the prices of oil and gas). The results demonstrated the potential of controlled-release fertilization and pig slurry to contribute to climate change mitigation.

KEYWORDS
controlled-release, environmental impacts, life cycle assessment, mitigation, pig slurry, urea

1 | INTRODUCTION

Environmental impacts associated with the increase in agricultural production are nowadays a critical issue, and public demands are guiding the development of new practices, both on the supply and demand sides. Consumers now prefer fresh, local, and less processed foods (with short supply chains, reducing dependence on energy-intensive storage), and reduced packaging. On the supply side, producers still consider the environment a problem and risk factor. Still, researchers have been assessing different production processes from environmental perspectives to provide feedback on the best available practices.

The global consumption of fertilizers is mainly driven by three fertilizer nutrients (nitrogen, phosphate, and potassium). It is estimated that 75% of the cultivated agricultural land depends on mineral fertilizers, with approximately half of the amount applied to cereals.[1] Agricultural food production doubled in 1982–2017, with a significant increase in nitrogen and phosphorus fertilization.[2]

Although agricultural production systems with high yields do not always contradict environmental safety, the excessive use of N fertilizer can cause adverse impacts.[3] The application of fertilizers can be a significant contributor to the overall carbon footprint (equivalent to GHG emissions) of agricultural products,[4] as verified by Carvalho et al.[5] when quantifying the GHG emissions of biodiesel production from refined soybean oil in Brazil, where 20% of the emissions could be attributable to the fertilizers employed in the production of soybean. When assessing the overall GHG emissions of corn and wheat, Abrahão et al.[6] also verified that fertilizers were also the main contributor (liquid fertilizers 69% of emissions, and compound fertilizers 18% of emissions).

Recognizing the importance of fertilization, Life Cycle Assessment (LCA) is a validated, consolidated methodology that can be applied to quantify the potential environmental impacts and verify the possibilities of trade-offs by comparing alternative products and technologies.[7] Hasler et al.[8] presented LCAs for different fertilizer product types and concluded that an optimized fertilization strategy could reduce the environmental burden by up to 15%.

The combined application of fertilizers is an attractive, viable approach to address the decrease of soil fertility in intensive cultivation conditions and possibly mitigate GHG emissions. The combination of organic and mineral fertilizers was successfully employed for corn, leading to higher crop yields and lower environmental risk compared to sole mineral fertilization.[9] The use of industrial residues (which present complex disposal) can also be an alternative. Industrial textile biosolid was employed for elephant grass fertilization and resulted in lower GHG emissions[10] and better total production with higher fiber content[11] than chemical fertilization. This highlights the necessity of comparing different agricultural practices to identify the option with the lowest environmental burden. Also, because the agricultural sector has been experiencing an intensification of livestock production, manure management has emerged as a challenge and environmental problem. Different corn production scenarios were compared in Spain, and it was verified that organic digestate (cow manure) fertilizers could help offset GHG emissions in comparison with mineral fertilizers.[12]

Besides the limited studies on comparing agricultural fertilization practices in Mediterranean areas, none have considered pig slurry as an alternative. There are insufficient primary data, and fragile methodologies have been adopted to satisfice* necessities. At this point, we present the innovations that will be added to our research to even further expand the existing knowledge base. Building upon the statement that fertilizers should be part of every LCA of food and agricultural products,[8] this is the first study to quantify and compare the GHG emissions associated with four different types of fertilization in the production of corn: traditional corn fertilization, controlled-release fertilization and two types of fertilization with pig slurry. The latter is added to address the recent environmental concern associated with the disposal of pig slurry in pig farming practices. Actual field data were obtained and employed within the LCA to verify the potential to mitigate climate change by applying pig slurry instead of commercial fertilizers to corn crops.

2 | MATERIAL AND METHODS

The LCA methodology has been widely employed to quantify the environmental impacts of products, processes, and activities. The LCA can include the extraction of raw materials, manufacture, processing, transportation, operation and maintenance, and final disposal. The procedure is a phased approach, with four steps: definition of goal and scope, inventory analysis, impact assessment, and interpretation.

