Soil organic matter performance in grasslands

G. Crespo
Instituto de Ciencia Animal, Apartado Postal 24, San José de Las Lajas, Mayabeque, Cuba
Email: gcrespo@ica.co.cu

An updated review was conducted to discuss knowledge on soil organic matter (SOM) performance in tropical pastures. Among the main factors affecting the amount and the characteristics of the SOM in these ecosystems, there were the leaf litter, the management intensity, the grassland degradation, the pasture root system, the earthworm population, the physical properties of the soil, its use, and the nature of the organic matter. Besides, an analysis was performed about C sequestration in the soil and the ways for increasing it, and diminishing the greenhouse effect magnitude. The main international trends were assessed as to SOM research.

Key words: *SOM, grasslands, tropics, C catch*.

INTRODUCTION

The soil life depends on the water, the chemical elements, and the organic matter. Photosynthesis produces plant growth, involving the gross primary production. Ernst (2004) has described the effect of different plant types on soil quality and health variation.

The soil organic matter is composed of all the dead organic materials, from animal or plant origin, and of organic products coming from their transformation. A small fraction of the organic matter includes partially transformed materials, and other fully transformed, of dark color and high molecular weight, called humic compounds (Burbano 2004).

The permanent grasslands produce very intense effects on the soil OM content and transformations. Primarily, they affect the plant species, the activity of the macro and microorganisms and the management intensity, among other factors (De Olliveira *et al*. 2004, Müller *et al*. 2004, Agbein and Adeniyi 2005 and Frost and Siri Prieto 2009).

The objective of this review is the analysis of the knowledge on the nature of the soil organic matter (SOM) in grasslands, its performance, and the different factors affecting it. Also, the update of the research on this subject worldwide is intended.

FACTORS AFFECTING SOM IN GRASSLANDS

Leaf litter. The continuous changes in the use of soils produce notable variations in the input of leaf litter. In many regions of South America, such as Ecuador, Brazil and others, forests are cut down frequently to turn them into grasslands. Frequently, tree species invade these grasslands and diminish their productivity. Later, they finished abandoned. In Ecuador, Potthast *et al*. (2010) compared soil samples from an active grassland of *Setaria sphacelata*, and from another abandoned and invaded by weeds. The grass (C_4) and the tree (C_3) leaf litter differed in the C: N ratio (33 and 77, respectively) and in the lignin content (18 and 45 %, respectively). The massive grass removal by the weed diminished the pH, the organic C and N in the soil, as well as its biomass and microbial activity, with rise in the actinomycete population. The authors mentioned found preferential mineralization of organic C, from the grass leaf litter.

In Thailand, Waring and Gibson (1994) studied the physical and chemical changes occurred in soils occupied by grasslands of perennial legumes, and in some others sown by seasonal crops for a long period of time. At the end of the study, they found larger average diameter of the particles in the soils occupied by the legumes. There was not pH change by effect of the treatments, but the cationic change capacity (CCC) was increased, from only 0.84 cmol (+) kg^{-1} in the crops to 1.40 cmol (+) kg^{-1} in the plots with siratro (*Macroptillium atropurpureum*). The soil N gain in the grassland with the legume varied between 49 and 192 kg N ha^{-1}.

Management intensity. The knowledge on the change of the SOM by the effect of the management intensity in grasslands is not yet enough. In this regard, Dubeux *et al*. (2006) noted the effect of the management intensity of a kikuyo grass pasture (*Pennisetum clandestinum*, Flügge) on the content of the light fraction of the SOM. They found that the C and N concentration in the soil mass was not affected by the management intensity, but it had indeed effect on the light fractions of the organic matter. Thus, with the smaller management intensity the particles < 53 µg had the largest C and N concentrations. This would show that, by increasing the management intensity, the SOM fractions of slow release would favor the C sequestration and the potential soil fertility. Nevertheless, the negative effect and the questionable sustainability should be taken into account in the intensive systems that utilize large amounts of fertilizers.

The grassland exploitation time produces space and time changes in the SOM content. Haynes (2000) found rise in the OM content, in a permanent grassland, with more than nine years of management, which was manifested by the increase in the microbial C, from 1.0 to 2.2 %, the organic C, the light fraction of organic C, from 1.8 to 4.6 %, and of the water-soluble C, from 0.7 to 1.2 % of the organic C.

