Low-Carbon Technology in Brazilian Semiarid Ecosystems

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Abstract
Agriculture is a vulnerable sector to the climate changes, and Brazil is one of the major contributor of greenhouse gases (GHSs). Thus, the implementation of effective strategies for both mitigation and adaptation to climate change for agriculture is very important for development and also to infer sustainability to the Brazilian agricultural sector. The "low-carbon agriculture" aims to develop processes and technologies that promote mitigation of GHG emissions in agriculture and enable the adaptation of the agricultural sector to climate change. Thus, in Brazilian semiarid region, developing technologies with no-tillage systems concomitant with green manure and agrosilvopastoral systems are adapted to climatic conditions to infer sustainability in the livestock and agricultural sectors.

INTRODUCTION

The greenhouse gas (GHG) emissions have their dynamic emission to the atmosphere related to agricultural production processes, changes in land use, the burning of fossil fuels, and industrial activities. In a global level, changes in land use added to the agricultural production processes contributed 22% of carbon dioxide (CO_2) emissions, 43% of methane (CH_4) emissions, and 85% of nitrous oxide (N_2O) emissions. In Brazil, historically, this sector contributed 75% of CO_2 emissions, 91% of CH_4 emissions, and 94% of N_2O emissions, considerably higher in relation to global averages.[1] Thus, conservation technologies, based on low-carbon (C) agriculture, are fundamental to mitigate the impact of land use change and climate change on GHG emissions.

Studies directed to determining the impact of land use change and climate changes in C stock are sporadic in the Brazilian semiarid region, mainly because of large variability and mosaic distribution of the soils and vegetation.[2] This question assumes greater importance in the face of climate change scenarios for the Brazilian semiarid region in which extreme events would negatively impact agricultural production.[3–4] Thus, this entry presents the main concerns related to the land use change and agriculture in Brazilian semiarid region, and the low-C agriculture technologies adapted to climate conditions that will imply sustainability to regional production system.

LAND USE CHANGE IN THE BRAZILIAN SEMIARID

The Brazilian semiarid region, with 969,589 km^2, has 28 million people, including urban areas, representing 11% of the country, and 1.6 million agricultural establishments, with 95% classified as family farms. Caatinga is the most representative Brazilian semiarid biome, with an approximate area of 844,453 km^2,[5] which is formed mainly by low trees and shrubs, many of which have thorns, microphyll and xerophytic characteristics, and herbaceous with great importance because of its foraging, medicinal and apicultural value.[6] However, the change of land use with the use of woody plants for energy

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production together with the use conversion aimed at agricultural production is responsible for the removal of 46.38% of caatinga vegetation.[7] Livestock is the main land use followed by rainfed agriculture and irrigated agriculture, changing the soil C stock. In this sense, Sampaio and Costa[8] estimated that the average soil C stocks in caatinga areas, native pasture, planted pasture, and crops are 100, 90, 80, and 70 Mg ha^{-1}, respectively.

TECHNOLOGIES TO MITIGATE THE LAND USE CHANGE AND CLIMATE CHANGE IMPACTS

No-till farming, green manures adoption, agroforestry systems, silvopastoral systems, and organic farming are technologies used in semiarid region to increase the soil organic C content, consequently reducing the GHG emissions.[9–11] They are fundamental to consolidate a low-C agriculture adapted to the soil and climatic conditions of the Brazilian semiarid.

No-Till System and Green Manure

In the Brazilian agricultural soils, no-till contributes to both increased soil microbial biomass and C sequestration, with increments from 5.2 to 8.5 Mg C ha^{-1}, superior to soil under conventional tillage.[12] However, there are difficulties to implement that practice in the Brazilian semiarid region due to climatic limitations and the traditional requirement of crop residues to livestock feed.[13] Conversely, the priority of the soil conservation in Brazilian semiarid region with the use of cover crops and its residues allows the increase of water infiltration and retention, the increase of organic matter content, the decrease of soil temperature oscillations and evaporation, and, subsequently, the decrease of the salinization process. In this sense, many studies have focused on no-tillage system development for corn crops,[14,15] melon,[16] cowpea,[17] and watermelon.[18] All the proposed crop systems consist of rotation, succession, or intercropping, with emphasis on the green manure use. Among the technologies studied and implanted with no-till system in Brazilian semiarid region stands out the use of plant cocktails. Thus, the studies of irrigated areas in Brazilian semiarid region have been developed using plant cocktail as green manure in mango crop (since 2005) and melon crop (*Cucumis melo* L.; since 2011), as technology for low-C agriculture.

Studies have already been developed with species cultivated as plant cocktail, covering different proportions of grasses, legumes, and oilseeds to evaluate the best composition in the culture under study.[19] Grasses generally contributed to relatively large amounts of biomass and characterized by a high C/nitrogen (N) ratio that increases the persistence of soil cover over time.[20] On the contrary, the leguminous species, which fix atmospheric N, have high levels of N in plant biomass, and their residues generally have low C/N ratio with relatively fast decomposition that promotes a small soil cover.[21] The Brazilian semiarid region has a potential to add large amounts of C and nutrients in the soil of agricultural systems in a short period by means of the green manure crops (Table 1). The plant cocktail biomass increases the rate of adding C that may be stored in the soil system over time.