The first step encompasses the system boundaries and functional unit (to which all material and energy flows relate to). The second step builds the inventory, including all input and outputs associated with the functional unit (reference for the subsequent steps). The third step applies an environmental impact assessment method to quantify the (potential) environmental impacts caused by the emissions analyzed in the previous step. The final step is the analysis of results, discussion, with conclusions and recommendations. A complete description of LCA can be found in Guinée.[13]

The software used for the development of the LCA was SimaPro® 9.0.0.35,[14] which follows the procedures of ISO 14040[15] and 14044.[16] The database employed was Ecoinvent.[17] Recognizing that climate change is currently often seen as the most pressing environmental threat, the environmental impact assessment method selected was IPCC 2013 GWP 100y,[18] which employs the conversion factors published in the IPCC reports to group atmospheric pollutants in a common metric, expressing the results in terms of kg CO_2-eq. This indicator is also known as the carbon footprint and herein will account for the processes that contribute to the emission of GHG during the manufacture and transportation of fertilizers. The functional unit utilized herein encompasses the fertilizer inputs and required transportation for one hectare throughout 1 year. The only difference between the four treatments was the fertilizer itself and the processes related to fertilization (production and transport mainly), with all other procedures (irrigation, seeds, harvest, and others) being carried out in the same way for all types of fertilization studied. This procedure reproduced the actual situation in the Mediterranean basin studied, and the intention was to understand the environmental impacts related to fertilization only. Field tasks associated with the fertilization process itself (machinery for deposition on the agricultural plots) were considered the same for the four treatments.

The study was based on actual data and information on the inputs applied and procedures performed by corn farmers in the Ebro river valley in Spain. Part of the data was obtained from a 7.38 km^2 basin, where several hydrological, geological, climatic, and agricultural studies have been performed throughout more than 15 years by the authors.[6,19–27] Data obtained from these studies include, but are not limited to: dynamics of the transition of the basin into irrigated land, irrigation systems implemented, established crops, irrigation volumes applied, type and quantities of seeds, fertilizers, and pesticides used, and standard irrigation system materials. The studies of Kongshaug[28] and Davis and Haglund,[29] which investigated the use of energy in the production processes and emissions from fertilization production, were utilized to compute missing data.

The comparison was made for the traditional corn fertilization (type A), controlled-release fertilization (type B), considered by many farmers and organizations to be more efficient due to slow-release,[30,31] and fertilization with pig slurry (type C), also very common in the Ebro valley and other areas of the world where there is pig farming (Table 1).

In addition to these three types of fertilization that are usually used by corn farmers, an additional alternative was tested: low-urea pig slurry alternative (type D) (Table 1). The nitrogen values used were

TABLE 1 Inventory of inputs for corn fertilization type A (traditional), type B (controlled-release), type C (pig slurry), and type D (pig slurry alternative)

	Quantity			
Inputs	**Type A**	**Type B**	**Type C**	**Type D**
NPK 8–15-15	625 kg/ha·year	625 kg/ha·year	625 kg/ha·year	625 kg/ha·year
Urea	750 kg/ha·year	150 kg/ha·year	380 kg/ha·year	50 kg/ha·year
Encapsulated urea	—	270 kg/ha·year	—	—
Capsule	—	30 kg/ha·year	—	—
Pig slurry	—	—	50,000 kg/ha·year = 170 kgN/ha·year	50.000 kg/ha·year = 170 kgN/ha·year
Transport NPK and urea	12 km (one way) 2 doses	12 km (one way) 1 dose	12 km (one way) 2 doses	12 km (one way) 2 doses
Transport pig slurry	—	—	3 km (one way) 1 dose	3 km (one way) 1 dose

TABLE 2 Greenhouse gas emissions for four types of fertilization for corn crops

Fertilization type	GHG emissions (kg CO_2-eq/ha·year)
Type A (traditional)	3251
Type B (controlled-release)	2191
Type C (pig slurry)	2160
Type D (pig slurry alternative)	1030

still considered productive by many farmers, with total nitrogen fertilization corresponding to 243 kg N/ha·year.

