

Soil carbon storage in three tropical bovine cattle systems under exploitation

Sandra Lok, S. Fraga, Aida Noda and M. García

Instituto de Ciencia Animal, Apartado Postal 24, San José de las Lajas, Mayabeque, Cuba
Correo electrónico: slok@ica.co.cu

In areas of the Institute of Animal Science during the years 2004, 2005 and 2006 was determined the soil carbon storage in three tropical cattle raising systems under exploitation with bovine cattle: a) silvopastoral based on *Panicum maximum* and *Leucaena leucocephala*; b) monoculture of *Panicum maximum* and c) grass association with a mixture of creeping legumes. In each one of the systems soil carbon storage (SCS), organic matter and apparent density were determined. Botanical composition, frequency of species appearance and soil cover were evaluated in each system. In all systems, the highest carbon deposit occurred from 0 to 15 cm depth. The silvopastoral system and that of the legume mixture increased the SCS with the time of exploitation, which varied from 54.4 to 65.3 t ha⁻¹ and from 50.6 to 60.4 t ha⁻¹, respectively. The system with guinea grass monoculture decreased the SCS with the time of exploitation, which was of 60.4 to 43.7 t ha⁻¹. It is concluded that SCS contents are in function of the use and management of the soil and directly related to the organic matter content. In the depth from 0 to 45, the greatest accumulation of CSC occurred in the first 15 cm. The silvopastoral system and that of the creeping legume mixture had a gradual increase in the SCS with the exploitation time, which turns them into viable alternatives for carbon capture in grassland agricultural ecosystems. The monoculture system showed decline signs, with which were related their lower values in the SCS. It is recommended to use silvopastoral systems and of creeping legume mixtures to improve the soil C storage and to attain systems of stable and productive improved grasses.

Key words: *silvograzing, monoculture, creeping legumes*

Carbon dioxide (CO₂), owing to its harmful effect, is the gas of greatest importance regarding global warming. By reason of the gas residence time in the atmosphere, the CO₂ volume produced every year increases its concentration in the atmosphere. A way of mitigating these effects is its storage in the biomass by the photosynthesis and, in the soil, through the accumulation of organic matter.

The terrestrial soil contains much more carbon than the air (Botero 2011). The quantity of carbon contained in the first superficial meter of the soil reaches 2.500 Gt. From these, 1.550 Pg are in the form of organic carbon and the rest, 950 Pg as inorganic carbon. The carbon contained in the vegetation is of 560 Pg (Anon 2011).

The soil carbon reservoir is very different from some regions to others. In arid zones, the carbon contained in the first soil meter is approximately of 30 t ha⁻¹ and of 800 t ha⁻¹ in the peat bogs of high latitudes. On average, its content ranges between 50 and 150 t ha⁻¹ (Lal 2004). Recent estimates suggest a net C release in the tropics, owing to deforestation, between 0.42 and 1.60 Pg year⁻¹, from which 0.1 to 0.3 Pg, are due to a decrease in the soil organic matter. Tropical soils emit to the atmosphere a carbon quantity which is only surpassed at world scale by its release due to fossil fuels consumption (Botero 2011). It is considered that since 1800, the atmospheric CO₂ concentration was increased by more than 25% (EPA 1994).

Cattle systems, formed by four basic components (soil-plant-animal-man) have great complexity in their interrelationships and can contribute to carbon storage, precisely in view of this wide range of possible

combinations and functions. The accumulated carbon in the soil depends on the type of soil, its use, management and depth. These aspects are determinant for the existence and decomposition of the organic matter, as primary source of carbon storage. Each cattle system must contribute in a singular way to this process of C capture. Thus, the objective of this paper was to determine the soil carbon storage of three tropical cattle systems under exploitation.

Materials and Methods

The study was carried out during 2004, 2005 and 2006 in areas of the Institute of Animal Science, located in San José de las Lajas municipality, Mayabeque province between 22° 53' NL and 82° WL and at 80 m a.s.l. (Anon 1989).

Three grasslands were studied: a) silvopastoral based on *Panicum maximum* and *Leucaena leucocephala*; b) monoculture of *Panicum maximum* and c) Grass association with a mixture of creeping legumes.

The silvopastoral system based on *Panicum maximum* and *Leucaena leucocephala* at the beginning of the trial had eight years of exploitation and was divided in eight paddocks of 0.26 ha each, for a total area of 2.08 ha. *P. maximum* represented 71% of the botanical composition, followed by 10.5% of *Cynodon spp.*, 10% of weeds, 6% of *C. nlemfuensis* and 3% of herbaceous legumes. Also, it had approximately 14.4% of clear soil. The population of *L. leucocephala* was of 9014 plants ha⁻¹, with an average height of 2.3 m. The animal mass was mainly formed by Holstein, Siboney and crossbred cows. During the evaluation period, the

average stocking rate was of 2.7 LAU ha⁻¹ and rotations were carried out every 57 and 28 d as average in the poor rainy and rainy seasons, respectively.