Pasture degradation. According to Müller *et al.* (2004), pasture degradation constitutes one of the most serious problems related to the use of soils in the Amazonas region, thus, many farmers plant new wood areas. By examining the relationship between pasture degradation and some soil properties, these researchers found out great decline in grass biomass as the grassland had greater degradation. They also noted that the recovery was very efficient and fast by sowing *Andropogon gayanus* and *Panicum maximum*, species that attained larger productions of aerial and underground phytomass.

De Oliveira *et al.* (2004) found that in Los Cerrados prairies, in Brazil, the productivity of the forages and of the animals diminished several years after establishing grasslands improved with Brachiaria and other grasses from Africa. They warned that if measures were not taken to remedy that situation, these areas would be covered again by weeds and the soils would start to make compact and be degraded. In these situations, low accumulations of leaf litter, OM, and microbial biomass have been observed in the soils. Out of the results from this research, the authors recommended as more actual and simpler indices of the soil deterioration in a grassland, the rate of leaf litter deposition, the content of C in the microbial biomass and the pasture sprouts after the grazing.

The root system. Besides supplying water, nutrients, hormones, and serving as mechanical support to the plants, roots contribute to the rise in the SOM, by increasing the organic C, the N, and the microbial biomass. It has been stated that the C from the roots is retained and forms more stable aggregates in the soil compared with that from the aerial biomass (Trujillo *et al*. 2006 and Frageria and Moreira 2011).

Although usually roots contribute only with 10 and 20 % of the total weight of a plant, a well-developed root system is essential for its growth and development. Although the development of this organ is genetically controlled, the environmental factors are also of great influence (Trujillo *et al*. 2006).

The effect of fertilizers on root growth is similar to that exerted on the aerial part. However, the magnitude of the response may vary. In nutrient defficient soils, the weight of the root and the volume of root hairs respond frequently to a quadratic equation, when fertilizer is added to the soil. Nevertheless, the largest part of the root system in pastures is located in the layer at 0-20 cm of the soil level (Hernández 2003).

Frageria and Moreira (2011) noted that the utilization of species and cultivars of biotic and abiotic stress tolerant plants, together with the application of adequate culture practices, may improve the function of the root system in plants under favorable and unfavorable environmental conditions.

According to Trujillo *et al*. (2006), the understanding of the C accumulation processes in the grassland soils is little, because the information about the production, the transformation, and the decomposition of the roots is still insufficient. These authors found that, in a well-managed *Brachiaria humidicola* grasland, the production of roots was double, compared with a native prairie. This, together with higher poor quality leaf litter production (higher C:N and C:P ratios), propitiated larger C accumulation in the soil.

Earthworms. Blanchart *et al*. (2004) demonstrated the notable influence of roots and earthworms on the stability of the OM content, the biological activity, the porosity and the stability of the soil aggregates in grasslands. Previously, Guggenberger *et al*. (1996) concluded that wastes of plants rich in carbohydrates are responsible for the structural stability of the feces (casting) from earthworms, besides the mucopolysaccharides present in the microorganisms of the gastrointestinal tract of these animals. These authors noted that the microbial metabolism of plants with high content of carbohydrates releases mucilages and other metabolites that increase the permeability of the mineral particles, which contributes to the stability of the feces.

Earthworms play important functions in the soil N cycle. By means of their activities, they affect direct and indirectly, the OM mineralization. At the same time, the soil OM influences favorably the earthworm population. Van Vliet *et al*. (2007) found that grasslands with higher SOM contents had also the largest earthworm populations (up to 858 u/m^2). These grasslands had also the highest values of biomass from the roots. Besides, by increasing the OM content (from 5 to 10.2 %), the potential mineralization of nitrogen was increased in six months, from 138 to 310 kg of N.

Physical properties. It has been proved that tropical soils, mainly the Oxisols, have excellent physical characteristics when are well managed. They are outstanding due to their high rate of infiltration and stable structure that, thus, permit them to assimilate adequately the mechanized agriculture. However, in Colombia, in the Eastern Plains, Amézquita *et al*. (2004) noted fast deterioration of the physical properties in these soils, when they used intensely the disc plowing and the cultivator. In these circumstances, they recommended the establishment of improved pastures of deep roots, with minimum tillage. This type of pasture made up and maintain a productive soil layer, with improved physical, chemical, and biological properties, primarily in respect to the SOM content and the size and stability of the aggregates.

