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Carbon Sequestration Potential in the Savannas Ecosystems of Venezuelan Flatlands

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Abstract

The flatlands occupy 28% (25Mha) of Venezuela. They are dominated by ecosystems of savannas with different landscapes, soils, and vegetation adapted to acid soils, low fertility and subjected to frequent fires. Historically, they are predominantly used as extensive cattle ranching. Nevertheless, the agricultural use has been intensified at the expense of many natural savannas. These land use changes may affect the storage and the potential for C sequestration in their soils. Through an extensive review of literature of the soils in the Venezuelan flatlands, we calculated the stocks of soil C for each major landscape, ecosystems and land use type, by using existing data on C content (%), bulk density and extent, down to a depth of 0-30 cm. The C contents increase from the eastern drier flatlands to the more humid and younger western flatlands, and from seasonal to hyperseasonal and semiseasonal savannas. The poorly drained plains, about 20% of the flatlands, store the highest C (323.8 Tg C). In well drained savannas, introduced pastures increased the storage. If all the flatlands were covered with well managed pastures, it would have a potential of sequestration of around 0.54 Pg C.

Key words: sequestration of C; Venezuelan flatlands; savannas; farming systems.

Introduction

The Neotropical savannas are ecosystems that cover approximately 269 Mha in South America. They constitute one of the most extensive areas with potential to increase different kinds of agricultural production. These savannas are located in Brazil (204 Mha), Venezuela (25 Mha), Colombia (23Mha), Bolivia (13 Mha) and Guyana (4 Mha). They generally are defined by perennial grasses with disperse woody species, where water availability follows a seasonal pattern. The savannas of Brazil and Guyana have evolved from ancient Precambrian shields, while the flatlands of Venezuela, Colombia and Bolivia are formed mostly from younger quaternary sediments from the Andes.

In Venezuela, the savannas occupy around 25 Mha or 28% of its territory. They are dominated by grasses that growth in dystrophic soils. Well drained soils are predominant, but there are also extensive areas with poor drainage during the rainy season, with different adapted pastures. All soils are subjected to a dry season (4 to 6 months) and a wet season for the rest of the year. Other factor important in its formation and functioning is the recurrent anthropic fires during the dry season.

Due to the low quality of the native pastures, the most extended type of land use is extensive grazing. But in the last decades, it is being partly substituted by a more intensive grazing, including introduced pastures and rotations with cereals and other agricultural uses (beans, sunflower, and planted forest like Pinus, Eucaliptus, etc.)

Early studies show that the conversion of native savannas to introduced pastures increase the soil organic matter (SOM) (Fisher et al., 1997), diminish the net flow of greenhouse gases to the atmosphere, and increase the net income of C in the ecosystem (Rondón et al., 2006). López-Hernández et al. (2014) point out an increase in the C content due to the change of tillage in annual crops and the use of different cover crops associated to maize (Hernández-Hernández et al., 2013). The recent development of new an adequate farming systems (Valencia et al., 2004), together to long term evaluations (San José et al., 2003) show that the transformation of native savannas to pastures or to annual crops with an appropriate management could be considered sustainable.

The increase of SOM, with the change of land use from native savannas to pastures or crops is quite complex. This is mostly due to the different landscape positions: alluvial plains, eolic plains, elevated plateaus and rolling-hills (Berroterán, 1988; Schargel, 2003), also to the different climates; from the drier eastern plains to the more humid in the west, and also to the four types of functional vegetation communities: seasonal, hyperseasonal, semiseasonal and gallery forest (Sarmiento, 2000). The available information on soil C is very fragmented and there is lack of a uniform methodology that limits a proper interpretation and extrapolation of the available data.

Among the major difficulties to know properly the storage and evaluate the potential sequestration of soil C are: i.-Values of C expressed in terms of concentration ii.-lack of soil bulk density values iii.- values determined at shallow depths.

The objectives of this paper, based on an exhaustive review of literature of soils in the flatlands of Venezuela, were: i.- to compile the results published about of C (%) at depths from 0 to 30 cm and its bulk density and ii.- to estimate the storage and potential sequestration of C in the soil, derived from the changes in land use in this ecoregion. These estimates assume homogeneity in the landscape units and the average of C content.

Methodology

From an extensive search of bibliography we obtained data from: areas of the main types of landscapes and their ecosystems, the area of the main land use types, the soil C content (%), bulk density of the first 30 cm of soil, the distribution of the principal suborders of soils (Berroterán,1988; PINT, 1979; Schargel, 2003; Comerma y Luque, 1971; Hernández-Hernández et al., 2004; López-Hernández et al., 2014; Zinck y Stagno, 1966). For each paper reviewed, we calculated the stock of C for each depth, using the values of C content (%) and the corresponding bulk density; followed by the estimationof Cthat had been stored per hectare in the firsts 30 cm. Later, we calculated the accumulation of C in the soil for the different landscape units, using the average of C stock, the values of extend of the ecosystems and types of land use.

Results

We found Venezuelan flatlands represents around 28% of the country i.e 26.2 Mha. The most extensive landscape unit correspond to the alluvial and eolic plains (14.17 Mha), from them, the poor–drained savannas cover 7.45 Mha and the well-drained 6.42 Mha. The elevated plateaus (Mesas) cover 6.48 Mha and the rolling hills 3.15 Mha. The variety of landscapes shows also a diversity of soils, the alluvial plains have mostly Inceptisols, Mollisols, Alfisols and Vertisols, while the eolic plains have Ultisols and Entisols. In the elevated plateaus, dominate Ultisols and Oxisols, whereas in the gallery forest are mostly Inceptisols. The seasonal savannas occupy 56% of the area, with ranges between 0.8- 3.5% and 1.2-1.8% g.cm3 for C content and the bulk density respectively, being the lowest values under forest and the highest values in the seasonal savannas. The levels of C content show two increasing tendencies: i.- geographical, from the east to the west and ii.-) ecological systems, from seasonal savannas to hyperseasonal , semiseasonal and forest (Table 1).