The monoculture of *Panicum maximum* had 24 years of exploitation at the beginning of the evaluation. It was formed of 10 paddocks of 0.55 ha each, for a total area of 5.53 ha. Initially, its botanical composition was of 68% of *P. maximum*, 18.9% of weeds (*Sida acuta*, *Paspalum notatum* and *Bouchea prismatica*) and 13% of herbaceous legumes, with 8.3% of clear soil. The average stocking rate was of 2.7 LAU ha⁻¹. Rotations every 57 and 28 d were made as average in the poor rainy and rainy seasons, respectively.

The association of grasses with a creeping legume mixture, exploited uninterruptedly since 1994, had a botanical composition of 61.6% of legumes (*Neonotonia wightii* and *Macroptilium atropurpureum*), 21.7% of *Cynodon nlemfuensis* and 16.3% of weeds (*Sida acuta*, *Mimosa pudica*, *Paspalum notatum* and *Dichanthium annulatum*), with only 1.1% of clear soil. The legume of highest presence in the grassland was *N. wightii*. This grassland occupied a total area of 6 ha, divided in eight paddocks, of 0.75 ha each. A stocking rate of two animals ha⁻¹ of Zebu and Charolais breeds was maintained in the grassland. The average duration of each fattening was of 65 d, with an initial average live weight of 214 kg and average final live weight of 270 kg, representing an average gain of 861 g animal⁻¹ day⁻¹. During the poor rainy period, there were 10 d of occupation and 49 d of rest. In the rainy period, the occupation days were seven, and 49 of rest, for a total of six rotations per year. The animal management was maintained stable during the evaluated years, in correspondence with the demands of the cattle raising technologies applied to each grassland. In this period there were no cultural labors (fertilization, irrigation, renovation or rehabilitation, pest control and rotation). Supplementary feeds were supplied to cover the requirements of the animals according to the feeding balance.

In the rainy season of 2003 an evaluation of the botanical composition and the soil cover were realized. The evaluation allowed selecting two representative paddocks of the vegetative performance of each one. This selection was made from the analysis of the statigraphs of central tendency and of dispersion for the botanical composition (mean X, SD and CV) and soil cover (SD). In this way, paddocks with these statigraphs more close to the mean were selected.

The botanical composition was determined in 80 frames ha⁻¹, randomly distributed in each paddock by the method of t'Mannetje and Haydock (1963). Biomass availability was established twice by climatic season by the method of Haydock and Shaw (1975). Soil cover and density by species were calculated according to the method of Huss *et al.* (1996) in 0.25 m² frames, distributed every 15 steps by the diagonal of the paddock. These represented between

five and nine frames per paddock.

For the edaphic study, a prospecting pit of 1.30 m width x 2.0 m long x 1.0 m depth was opened in each selected paddock. The soil carbon stored (SCS) and its evolution in time were determined for three depths (0 to 15 cm; 15 to 30 cm; 30 to 45 cm). For each one four samples were taken. While SCS at 45 cm depth was obtained by the summation of this indicator for each depth analyzed.

For estimating the soil carbon (SC) the organic matter was determined by the method of Walkley and Black (1934). Later, the resultant organic matter percentage was divided by 1.7 (McVay and Rice 2002 and Miranda *et al.* 2007). For apparent density (AD) a cylinder of sharp base, with a volume of 106.76 cm³ (8.5 cm length and 4 cm diameter) was used according to the recommendation of Martin and Cabrera (1987). Three samples were taken for each depth.

The SCS (t C ha⁻¹) was estimated from the percentage of C in the soil (% SC), the apparent density (AD) and the sampling depth (D):

$$SCS = \% CS \times AD \times D$$

The statistical package InfoStat (2001) was employed. A linear model of variance considering the effects of years and depths was applied.

Results and Discussion

In table 1 is shown the performance of the soil carbon stored in each system for each depth evaluated.

AQUI TABLA 1

As sampling depth was increased in the three systems there was a tendency to show lower values of this indicator. This was in correspondence with the organic matter content of the soil (figure 1), that must decrease in a natural way with the depth increase (Cairo and Fundora 1994), since at the 0 to 15 cm depth occurs the highest deposit of organic matter by effect of the accumulation of litter, the subterranean phytomass and the proximity to feces deposition places.

All this generates a superior biological activity and, thus, greater possibilities for soil carbon capture. De Petre *et al.* (2006) stated that the carbon accumulated in the upper soil strata has greater amount and variability because is in function of the change in the use and management of the soil. This coincides with what was stated by Robert (2002), who assures that the soil carbon varies with depth, and is in correspondence with the type of soil and with the content and decomposition of organic matter.

