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Brazil has been increasingly standing out in the areas of agriculture and livestock while at the same time, in these sectors there are increasing concerns regarding greenhouse gas (GHG) emissions. With respect to beef cattle, the country has the largest commercial herd, is the second largest beef producer and the largest beef exporter worldwide (USDA, 2018). In this scenario, considerable participation of livestock activity in GHG emissions is expected, both in total emissions and in the agricultural sector (Oliveira, 2015). According to the Annual Estimates of GHG Emissions in Brazil (Brasil, 2017), in 2012, the agricultural sector was responsible for 37% of total equivalent carbon dioxide (CO_2) emitted into the atmosphere in the country. Beef and dairy cattle enteric methane (CH_4) emissions contributed, respectively, with 75 and 12% of the total methane emissions in the agricultural sector. Thus, only CH_4 emissions from beef cattle enteric fermentation accounted for 17.2% of total CO_2 equivalent emissions and when summed together with dairy cattle enteric emissions the percentage of total CO_2 emissions rises to 19.9%. There are still emissions from excreta, feces and urine, which emit nitrous oxide (N_2O) after being deposited on the soil, further contributing to increasing GHG emissions in livestock, considering that this greenhouse gas has a global warming potential 298 times higher than CO_2.

Therefore, livestock has a large share in Brazil's greenhouse gases emissions. Nevertheless, it is well known that the population is increasingly informed

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about this and is increasingly concerned about how food is being produced, about the carbon footprint and global warming. Thus, issues related to the environment and its sustainability are increasingly significant, especially in more developed countries to which Brazil exports meat.

In this scenario, sustainable production systems prove to be valuable and promising. According to Lorenz and Lal (2014), some agroforestry systems have drawn more attention due to their ability to capture atmospheric CO_2 and store carbon in plants and soil. According to Oliveira et al. (2017), crop-livestock-forest integration (CLF) is a suitable production system that provides adequate productivity and offsets livestock GHG emissions providing a positive carbon footprint. Several studies mention the advantages of integrated systems because of the synergy that takes place between the components, such as more efficient use of fertilizers and conditioners, resulting in productivity gains and sustainability (Vilela et al., 2011; Pacciullo et al., 2017). In addition, the CLF system promotes diversification of farm activities (Balbino et al., 2011; Vilela et al., 2011) leading to more economic security for agricultural properties. Mainly due to their higher yields and to diversification of agricultural activities, the use of integrated systems instead of, for example, the use of conventional planting of trees to offset greenhouse gas emissions is more advantageous.

In 2012, the Brazilian government established the *Sector Plan for Mitigation and Adaptation to Climate Change for the consolidation of a Low-Carbon Economy in Agriculture*, also named *The ABC Plan* (The Low Carbon Agriculture Plan). The general objective of this plan is to promote the mitigation of GHG emissions in agriculture within the scope of the National Policy on Climate Change (PNMC), thereby improving efficiency in the use of natural resources, increasing the resilience of productive systems and rural communities, and enabling the adaptation of the agricultural sector to climate change. The ABC Plan is, therefore, a public policy that has, as its main commitments, several strategies to increase the adoption of sustainable production technologies, among them CLF systems (Brasil, 2012).

As stated by Cordeiro et al. (2011), the ABC Plan is a set of actions that promotes “low” GHG emissions by the agricultural sector, and not “zero” emissions, which would be impossible to do in practice. The above mentioned authors also stress that the ABC Plan aims to ensure continuous and sustained improvement of management practices to reduce GHG emissions and to increase atmospheric CO_2 fixation in vegetation and soil by Brazil's agriculture.

In this context, Embrapa developed the "Carbon Neutral Brazilian Beef" (CCN), concept which may contribute to foster the implementation of more sustainable livestock production systems, such as the CLF system, especially with respect to the environment through the introduction of the tree component, which is capable of offsetting methane emitted by cattle in order to add value to the meat produced in these systems (Alves et al., 2010).