The pig slurry application followed the maximum permissible application rate of livestock manure to land specified in European regulations of 170 kg N/ha·year.[32] For pig slurry transport, the pig farms usually are less than 3 km from the cultivation area, and the transportation is carried out by tractors, with a 20 m^3 bucket capacity. In commercial fertilizers, the average distance between the cooperative or

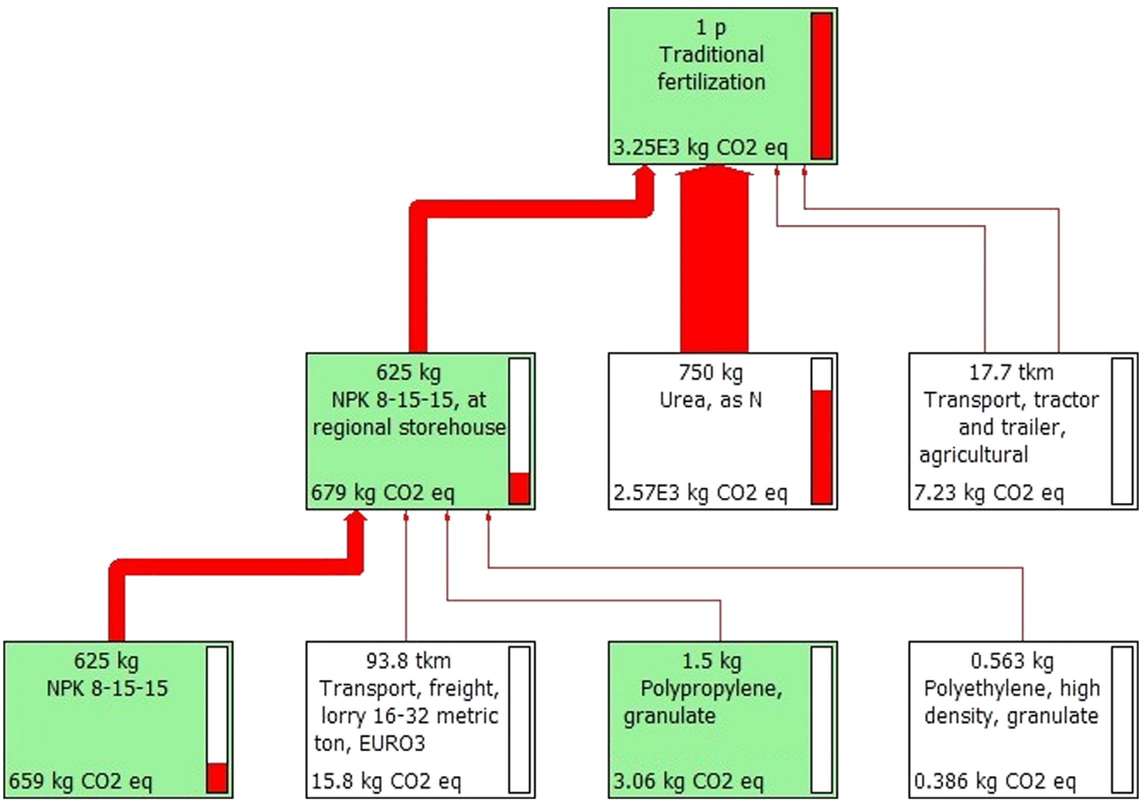

FIGURE 1 Annual emissions per hectare associated with traditional fertilization (type A) for corn crops [Color figure can be viewed at wileyonlinelibrary.com]

other fertilizer suppliers and the growing areas (12 km) was considered. For controlled-release fertilization, 10% of the weight corresponds to the capsules, which are produced from organic polymers (corn starch-based).

3 | RESULTS

Through the considerations made in the inventory step, it was possible to estimate the GHG emissions of the four types of fertilization in corn cultivation (Table 2). The type of fertilization that presented the highest GHG emissions was type A (traditional), which is widely employed in the Ebro River valley, in Spain, and other agricultural areas of Europe and the world. Type A GHG emissions were 48% higher than controlled-release fertilization (type B), demonstrating that controlled-release can significantly reduce GHG emissions from corn fertilization.

The main contribution to the high GHG emissions of type A fertilization was urea (Figure 1), responsible for 79% of the emissions (2570 kg CO_2-eq/ha·year). The contributions of NPK 8-15-15 and transportation were minimal compared to urea. Regarding road transportation, the EURO3 refers to the European emission standards that define the acceptable limits for exhaust emissions, established in 2000.

In type B fertilization, with controlled-release, the main contribution to emissions was derived from urea (Figure 2). However, as the total urea values were lower than in type A fertilization, the negative environmental impacts were lower. The capsules were responsible for only 3.2% of the type B emissions.

Fertilization with pig slurry (type C) resulted in impacts close to the controlled-release fertilization (type B), with emissions of 2160 kg CO_2-eq/ha·year. This result demonstrates the potential of using this residue as a fertilizer, contributing to reducing GHG emissions from agricultural areas and being an environmentally viable destination for a residue produced in large quantities in various regions of the world.