With the increase of the exploitation time, the silvopastoral system and that of the legume mixture increased the carbon stored in the soil (SCS) at the 0 to 45 cm depth (table 1). In the first of them was of 54.4 to 65.3 t ha⁻¹, while in the second varied from 50.6 to 60.4 t ha⁻¹. The monoculture system decreased the SCS, from 60.4 to 43.7 t ha⁻¹. The amount of carbon stored in the soil of tropical grasslands has been estimated

Table 1. Carbon stored in the soil in the evaluated systems

System	Depth (cm)	Carbon stored in the soil (t ha ⁻¹)			SE and Sign
		2004	2005	2006	
Silvopastoral	0 a 15	20.0 ^a	22.9 ^b	25.9 ^c	0.05 ***
	15 a 30	18.8	21.3	19.8	0.14 NS
	30 a 45	15.6 ^a	18.1 ^{ab}	19.6 ^b	0.04 *
	Total evaluated (0 a 45 cm)	54.4 ^a	62.3 ^b	65.3 ^c	0.02 **
Monoculture	0 a 15	22.1 ^b	22.0 ^b	15.6 ^a	0.08 ***
	15 a 30	21.1 ^b	19.3 ^b	14.6 ^a	0.10 **
	30 a 45	17.2 ^b	14.6 ^{ab}	13.5 ^a	0.02 *
	Total evaluated (0 a 45 cm)	60.4 ^c	55.9 ^b	43.7 ^a	0.11 ***
Legume mixture	0 a 15	20.0 ^b	18.2 ^b	22.6 ^c	0.02 *
	15 a 30	17.4 ^a	18.4 ^{ab}	20.0 ^b	0.03 *
	30 a 45	13.2 ^a	13.5 ^a	17.8 ^b	0.10 *
	Total evaluated (0 a 45 cm)	50.6 ^a	50.1 ^a	60.4 ^b	0.12 *

*P < 0.05, **P < 0.005, *** P < 0.001

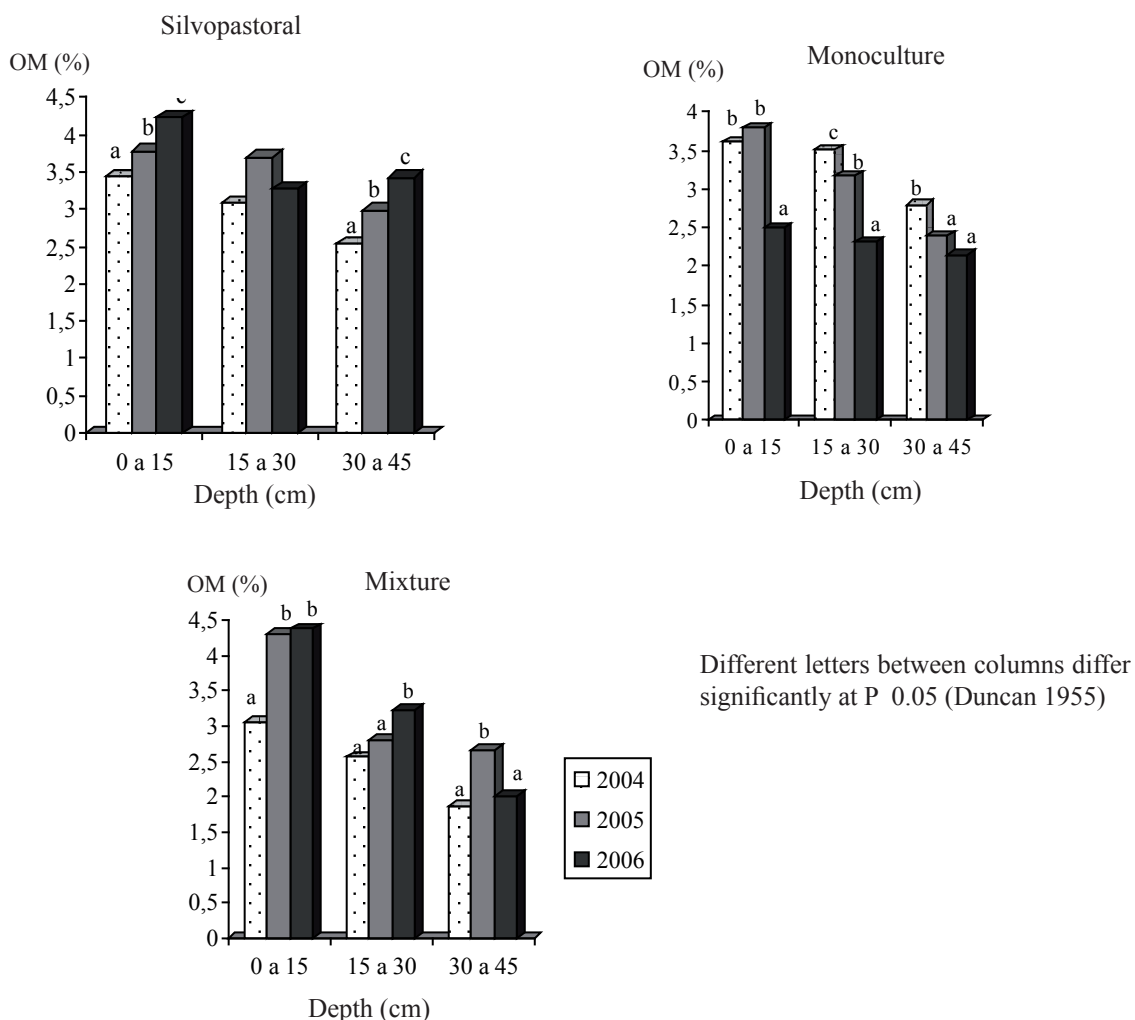


Figure 1. Soil organic matter contents in each system evaluated

between 16 and 48 t C ha⁻¹ at the 0 to 30 cm depth (Botero 2011), information agreeing with the results of this study.

