# Study to estimate greenhouse gases from soybean cultivation as a function of production variables

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**Abstract**. *Over the past few decades and specially after the Paris Protocol engagement by many Counties associated with the UN, discussions about greenhouse gases (GHG) and the environmental impacts of the agriculture sector have increased. Given the urgency of decreasing GHG emissions, this research was conducted to understand how to calculate the GHG emissions of our most economically important grain, soybeans. Thus, it will be possible to identify in which parts of the soy production process there is the largest GHG emissions. This research seeks to identify and quantify the main stages and inputs present in soybean cultivation in Brazil to calculate the emission of GHG stemming from those different variables. The long-term aim of the research is to find suitable combinations of production variables that could reduce the GHG emission from this important nutritional and economic culture and provide market guidance for future investment in the sector.*

**Key words.** Soy, GHG emissions, Sustainability

## Introduction

Brazil is currently the largest soybean producer in the world (CONAB 2022). In 2021, 67.74 million hectares were destined for grain cultivation, with 33.313 million hectares, 49.2% of the total area (Embrapa 2022), only for soybean. Generating a production of 135.409 million tons of soybeans. The State of Mato Grosso, located in the Brazilian Midwest, is the number one producer, cultivating 26.55% of the national production. The forecast for the 2022 yield is even higher, with an estimate of reaching 152.4 million tons of soybeans.

This oilseed is the main grain exported by Brazil, with China as its main market. In 2021, soybean exports generated US$31.2 billion for the country, and until the month of September 2022 it has generated US$122.1 million, which represents 43.14% of all agribusiness exports (Agrostat 2022).

On the other hand, the soybean-related activities seem to have had also a significant downside. A bibliographical review involving the few specific sources found on the subject has suggested that this culture is based in an agricultural system that relies heavily on the use of fossil energy, chemical fertilizers, pesticides, high mechanization, with consequent few job openings, and genetically modified seed varieties to increase productivity. Furthermore, the uncontrolled expansion of the soy monoculture has helped to promote deforestation in very important brazilian ecosystems, like the Cerrado, of which 50% only remains (IPAM 2022) and the Amazon Forest, with an estimated 17% of the area already deforested (INPE 2022).

In this research the processes involved in soy production were surveyed, as well as the calculations needed to obtain the direct GHG emissions of each of the processes.

## Objectives

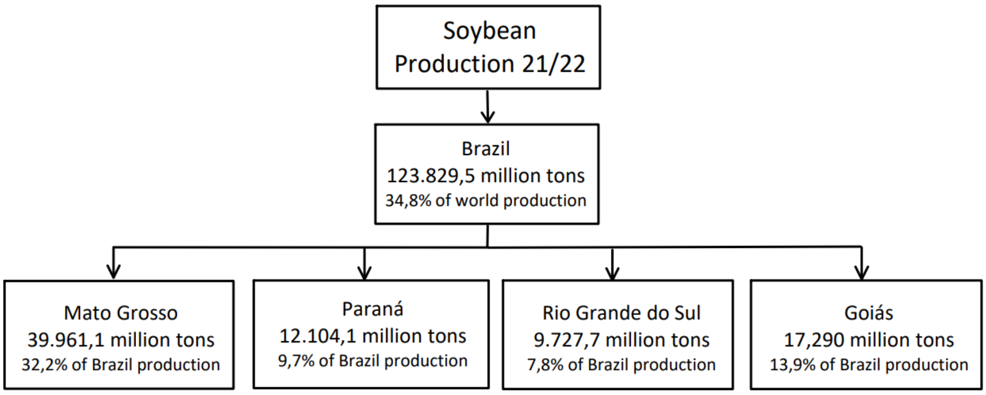
This research is part of a GCSP project that aims to ultimately provide guidance to ESG-sensitive agricultural entrepreneurs which seek to establish a more balanced approach concerning the productivity and the CO2 emission aspects of soy agriculture, as well as provide market guidance for future investment in the sector. Thus, after an analysis, the producer will know which are the best processes for a certain region that emit the least amount of GHG, besides knowing the approximate number of gases he is emitting and can compensate this emission by planting vegetation to absorb the equivalent gases.