The abundance of the stable aggregates in the soil depends notably on the SOM content. The aggregates constitute the structural unit that groups the primary particles that are clustered tightly, in higher magnitude than the particles all around. Wei *et al*. (2006) proposed a model accounting for the mechanism of aggregation of the soil particles, based on the hypothesis that the macroaggregates (>250 μm) are collections of microaggregates (< 250 μm), retained by OM bands. According to these authors, the young plant wastes, rich in C, are involved in the formation and stability of the microaggregates.

The nature and properties of the aggregates are determined by the amount and quality of the eplant residues and the humic compounds, as well as by the degree of interaction with the rest of the particles in the soil. The management practices, such as the culture methods, the treatment of wastes, the amendments and the soil fertilization favor the aggregation of particles (Six *et al*. 2004). Nevertheless, further research is needed to understand better the mechanisms of formation of the aggregates and their response to human activities.

Soil utilization. The changes in soil utilization may modify markedly the content and nature of the SOM. Studies of Stuart Grandy *et al*. (2009) have contributed to the knowledge of this problem. These authors compared in twelve sites the variations in the chemical composition of the SOM and the microbial communities. The regions represented a wide range of the different soil uses. In this study, they found out a considerable variation in the chemical properties of the SOM in the different sites. Nevertheless, they noted that this performance cannot be attributed completely to the utilization of the soil "per se", but to the variation of the edaphic properties and to the specific management practices within each category of soil use. They concluded that the categories of use are not a clear indicator of the variation in the chemical composition of the SOM, when there is variation in the edaphic properties and the management practices. Thus, they propose the indicators enzymatic activity, fungi-bacteria ratio, and texture, aspects that evidence the interactions between the microbial activity and the chemical composition of the OM.

Nature of the SOM. Several researches have been conducted to know better the nature of the SOM fractions in different ecosystems. Tian *et al*. (2010) proved that the content of the catalase enzyme is the indicator that identifies the best the soluble organic compounds and those of low molecular weight. These fractions are precisely those having higher amount of energy, carbon, and nutrients for the microbial activity. Therefore, they play an important function in the several soil processes. The comparison between the ecosystems indicates that the agriculture/livestock rearing integration showed soils with greater concentration of soluble organic C (78 μg/g), phenolic compounds (1.5 μg/g), reducing sugars (23 μg/g) and amino acids (0.76 μg/g). Moreover, this research proved that only the enzyme peroxidase was correlated significantly with the chemical composition of the OM and the soil soluble C.

C CATCH IN GRASSLAND ECOSYSTEMS

The changes in soil utilization and the management practices influence, frequently, the C catch and its release to the atmosphere. In Brazil, studies of Nunes Carvalho *et al*. (2010) demonstrated that the conversion of a native grassland into another with improved species affected favorable the input of C in the soil, according to the management. In the grassland with improved species on fertile soil, the average accumulation was of 0.46 Mg ha^{-1} year^{-1}, whereas in the grasslands established on poor soils, the C losses were between 0.15 and 1.53 Mg ha^{-1}year^{-1}. The integrated agriculture/livestock rearing systems have shown positive values of C accumulation, that varied from 0.82 to 2.58 Mg ha^{-1}year^{-1} (Frost and Siri-Prieto 2009) and, thus, reduce the release of CO_2 to the atmosphere.

An strategy used to renovate the degraded or unproductive native grasslands is the establishment of improved pasture species to sequestrate the organic C of the soils. The C, N and P from the microbial biomass are the most active biological fractions of organic C, and are, thus, the most useful indicators to determine the soil status in the ecosystems. Researches of Agbein and Adeniyi (2005) in several grasslands of Nigeria for five years proved similarly.

In Brasil, Da Silva *et al*. (2004) also reported the importance of the improved pasture species to increase the catch C in the soils, and diminish the environmental contamination. These authors emphasized that this discovery could have great magnitude in the 204 millions of hectares of grasslands in Los Cerrados in Brazil. The highest values of C storage were found in Panicum maximum grasslands, with 100 mg C ha-1.

In Martinica, Chevalier *et al*. (2000) found in vertisol soils covered by Pangola grass (*Digitaria decumbens* Stent) with five years of establishment, C increment of 6 g C kg^{-1} in the layer at 0-10 cm, and of 2.5 g C kg^{-1}, at 10-30 cm. A total of 8.5 mg C ha^{-1} up to the depth of 30 cm. The space variation of the organic C in the soil was explained by the variability of the plant coverage and the physical structure of the vertisol.