This performance can be associated with the characteristics of each system regarding the species found, its botanical composition, its plant biodiversity, the soil cover and the management to which they were

submitted. Ávila *et al.* (2001) asserted that the use and management of the soil, is determinant in the SCS performance.

The silvopastoral system had high soil cover (figure 2) for both seasonal periods, with values ranging between 95.8 and 99.8 %. Also, in its botanical composition

(figure 3) there was guinea grass predominance as basal pasture, which was maintained between 73 and 89 %, with marked density increase between years (figure 2), which varied between 5.8 and 9.6 plants m². These characteristics indicated that the system had a favorable evolution with the increase of the exploitation time and could have influenced in the improvement of the soil organic matter contents (figure 1), which is one of the main factors for carbon fixation, since the carbon is stored in the soil mainly as part of the organic matter. This represents more than 1 400 GT (1 Gt = 1015 g), almost double than that existing in the atmosphere (Post *et al.* 1982). Furthermore, grasses used in tropical animal production are generally of C₄ metabolism, which gives them greater capacity to integrate the CO₂ in the plant organic matter. This organic matter can be consumed by the animals, and great part of it (30 – 70 %) returns to the soil as feces and urine. Part of the plants become senescent, pass to integrate part of the litter and organic residues deposited on the soil and are rapidly decomposed by the soil microorganisms (López *et al.* 2011).

Botero (2011) indicated that the efficiency for carbon fixation in grasslands with improved pastures lies in

that they generally possess deep radical systems, which can strongly contribute to the net primary productivity of the species and, thus, to the carbon immobilization capacity. In the case of silvopastoral systems, by the presence of trees or shrubs, this efficiency can be greater, precisely by the depth and abundance of their radical systems, not occurring exactly in this way in grass pastures.

Miranda *et al.* (2007) considered the silvopastoral systems as a sustainable and viable alternative, since they are capable of generating environmental services by constituting important carbon drains and very advantageous for its capture. Studies carried out by these authors, on comparing a farm with natural grasslands and another with an agroforestry system, showed that the carbon stored in the soil by the silvopastoral system was higher than that sequestered in the system with natural pasture which was 24 and 19.5 t ha⁻¹, respectively.

The system with creeping legumes mixtures increased the SCS throughout the years of exploitation, similarly to the silvopastoral system. It was also characterized by the high soil cover, showing no significant differences between years in each seasonal

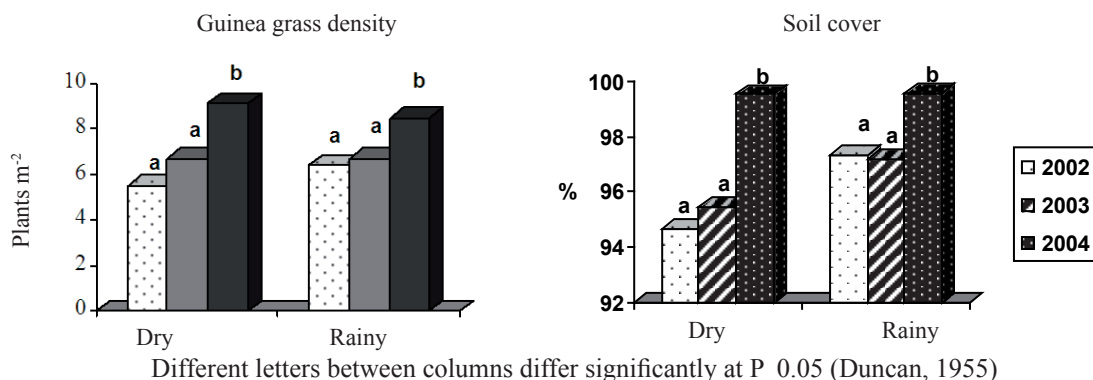


Figure 2. Performance of the soil cover and the guinea grass density in the silvopastoral system