This part of the project is concerned with (i) identifying the main parameters associated with the soy culture processes and (ii) to identify accepted metrics to convert CO2 emissions associated with each activity or step of the process. For this analysis, production methods are presented and the GHG emissions associated with each alternative are calculated.

## Literature Review

The three main producers in Brazil are Mato Grosso in first place followed by Goiás, Paraná and Rio Grande do Sul, as shown in figure 1.

Figure 1 - Soybean production in Brazil, by Brazilian states.




Source: Embrapa 2022, adapted by the author.

It is important to understand the supply chain of this high demand. According to data from the Brazilian Association of Soy Producers (Rodrigues 2021), 49% of Brazilian soy is processed: 79% becomes bran and 21% becomes oil (for both "cooking" and biodiesel industry). In addition, 44% of the grains in natura are exported and will also be used to meet mainly the agricultural demand. The remaining 7% are kept in stock for various purposes. Of the 79% that becomes bran, 48% is for animal feed and the rest is exported. Thus, of the total amount of soy that is not exported 55% is for animal feed (Aprosoja 2016).

In the production of this grain, several processes are involved, including soil preparation, sowing, addition of fertilizers and harvesting, that is, the soybean life cycle starts with the harvest of the previous crop and ends with its own harvest. (Embrapa 2021). Emissions related to post-harvest storage, transport and soybean processing were not considered, as well as irrigation.

The calculation methodology was based on the 5th evaluation report of the Panel Intergovernmental Framework on Climate Change (IPCC) through the characterization or global warming potential (GWP) (IPCC 2006), since for the calculation of CO2 some conversions are used, and the most used is the GWP.

The IPCC has developed and continues to develop a series of principles and methodological procedures for measuring the emission of greenhouse gases. Within these principles and procedures, the concept of Tiers (level) was created.

A Tier represents the level of methodological complexity that is adopted. In this work, Tier 1 was used, which is recommended for situations where emission factors are not available country-specific, or limitations on activity data such as, for example, information on land use and Tier 2 as well, which is recommended for situations where emission factors are available specific to the main conditions of the country or region. (GHG Protocol 2015).

Table 1 - Selected parameters in soybean production in Brazil

| | |
|---|---|
| **Soil preparation** | Limestone |
| **Planting technique** | No-tillage |
| **Fertilization** | Sintetic |
| **Harvesting technique** | Mechanical |

Source: author

### Nitrogen application

### Sintetic fertilizers

An essential component of proteins is nitrogen (N), which makes the crop need large amounts of this nutrient. The main form of N replacement in agricultural systems is by nitrogen fertilizers. However, its use implies greenhouse gas (GHG) emissions from the soil, in this case, nitrous oxide ($N_2O$). Equation 1 is used to calculate nitrous oxide emissions from the use of synthetic fertilizers. The emission factors are presented in Table 1. To calculate the $CO_2$ equivalent of the $N_2O$ emission, the Potential for Harm of each gas was considered, which means how much it interferes with the greenhouse effect in a century, compared to an equivalent amount of $CO_2$ issued in the same period. The GWP index of $CO_2$ is 1 and of $N_2O$ is 298. So, in the end the result of equation 1 needs to be divided by 298.

$$N_2O_{fert} = Q_{fert} \times (1 - Frac_N) \times FE_N \times \frac{44}{28} \quad (1)$$

Where,

$N_2O_{fert}$ is the emission of nitrous oxide associated with the application of synthetic nitrogen fertilizers (Kg $N_2O$ -N / Kg of applied fertilizer);

$Q_{fert}$ is the amount of N applied as nitrogen fertilizer (Kg);

$Frac_N$ is the fraction of applied N that volatilizes in the form of NH3 and NOx (%);
$FE_N$ is the emission factor (%)
44/28 is the Conversion of N-$N_2O$ to $N_2O$

Table 2 presents some of the parameters used to calculate emissions associated with the use of sintetic fertilizers.