However, there are still many questions regarding the design of a CLF system, in order to balance the production of the components involved in the system along with the system's sustainability.

Thus, the objective of this paper is to demonstrate the potential of the crop-livestock-forest integration system as a strategy of Brazil's agriculture to offset greenhouse gas (GHG) emissions.

Offsetting GHG emissions in an Integrated CLF system in the Brazilian Savannah (Cerrado Biome)

The assessment of GHG emissions compensation was carried out in a field at Embrapa Cerrados, Planaltina, the Federal District, Brazil in an experiment with crop-livestock-forest integration that was implemented in 2009. The experiment includes different arrangements of eucalyptus trees. The differences are in the number of trees per hectare, the number of tree lines and the spacing between the rows. Initially the first experiment phase included silviagriculture and later on the silvipastoral phase. In the same area there is a treatment without trees, in which pasture was recovered by crop-livestock integration (CL). The carbon balance measurements were performed in the treatment without trees (crop-livestock integration system - CL) and in a double-row eucalyptus trees treatment (crop-livestock-forest integration system - CLF) with 22 m spacing between the rows, totaling 417 trees per hectare (Table 1).

Table 1. Timeline of the crops in the CL and CLF treatments from 2009 to 2016 in the long-term experiment at Embrapa Cerrados, located in Planaltina, DF.

Treatment	Year 0 2009	Year 1 and 2 (2010 and 2011)	Year 3 2012	Year 4 to 8 (2013 and 2016)
CL	Agricultural phase		Pastoral phase	
	Sorghum	Soybean	Soybean + Sorghum + Piatã palisadegrass	Piatã palisadegrass
CLF[1]	Agroforestry phase		Agrosilvipastoral phase	
	Sorghum	Soybean	Soybean + Sorghum + Piatã palisadegrass	Piatã palisadegrass

[(1)]Eucalyptus planted in year 0, in February 2009 along with sorghum. The spacing between rows was 22 m and between plants 2 m.

In the experimental area the soil carbon stock, the plant biomass (forest component only) and the emissions from soil gases (N_2O) and animals enteric fermentation (CH_4) were all measured.

Currently, when establishing a CLF system it is recommended to intercrop annual crops with trees in the first year, and in the subsequent year, to implement pasture. In this way, a main summer crop is planted, followed by a second crop of corn or sorghum intercropped with pasture between the rows of trees. Depending on the region's climatic constraints, when only a summer crop is possible, forage seeds may be intercropped with, or even oversown (depending on the species to be used in the system) the annual crop. On the other hand, depending on soil fertility and productivity levels of the area, it is possible to choose to prolong the agricultural phase in the initial phase of the CLF system (agroforestry phase), thus promoting better results in terms of soil recovery when compared to the use of pastures without the use of lime and fertilizers. Depending on the land's topography, the alignment of tree plantations can take place in the North-South direction, prioritizing aspects of soil conservation. However, with the growth and development of the tree component, this alignment favors shading in the spaces between the rows, impairing the development of crops. In areas where it is possible to proceed with the implantation of the trees in the East-West direction, the crop phase may be extended for a longer period of time, especially if larger spacing between the rows is used, varying between 30 m to 60 m. This spacing may increase pasture production in the silvopastoral phase when compared to smaller spacing between rows

Nitrous oxide (N_2O) emissions in the CLF system

In the initial phase of the system, or agroforestry phase, N_2O emissions were attributed to the cultivation of grains, soybeans and sorghum, which in the two cycles emitted approximately 1.06 kg of $N_2O.ha^{-1}$ or 315 kg of $CO_2eq.ha^{-1}$ (Oliveira et al., 2017). These emissions are considered similar for the two systems, CL and CLF, due to the low or zero interference of the forest component in the initial phase.