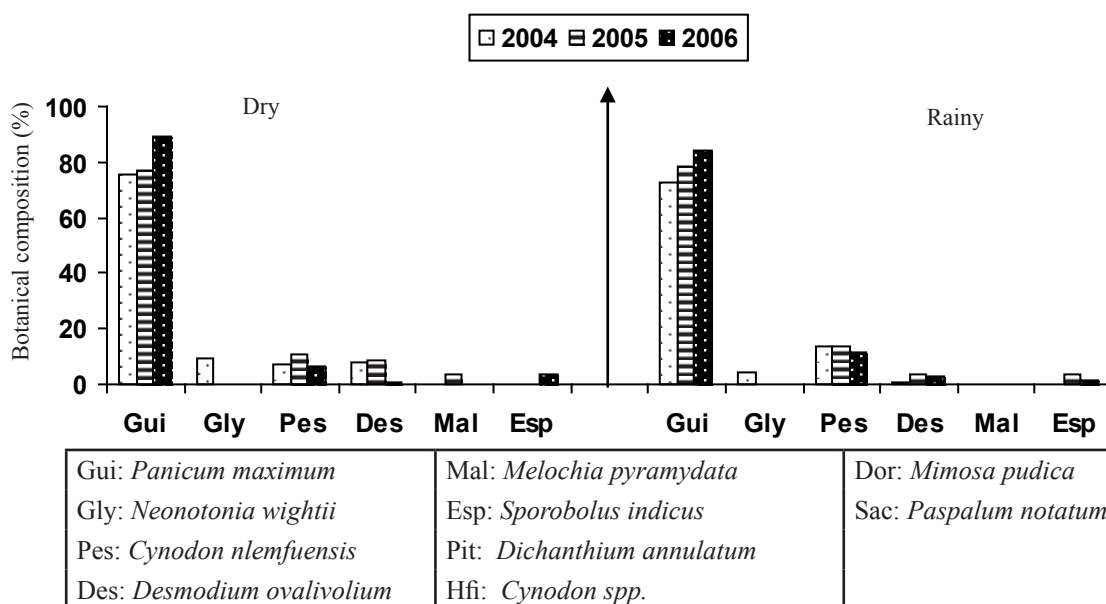


Figure 3. Performance of the botanical composition in the silvopastoral system

period and was approximately between 96.5 and 99 % for the dry and rainy seasons, respectively (figure 4). Its botanical composition was dominated by the presence of the legumes with values between 50 and 80 % in the dry season, while in the rainy season was between 75 and 80 % (figure 5). The creeping legumes tend to maintain the soil covered and produced high litter contents (Crespo *et al.* 2005), which together with its low C:N relationship favors soil nutrient recycling. In that connection, Crespo (2003) stated that the decomposition process of such residues and of other plant components occurs more rapidly in grasslands based on legumes.

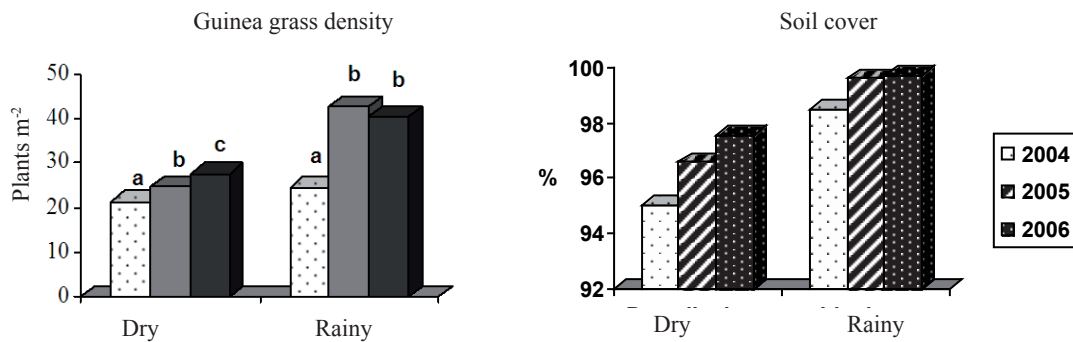
According to Vargas and Valdivia (2005), the creeping legumes allow the recuperation of soil fertility because they improve the structure and the pH, favor the biodiversity of the edaphic fauna and the soil cover. They also make feasible greater carbon capture. Different studies have documented that the SCS content between 20 and 80 cm soil depth, can be duplicated or tripled with legume inclusion in the grasslands (Arias *et al.* 2001).

The system with guinea grass monoculture decreased the SCS with the exploitation time (see

table 1). Also, it showed a performance characterized by the decrease of the guinea grass density as base pasture (figure 6), with the consistent grass reduction in the botanical composition of the grassland and the weed and natural pastures increase with the exploitation time of the system (figure 7). In turn, there was greater soil cover in the evaluated years. This was mainly due to less desirable species as *Sporobolus indicus* and *Paspalum notatum*.

The system with guinea grass monoculture exhibited organic matter values in the soil for the three depths studied, which were lower than the rest of the systems under study (figure 1). This factor might be determinant in the SCS performance and could be due to the plant characteristics that showed not only low nutritive value but also poor favorable C:N relationship for the decomposition of the organic matter deposited in the soil. These characteristics evidenced signs of grassland decline and could be related to the management system.