For the remaining natural systems, the highest capacity to accumulate C in the first 30 cm is found in the alluvial plains, especially the ones occupying the lower positions or with poor drainage. In Table 2 we can observe that in the well-drained plains, introduced pastures increase significantly the C stock, while annual crops under conventional tillage and the forest plantations reduce their storage in the order of 12 and 35%, respectively. Nevertheless, there are no visible changes with minimum or non-tillage.

Table 1. Carbon content and stocks in the top 30 cm of soils from Venezuelan flatlands.

Regions	Landscapes	C stocks (MgC.ha^{-1})	*C (%)*
	Recent alluvial plains		
West	Deciduous forests	77.0 ± 19.4	5.0 ± 1.3
	Hyperseasonal savannas (lowlands)	45.2 ± 17.3	3.2 ± 1.4
	Semiseasonal savannas (lowlands)	61.5 ± 12.0	5.2 ± 1.1
	Alluvial Plains from the Pleistocene		
West	Hyperseasonal savannas (lowlands)	39.0 ± 8.5	2.6 ± 0.6
	Seasonal savannas	33.5 ± 6.4	2.2 ± 0.5
East	Seasonal savannas	42	0.9
Central	Seasonal savannas	46	2.9
	Eolic Plains		
West	Poorly drained savannas	65 ± 7.1	4.2 ± 0.3
	Well drained savannas	22 ± 4.2	1.4 ± 0.2
	Elevated Plateaus		
West	Seasonal savannas	24 ± 9.9	1.6 ± 0.7
East	Seasonal savannas	17.7 ± 7.5	0.8 ± 0.5
Central	Seasonal savannas	51.3 ± 22.5	3.5 ± 1.6
	Rolling hills		
Central	Seasonal savannas	31	3.3

Original data from: Campos (1999), Colmenares et al. (1974), Comerma and Chirinos (1976), Gómez (2004), Güerere (1992), Hernández-Hernández et al. (2004), Hernández-Hernández and Domínguez (2002), Hernández-Hernández and López-Hernández (2002), Malavé (1981), Pérez-Materán et al. (1980), PINT(1979; 1985; 1990), Schargel (1972; 1978), Westin (1962), Zinck and Stagno (1966). Tomado de Rondón et al. (2006).

Discussion

Historically, the savannas have been used with extensive cattle ranching, including frequent fire in the dry season to renovate the outbreak of the more palatable nayive grasses; crops in more fertile soils in areas along the rivers; and wood extraction in natural forest. Animal husbandry has been intensified with the introduction of improved pastures: Brachiarias, Panicums and Digitarias, among others, with the purpose to increase the double purpose cattle (milk and beef). Besides intensification with crops like maize, sunflower, sorghum, beans, cotton, sugarcane, cassava, bananas, minor fruits, and forest plantations, mainly *Pinus caribaea* and *Eucaliptus sp*. At present we have around 6 Mha of introduced pastures, 2 Mha of annual crops and 0.8 Mha of planted forests. All these uses represent around 29% of the ecoregion, remaining under native grasses about 17 Mha and 1.5 Mha under native forest.

Considering that the expansion of the agricultural frontier in Venezuela is mostly concentrated in the flatlands ("Llanos"), the risk to decrease the C stock in the soils is high (López-Hernández et al., 2014), and moreover, if the gallery forest are cleared. The substitution of native grasses for introduced pastures has augmented the capacity to storage C in the soils (Hernández-Hernández et al., 2013), especially in the alluvial plains. Forest plantations have not promoted an increase of C, especially the ones of *Pinus caribaea* in the eastern plains, where the decomposition rate is low (Campos, 1999).

In summary, for the top 30 cm of the savanna soils, we estimate a C stock of 1.3 Pg C, and if we assume the same storage down to 100 cm depth, it would result in 0.52% of C for the whole ecoregion. These estimates should be looked upon carefully, due that we assume homogeneity of the functional units and the C content was estimated with limited data. Considering that all the ecoregion could be converted into well managed pastures, the C sequestration potential would be 0.54 Pg.

Table 2. Estimated C stocks for the main land use systems in the Venezuelan flatlands.

Landscape position/land use	**Area (Mha)**	**Estimated Carbon stocks (0-30 cm depth) MgC.ha^{-1}**
Remaining natural systems		
Elevated plateaus	5.04	35.66
Well drained lowlands	4.81	43.16
Poorly drained low plains	5.45	59.41
Rolling hills	1.66	40.00
Gallery and deciduous forest	1.52	75.00
Subtotal	***18.48***	
Modified systems		
Introduced pastures	5.00	78.00
Annual crops, conventional tillage	0.83	38.10
Annual crops, reduced tillage	0.17	43.20
Tree plantations	0.80	27.00
Urban, water bodies etc.	0.90	
Subtotal	**7.70**	
Total	**26.18**	

Published in (Rondon et al. 2006)

Conclusions

The Venezuelan savannas have a great potential to sequester C in their soils, but there is a large variation according to the landscape unit and the geographical location. The alluvial and the eolic plains have the largest capacity, due to their extent and to the high C content in the upper 30 cm of their soils. Data indicate that this capacity increases toward the western llanos, probably due to an increase in rainfall as it gets closer to the Andean piedmont. It is necessary to obtain more data on soil C, including information on bulk density and georeferncing it to have a precise plotting. All these studies are very necessary due to Neotropical savannas play an important role in the biogeochemical cycles, are a reservoir of biodiversity and provide important ecosystem services.

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