There is a lack of studies on no-till system impact and green manure on C dynamics in the Brazilian semiarid soil, both taking into account the topsoil along the profile. In Brazil, the studies carried out throughout the territory estimated that soil C stocks are 39, 52, 72, and 105 Pg in 0.0–0.3, 0.0–0.5, 0.0–1.0, and 0.0–2.0 m layers, respectively.[22] The distribution of C on profile decreases significantly with the soil use, initially in surface and after in subsurface,[23] demonstrating that there are significant differences between the surface C and C in depth.[24]

The roots contribute twice as much to the soil organic C compared to plant aerial part due to a higher proportion of lignified tissue.[25] The production of biomass and the root cycling, especially the thin ones, influence the amount and dynamics of C in soil. The root cycling is regulated by soil moisture and temperature and microbial activity due to their biochemical characteristic[26] or associated with plant hormonal and physiological reactions. In arboreal stratum, due to the high renewal rate over the tree life cycle, there is a high rate of adding C to the root system.[27] Consequently, in addition to the aerial biomass contribution of the green manure is also important to quantify the production of root biomass and the nutrient accumulation by the roots along the soil profile. It was verified that green manure cultivated

Table 1 Production of dry matter and nutrient accumulation in the aerial part of plant cocktail and spontaneous vegetation (Petrolina, Embrapa semiarid region, 2013).

Green manure	Dry phytomass (Mg ha^{-1})	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})	Ca (kg ha^{-1})	Mg (kg ha^{-1})	S (kg ha^{-1})
75% L + 25% NL	10.61	212.41	55.47	319.31	133.15	100.00	74.87
25% L + 75% NL	11.00	126.50	49.18	360.07	177.02	155.85	75.76
Spontaneous vegetation	3.99	78.68	22.66	105.52	43.43	38.81	29.68
CV (%)	21.68	23.12	32.15	26.75	24.91	27.84	23.06

Note: L, legumes; NL, no legumes.

in the Brazilian semiarid region added quantity of biomass (5.0–5.6 Mg ha^{-1}) and nutrient [N: 70.1–80.4; phosphorus (P): 4.2–5 3; potassium (K): 39.9–40.0; calcium (Ca) 39.8–47.7; magnesium (Mg): 5.8–7.3; and sulfur (S): 6.3–6.8] along the upper soil profile when compared with the spontaneous vegetation (biomass: 1.5 Mg ha^{-1} and N: 38.6; P: 2.0; C: 10.9; Ca: 17.7; Mg: 2.8; and S: 3.3). These observations do not include plant exudates and mucigels released by the root system during the development of the green manure. Thus, the use of plant cocktails as green manure in both mango crop and melon crop, even for a short period of time, increased the content of soil organic matter, initially occurring in the surface and subsurface layers. It was also observed that the highest C/N ratio influences the behavior of the humic fractions, indicating the formation of humus with less fulvatic character.[28]

Understanding the dynamics of organic matter and accurately estimating C stocks in surface and subsurface are important to the development of technologies and sustainable agricultural systems and involve long-term studies. Lima[29] evaluated the melon C footprint produced in Brazilian semiarid region, comparing the following production systems: conventional system used by most producers in the region and the conservationist system, in development and experimental scale with three-year cultivation, using no-tillage with green manure via plant cocktail. The conservationist system uses plant cocktail (composition: 75% legume species and 25% of no legumes species) as green manure without incorporation in soil. The C footprint results for a ton of melon produced and transported to the consumer market (State of São Paulo, about 2000 km) were 821 kg CO_2eq in conventional system and about 639 kg CO_2eq in conservationist system. The conventional system demands larger amounts of synthetic fertilizers, resulting in direct N_2O emissions and indirect NH_4 and NO_3^{2-} emissions that affect the melon C footprint, whereas conservationist system has lower contribution due to lower loss C, considering the amount of C returned to the soil by green manure biomass used.

Agroforestry System

The agroforestry system is a sustainable practice of natural resource management that combines forest species, agricultural crops, and/or livestock in the same exploitation area, simultaneous or in temporal sequence. This technology aims to ensure the production stability and diversity, increase productivity, improve soil fertility, and increase the supply of a good-quality forage.[30] Besides, it reduces GHG emissions and increases the C stock in the soil and plant system.[31]

