

Estimation of the Carbon Footprint in Rice Crops of the ASOZULIA Irrigation District, Norte de Santander, Through the Application of Life Cycle Analysis

Estimación de la huella de carbono en cultivos de arroz del distrito de riego de Asozulia, Norte de Santander, mediante la aplicación del análisis del ciclo de vida.

Recibido: 26 de agosto de 2022

Aprobado: 4 de diciembre de 2022

Forma de citar: LJ. Melgarejo Castañeda, F. R. Arencibia Pardo, and B. Peña Rodríguez, "Estimation of the Carbon Footprint in Rice Crops of the ASOZULIA Irrigation District, Norte de Santander, Through the Application of Life Cycle Analysis", *Mundo Fesc*, vol. 13, no. 26, pp. 7-22, May 2023, doi: 10.61799/2216-0388.1315.

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Abstract

The present study carries out an estimate of the carbon footprint in the rice crops located within the Irrigation Ringy district, Santander Norte, Colombia, through descriptive research that uses as a methodological reference The analysis of the life cycle established in international standards ISO 14040 and ISO 14044. In the first instance, the production system is divided into three segments (studies of study) to collect primary information of the balance sheets of mass and energy that are intervened, subsequently, the inventory of CO₂ emissions is built using the Ecoinvent database 3.1, the inventory data is processed through the LCA-Manager software to quantify the impact on the carbon footprint generated in each of the study blocks. Within the results, it was found that for each hectare of culture the system issues 7,316 KG CO₂ EQ and that the factors with the highest incidence in their order are watering, urea, fertilizers, burning of vegetable material, fuels, agrochemicals, seed, agricultural machinery, and lubricants. Finally, the following strategies are proposed as alternatives to reduce carbon footprint: implementation of precision agriculture technologies, laser bearing leveling for zero slopes, modernization of agricultural machinery park, machining transplant technique, favorable agronomic practices to recover the soil, disposal of burns, preventive maintenance and predictive plan and training plan for staff. Keywords: rice, life cycle analysis, environmental impact, carbon footprint

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Palabras clave: Rice, Life cycle analysis, Environmental impact, Carbon footprint

Resumen

El presente estudio realiza una estimación de la huella de carbono en los cultivos de arroz ubicados dentro del distrito de Riego Ringy, Santander Norte, Colombia, a través de una investigación descriptiva que utiliza como referencia metodológica el análisis del ciclo de vida establecido en las normas internacionales ISO 14040 e ISO 14044. En primera instancia, el sistema de producción se divide en tres segmentos (estudios de estudio) para recolectar información primaria de los balances de masa y energía que se intervienen, posteriormente, se construye el inventario de emisiones de CO₂ utilizando la base de datos Ecoinvent 3.1, los datos del inventario se procesan a través del software LCA-Manager para cuantificar el impacto en la huella de carbono generada en cada uno de los bloques de estudio. Dentro de los resultados, se encontró que por cada hectárea de cultivo el sistema emite 7,316 KG CO₂ EQ y que los factores con mayor incidencia en su orden son riego, urea, fertilizantes, quema de material vegetal, combustibles, agroquímicos, semillas, maquinaria agrícola y lubricantes. Finalmente, se proponen las siguientes estrategias como alternativas para reducir la huella de carbono: implementación de tecnologías de agricultura de precisión, nivelación láser para pendientes cero, modernización del parque de maquinaria agrícola, mecanizado de la técnica de trasplante, prácticas agronómicas favorables para la recuperación del suelo, eliminación de residuos quemados, mantenimiento preventivo y plan predictivo, y plan de capacitación para el personal. Palabras clave: arroz, análisis del ciclo de vida, impacto ambiental, huella de carbono

Introduction

In 2015, the 2030 agenda and the Sustainable Development Goals (SDG) were established, due to the alterations that planet Earth has presented and the identification of risks that threaten the survival of humanity, which became a fundamental guideline of the public policy of nations from their development plans [1].

Later in 2019, during the COP25 or climate change summit, through the report "climate change and the earth" global concern was expressed regarding the negative impact generated on the environment by agricultural activities, specifically with regard to global warming. Global warming affects agricultural productivity, reduces food availability, causing famine and changes in nutritional diets; On the other hand, it causes strong natural phenomena and the proliferation of diseases [2].