The pasture component of the system in the silvopastoral phase (CLF system) emitted 1.02 kg of N_2O or 305 kg of CO_2eq annually and in the CL system emitted 1.42 kg of N_2O or 423 kg of CO_2eq (Carvalho et al., 2017), considering the Global Warming Potential (GWP) related to the CO_2 of 298 according to IPCC - Intergovernmental Panel on Climate Change (2013). Thus, after the first year of N_2O emissions in the grain production phase, the systems continue to emit approximately 305 kg and 423 kg of CO_2eq, respectively for CLF and CL. As a result, emissions in the form of N_2O will need to be neutralized to offset GHG emissions.

Methane (CH_4) emission by cattle enteric fermentation

With the introduction of animals in the area, the emissions of enteric methane (CH_4) on the part of the animals begins. Emissions of this gas in the production system can vary according to the stocking rate of the area and the quality of the pasture eaten by the animals. Under the conditions of the experiment, the stocking rate in the CLF system was 1.7 $head.ha^{-1}$ (1.1 AU-animal unit. Ha^{-1}), which resulted in emissions of 2,000 kg of $CO_2eq.ha^{-1}.year^{-1}$ from enteric CH_4, considering GWP of 25 in relation to CO_2, according to the IPCC (2013). In the treatment without trees (CL), the stocking rate was 3 $heads.ha^{-1}$ (2.0 $UA.ha^{-1}$), providing emissions of

3,400 kg CO_2eq.ha^{-1}.year^{-1} from CH_4 (Guimarães Júnior et al., 2016).

Thus, if we sum up the emissions after 2 years of establishment of the system, 2,672 kg of CO_2eq.ha^{-1}.year^{-1} were observed for the CLF system and 4,072 for the CL system. Emissions of N_2O and CH_4 must be added by the excreta, which will be presently accounted for according to Lessa et al. (2014). Even though it is known that the emissions caused by bovine excreta are much lower than what is recommended by the IPCC, these should not be disregarded (Lessa et al., 2014; Cardoso, 2016).

Carbon stock and plant biomass

The main ways by which atmospheric CO_2 can be captured, and then stored, by the production system is through its transformation into soil organic matter and, mainly, through its transformation into plant biomass from the forest component. Although carbon (C) is stored in the form of soil organic matter, cases where C stocks in the soil under agricultural systems outweigh the stocks of adjacent native vegetation are less common. In other words, it is difficult to obtain a positive carbon balance if the forestry component is not included in the agricultural production system. For example, in the ILPF system, a single tree accumulated, on average, 30.2 kg of C. year^{-1} (considering 45% C of the plant's dry biomass mass). This is equivalent to the sequestration of 110.5 kg of CO_2.year^{-1} from the atmosphere for each tree inserted in the system. In this calculation, all the tree components (leaves, branches, bark, stem, excluding only the roots) were considered to store C. However, true immobilized carbon is concentrated in the wood of the tree trunk.

So, it is possible to say that a CLF system will be more efficient in sequestering C from the atmosphere in direct proportion to a greater number of trees in the area. However, care must be taken so that an excessive number of trees in the ILPF system does not compromise the performance of the intercrop crops, due to competition for light, water and nutrients.

Recommendation for a CLF arrangement to offset GHG emissions

Initially, it is necessary to adequately plan the system aiming at a correct distribution of the forest component within a CLF system. Nevertheless, it is important to define which strategy will be followed in order to implement the CLF system so as to mitigate the GHGs. It is possible that only a percentage of the farm will be used by the CLF system, so that this percentage is able to offset all GHG emissions from the cattle on the property. For this, a greater number of trees/ha is needed in areas with CLF system. Another option is for the CLF system to be distributed throughout the entire production area of the rural property, observing the number of trees/ha so that there is no excessive shading of the pasture causing loss of productivity.