The agrosilvopastoral system is the predominant agroforestry system in Brazilian semiarid region, combining crops, forest species, and animals in the same area. There is also the silvopastoral system with the introduction of animals in areas with permanent and commercial tree species or with the introduction or maintenance of the tree component (native or exotic) in cultivated pastures and adapted to the region.[32] Studies have shown that the preservation of natural trees during the cutting of caatinga trees or cultivation of native or introduced species may contribute to the preservation or restoration of soil fertility in agricultural or pasture areas in northeast semiarid region of Brazil. Sacramento et al.[11] evaluated the changes in soil C stocks in the layer of 0–40 cm, after 13 years of experiment installed in a typical orthic luvisols. They observed that silvopastoral agroforestry farming systems (97.59 Mg ha^{-1}) and agrosilvopastoral (71.64 Mg ha^{-1}) and traditional (with clearing of vegetation, burning, and cultivation during two to three years; 68.16 Mg ha^{-1}) systems had lower C stocks compared to the remaining caatinga vegetation (134.65 Mg ha^{-1}); however, the agroforestry systems outperformed the traditional system. But, some studies have shown that measurements of changes in some soil variables in agroforestry systems, such as total organic C, are imperceptible in less than 10 years.[33]

Drumond[34] highlighted that the main arboreal species with multiple potential use for agroforestry systems in the Brazilian semiarid region are as follows: Leucaena (*Leucaena leucocephala*), Gliricidia (*Gliricidia sepium*), Mesquite (*Prosopis juliflora*), Sabiá (*Mimosa caesalpiniifolia*), and Eucalyptus (*Eucalyptus* sp.). These species have forestry development in areas dependent on rain with an average annual rainfall ranging from 500 to 700 mm.

Among the agrosilvopastoral models, the following stand out: 1) pastures cultivated with grasses: Buffel (*Cenchrus ciliaris*), Aridus grass (*Cynodon dactilum* var aridus), and Urochloa (*Urochloa moçambisensis*); 2) Leucaena protein banks (*Leucaena leucocephala*) grown in rows (4.0 × 1.0 m) and intercropped with maize and/or beans; 3) Gliricidia protein banks (*Gliricidia sepium*) grown in rows (4.0 × 1.0 m) and intercropped with maize; 4) cactus areas planted with the giant varieties (*Opuntia ficusindica*) and round varieties (*Opuntia stricta*), in a dense system, spacing 1.0 × 0.25 m and 1.0 × 0.5 m, respectively, and in single-row system (3.0 × 0.25 m) intercropped with Gliricidia (*Gliricidia sepium*), on lines and corn in between rows; 5) reforested areas with Sabiá (*Caesalpinia echinata*) established in spacing of 10.0 × 3.0 m; and 6) live fences with forage gliricídia.[35] Among all systems, we highlight the importance of using leguminous species for biological N fixation.

The planting in alleys is also a technique used in Brazilian semiarid region to improve the quality of soil. It consists of plant trees in rows properly spaced between them, where among the lines are cultivated crops at the beginning of the rainy season. The main objective of this system is to increase the organic matter content, nutrient cycling, and addition of N in by green manure.[36]

The main leguminous species used as alley farming are as follows: Crotalaria (*Crotalaria juncea*), Jack Bean (*Canavalia ensiformis*), Black mucuna (*Styzolobium* *aterrimum*), Guandu (*Cajanus cajan*), Leucaena (*Leucaena leucocephala*), Gliricidia (*Gliricidia sepium*), Sabia (*Mimosa caesalpiniifolia* Benth), and Canafístula (*Peltophorum dubium*). The choice of these species will depend largely on weather conditions, soil types, and culture characteristics.[37]

Gliricidia sepium, e.g., is a legume largely used in alleys farming due to good development conditions under water stress and high capacity of biomass production.[38] Studies by Marin et al.[38] evaluated the corn production and chemical composition and soil characteristics modifications with the use of Gliricidia in alley farming system in the semiarid region. They observed that the use of *G. sepium* did not alter the levels of total organic matter but significantly increased the light organic matter content, available P, and extractable K in soil.

Oliveira et al.[39] evaluated the carbon management index (CMI), calculated from the C stock index and lability index,[40] among the conventional agricultural systems and agroforestry systems in the semiarid region of Ceará, Brazil. They observed that the CMI showed the highest values for the agrosilvopastoral system (120–200%) compared to the silvopastoral (0–60%) and traditional (100–160%) systems. Therefore, according to the authors, agroforestry systems are effective for improving soil quality, increasing C stock, and promoting sustainability in these environments.

There are few studies involving the agroforestry systems impact on C stocks in soil and plant system, and also there are no systematic studies to assess the impact that integrates scenarios of global climate change in areas or long-term experiments in Brazilian semiarid region.

CONCLUSION

Agriculture and livestock are very important activities in the semiarid economy, characterized by caatinga biome. However, the extractive livestock, monoculture, excessive soil preparation, and lack of soil cover, promoted by land use changes, contribute to soil erosion, decomposition and mineralization, salinization, and/or sodification, decreasing the C stock in soil. Predicted impacts on climate change scenarios may potentialize the C stock reduction. Thus, the technologies and farming systems, such as no-tillage system associated with green manure and the agroforestry systems, are alternatives that can reduce GHG emissions, increase C sequestration, and mitigate the impact of climate change in the Brazilian semiarid region.

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