In Cuba, the studies of Miranda *et al*. (2007) demonstrated that the silvopastoral systems attain higher C catch in the soil (1.26 Mg of C ha-1year-1) than the grassland composed of grasses only (0.32 Mg of C ha-1year-1), whose economic gain was next to 1 300 dollars (USD) per year.

TRENDS OF RESEARCHES RELATED TO THE SOM IN GRASSLANDS

Many aspects, related to the nature and performance of the SOM, have not been clarified yet in grasslands. In this regard, the application of simulation, based on accurate databanks could explain a large set of question to be solved. At the end of the seventies, Smith (1979) described a model of intermediate resolution that accounted for the decomposition of the OM from a wide number of experimental data published in prestigious journals. Most of the organic and inorganic forms of N, P, and K were mathematically treated, together with the different transformations they experienced. Most of the transformations are controlled by microbes, and the dynamics of the microorganisms is explicitly exposed. A modeling of the general heterotrophic population is conducted, using organic C and N as energy, as well as the nitrifiers that oxide chemotrophically the nitrogenous compounds. This dynamic treatment of the microbes, among other things, studies the microbial immobilization of important plant nutrients.

Besides the simulation of the biological aspects in decomposition, the model deals with the physico-chemical processes of precipitation, input of fertilizer and native minerals, losses by wash, sorption of organic and inorganic ions by the soil colloids, condensation between organic N and aromatic compounds and exchange reactions. Also, the processes of functional dependence with the soil temperature and the humidity were included. For the clearness of the presentation, the reference model is divided into four submodels: for the N, P, K and for C as energy substrate. The total model couples with another model of plant growth, which permits simulating the full cycles of the elements in the soil-plant system.

Another aspect of great interest for further research on this subject will be the use of C isotopes (^{13}C) to identify the C sources in the soil and the rate of transformation of the SOM. This is especially important in tropical regions, where the wood areas (plants of C_3 pathway) are replaced by grasslands of improved grasses (plants of C_4 pathway), which would permit widening the knowledge on the status of the tropical ecosystems in the global cycle of C (Bernoux *et al*. 1998).

Matlou and Haynes (2006) underlined the need for continuing the studies on new analytical techniques of determination of organic C and N, soluble in the grassland soil. These authors recommended the method of extraction of these substances with water, when comparing it with the extractions with KSO_4 0.5M and KCl 2M.

Also, studies on the selection of indices that identify better the SOM changes are of great interest (Jan *et al*. 2009). They should be easy to determine and interpret.

REFERENCES

Agbein, J.O. & Adeniyi, T. 2005. The microbial biomass properties of a savanna soil under improved grass and legume pastures in Northern Nigeria. Agric. Ecosyst. Environ. 109:245

Amézquita, E, Thomas, R.J., Rao, J.M., Molina, D.L. & Hoyos, P. 2004. Use of deep-rooted tropical pastures to build- up an arable layer through improved soil properties of an Oxisol in the Eastern Plains (Llanos Orientales) of Colombia. Agric. Ecosyst. Environ. 103:269

Bernoux, M., Cerri, C.C., Neill, Ch. & Moraes, F.L. 1998. The use of stable carbon isotopes for estimating soil organic matter turnover rates. Geoderma 82:43

Blanchart, E., Albrecht, A.A., Chevallier, T. & Hartmann, C. 2004. The respective roles of roots and earthworms in restoring physical properties of vertisol under a *Digitaria decumbens* pasture (Martinique, WI). Agric. Ecosyst. Environ. 103:343

Burbano, H. 2004. Manejo biorgánico de la fertilidad integral del suelo. Seminario interbacional de producción y salud animal. Facultad de Ciencias Pecuarias. Universidad Nariño, Colombia

Chevalier, T., Voltz, M., Blanchart, E., Chotte, J.L., Eschenbrenner, V., Mahieu, M. & Albrecht, A. 2000. Spatial and temporal changes of soil C after establishment of a pasture on a long-term cultivated vertisol (Martinique). Geoderma 94:43

Da Silva, J.E., Resck, D.V.S., Corazza, E.J. & Vivaldi, L. 2004. Carbon storage in clayed Oxisol cultivated pastures in the "Cerrado" region, Brazil. Agric. Ecosyst. Environ. 103:357