The global dynamics of economies require organizations to continually look for opportunities to improve their processes, in order to be competitive in the market and guarantee their sustainability over time. For this reason, companies must implement strategies to reduce costs, increase productivity and make the most of resources. Productive sectors such as agriculture and specifically rice, require research that provides these types of tools to make them more productive and competitive.

Rice (*Oryza sativa* L.), due to the nutritional contribution it makes, is one of the cereals of greatest gastronomic importance, being a basic food for consumption by a large part of the population [3]. Furthermore, for Colombia, rice deserves a special chapter due to the high impact it has on the economy, job creation and per capita consumption [4].

Agricultural production of rice has been affected by the decreasing behavior of productivity and increased costs, which over the years have made said activity less competitive, therefore, the reconversion to other crops, sometimes illicit or the abandonment of the activity by the owners of these lands. Inappropriate practices within the process have impoverished the soil and affected its structure, in addition to this, they lead to increasing fertilization and the use of agrochemicals in order to control rice pests and diseases, as well as excessive water consumption in the irrigation of said crop. Which in turn causes a negative impact on the environment and especially the category of global warming [5].

The large-scale Land Adaptation District of the Zulia River was built in the early 1970s by HIMAT, today IDEAM and INAT, the areas of influence correspond to the municipalities of San José de Cúcuta and El Zulia, it includes an area of 45,494 hectares, of which, 43.7% (19,867 hectares) has land suitable for the implementation of agricultural crops. Currently, 15,857 hectares are irrigated through the district's infrastructure, which correspond to about 1,340 properties, in which cocoa, oil palm and especially rice are grown, the latter corresponding to 80% of production [6].

On the other hand, the set of Greenhouse Gas (GHG) emissions derived from a production or consumption activity represent its carbon footprint. Within the set of these aforementioned GHGs, the one that contributes the most to global warming corresponds to carbon dioxide (CO₂) emissions [7]. Rice is a traditional and essential food for Colombians thanks to its nutritional contribution and especially carbohydrates, in addition to being economically accessible to the entire population. With per capita consumption amounting to 43.2kg, rice is one of the products most consumed by Colombians [8].

In this sense, encouraging the increase in national rice production is a key component of food security that in turn contributes to boosting the country's economic growth. However, it is necessary that this purpose be carried out with comprehensive projects that include the sustainability component.

The present research aims specially to estimate the Carbon footprint of rice crops in the Asozulia irrigation district, Norte de Santander, through the application of Life Cycle Analysis, seeking to generate a key input that serves as a model to implement it in other organizations and develop actions that strengthen the rice sector and thus guarantee its sustainability, as well as the quality of life of farmers.

It is clear that actions must be implemented to mitigate the negative impacts that the agricultural sector generates on the environment, due to inappropriate production practices. In this sense, the term Life Cycle Analysis (LCA) becomes relevant and is shown as an important path to achieving this objective.

It is necessary to apply a clear and complete methodology, which is useful in terms of proposing an LCA to collect the pertinent information and generate the calculations that lead to obtaining the established objectives, which is why the ISO 14040 and 14044 [5] standards play a role. important, since they provide the optimal guide that helps describe all the phases involved in the activity (from extraction to the final use of said product).

LCA using the Ecoinvent tools and the LCAManager software makes it possible to identify the elements that have the most impact on the carbon footprint during rice cultivation. The identification of factors that negatively impact the environment allows the formulation and implementation of strategies based on work methods or production techniques that will minimize the impact generated.

The current investigation, using the LCA method, managed to identify the environmental impact in relation to the carbon footprint generated by rice crops in the Asozulia irrigation district, Norte de Santander, Colombia, in each of the cultivation phases: land preparation , sowing, harvesting and storing grain.

Materials and methods

The present work was developed by applying the life cycle analysis (LCA) methodology in the main stages of the rice cultivation process (land preparation, sowing, growth, development, harvest and storage of the paddy rice grain), taking as functional unit one cultivated hectare and as the limit of the system, all the areas destined for rice cultivation, in the area of the Asozulia irrigation district, Norte de Santander.