The main contribution to pig slurry emissions was also urea (60%), with NPK compound and transport accounting for only 34% of emissions (Figure 3). Pig slurry fertilization has been reproduced here as most farmers in the Ebro river valley do (as well as in other parts of Europe and the world). The relatively low emissions verified indicate that this is an environmentally viable agricultural path. Even so, these emission values could be further reduced by reducing the amount of urea applied so that the nitrogen fertilization

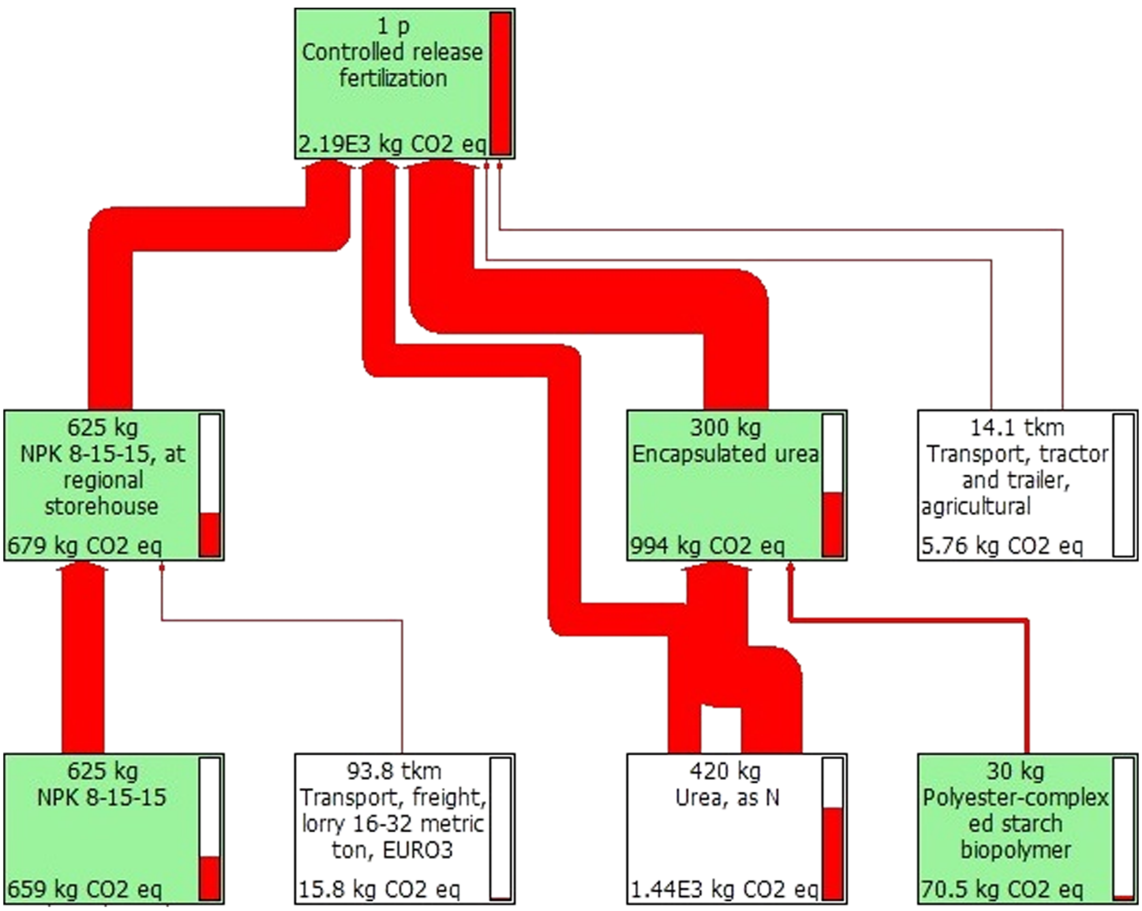

FIGURE 2 Annual emissions per hectare associated with controlled-release fertilization (type B) for corn crops [Color figure can be viewed at wileyonlinelibrary.com]