Table 2 - Emission factors from sintetic nitrogen fertilizer application

| $N_2O$ | |
|---|---|
| $FE_N$ | 0,8% |
| $Frac_N$ | 10% |

Source: GHG Protocol, 2015

**Limestone application**

Brazilian soils are mostly acidic, a characteristic that contributes to the appearance of toxic elements for plants, negatively affecting the crop. Limestone is the main product used to correct soil acidity. The emission of $C$ occurs through the thermal decomposition of limestone: $CaCO_3 \rightarrow CO_2 + CaO$. This reaction produces quicklime and carbon dioxide. Carbon emissions from fossil fuels used in the production of fertilizers include emissions from mineral extraction and fertilizer manufacture. The $CO_2$ emission in liming is calculated using equation 3 and the emission factor is presented in Table 3.

$$CO_{2limestone} = (Q_{calcitic} \times FE_{calcitic} + Q_{dolomitic} \times FE_{dolomitic}) \times \frac{44}{12} \quad (2)$$

Where,

$CO_2$limestone is the $CO_2$ emission associated with the application of limestone to the soil (kg $CO_2$);
$Q_{calcitic}$ is the amount of dolomitic limestone applied to the soil (kg);
$Q_{dolomitic}$ is the amount of calcitic limestone applied to the soil (kg);
$FE$ is the emission factor – carbon content in limestone (%);
$\frac{44}{12}$ is the conversion factor from C to $CO_2$ (dimensionless).

Table 5 shows what are the emission factors for limestone use.

Table 3 - Dolomitic limestone emission factor

| $Dolomitic\ limestone$ | |
|---|---|
| $FE_{calcitic}$ | 0,12% |
| $FE_{dolomitic}$ | 0,13% |

Source: GHG Protocol, 2015

**Fuel consumption**

The fuel consumption considered was in the part of the harvest using machinery. To calculate the emissions associated with the consumption of diesel oil, the emission factors presented in Table 3 and Equation 3 were used.

$$CO_{2\,diesel} = Q_{diesel} \times FE_{diesel} \quad (3)$$

Where,

$CO_{2\,diesel}$ is the CO emission associated with the consumption of diesel oil;
$Q_{\,diesel}$ diesel is the amount of diesel oil consumed (L);
$FE_{diesel}$ is the emission factor of diesel oil (kg $CO_2$ /L).

Table 4 - Emission factor for burning diesel

| **Burning diesel** | |
|---|---|
| $FE_{diesel}$ | 2,681 kg $CO_2$/L |

Source: IPCC,2006

The harvester operating speed is very important to control losses at the desired level. It is recommended to harvest at speeds between 4.0 and 6.5 km/h, depending on several factors. In order to avoid harvest losses, an adequate planning of the machine is necessary, which can be done by the formula given below (Emprapa 2013):

$$Cte = (V \times L \times Ef)/10.000 \quad (4)$$

Where,

$Cte$ is the effective capacity of work force (in ha/h);
$V$ is the displacement speed (in m/h);
$L$ is the effective operating width (in m);
$Ef$ is efficiency coefficient (for self-propelled harvesters, the value varies from 0.65 to 0.80).

**Crop residues**

Crop residues refer to the straw that remains after harvesting and the decomposition of this straw generates GHG emissions. The equations used to calculate $N_2O$ emissions from residues from soy. Again, as it is $N_2O$ and the work is evaluating the $CO_2$ emission, in the end the result of equation 6 needs to be divided by 298.

$$N_2O_{res} = [CROP \times Frac_{DMcrop} \times \frac{Res_{DM}}{CROP_{DM}} \times Frac_{NCRes}] \times FE_N \quad (5)$$

Where,

$N_2O_{res}$ is the emission of nitrous oxide associated with the application of synthetic nitrogen fertilizers fertilizers (Kg N2O/ Kg of fertilizer applied);
CROP is the annual production of the crop;
$Frac_{DMcrop}$ is the dry matter fraction of the harvested (marketed) product of each culture;
$\frac{Res_{DM}}{CROP_{DM}}$ is the ratio between dry residue and dry product, for each culture;
$Frac_{NCRes}$ is the N content of the shoot of each crop;
$FE_N$ is the emission factor.