Studies conducted by Ibrahim *et al.* (2007) showed that grasslands with improved pastures when they are deteriorated, as those in this study, do not usually make significant contribution to carbon sequestration,



Different letters between columns differ significantly at P 0.05 (Duncan, 1955)

Figure 4. Performance of the soil cover and the legume density in the system with creeping legume mixtures

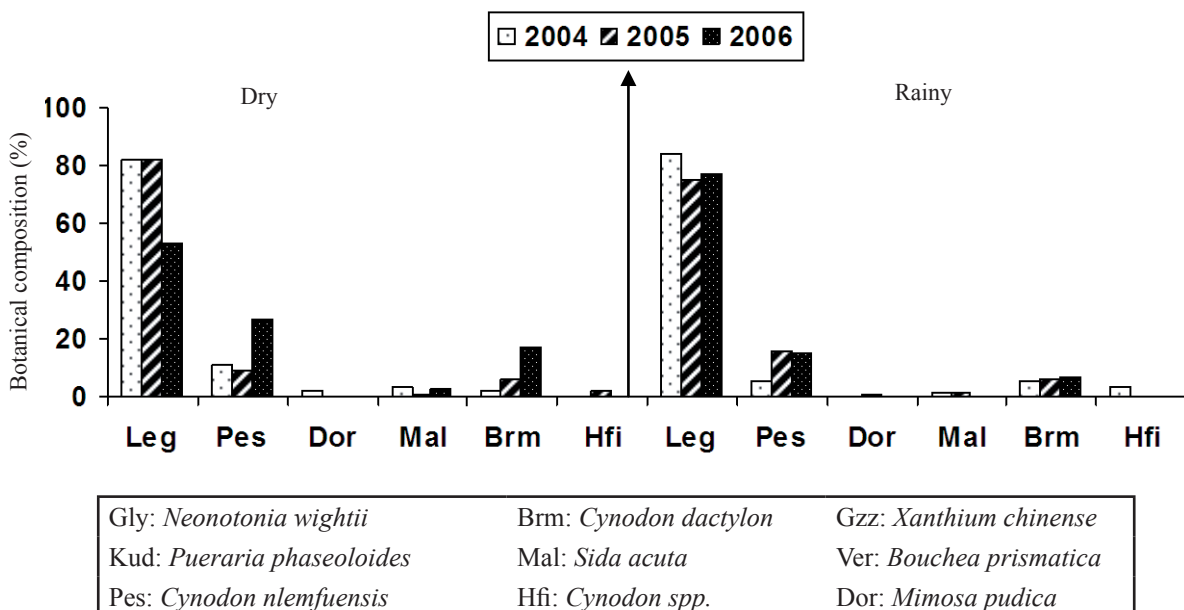


Figure 5. Performance of the botanical composition in the creeping legume mixture system

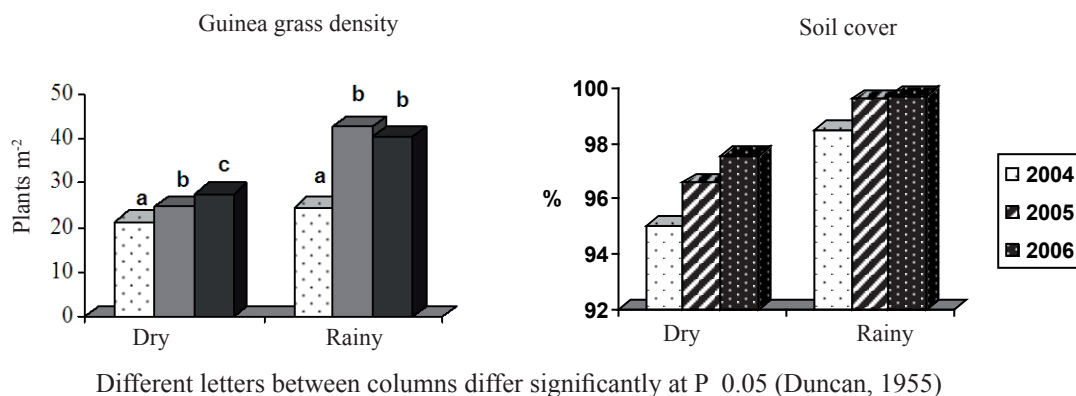


Figure 6. Performance of the soil cover and the guinea grass density in guinea grass monoculture system