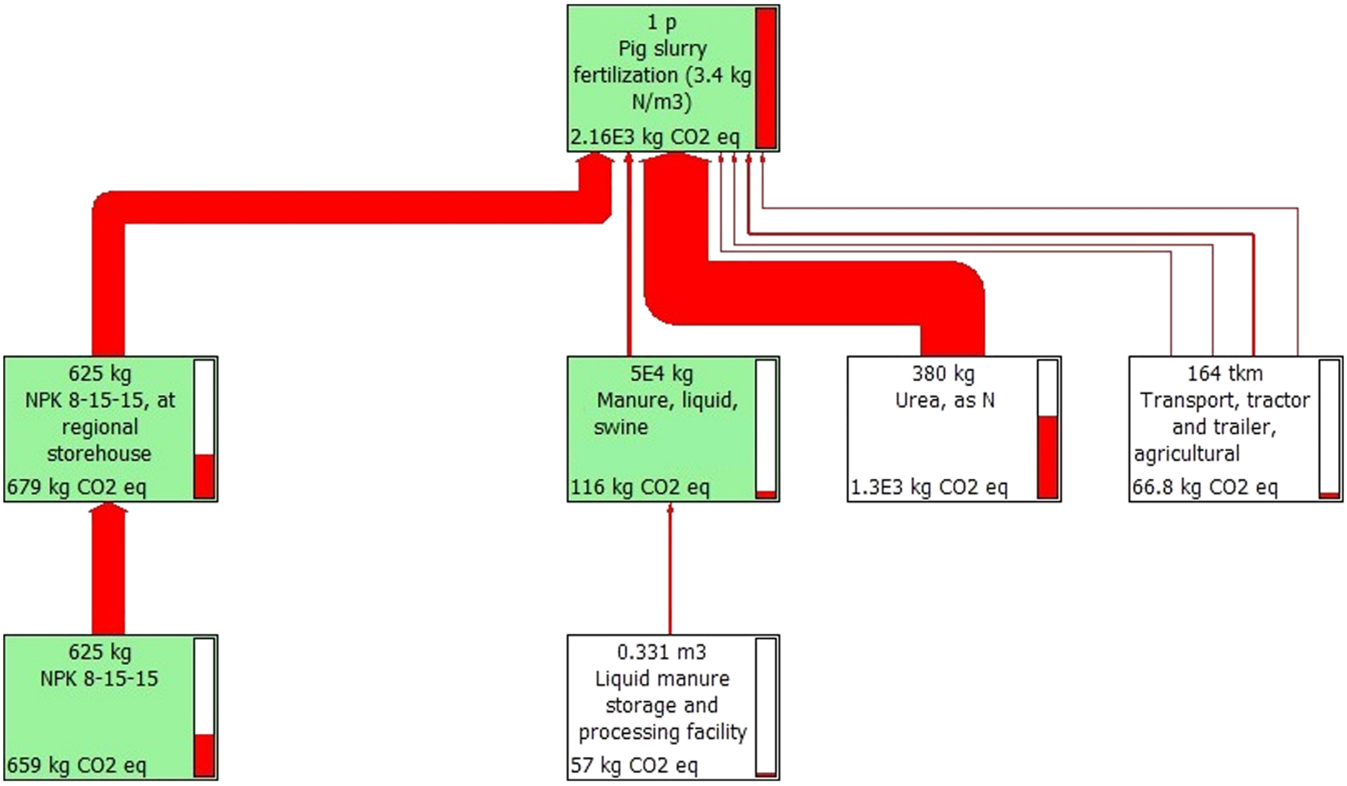

FIGURE 3 Annual emissions per hectare for pig slurry fertilization (type C) for corn crops [Color figure can be viewed at wileyonlinelibrary.com]

units are 243 kg N/ha·year, which is considered satisfactory for corn productivity.

This alternative was type D fertilization (pig slurry alternative), which demonstrated the lowest emission values in this study (only1030 kg CO_2-eq/ha·year). These emissions were 68% lower than type A (traditional), 53% lower than type B (controlled-release), and 52% lower than type C (pig slurry) (Table 2). The pig slurry alternative was the only type of fertilization in which the main contribution to the emissions was not from urea. With the nitrogen coming from pig slurry, it was possible to reduce urea's application to only 50 kg/ha·year. Thus, the main contribution came from NPK compound (66%), with urea in second place (17%) (Figure 4).

4 | DISCUSSION

Regarding comparison with existing scientific literature, the most critical aspects that hinder a direct comparison of results are the definition of the functional unit, the LCA method applied, impact allocation method, transparency of results, and lack of standardization when using the same methodology to model each inventory.[33]

Despite the application of other environmental impact assessment methods, other studies have verified lower negative environmental impacts using controlled-release (compared to traditional fertilization).[31,34] Noellsch et al.[35] and Gagnon et al.[36] demonstrated that controlled-release fertilization, despite initial higher economic costs, can be more profitable for the corn farmer. Noellsch et al.[35] verified that the application of controlled-release urea to low-lying areas of cornfields in claypan soils could improve crop performance and economic returns compared with urea application alone. Gagnon et al.[36] concluded that controlled-release fertilization can provide corn growers with greater flexibility in the fertilizer application timing, decreasing labor and reducing costs associated with multiple applications.

The application of pig slurry as fertilizer for corn crops was also considered an environmentally sound option in other studies.[37–40] Waste management is the most significant concern for pig production due to the high N and P content of animal excreta.[41] Therefore, its use as fertilizer can supply the needs of the crops, reduce eutrophication risks for water bodies, and reduce the impacts of the entire production chain of chemical fertilizers. Nevertheless, the maximum permissible application rate should always be followed. Bacenetti et al.[42] analyzed six corn fertilization scenarios and verified that pig slurry incorporation with straw collection presented better environmental results than mineral fertilizers.

A life cycle study compared pig slurry with synthetic fertilizer for corn production in Iowa (United States), and reported that pig slurry was better than synthetic fertilizer for abiotic depletion and about the same concerning eutrophication.[43] However, synthetic fertilizer performed better regarding global warming potential (due to the long-distance transport of pig slurry), which is the opposite of what was verified herein. In the actual case evaluated herein, the pig farms are usually less than 3 km from the cultivation area,