This methodology consisted of constructing the input and output flows for the stages of the process per functional unit (1 hectare), thus organizing a mass balance with commercial data of all the raw materials and inputs involved there; Next, the emissions inventory was prepared using the Ecoinvent v3.1 database, which becomes the necessary input to evaluate the environmental impact of the process, whose indicator is the carbon footprint, which for the study is established as kilograms of CO₂ equivalent per cultivated hectare. The present study can then be defined as descriptive research in which the researcher seeks to describe the context under investigation, to cover the objectives and interests of a specific population.

Applying this method, the aim is to determine properties, characteristics and profiles of people, groups, communities or any phenomenon that is subjected to analysis, measuring and collecting information independently or jointly about the variables, accurately showing the dimensions of the events in the community. context or situation [9].

Regarding the population determined in this research, they are the elements from which information will be obtained, and they will be well defined in time and space, so that, in the presence of a potential member of the same, it can be decide whether or not to include them in the studied population [10].

In line with what was established by [11], in relation to the definition of the instrument and the data that must be obtained in the study, the LCA Manager 1.3 Software was used, and the information from the Ecoinvent V3 database was used. .1 and the data collected from the primary source during the stages of rice cultivation, that is, land preparation, seed sowing, germination, tillering, bushing, heading, harvesting, transportation and storage of the grain.

The following figures 1 and 2 show a representation of the instruments used to collect the information.



Figure 1. Information collection instruments used.

The Ecoinvent database allowed inventories to be defined in the process stages and the LCA Manager 1.3 computer program was used to identify and quantify environmental impacts. In turn, this research implemented the LCA Manager, a computer tool that measures the environmental profile of industrial products and processes using the Life Cycle Analysis approach specified in the ISO-14040/44 series of standards [12], in where all phases of the product life cycle were analyzed.

Regarding the following illustration, it generally describes the methodology that was applied in the research:



Figure 2. Investigation methodology

Results and discussion

Results

The mass and energy flows involved in the rice cultivation process were identified using the block sampling method according to the limits and the functional unit (1 hectare of rice cultivation), dividing the system into three study blocks that They represent the stages of the process: 1) Preparation of the land and planting, 2) Growth and development of the

crop and 3) Harvesting and storage of the paddy grain.

The mass balances for each of the study blocks are presented below: Table 1 corresponds to the stage of land preparation and planting, the balance of block 2, corresponding to the stage of growth and development of the crop, is presented Table 2 and Table 3 show the balance corresponding to harvesting and grain storage.

Table I. Mass balance for block 1 of the study (land preparation and seed sowing)

Tickets	und	Unit/ha
Urea 46%	kg.	75.00
Diammonium phosphate (DAP) 18-46-0	kg.	132.00
dolomite lime	kg.	285.00
LINAP 90 Micro emulsifiable	l.	0.10
Bolero	l.	0.98
VECOL glyphosate	l.	3.00
GOAL 480	l.	0.12
Ronstar Evolution	l.	2.00
Prowl 400 EC	l.	0.45
Diesel	l.	111.30
Gasoline	l.	29.10
Oil 20W 50	l.	0.03
10W hydraulic oil	l.	0.15
Lithium semi-lubricating grease	kg.	0.40
Valve grease 80W90	kg.	1.09
Irrigation water	m ³	8245.00
Burning of plant material	Tn.	5.00
rice seed	kg.	180.00
Tractor tires (55 kg)	kg.	0.18
Tractor	kg.	0.46

Source: Interviews and production reports provided by producers of the Asozulia Irrigation District (2020 – 2021).