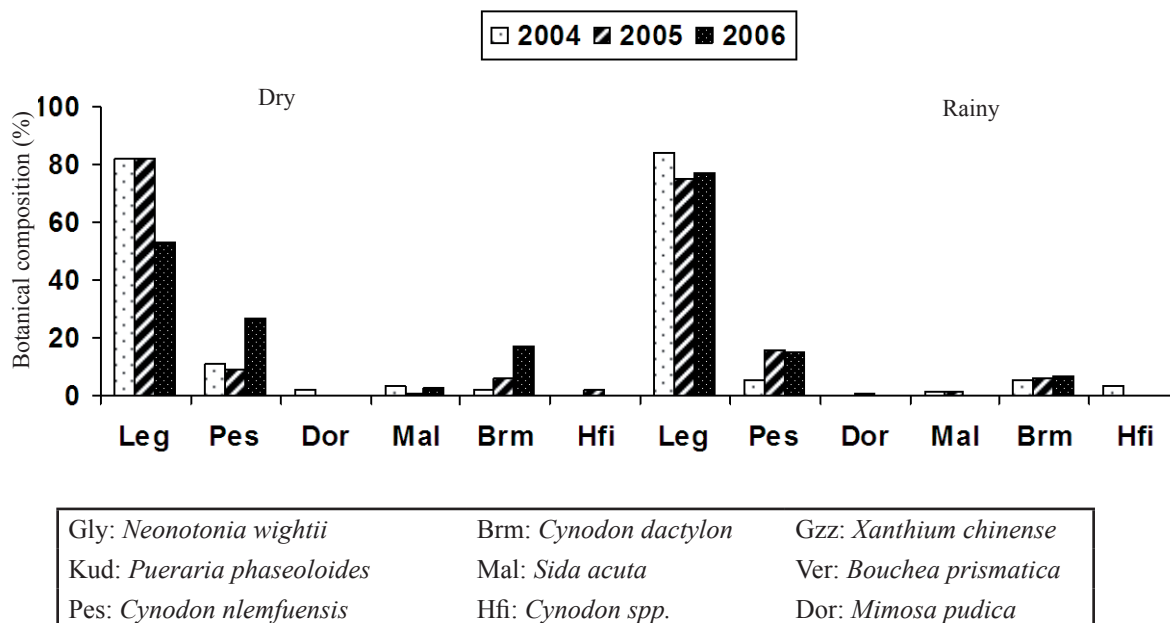


Figure 7. Performance of the botanical composition in the guinea grass monoculture system

they can even emit carbon to the atmosphere. However, respecting the degraded pastures, the improved species with trees generate land uses with greater potential for carbon sequestration. Also, these authors found that systems with improved pastures, without degradation or deterioration, could contribute to carbon capture with values between 81.3 and 132.5 t C ha⁻¹. Results cited indicate that improved pastures, provided they are not deteriorated, can store high SCS contents, which is related to its high biomass production, their possibilities for greater organic matter depositions and with the characteristics of their radicular systems, which directly contributes to their possibilities to soil carbon storage. Therefore, it can be inferred that attaining improved pasture systems, stable and productive, could be a way to attain carbon captures in correspondence with the potentialities of each system.

Results of SCS performance in the studied systems agree with those reported by Arias *et al.*

(2001) and Giraldo *et al.* (2006). These latter authors found in three systems studied (a field without trees and two silvopastoral systems) in Colombia, values between 15 and 25 t of C ha⁻¹ at the 5-15 cm depth and of 13.2 t as average in the first 10 cm. The reach of the different SCS levels is associated with the grazing management, type of soil, physiological status of the pasture and nutrient content (Fisher and Trujillo 200).

In reports from FAO (2008) the total distribution of soil carbon supply, was analyzed according the main ecological zones. These show large differences in the organic carbon storage, above all regarding the temperature and rainfall. The carbon supplies in the soil down to one meter depth vary between 4 kg m⁻² in arid zones and 21-24 kg m⁻² in polar or boreal regions, with intermediate values of 8 to 10 kg m⁻² in tropical zones (Espinosa 2006).

Under tropical conditions it is important to investigate the C dynamics in the soil and its relationship with

the global C cycle. This information will be useful to identify the agronomical practices increasing carbon storage, which will contribute to the sustainable production of the cultures.

It is concluded that SCS could be an indicator of the functioning, efficiency and stability of the grasslands, since it is the result of the combination of the management, the type of soil and its own characteristics, the vegetation found and the biological activity. In the evaluated systems, at 0 to 45 cm depth, the highest accumulation of SCS occurs at the first 15 cm. The silvopastoral system and that of the creeping legume mixture had gradual increase in the SCS with the exploitation time, constituting, thus, viable alternatives to contribute to the ecological and environmental improvement in agricultural ecosystems of grasslands. Their performance evidenced that more diverse and adequately managed systems can achieve better values of SCS. On the other hand, the monoculture system showed low SCS values and signs of decline by the increase of weeds and involution of some indicators of edaphic stability related to the performance of such indicator.

It is recommended to use diversified grassland systems, as the silvopastoral and the mixtures of creeping legumes, to improve C storage in the soil and to attain stable and productive systems of improved pastures, in correspondence with their potentialities. Also, further studies on SCS in different types of grasslands are suggested and to divulge these results for better comprehension and knowledge of the functioning of these systems.