De Oliviera, O.C., de Oliveira, I.P., Alvers, B.J.R., Urquiaga, S. & Baddey, R.M. 2004. Chemical and biological indicators of decline/degradation of Brachiaria pastures in the Brazilian Cerrado. Agric. Ecosyst. Environ. 103: 289

Dubeux Jr, J.C.B., Sollenberger, L.E., Comeford, N.B., Scholberg, J.M., Ruppieri, A.C. & Vendramini, J.M.B. 2006. Management intensity affects fractions of soil organic matter from grazed bahiagrass swards. Soil Biol. Biochem. 38:2705

Ernst, W.H.O. 2004. Vegetation, organic matter and soil quality. Dev. Soil Sci. 29:41

Frageria, N.K. & Moreira, A. 2011. The role of mineral nutrition on Root growth plants. Adv. Agron. 110:251

Frost, O. & Siri-Prieto, G. 2009. Impact of perennial pasture and tillage systems on carbon input and soil quality indicators. Soil Tillage Res. 105:260

Guggenberger, G., Thomas, R,J. & Zech, W. 1996. Soil organic matter within earthworm casts of an anecic-endogeic tropical pasture community, Colombia. Appl. Soil Ecol. 3:263

Haynes, R.J. 2000. Labile organic matter as an indicator of organic matter quality in arable and pastoral soils in New Zealand. Soil Biol. Biochem. 32:211

Hernández, N. 2003. Caracterización de los componentes de la fitomasa de un pastizal tradicional y cuatro ecosistemas derivados de éste. Bachelor Thesis. Fac. de Biología. Universidad de La Habana- Instituto de Ecología y Sistemática CITMA. p. 38

Jan, M.I., Roberts, S.K., Tonheim, S.K. & Jones, D.L. 2009. Protein breakdown represents a major bottleneck in nitrogen cycling in grassland soils. Soil Biol. Biochem. 41:2272

Matlou, M.C. & Haynes, R.J. 2006. Soluble organic matter and microbial biomass C and N in soils under pasture and arable management and the leaching of organic C, N and nitrate in Lysimeter. Appl. Soil Ecol. 34:160

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 30:4

Müller, M.M., Guimaraes, M.F., Desjardins, T. & Mitja, D. 2004. The relationship between pasture degradation and soil properties in the Brazilian Amazon: a case study. Agric. Ecosyst. Environ. 103:279

Nunes Carvalho, J.L.N., Silva Rusi, G., Cerri, C.E.P. & Nernoux, M. 2010. Impact of pasture, agriculture and crop-livestock systems on soil C stocks in Brazil. Soil Tillage Res. 110:175

Potthast, K., Hamer, U. & Makeschin, F. 2010. Impact of litter quality on mineralization processes in managed and abandoned pasture soils in Southern Ecuador. Soil Biol. Biochem. 42:56

Six, J., Bossuyt, H., Degryze, S. & Denet, K. 2004. A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. Soil Tillage Res. 79:7

Smith, O.L. 1979. An analytical model of the decomposition of soil organic matter. Soil Biol. Biochem. 11:585

Stuart Grandy, A., Strickland. M.S., Lauber, C.L., Bradford, M.A. & Fierer, N. 2009. The influence of microbial communities, management and soil texture on soil organic matter chemistry. Geoderma 150:278

Tian, L., Dell, E. & Shi, W. 2010. Chemical composition of dissolved organic matter in agroecosystems: Correlations with soil enzyme activity and carbon and nitrogen mineralization. Appl. Soil Ecol. 46:426

Trujillo, W., Fisher, M.J. & Lal, R. 2006. Root dynamics of native savanna and introduced pastures in the Eastern Plains of Colombia. Soil Tillage Res. 87:28

Van Vliet, P.C.J., van der Stelt, B., Rietberg, P.I. & de Goede, R.G.M. 2007. Effects of organic matter content and earthworms and nitrogen mineralization in grassland soils. Eur. J. Soil Biol. 43:222

Waring, S.A & Gibson, T.A. 1994. The soil fertility effects on leguminous hay pastures in north-east Thailand. II Effects on soil physical and chemical parameters. Field Crops Res. 39:129

Wei, Ch., Gao, M., Shao, X. & Pan, G. 2006. Soil aggregate and its response to land management practices. China Particuology 4:211

Received: March 23, 2011