Table II. Mass balance for block 2 of the study (crop growth and development)

Tickets	und	Unit/ha
Urea 46%	kg.	150.00
Diammonium phosphate (DAP) 18-46-0	kg.	50.00
Rice Fertilizer	kg.	50.00
Potassium Chloride 60%	kg.	150.00
Crezinc - P	l.	1.00
AGRISPON SL	l.	0.30
Cosmo ind	l.	0.51
Cosmo Waters	l.	0.20
Propanil (Stam M4)	l.	5.00
Stadium	l.	1.00
Aura (agromillennium)	l.	1.00

Dash (comes with aura) - Emulsifiable Concentrate (EC)	l.	0.70
Facet SC	l.	2.30
Amine 720	l.	0.40
Biofermext (microorganism)	l.	2.30
VOLIAM FLEXI	l.	0.45
RAUS	l.	0.45
Diesel	l.	36.00
Gasoline	l.	10.00
Irrigation water	m ³	10,098

Table III. Mass balance for Block 3 (Harvest collection and final grain storage)

Tickets	und	Unit/ha
Diesel	l.	96.20
Gasoline	l.	9.00
Oil 20W 50	l.	0.02
10W hydraulic oil	l.	0.10
Lithium semi-lubricating grease	kg	0.37
Terpel ULTREK 50 Monograde API CF/SF lubricating oil	l.	0.20
Transport of cargo to the mill	Tn/km	0.20
Tractor Tires (55 kgs)	kg.	0.14

The second result corresponds to the identification and quantification of the environmental impact, as mentioned in the methodology, the HdC indicator was selected within the global warming (GC) category, once the mass balances are obtained, the inventory of GHG emissions for each of the polluting factors of rice cultivation.

The inventory of GHG emissions for the object of study was built using the Ecoinvent version 3.1 database, which compiles information from countless environmental impact studies throughout the life cycle of products and processes, also analyzing energy consumption, transportation, extraction of raw materials, waste, etc., that is, it is a highly reliable source of secondary information.

Finally, the data extracted from the inventory are modeled with the mass balance to characterize the environmental impact at each stage of the rice cultivation process, thus obtaining the estimate of the HdC per hectare for the rice crops of the Asozulia irrigation district through the Life Cycle Analysis (LCA) methodology established in the ISO 14040-14044 standards [12] and with the LCA Manager 1.3 computer tool. Graphs 1, 2 and 3 present the polluting factors and kg emissions. CO₂ equivalent per hectare of crop for each of the study blocks that were listed in tables 1, 2 and 3 respectively.

The contaminating factors of the process by study blocks with the greatest impact on the carbon footprint of the process are: a) Block 1: irrigation, urea, burning of plant material, diammonium phosphate fertilizer, Diesel and seed. b) Block 2: irrigation, Urea, diammonium phosphate, potassium chloride, acetamide-anilide compound, ammonium

nitrate and Diesel mainly. c) Block 3: Diesel, gasoline and wear of agricultural machinery mainly.

Below, figures 3, 4 and 5 present the emissions given in kg of CO2 equivalent per ha. of cultivation for each of the study blocks and by contaminating factor identified within the process. In turn, these values become key input for the preparation of impact mitigation proposals or for the study recommendations.

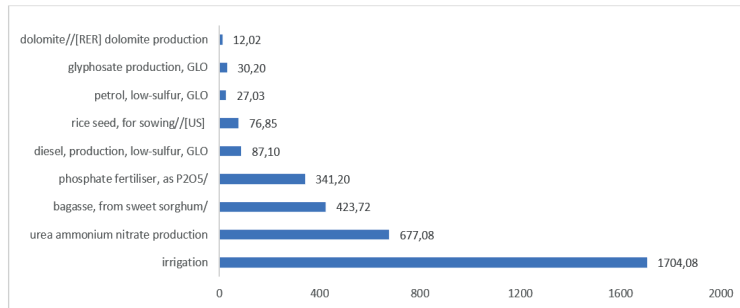


Figure 3. Emissions of kg of CO2 equivalent from block 1 (land preparation and planting) per hectare of the crop