References

- Anon 1989. Atlas nacional de Cuba. Ed. Instituto de Geografía de la Academia de Ciencias de Cuba e Instituto de Geodesia y Cartografía. La Habana
- Anon 2011. El dióxido de carbono, emisiones y sumideros. Available: <<http://www.homepage.mac.com/uriarte/caracteristicasco2.html>>. [Consulted: marzo 2011]
- Arias, K., Ruiz, C., Milla, M., Fabio, H. & Escobar, A. 2001. Almacenamiento de Carbono por *Gliricidia sepium* en sistemas agroforestales en Yaracuy, Venezuela. *Livest. Res. Rural Develop.* 13:5
- Botero, J. A. 2011. Contribución de los sistemas ganaderos tropicales al secuestro de Carbono. Available: <<http://www.fao.org/DOCREP/006/Y4435S/y4435s07.htm>> [Consulted: abril 2011]
- Brown, S. & Lugo, A. 1984. Biomass of Tropical Forest: a New Estimate Based on Forest Volumes. *Sci.* 223:1290
- Cairo, P. & Fundora, O. 1994. Constituyentes principales de la materia vegetal. In: *Edafología*. Ed. Pueblo y Educación. La Habana, Cuba. p.73
- Crespo, G. 2003. Avances en el conocimiento del reciclaje de los nutrientes en los sistemas silvopastoriles. In: *Curso Internacional Ganadería. Desarrollo Sostenible y Medio Ambiente. Modelos Alternativos.* p. 31
- De Petre, A., Karlin, U.O., Ali, S. & Reyner, N. 2006. Alternativas de sustentabilidad del bosque nativo del Espinal. Área Captura de Carbono. Proyecto Bosques Nativos y Áreas Protegidas. Argentina Banco Mundial - N° 4085-AR.
- EPA 1994. Inventory of U.S. greenhouse gas emissions and sinks: 1990-1993. U.S ENVIRONMENTAL PROTECTION AGENCY. National center for environmental publications and information. Cincinnati. 74 pp.
- Espinosa, Y. 2006. Secuestro de Carbono en el Suelo. Red Engormix. Available: <<http://www.078-p0.htm>> [Consulted: abril 2011]
- FAO 2008. Evaluación de la degradación del suelo en zonas áridas. In: Informe presentado al Programa de Naciones Unidas para el Medio Ambiente (PNUMA) e Información Mundial del Suelo (ISRIC). Available: <<http://www.fao.org>>. [Consulted: 23/6/2010]
- Fisher, M. & Trujillo, W. 2000. Fijación de carbono por pastos tropicales en las sabanas de los suelos ácidos neotropicales. En: *Intensificación de la ganadería en Centroamérica: beneficios económicos y ambientales.* C. Pomareda y H. Steinfeld (Eds.). CATIE/FAO/SIDA. San José, Costa Rica. Pp. 115-135
- Giraldo, L.A., Zapata, M. & Montoya, E. 2006. Estimación de la captura de carbono en silvopastoreo de *Acacia mangium* asociada con *Brachiaria dyctioneura* en Colombia. *Pastos y Forrajes* 29:421
- Haydock, K. P. & Shaw, H. H. 1975. The comparative yield method for estimation dry matter yield of pasture. *Aust. J. Exp. Agric. Anim. Husb.* 15: 663
- Huss, D. H., Bernandon, A., Anderson, D. & Brun, J.M. 1996. In: *Principios de manejo de praderas naturales.* FAO. INTA. Chile. 156 p.
- Ibrahim, M., Chacón, M., Cuartas, C., Naranjo, J., Ponce., G., Vega, P., Casasola, F. y Rojas, J. 2007. Almacenamiento de carbono en el suelo y la biomasa arbórea en sistemas de usos de la tierra en paisajes ganaderos de Colombia, Costa Rica y Nicaragua. *Agroforestería en las Américas.* No 45. p. 27
- InfoStat 2001. Software estadístico. Manual de usuario. Versión 1. Córdoba, Argentina.
- Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security, *Sci.* 304:1623
- López, A., Schlönvoigt, A., Muhammad, I., Kleinn, C. & Kanninen, M. 2011. Cuantificación del carbono almacenado en el suelo de un sistema silvopastoril en la zona Atlántica de Costa Rica. *Rev. Agroforestería en las Américas.* Vol. 6. No. 33. Available: <<http://web.catie.ac.cr/informacion/rafa/rev23/ntc23.htm>>. [Consulted: octubre 2012]
- Martin, N. J. & Cabrera, R. 1987. Determinación de la estabilidad estructural. Método del tamizado en seco y en húmedo. En: *Manual de actividades proteicas del suelo.* Ed. Instituto Superior de Ciencias Agropecuarias de la Habana, Cuba. p. 136
- McVay, K.A. & Rice, C.W. 2002. Soil organic carbon and the global carbon cycle. Kansas State University. Available: <<http://www.oznet.ksu.edu>> [Consulted: octubre 2007]
- Miranda, T., Machado, R., Machado, H. & Duquesne, P. 2007. Carbono secuestrado en ecosistemas agropecuarios cubanos y su valoración económica. *Estudio de caso. Pastos y Forrajes* 30:483

- Post, W.H., Emanuel, W.R., Zinke, P.S. & Stangenberger, A.G. 1982. Soil carbon pools and world life zones. *Nature* 298:156
- Robert, M. 2002. Captura de carbono en los suelos para un mejor manejo de la tierra. FAO.p. 65
- t'Mannetje, L. & Haydock, K. P. 1963. The dry weight with rank method for the botanical analysis of pastures. *J. Brit. Grass. Soc.*18: 268
- Cuban Journal of Agricultural Science, Volume 47, Number 1, 2013.
- Vargas, Y. & Valdivia, L. A. 2005. Recuperación, mediante leguminosas rastreras, de suelos degradados (ex cicales) en la Selva Alta del Perú. *Mosaico Cient.* 2:78
- Walkley, A. & Black, A. 1934. An examination of the Degtjoreff method for determination soil organic matter, and a proposed codification of the chromic acid titration method. *Soil Sci.* 37:29

Received: June 15, 2012