Experiments at Embrapa Cerrados demonstrate that if only 15% of the production area is dedicated to a CLF system (North-South alignment with 417 trees/ha), this would suffice to offset all methane emissions from cattle and nitrous oxide (from the soil and excreta of cattle) added to the initial emissions from the crop phase (N_2O). It should be noted that there is also C storage in the roots of the trees, which has not been calculated. (Table 2).

Table 2. Carbon balance in seven year old CL and CLF systems - Embrapa Cerrados.

System	ECH_4 [(1)]	N_2O excreta[(2)]	Average annual N_2O soil emission[(3)]	Stocking rate ($head.ha^{-1}$)	Soil carbon[(4)]	Trunk carbon fixation[(5)]	Accumulated average annual emission[(6)]	Annual Carbon balance[(7)]
CL	3.4	0.527	0.407	3.0	4.7	0	3.84	+0.86
CLF	2.0	0.298	0.306	1.7	3.5	20.7	2.31	+21.89

(1) Enteric animal emission of CH_4 (Mg of $CO_2eq.ha^{-1}.year^{-1}$) with global warming potential - PAG (100- time horizon in years) related to CO_2 = 25 (IPCC, 2008), considering six years of the system with animals for calculation purposes (ILP = 2.91 and ILPF = 1.71);

(2) Emission factor of bovine excreta (Lessa et al., 2014) in Mg of $CO_2eq.ha^{-1}.year^{-1}$ considering six years of the system with animals for calculation purposes;

(3) N_2O (Mg of $CO_2eq.ha^{-1}.year^{-1}$) emitted by the soil under pasture and grains with global warming potential - PAG related to CO_2 = 298 (IPCC, 2008), average of the seven years of the system (six years of pasture + one year under grain culture);

(4) Average C sequestration by the soil to a depth of 100 cm;

(5) Considering the volume up to the commercial height of the tree trunk (Mg of $CO_2eq.ha^{-1}.year^{-1}$);

(6) Average annual emission (Mg $CO_2eq.ha^{-1}.year^{-1}$) (enteric CH_4 + soil N_2O + N_2O excreted);

(7) Considering a population of 417 trees per hectare at seven years of age, considering the annual emissions of enteric CH_4 for six years (real condition) and accumulated N_2O emissions over the seven years.

Although the CL system has a positive C balance, demonstrating that a well-managed production system tends to emit less C than it accumulates, this positive balance is based on the sequestration of C by the soil. This occurs, in large part, due to the root system of the plant components, especially of the pasture, and the straw (litter) deposited on the soil. However, the rate of C accumulation in the soil tends to stabilize over time, when the C stock in the soil under the agricultural system approaches original values observed in native vegetation. Thus, under these conditions, the accumulation of C in the soil will tend to be zero, since the soil will be very close to its maximum capacity to store carbon.

Finally, it can be stated that, depending on the objective, the forestry component of the CLF system is a viable option for storing atmospheric CO_2 in the form of wood.

Final remarks

Despite the importance of cattle ranching for Brazilian society, GHG emissions have been stigmatizing this economic activity as a major villain of climate change. Crop-livestock-forest integration is a viable alternative from an environmental point of view to make Brazilian livestock farming neutral in terms of GHG emissions.

Preliminary data show that the allocation of 15% of the total pasture area to the ILPF system, with a density rate of 417 trees. ha^{-1}, would be enough to compensate all GHG emissions from livestock (CH_4) and pasture (N_2O), leaving a positive carbon balance on the farm. That is, a property with 1000 ha of pasture must allocate 150 ha to the CLF system (417 trees.ha^{-1} with a stocking rate of 1.7 head.ha^{-1}) and 850 ha to the CL system (stocking rate 3 heads.ha^{-1}) to offset GHG emissions. Another way would be the distribution and maintenance of approximately 70 trees/ha on the entire pasture area, considering a stocking rate close to 1.7 head.ha^{-1}, in order to obtain similar results. The spatial arrangement of the trees may be at the discretion of the producer, observing what is most appropriate for his property and facilitating the management of all components of the system.

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