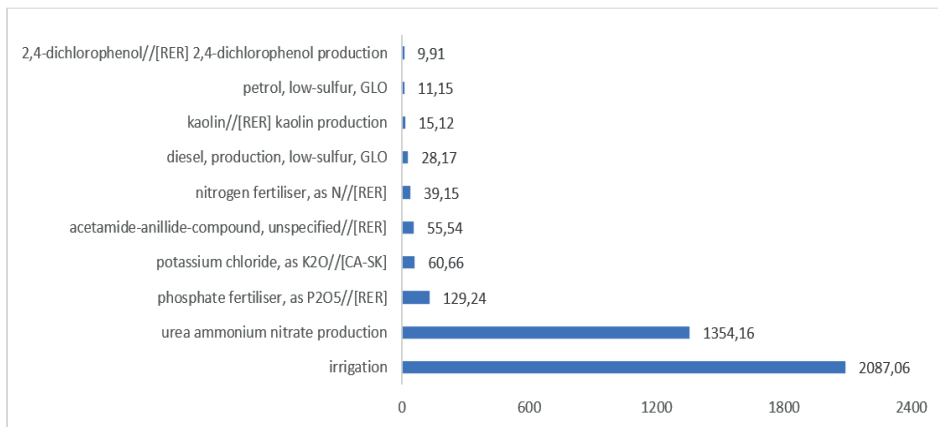


Figure 4. Emissions of kg of CO2 equivalent from block 2 (crop growth and development) per hectare of the crop

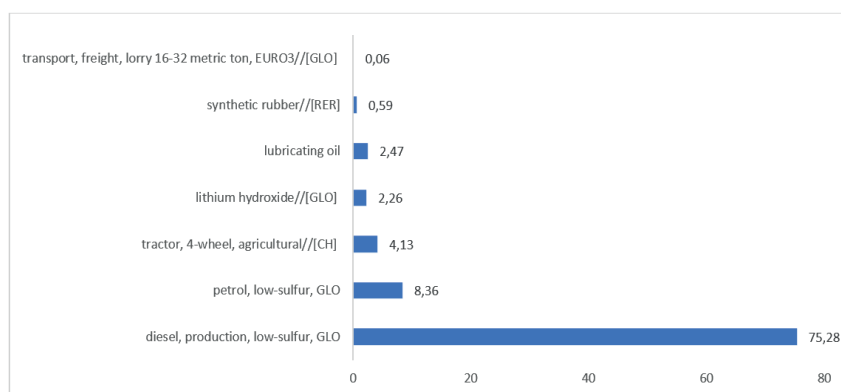


Figure 5. Emissions of kg of CO2 equivalent from block 3 (harvest collection and storage) per ha of the crop

Referencias

of the three study blocks were consolidated, the factors that have the greatest impact on CO₂ emissions for the production of green paddy rice were determined (see graph 4), which in order are: irrigation, urea, fertilizers, burning of plant material, fuels, agrochemicals, seeds, agricultural machinery and lubricants (see figure 6).

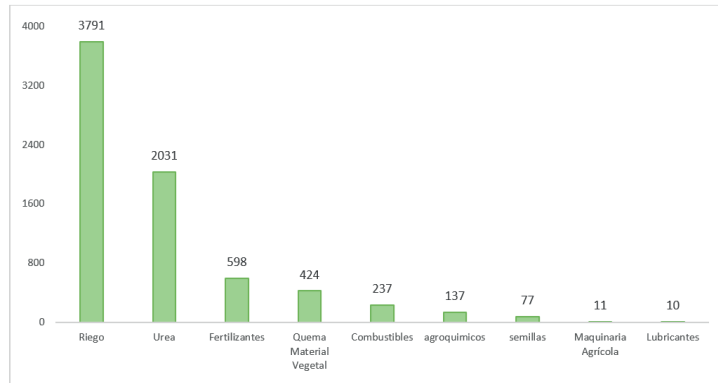


Figure 6. Total emissions of kg of CO₂ equivalent per hectare of rice cultivation

Likewise, a summary of the impact generated in each of the study blocks or stages of the process is presented, obtaining similar and very significant values, mainly in the first two stages of the process (see Table IV).

Table IV. Emissions of kg of CO₂ equivalent per hectare of rice cultivation in each of the study blocks

Stages of the process	kg CO ₂ eq.	% incidence
Block 1 - Land preparation and planting	3410.8	47%
Block 2 - Crop growth and development	3811.9	52%
Block 3 - Harvest and storage	93.16	1%
Total - Rice cultivation and harvest (1 ha)	7315.87	100%

According to Table IV, block 1, which corresponds to land preparation and planting, emits 47% of all CO₂ in the process, while block 2 of crop growth and development generates 52%, being the most polluting. Although block 3 for harvesting and storage only produces 1% of the emissions. These results show the need to take actions to reduce the environmental impact generated by block 1 and 2 to reduce emissions from this agricultural activity.

