María Cristina Amézquita, Enrique Murgueitio, Muhammad Ibrahim and Bertha Ramírez

CHAPTER VII

Carbon sequestration in pasture and silvopastoral systems compared with native forests in ecosystems of tropical America

Abstract

This research aims at identifying pasture and silvopastoral systems that provide economically attractive solutions to farmers and offer environmental services, particularly the recovery of degraded areas and Carbon (C) sequestration, in four ecosystems of tropical America vulnerable to climate change. Soil C stocks, C contents in biomass, and socio-economic indicators were evaluated in a wide range of pasture and silvopastoral systems under grazing, in commercial farms under conservation management practices. At each ecosystem and site, C evaluations were also performed for native forest (positive reference) and degraded soil (negative reference). Results of five years of research (2002–07) show that improved and well-managed pasture and silvopastoral systems can contribute to the recovery of degraded areas as C-improved systems.

INTRODUCTION

The deforestation of native forests and the final conversion of these areas into pastures represent the most important change in land use in tropical America (TA) in the last 50 years (Kaimowitz, 1996). Close to 77 percent of agricultural lands in TA are currently under pastures (FAO, 2002) and, because of poor management, more than 60 percent of these lands are severely degraded (CIAT, 1999–2005). Improved, well-managed pasture and silvopastoral systems represent an important alternative to the recovery of degraded areas and are a viable business activity for the producer (Toledo, 1985). Previous literature also suggests they have high potential for Carbon (C) sequestration (Veldkamp, 1994). The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC COP3, 1997) – last ratified on 16 February 2005 – and subsequent agreements of the United Nations (UNFCCC COPs 4–15, 1998–2007) suggest the reforestation or afforestation of degraded areas, including those currently under degraded pastures. This policy could have a negative impact on the economic production and social welfare of livestock producers in TA, especially intermediate and small producers. Therefore, it is necessary to find sustainable alternatives that combine mitigation of poverty with economic production and supply of environmental services, especially C sequestration.

This article presents the findings of five years of research (2002–07) generated by an international research project implemented by two Colombian institutions (Centro para la Investigación en Sistemas Sostenibles de Producción Agropecuaria [CIPAV] and Universidad de la Amazonia) and three international research centres (Centro Internacional de Agricultura Tropical [CIAT], Cali, Colombia; Centro Agronómico Tropical de Investigación y Enseñanza [CATIE], Turrialba, Costa Rica; and Wageningen University and Research Centre, the Netherlands) financed by The Netherlands Cooperation. This project evaluated C accumulation in soils and plant biomass in a range of tropical pasture and silvopastoral systems and compared these results with those for native forest (positive reference system) and degraded pasture (negative reference system) in four ecosystems of TA that are susceptible to the adverse effects of climate change: (i) eroded hillsides of the Colombian Andes; (ii) tropical rain forests in Colombia's Amazon region; (iii) subhumid tropical forests along Costa Rica's Pacific coast; and (iv) tropical rain forests along Costa Rica's Atlantic coast. The present research aims to identify the pasture and silvopastoral systems in each ecosystem that represent an alternative for farmers that is not only economically viable, but also environmentally beneficial, hence contributing to the recovery of degraded areas and to C sequestration.

Research results generated by this international project have been published in conference proceedings, international journals and lately in the scientific book entitled *Carbon sequestration in tropical grassland ecosystems,* edited by Leendert 't Mannetje, Maria Cristina Amézquita, Peter Buurman and Muhammad Ibrahim, published by Wageningen Academic Publishers in 2008. Publications include Mannetje *et al.*, 2008; Amézquita *et al.*, 2005a,b; 2006; 2008a,b; Buurman, Ibrahim and Amézquita, 2004, Buurman, Amézquita and

Ramírez, 2008; Gobbi *et al.*, 2008; Ramírez *et al.,* 2008; Rodíguez-Becerra, 2008; Van Putten and Amézquita, 2008. The present article summarizes project results referred to C evaluations (2002–2007).

MATERIALS AND METHODS

Experimental sites

Field research was conducted on producer farms at sites representative of each target ecosystem. Sites selected in the eroded hillside ecosystem of the Colombian Andes were Dovio (1 900 m a.s.l, 1 043 mm annual precipitation, 18.5 ºC annual mean temperature, slopes between 45 and 65 percent, moderately acid poor soils with pH 5.2–6.2) and Dagua (1 350 m a.s.l. 1 100 mm annual precipitation, 21.5 ºC annual mean temperature, slopes between 25 and 45 percent, poor acid soils with pH 5.0–5.8). In humid tropical rain forest ecosystem of Colombia's Amazon region, evaluations were carried out at two sites with differing topography: La Guajira farm (flat topography, 400 m a.s.l., 4 500 mm annual precipitation, 32 ºC mean temperature, and poor, very acid soils with pH 4.0–4.6) and the Beijing farm (rolling topography, with <10 percent slope, 258 m a.s.l., 4 500 mm annual precipitation, 32 ºC annual mean temperature, and poor, very acid soils with pH 4.0–4.6). In Costa Rica's tropical rain forest ecosystem, evaluations were carried out in Esparza (200 m a.s.l., 3 500 mm annual precipitation, 29 ºC annual mean temperature, poor soils less acid than those of the Amazon region, with pH 5.0–5.6). Finally, for Costa Rica's subhumid tropical rain forest, evaluations were carried out in Pocora (200 m a.s.l., 2 500 mm annual precipitation with five to six months of drought, 27 ºC annual mean temperature, and soils similar to those of Esparza).

Producer cattle farms, where C evaluations were performed, are managed under conservation practices such as minimum tillage, associations of forage grasses and legumes both herbaceous and tree legumes as nitrogen (N) supply, use of organic fertilization combined with minimum required applications of chemical fertilizers, and manual weed control among others – all these practices contributing to a sustainable use of soil, water, plant and animal resources.

Carbon assessment

The C accumulation in soil and plant biomass was assessed in pasture and silvopastoral systems already established (10–20 years) on commercial livestock farms. To achieve precise estimates, a sampling design that controlled the main sources of variation in C sequestration was used. Sources of variation were local site-specific conditions, such as altitude, temperature, precipitation, slope and soil type; current land use; and history of use. Two spatial replicates/system were used with 12 sampling points/spatial replicate/ system and four soil depths (0–10, 10–20, 20–40 and 40–100 cm). Apparent density, texture, pH, total C, oxidable C, total N, phosphorous (P) and CIC were measured, using international analytical methods (USDA, 1996) at each sampling point/depth. