Life cycle inventory of physic nut biodiesel: comparison between the manual and mechanized agricultural production systems practiced in Brazil

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Abstract The physic nut (Jatropha curcas L.) is an oleaginous species recently introduced into Brazil for energy purposes. The technological framework for the development of the physic nut biodiesel productive chain in Brazil is still being set up. Two production systems are in practice at the agricultural level, the small scale manual system and the medium scale mechanized system. The objective of the present research was to assess the environmental performance of these two production systems by elaborating life-cycle inventories (LCIs) using a cradle-to-gate approach. The main environmental aspects of these LCIs are the synthetic fertilizers, pesticides, land-use changes and its emissions and the occupation of the land. Making use of the residues from the agroindustrial physic nut chain and the use of biological pest control methods could improve the environmental performance of these systems.

1 Introduction

Physic nut is an oleaginous species that originated in Central America and started being introduced into Brazil for motives of energy production in 2005. Interest in this species is due to its elevated oil productivity (1.5 t/ha) and its ability to adapt to marginal, degraded areas. Currently physic nut plantations account for about 60 thousand ha in Brazil in the Central-West, North and Southeast regions, but there are estimates that this could reach 750 thousand ha by 2020.

The physic nut biodiesel productive chain is currently being established in Brazil, and the technologies of grain, oil and biodiesel production are being adjusted to the conditions found in Brazil. At the agricultural level, the production systems currently practiced correspond to a small-scale system employing minimal cultivation and manual labor; and a second, medium-scale system, making use of conventional soil preparation and mechanization techniques.

Since it is an exotic species recently introduced into the country, a potential alternative source of energy to other fuels of vegetable origin whose productive chains have already reached high levels of development, such as sugarcane ethanol and soybean biodiesel, the potential environmental impact of producing physic nut biodiesel in Brazil deserves attention.

The objective of the present study was to evaluate the agricultural performance of the agricultural phase of physic oil biodiesel production using both manual and mechanized sytems, by way of the elaboration of their life cycle inventories.

2 Methods

2.1 Definition of the objective and scope

The methodological structure of this study was based on the ISO 14044 norm. The objective was to evaluate the environmental performance of two physic nut grain production systems practiced in Brazil: the manual and mechanized systems. The study was justified by the recent implantation of the physic nut crop in Brazil for energy purposes, with considerable perspective for expansion. The evaluation aims at offering subsidies to orientate adjustments to the physic nut grain production systems, with a view to improving their environmental performance. The target public were researchers, extension workers and other components of the physic nut biodiesel production chain.

The manual and mechanized physic nut production systems were defined as the product systems. The manual system is practiced on a small scale (up to 10 ha) employing minimal cultivation techniques and manual labor; the mechanized system is practiced on a medium scale (up to 100 ha) and employs conventional soil preparation techniques and mechanized labor.

The function of both systems is to produce physic nut grains destined for the synthesis of biodiesel. The functional unit of the systems is the production of physic nut grains in an area of 1 ha for 20 years. The reference flow was defined as the production of 79,500 kg dry physic nut grains.

The elementary processes included at the boundary of the product systems are the production and distribution of electrical energy, diesel oil, agricultural inputs [except the manufacturing of seeds, aluminum phosphate, copper sulphate, sulphur, fipronil and nonylphenol ethoxylate and the manufacturing and transport of raffia sacks, due to the unavailability of the data] and the production of physic nut seedlings and grains, including the post-harvest treatment. The manufacturing of agricultural machinery was not considered in this inventory. With respect to the criteria used to exclude the entrance of items, all those that attend the defined technological standard were considered in the LCIs.

With respect to the type and source of the data, the agricultural inputs correspond to the secondary data collected in adequate, up to date bibliographical sources [mainly 1] and information provided by specialists [2]; data referring to natural resources, to the manufacturing of agricultural inputs and to the production and distribution of electrical energy came from the data base Ecoinvent 2.2; the data referring to the manufacturing of diesel oil were obtained from Florin et al. (2008) [3]. The data on emmissions were estimated based on models found in the scientific literature [4,5,6,7,8,9,10].

With respect to the data quality criteria, the temporal coverage includes the period from 2006 to 2010 and the geographical coverage the current Brazilian producing regions. With respect to technological coverage, the manual production system employs minimal cultivation and manual labor at all steps of the crop, harvest and post-harvest handling, whereas the mechanized system employs conventional soil preparation and mechanization for the operations of plowing, liming, harrowing, furrowing, chemical fertilizing, leaf fertilization combined with phytosanitary treatment, hoeing and threshing. The technical recommendations for the Brazilian savanna were adopted as the reference for both systems and for small and medium sized production scales [1,2]. All the flows involved in the physic nut grain production systems were measured or estimated in this study, and the group of data were considered consistent.

The main presuppositions assumed in this study were: a) the density of the physic nut crop was 1250 plants/ha; b) its productive longevity was 20 years; c) the productivity was 4,500 kg dry grains/ha/year on reaching its maximum productive potential; d) the crop was not irrigated; e) the husks removed during dehusking on the farm constituted the solid residue; f) the distance between the storehouses and the farms was 70 km and 100 km for the manual to the mechanized systems, respectively (considering that the manual system was practiced in small production units, mostly in the Southeast region, more densely populated, whereas the mechanized system was practiced in larger units in the Center-West region and in the State of Tocantins, less populated areas); g) the carbon dioxide (CO_2) sequestered from the atmosphere during the growth of the physic nut plants was computed as an input from nature. A recognized limitation of this study was related to the fact that the physic nut productive chain is still in its implantation phase. This represents a difficulty in obtaining reliable, representative data for the inventory. Moreover, data obtained refer to the current technological stage of the productive chain, which could alter significantly as it develops.

2.2 Elaboration of the physic nut grain production inventory

To elaborate the physic nut grain production inventory, an annual production per ha of 200 kg was considered for the first year; 800 kg for the second year; 2000 kg for the third year; and 4500 kg for the 4th to the 20th years [2].

With respect to the natural resources, the prior use of the land for extensive pasture was assumed, transformed into a permanent crop.

The amount of CO_2 sequestered during the growth of the physic nut plants was calculated by adding up [the mass of the aerial part of the plant (excluding the leaves and fruits, 3.9 kg/plant * 1250 plants/ha) multiplied by the percent C (51.2%)] and the [mass of the plant roots (1.6 kg/plant * 1250 plants/ha] multiplied by the percent C (52%)], multiplied by the conversion factor for C into CO_2 (44/12) [11].

The consumption of agricultural inputs considered the recommendation of Dias et al. (2007) [1], adjusted by Laviola (2009) [2]. The adjustments corresponded to transforming the values originally calculated for a density of 1111 plants/ha to a density of 1250 plants/ha.

The exclusive use of limestone as an agricultural corrective throughout the entire production, was considered in this study, using the amount indicated for the first years. More limestone was used in the mechanized system because it was applied as a corrective to the entire area during soil preparation, whereas in the manual system it was only applied to the holes.

The organic fertilizer (poultry manure) was only used in the manual production system, with a mean density of 0.3 g/ cm^3 and N content of 3%. The formulated NPK fertilizer (urea as N; single superphosphate as P_2O_5; and potassium chloride as K_2O), corresponding to: 0 to 1 year, 20-00-15; after 1 year, 20-10-15. It was considered that urea contains 46.67% of N; potassium chloride (KCl), 63.65% of K_2O; and single superphosphate (SSP), 18.4% of P_2O_5. Only the mechanized system used leaf fertilizer. In addition to KCl, this contained boric acid, zinc monosulphate (with 20% zinc), copper sulphate (with 26.36% Cu) and sulphur. The copper sulphate and sulpher also act as pesticides (the former as a fungicide and the second as an acaricide and fungicide). The amounts of leaf fertilizer indicated in the chapter on "Custos e Rentabilidade" [1] were adopted, adjusted for a density of 1250 plants/ha, considering 5 chemical elements and equal amounts of each element.

As yet no pesticides have been approved in Brazil for use with the physic nut crop and thus the study was carried out with the hypothesis of using: glyphosate as the herbicide; fipronil as the formicide; equal amounts of thiametoxam and lambda-cyhalothrin (87% in the commercial product; piretroid chemical group) as the insecticide; abamectin (1.8%; biopesticide) as an insecticide/acaricide; methyl thiophanat (70%; benzimidazole) as the fungicide [2]. Generic inventories were used for the "production of insecticides" and "production of fungicides".

Only the mechanized production system consumed diesel oil in its agricultural operations. To calculate the diesel oil consumption, three applications of formulated fertilizer/year were considered, the first being combined with liming; two hoeings/year (as from the 2nd year) and the transport of the harvest (as from the 2nd year) [1,2]. The hours spent in the agricultural operations were calculated according to Dias et al. (2007) and Laviola (2009) [1,2]. The diesel oil consumption per agricultural operation was calculated according to Nemecek & Kägi (2007) [9].

A load factor of 50% was considered in the transport steps. In the calculation of the transport of the diesel from the refinary to the gas stations, it was assumed that: a) the diesel oil came from the refinary closest to the production area (at a distance of 246 km); b) the diesel oil production LCI constructed for the refinery REPLAN was representative of all the Brazilian refinaries [3]; c) the transport of the diesel oil from refinary to gas stations was done directly by road in tankers with a mean capacity of 45 m^3. The diesel oil was transported from the gas stations to the farms, distant 100 km, by road in trucks.

To estimate the change in the stock of C in the soil due to the land-use change (ΔC_{LUC}), it was considered that: a) the area transformed into physic nut crop was formerly pasture; b) grassland has a stock of C in the biomass of 5 t/ha [8]; c) the biomass of a physic nut plant contains 2.83 kg of C [11]. The value for ΔC_{LUC} is calculated by difference between the stock of C in the original use of the soil and the stock of C in the current use of the soil. The CO_2 emissions due to the land-use change (CO_{2LUC}) were calculated by multiplying ΔC_{LUC} by the conversion factor of C to CO_2, assuming a discount period of 20 years (IPCC standard).

The CO_2 emissions caused by the use of dolomite limestone and urea were calculated according to IPCC (2006) [8]. The methane emissions (CH_4) resulting from the reduction in the soil retention capacity caused by the use of the N were calculated considering that for each 150 kg N/ha applied in the form of ammonia, the methane reducing capacity of the soil decreases by 1 kg/ha [5].

Estimates of the N_2O emissions caused by the grain production considered: a) the input of urea as a synthetic nitrogenated fertilizer; b) the input of manure as an organic fertilizer exclusively for the manual production system; c) the emissions of N_2O caused by mineralization of the N in mineral soils, associated with a loss of C from the soil, as a result of the changing use of the soil or its management (F_{SOM}). The calculations were carried out according to the IPCC (2006) [8]. In the calculation of F_{SOM}, a standard value of 15 was adopted for the C:N ratio, adequate in situations involving a land-use change from grassland to cropland.

The atmospheric emissions of nitrogen oxides (NOx) generated by the production of physic nut grains corresponded to 10% of the emissions of N_2O [5]. Specifically in the case of mechanized production, the emissions of N_2O and Nox already considered should be summed up with the emissions of these gases generated by the combustion of the diesel oil. To calculate the emissions of ammonia (NH_3) derived from the use of urea, an emission factor of 0.1 was used, to be multiplied by the amount of N in the nitrogenated fertilizer [8].

To calculate the PO_4 emissions for the water and soil, resulting from the use of SSP, it was assumed that: a) part of the P in the fertilizer system was exported to the crop; b) the fruits harvested leave the product system; c) the biomass corresponding to the leaves returns annually to the soil; d) the biomass corresponding to the stalks, branches and roots leaves the system at the end of the productive cycle; e) the mass of dried grains corresponds to 62.51% of the total mass of dried physic nut fruits; f) the dry fruits contain 0.86% P; g) a mature physic nut plant produces 3.9 kg (dry weight basis) of aerial biomass (except the fruits and leaves) and 1.6 kg (dry weight basis) of subterranean biomass with a P content of 0.1% (value found in the literature for other fibrous parts of plants) [11]. The excess of P in the system is calculated from the difference between the P carried in the fertilizer and that exported to the crop. Of this excess P, 0.29% are leached into the subterranean waters and the rest accumulates in the soil [10].

With respect to the calculations of heavy metal emissions coming from the fertilizers, including the copper sulphate and zinc monosulphate used as leaf fertilizer in the mechanized system, the fractions exported to the crop were not considered, since the type of crop and the soil and climate conditions affected this exportation and no specific values for physic nut and for Brazil are available, and also, physic nut is a perennial crop and hence the majority of the biomass is maintained in the agricultural system after the annual harvest of the fruits. Thus the total amount of heavy metals entering the agricultural system will be reverted as emissions to the environment. It was considered that part of the heavy metals emitted to the soil is lost as run-off to surface waters (0.01%). The emissions to the soil were calculated by difference between the amount of heavy metal entering the system and the amount emitted to the surface waters [5]. The heavy metal contents in the nitrogenated fertilizer corresponded to the mean of the value reported by Canals (2003) [5] and Schmidt 2007 [10].

For the mechanized production system, there were emissions generated by combustion of the diesel oil consumed in the agricultural operations. The emissions of hydrocarbons (such as NMVOC), benzene, benzo(a)pyrene, aromatic polycyclic hydrocarbons, carbon monoxide (CO), CO_2, CH_4, NOx, N_2O, NH_3, sulphur dioxide (SO_2), Cd, Cr, Cu, Ni, Pb, Se and Zn, as also the emissions of particulate material with a diameter <2.5 μm, were calculated according to Nemecek & Kägi (2007) [9].

With respect to the emission of pesticides to the environment, the amount of the active principle of the pesticide applied to the crop (per ha/20 years) was used as a base for the calculations. The metabolites generated by degradation of the pesticides were not considered. The fate analysis suggested by Haushild (2000) [4] was adopted to estimate the emissions of pesticides into the environment.

The total amount of active principle of the pesticide applied to the crop was divided into fractions derived from the production area by the wind and reaching the surrounding environment (f_{drift}) or deposited on the plants (f_{plant}) or on the soil surface ($f_{soil\ surface}$). The fractions that reach the plants or the soil can volatilize ($f_{vol\ plant}$ and $f_{vol\ soil}$). The fraction in the soil can be run-off into surface waters ($f_{run\text{-}off}$) or by leaching into subterranean waters (f_{leach}) or to surface waters, if the soil is drained. Part of the contaminants in the soil are degraded by microbial activity (f_{degrad}) and part remain in the soil to the end of the productive cycle.

Only the pesticide applied to the border of the crop (frontier of the production area up to 30 m in the direction of the center of the production area) suffered from the effect of wind drift, f_{drift} [5]. Assuming that the production areas had a square format, the border areas corresponded to 34347.6 m^2 and 116400 m^2, or 34.35% and 11.64% of the total production area for the manual and mechanized systems, respectively. For shrub crops, in which the application of pesticide is done when the plants are fully foliated (as in the case of physic nut) [2], the pesticide drift emission factor is 0.24% [4,5]. Thus to calculate f_{drift}, the amount of active principle of each pesticide applied was multiplied by the percent referring to the border of the crop and by the drift emission factor.

The amount of pesticide remaining in the system, subtratcting f_{drift}, was divided between f_{plant} and $f_{soil\ surface}$. Empirical estimates have been used to estimate f_{plant}, obtained by varying the leaf density and the concentration of the pesticide solution, obtained in studies carried out in New Zealand in apple orchards (MANKTELOW, 1998, cited by CANALS, 2003) [5], and were adopted in the present study. For the physic nut crop, the pesticide is applied when the plants are fully foliated and the concentration of the solution is relatively high, 400L/ha [2], and so a percent retention by the plant of 85% was considered [5]. Thus to calculate f_{plant}, the value for f_{drift} was subtracted from the quantity of active principle applied to the crop. The rest was multiplied by 0.85. The value for f_{soil}

$_{\text{surface}}$ was calculated by subtracting the values for f_{drift} and f_{plant} from the total amount of active principle applied to the crop.

The values for $f_{\text{vol plant}}$ and $f_{\text{vol soil}}$ were calculated by multiplying f_{plant} or $f_{\text{soil surface}}$ by their respective emission factors, calculated according to Hauschild (2000) [4]. The values used for the vapor pressure and half-life$_{\text{soil}}$ of the pesticides in this calculation can be found in the specialized literature [12,13,14]. The value for the half-life$_{\text{plant}}$ of glyphosate is 35 days [5] and for abamectin 0.21 days. The values for the half-life$_{\text{plant}}$ of the other substances are not available, and thus the mean values of 34.4 days for pesticides, or 4.6 days for fungicides [5], were used. The residence times of the pesticides (in the plant and soil) were calculated by multiplying the values for the half life (in the plant and soil) by 1.443. The fractions $f_{\text{vol plant}}$ and $f_{\text{vol soil}}$ were added together to give f_{vol}.

The $f_{\text{run-off}}$ was calculated by multiplying $f_{\text{soil urface}}$ by 0.0001 [4].

In order to estimate the value for f_{leach}, the attenuation factor (AF) was first calculated, according to Paraíba & Miranda (2003) [7]. The data referring to the soil correspond to a type representative of the Brazilian savanna, Typic Orthic Neosol Quartzarenic Brazilian, characterized by being prone to leaching (hence the worst case of a real situation), and were obtained by Paraíba et al. (2003) [6]. The soil organic carbon partition coefficient (K_{oc}), the molecular weight and the solubility in water of the pesticides can be found in the specialized literature cited above. The value for f_{leach} was calculated by: $f_{\text{leach}} = AF * (f_{\text{soil suface}} - f_{\text{vol soil}} - f_{\text{run-off}})/L * \delta$, where L is the depth soil and δ is the soil porosity.