Discussion

An analysis of the results was carried out in contrast to the bibliographic review on the estimation of HdC in each of the stages of rice cultivation and four (4) groups of contaminating factors were identified that must be intervened to achieve a significant reduction. in the HdC. The following describes each of them:

G1. Soils with steep slopes were identified that increase water circulation and consumption. On the other hand, flooding of the land causes transformations in the soil that influence the emission of GHGs, also due to the physicochemical processes that occur there. The main resource used for the production of paddy rice is water (18,343 m³/ha) and this situation plus the continuous expansion of the agricultural area has increased the demand for liquid to levels close to 14 m³/s, being the same flow rate as it has the Zulia River [6] in the summer, which puts the sustainability of the crop at high risk.

G2. High density of seeds per crop area because the broadcast sowing technique is used, which is carried out randomly and does not guarantee a uniform distribution, which, added to the mud or flood preparation method, generates a favorable environment for the growth of weeds, which increases competition for nutrients, a situation that has an impact on the excessive consumption of seeds and the increase in the application of fertilizers and herbicides in the initial stage of the crop.

G3. Affectation is observed in the structure of the soil caused by poor practices in soil preparation and inadequate use of agricultural mechanization. The preparation of the soil generates the loss of structure, preventing spaces from forming (porosity) for the containment of water and air necessary for the roots. In addition, crusts form on the surface that do not allow water to be retained. On the other hand, agricultural machinery favors compaction, resulting in the death of the roots, because hard layers form beneath the soil that do not allow their growth and expansion, generating difficulties when adsorbing fertilizers and water, as well as for the anchoring of plants, which causes overturning.

G4. Machinery with obsolete technologies and poor combustion processes. Absence of preventive and predictive maintenance plans in the fleet of vehicles and agricultural machinery. This situation causes effects on the soil structure, but, in addition, it is demanding greater fuel consumption, greater machining time and less effectiveness in the scheduled tasks. In addition to this, it causes greater rotation of spare parts and lubricants and process stops.

Taking the above into account, a comparative analysis is carried out with recent literature on the dynamics that exist between rice production and the carbon footprint. From this, it is found that rice cultivation has been recognized as one of the most essential crops worldwide, with a significant per capita consumption [13]. However, rice production is associated with considerable generation of carbon dioxide (CO₂) and other greenhouse gases, as noted by [13]. This crop, although it is essential for feeding a large part of the population, is closely related to these emissions through its production chain, from the agricultural process to marketing.

For this reason, the results of the study agree that these processes contribute significantly to GHG emissions, as indicated by the Agrocadenas observatory of Colombia and the analysis carried out by [14]. Although the methods used to measure the carbon footprint have evolved since the 1970s, currently, there are advanced tools such as Life Cycle

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obtaining reliable information to assess the problem, such as the case of the Zulia River District in Colombia, which allows us to characterize that there are significant emissions and determine the stages where most pollution and effects on the environment are generated.

In this way, it can be said that climate change and its consequences, such as increased temperatures, decreased precipitation and climate variability, represent an additional challenge for agricultural production in this region, as pointed out by ECLAC and the FAO. Similarly, the impact of climate change on different crops, projected by NASA, indicates important changes in yields, due to climate alterations and high GHG emissions [15].

Consistent with GreenFacts [16] there is a symbiotic relationship between agriculture and climate change that raises significant concerns, as emissions from agricultural activities contribute to global warming and, in turn, climate change adversely affects agriculture. This harmful interaction is evident both in crop yields, as well as in the economy and food security.

Therefore, the results agree with other studies [15] and [17], which highlight that, although rice is a fundamental pillar in the diet and economy of various regions, its production has a significant impact on CO₂ emissions. It is important to implement methods such as Life Cycle Analysis (LCA) and the measurement of the Carbon Footprint (HC) as important steps to understand and mitigate this environmental impact. Furthermore, in line with this research, the need to reduce the negative effect of rice production and advocate for more sustainable practices in agriculture is raised.