The parameters for calculating crop residue emissions are described in Table 5.

Table 5 - Emission factor for burning diesel

| $\frac{Res_{DM}}{CROP_{DM}}$ | $Frac_{NCRes}$ | $Frac_{DMcrop}$ |
|---|---|---|
| 1,98 | 0,009 | 0,87 |

Source: GHG Protocol, 2015

There are technologies that increase GHG emissions and other technologies that reduce GHG emissions. Regarding the ones that enhance the emissions are: deforestation, soil erosion, pasture degradation, soil mechanization, among others. In contrast, agricultural practices that restore the capacity of soils as carbon sinks, being, therefore, technologies that mitigate carbon emissions, are no-tillage technique, reforestation, recovery of degraded pastures, planting of perennial crops, adequate use of fertilizers chemicals and organic fertilizers, adoption of Agroforestry Systems (SAFs), sanitary treatment of dejects and organic residues, with energetic use of biogas, among others Emprapa s.d.).

The no-tillage system is the most sustainable due to the accumulation of organic matter in the soil. This accumulation over a long period is the fixation of carbon in the soil in the form of organic matter and is known as carbon sequestration. Thus, soils managed under this technique without soil preparation and with the addition of straw pass from the condition of source of CO2 towards the atmosphere to the condition of assimilation of CO2 into the soil (Emprapa s.d.).

## Results and Discussion

To model the equations presented in the literature review, a soybean plantation area of 750 hectares located in Rio Grande do Sul was used as a basis (Dotto 2017). The modeling was done in Vensim software, which mainly supports continuous simulation. Four (4) parameters were considered: fuel used by the machines in the harvest, application of nitrogen fertilizer, dolomitic limestone in the soil and harvest residue. The simulation period was 12 months with two steps, one of 2 months and the other of four months since the soybean harvest time varies according to these intervals in Brazil. The results are presented in table 6 and 7.

Table 6 - CO2 total plantation emissions (Kg de $CO_2$) with 2 months gap

| 2 meses | 4 meses | 6 meses | 8 meses | 10 meses | 12 meses |
|---|---|---|---|---|---|
| 266009 | 532019 | 798028 | 1,06e6 | 1,33e6 | 1,6e6 |

Source: author

Table 7 - CO2 emissions (Kg de $CO_2$) of the four parameters for 1 harvest

| Limestone | Diesel | Fertilizer | Crop residue |
|---|---|---|---|
| 8250 | 124003 | 186,871 | 564,815 |

Source: author

**Conclusion**

This is an estimation of GHG emissions from soybean cultivation in Brazil. The most used methods from soil preparation to harvest were considered. A case study was done to test the calculation methods researched on a real case of a 750-hectare farm in the Rio Grande do Sul region. It was possible to observe that for one production 8250 kg of $CO_2$ are emitted for the use of limestone, 186,871 kg of $CO_2$ for the use of fertilizer, 124.003 kg of $CO_2$ for the use of diesel at harvest, and 564,815 kg of $CO_2$ generated from the waste that remains after harvest. The total $CO_2$ emitted in one production run was 266.009 kg and the results indicated that the largest source of $CO_2$ in the soybean production is diesel used for the harvest machinery. Further studies comparing the methods and the main producing regions of the country are still needed. However, this study is already an indicator that producers should start paying attention to reduce $CO_2$ emissions. The ultimate goal of this work is to survey all the different soy production processes and the GHG emissions from each of them. In this way it will be possible to cross-reference these data to serve as a guide for selecting the most efficient production method in terms of minimizing GHG emissions for each of Brazil's soy production states, and this could be a new service to be offered to producers.

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