The soil leaves the product system after the harvest, when the remaining pesticide fraction starts being considered as an emission. Nevertheless this fraction can undergo degradation in the soil. The value for f_{degrad} was calculated according to Canals (2003) [5], considering the degradation rate of the pesticide in the soil to be the time between the annual pesticide applications and the 20th harvest of the production (which corresponds to 180 days for the herbicide; 90 for the insecticide, acaricide, fungicide and sulphur; and 240 for the formicide) [2]. The degraded fractions were calculated annually and then added up.

The emissions for the environmental compartments are calculated as: emissions to the air = $f_{\text{drift}} + f_{\text{vol}}$; emissions to surface waters = $f_{\text{run-off}}$; emissions to subterranean waters = f_{leach}; emissions to soil = $f_{\text{soil surface}} - f_{\text{vol soil}} - f_{\text{run-off}} – f_{\text{leach}} – f_{\text{degrad}}$.

3 Results and discussion

Tables 1 and 2 show the inventories for the production of physic nut grains by the manual and mechanized systems. The main environmental aspects involved in the production of the grains are the synthetic fertilizers, the pesticides, the land-use change and its emissions and the land occupation. Specifically for the mechanized production system, the aspects related to the consumption of diesel oil and its emissions must also be included.

Tab. 1: Main environmental aspects of the life-cycle inventory for the production of physic nut grains - inputs

Inputs (1 ha/20 years)	**Manual system**	**Mechanized system**
Products		
Jatropha curcas grains, at farm (kg)	7.95E+04	7.95E+04
Resources		
Carbon dioxide, in air (kg)	1.30E+04	1.30E+04
Occupation, permanent crop (ha a)	1.00E+00	1.00E+00
Transformation, from pasture, extensive (ha)	1.00E+00	1.00E+00
Transformation, to permanent crop (ha)	1.00E+00	1.00E+00
Materials and fuels		
Copper sulphate (kg)	-	1.23E+01
Fungicides, at regional storehouse (kg)	4.28E+01	4.28E+01
Insecticides, at regional storehouse (kg)	6.35E+01	6.35E+01
Limestone, milled, packed, at plant (kg)	4.60E+03	6.60E+03
Potassium chloride, as K_2O, at regional storehouse (kg)	1.85E+03	1.86E+03
Poultry manure, dried, at regional storehouse (kg)	2.00E+04	-
SSP, as P_2O_5, at regional storehouse (kg)	1.18E+03	1.18E+03
Urea, as N, at regional storehouse (kg)	2.46E+03	2.46E+03
Zinc monosulphate, $ZnSO_4.H_2O$, at plant (kg)	-	1.23E+01
Diesel, from crude oil, consumption mix, at refinery, 500 ppm sulphur 500 (kg)	-	2.25E+03
Transport		
Diesel transport from gas station to farm, by van, <3.5t	-	2.25E+02
Diesel transport from refinary to gas station, by lorry transport, >32 t, Euro	-	5.53E+02

The synthetic fertilizers are responsible for the emission of heavy metals to the soil (the most important being Cd, Zn, Hg and Se, in this order) and to the water (Hg and Se, in that order), substances causing impacts related to human toxicity and to aquatic and terrestrial ecotoxicity. The emissions derived from the agricultural use of urea, as in the case of ammonia (CH_3) and nitrogen oxides (NOx) - which contribute to the impacts of acidification and eutrophication, and indirectly of methane (CH_4) - which contributes to the impacts of global warming and photochemical oxidation - are also relevant. The phosphated fertilizer generates emissions of phosphate to the soil and to the water, a substance related to the impacts of human toxicity and eutrophication.

With respect to the pesticides, the most important emissions are those of lambda-cyhalothrin, abamectin and methyl thiophanat to the soil, substances which are also toxic.

The land-use change, formally pasture, transformed into a permanent crop, causes CO_2 emissions related to the impact of global warming. The biomass produced by the crop, on the other hand, sequesters carbon from the atmosphere, which could compensate the emissions from the combustion of the biodiesel. Thus the mobilization of the area occupied by the physic nut crop causes its own impact.