Finally, it is understood that rice production is essential for the world's diet, but it is not exempt from generating high GHG emissions, which in turn contributes to climate change that harms the global food supply [18]. In this way, the understanding of the carbon footprint and the detailed analysis of agricultural processes must be further investigated to take measures that mitigate this environmental impact and promote more sustainable practices in food production.

Conclusions

Using the block sampling method, the mass flows involved in the cultivation and harvest of rice were evaluated for 1 hectare of production. On average, one hectare of land produces 5.6 tons of green paddy rice and this is equivalent to 3,327 kg of commercial white rice. Therefore, the research developed will have a significant contribution due to the amount of production involved in the functional unit of the study, in addition to the impact on the population under study.

In terms of environmental pollution, the carbon footprint contribution corresponds to the emission of 7,316 kg of CO₂ equivalent per cultivated hectare, where 52% corresponds to the growth and development of the crop, 47% to land preparation and planting, and 1%

to the harvesting of the harvest and final storage of the grain. It is estimated then that, in Norte de Santander, rice cultivation can emit 190,000 kg of CO₂ equivalent for each year of production, taking into account that two production cycles are carried out per year, something that is undoubtedly worrying.

Taking into account the identification of contaminating factors, the difficult situation presented by crop irrigation and the high production costs that make the product less competitive in the market, strategies were formulated that aim to positively impact the process with greater efficiency of the resources and, therefore, reduction in the carbon footprint.

Sustainable rice production over time guarantees greater availability of food, which will serve to combat hunger and poverty. Likewise, the mitigation of global warming in rice farming is a significant contribution to human health, who will have better living conditions with lower risks to the environment.

Given the above, it is important to consider that Norte de Santander brings together nearly 1,600 production units, equivalent to 12,900 hectares, on which the largest agricultural activity in the department is carried out, impacting the generation of employment and the economic dynamics of the metropolitan area. of Cúcuta, which is why inter-institutional efforts must be combined (mayors, government, ministry of agriculture, universities, SENA, Fedearroz, Corponor, Banco Agrario, among others), with the purpose of formulating proposals and managing public investment resources to the financing and implementation of projects that allow minimizing the factors that have the greatest impact on the environmental impact.

It is necessary to promote the implementation of favorable agronomic practices such as crop rotation, use of organic waste, application of efficient microorganisms and elimination of burning with the purpose of conserving natural resources and soil structure. It is considered necessary to develop research on feasibility studies for the transformation of organic waste that is generated in the area and that can be incorporated into the soil to compensate for the deficiencies it presents.

The lack of precision during the process of irrigation, planting, cultivation and harvesting of rice is one of the factors that, in addition to causing high costs, also affects the generation of greenhouse gases, making the activity less competitive and productive and, therefore, therefore, putting its sustainability at risk. It is important, then, to implement modern technologies such as, for example, precision leveling with laser beams, precision planters, smart harvesters, satellite technology to study crop areas, unmanned aerial vehicles and the use of software to capture and process information that allows making correct decisions.

It is necessary that, together with universities and research centers, studies begin to be carried out that allow the construction of a plan for the modernization and automation of rice cultivation and harvesting, through the incorporation of advanced machinery,

equipment and technologies. that result in greater precision in the application of inputs and better production performance per hectare.

One of the most polluting factors of the process has to do with the planting technique used, which is why, supported by the acquisition of more modern machinery and technology, it is necessary to change to the mechanized transplant technique, with which, They obtain benefits for the productivity of rice and the reduction of contaminants in the process.

Another aspect that was identified in the production areas is the lack of training of the personnel who work in rice crops, for this reason, alliances with SENA and the universities of the region are necessary to train the workforce. qualified personnel and rural extension workers, especially in relation to agricultural machinery, mechanized work, soil preparation, pest control, fertilization, agroecological production, installation and maintenance of irrigation systems, as well as rural extension, management of agrochemicals, management of hazardous waste, among other topics of interest.

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