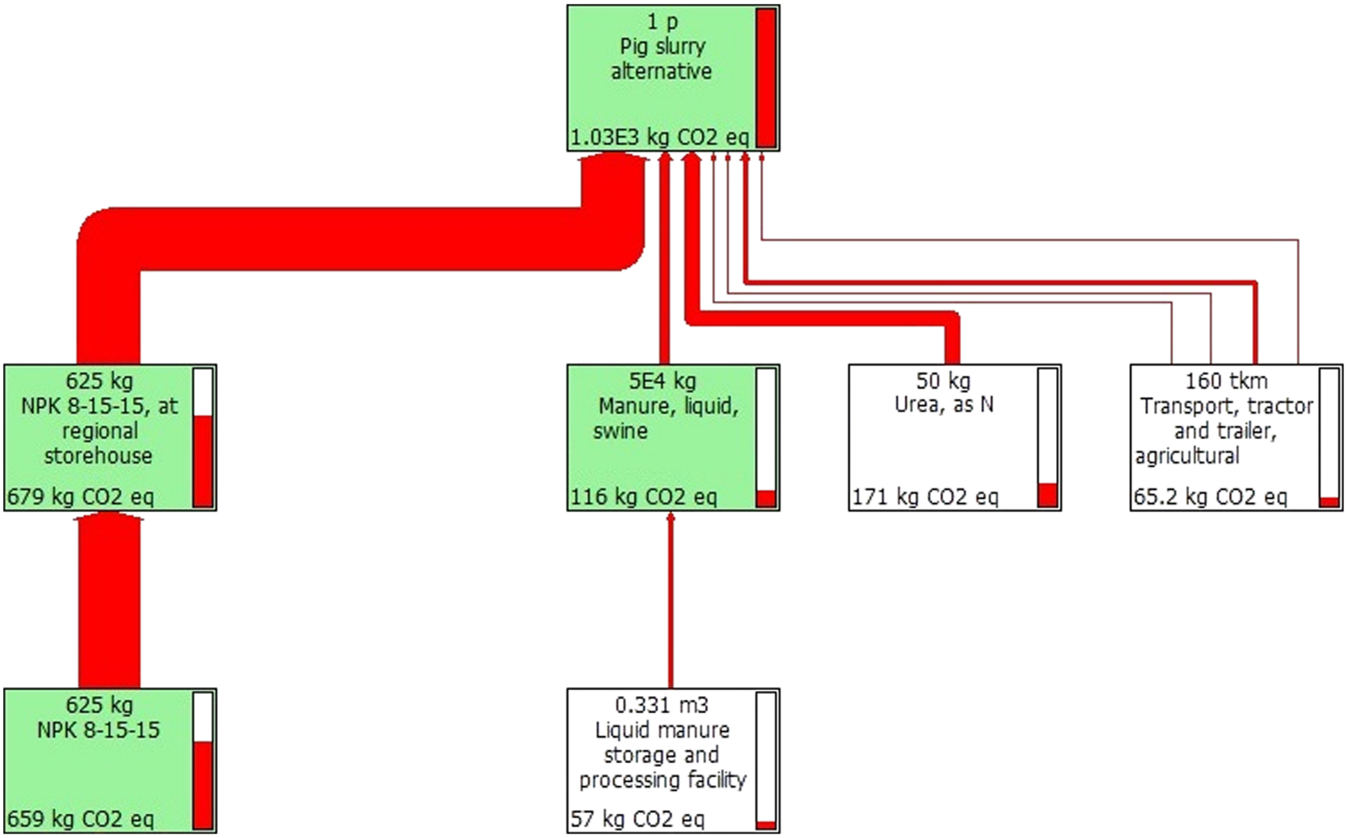

FIGURE 4 Annual emissions per hectare for pig slurry alternative fertilization (type D) for corn crops [Color figure can be viewed at wileyonlinelibrary.com]

being an advantage for fertilization types C and D. In this way, crop fields should be as close as possible to the pig farms to reduce the negative impacts of transportation. A 90 km distance would increase annual emissions associated with pig slurry alternative fertilization (type D) to 2810 kg CO_2-eq/ha·year, which is still better than type A (traditional) but worse than type B (controlled-release) (Table 2).

The reduction of N applied to the corn crops resulted in more significant drops in GHG emissions, which becomes apparent when comparing type C and type D (Table 2 and Figures 3 and 4). Some studies verified that it is possible to reduce N fertilization without reducing yields in corn crops.[44–46] Besides pig slurry, urea can be replaced by other residues such as sewage sludge, septic waste, and sludge compost,[47,48] dairy sludge,[49] tannery sludge,[50] and industrial sludge.[11,48]

Finally, it was verified that sustainable agricultural practices could be achieved while guaranteeing crop yield and limiting environmental impacts: the environmental performance of fertilization is highly dependent on its transportation and urea content, but overall, controlled-release and pig slurry fertilization were two good options from the viewpoint of GHG emissions. The pig slurry alternative (type D investigated herein) presented less urea in its composition and yielded a lower carbon footprint than the other options explored herein.

5 | CONCLUSIONS

This study quantified the GHG emissions associated with four different types of fertilization for the production of corn: traditional (NPK 8-15-15 and urea), controlled-release (NPK 8-15-15 and a combination of urea and encapsulated urea), and two types of fertilization with pig slurry (NPK 8-15-15, pig slurry and different amounts of urea).

The results of the LCAs revealed that traditional fertilization emitted 3251 kg CO_2-eq/ha.year, against 2191 kg CO_2-eq/ha·year for controlled-release fertilization. Pig slurry fertilization emitted 2160 kg CO_2-eq/ha·year, and low-urea alternative emitted only 1030 kg CO_2-eq/ha·year. The main contributor to the high GHG emission values of traditional fertilization was urea, responsible for 79% of the emissions.

Controlled-release and pig slurry fertilization are two good options from an environmental viewpoint, especially the pig slurry alternative option with less urea, which presented extremely low GHG emissions compared to the other options. The utilization of pig slurry solves the issue related to its disposal and can also be less expensive than using commercial fertilizer (as these prices follow oil and gas prices). The results demonstrated the potential of pig slurry to contribute to the mitigation of climate change, which is one of the most critical environmental issues nowadays. Although livestock manure is usually considered a problem, its utilization as fertilizer can help create a circular economy with value-added crops. The aforementioned aspects justify the creation of a research program of international relevance, founded on the experience accumulated and the already developed methodologies.

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AUTHOR CONTRIBUTIONS

Raphael Abrahao: Conceptualization; methodology; supervision; writing-original draft. **Monica Carvalho:** Formal analysis; methodology; software; writing-original draft; writing-review & editing. **Jesús Causapé:** Data curation; funding acquisition; supervision.

DATA AVAILABILITY STATEMENT

Data available upon request.

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ENDNOTE

* Accept an available option as satisfactory, as coined by Herbert Simon, 1956.

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