The main differences between the two production systems is due to the greater consumption of inputs by the mechanized system. Although organic fertilizer is not used in this second system, the consumption of limestone is greater and other consumables are introduced, such as leaf fertilizer and diesel. The emissions of nitrous oxide (N_2O) are smaller in the mechanized system, since organic fertilizer is not used. On the other hand, the emissions of CO_2 are greater in the mechanized system due to the greater consumption of limestone and diesel oil. The consumption of diesel oil also results in an increase in the emission of methane (CH_4). Thus the impact of the production of physic nut grains on global warming is greater for the mechanized system.

The consumption of diesel oil also results in an increase in the emission of nitrogen oxides (NOx) and heavy metals. The use of potassium chloride, copper sulphate and zinc monosulphate as leaf fertilizer also increases the emissions of these metals. The mechanized system also causes the emission to the atmosphere of heavy metals, principally of Zn, Cd, Se, Cu and Ni (in order of importance). The emissions of pesticides to the air are slightly reduced in the mechanized system, since the emissions caused by the wind by drifting are inversely correlated to the size of the area cultivated. Comparing the two production systems, the impacts with respect to human toxicity are very close, but relatively more important in the manual system.

With respect to the emission of particulate material <2.5 µm and of SO_2, resulting from the combustion of diesel oil, together with the emissions of CH_3 e NOx (common to both production systems), which make up the impact denominated as particulate material, with negative effects on human health, the weight of this factor is of importance in the general impact of the grain production systems, being greater for the mechanized system.

Despite the fact that the physic nut crop is not considered to be demanding with respect to nutrients and resistance to pests and diseases, the LCI for the production of the grains shows an elevated consumption of limestone and fertilizers, particularly of the organic and nitrogenated ones. Although the consumption of pesticides is not high in absolute terms, it is nevertheless high when compared to other perennial oleaginous crops such as palm oil.

Tab. 2: Main environmental aspects of the life-cycle inventory for the production of physic nut grains - outputs

Outputs (1 ha/20 years)	Manual system	Mechanized system
Emissions to air		
Ammonia (kg)	2.46E+02	2.46E+02
Benzene (kg)	-	1.64E-02
Benzo(a)pyrene (kg)	-	6.74E-05
Cadmium (kg)	-	2.25E-05
Carbon dioxide (kg)	2.19E+03	3.15E+03
Carbon dioxide, fossil (kg)	2.92E+02	7.30E+03
Carbon dioxide, land transformation (kg)	5.36E+03	5.36E+03
Carbon monoxide, fossil (kg)	-	1.19E+01
Copper (kg)	-	3.82E-03
Methane (kg)	1.64E+01	1.64E+01
Methane, fossil (kg)	-	2.90E-01
Nickel (kg)	-	1.57E-04
Nitrogen oxides, NOx (kg)	6.66E+00	1.01E+02
Nitrous oxide, N_2O (kg)	6.66E+01	5.40E+01
Particulates, < 2.5 µm		1.13E+01
Selenium (kg)	-	2.25E-05
Sulphur dioxide (kg)	-	2.27E+00
Zinc (kg)	-	2.25E-03
Emissions to surface water		
Mercury (kg)	9.41E-07	9.41E-07
Selenium (kg)	1.67E-06	1.67E-06
Emissions to groundwater		
Phosphate (kg)	2.34E-01	2.34E-01
Emissions to soil		
Abamectin (kg)	3.44E-04	3.44E-04
Arsenic (kg)	2.86E-02	2.87E-02
Cadmium (kg)	3.00E-01	3.00E-01
Chromium (kg)	1.69E-02	1.70E-02
Cobalt (kg)	1.03E-02	1.04E-02
Copper (kg)	4.74E-02	3.29E+00
Lambda-cyhalothrin (kg)	1.42E-02	1.42E-02
Lead (kg)	9.31E-02	9.36E-02
Phosphate (kg)	8.04E+01	8.04E+01
Mercury (kg)	9.41E-03	9.41E-03
Molibdenum (kg)	2.90E-02	2.90E-02
Nickel (kg)	4.14E-01	4.14E-01
Selenium (kg)	1.67E-02	1.67E-02
Thiophanat-methyl (kg)	2.10E-03	2.10E-03
Zinc (kg)	3.19E+00	5.65E+00

One could indicate as opportunities to improve the environmental performance of the production of physic nut in Brazil, the agricultural use of vegetable and agroindustrial residues from the productive chain itself, which could reduce the use of synthetic fertilizers, and the use of alternative technologies for the chemical control of pests and diseases, which would demand technological development.

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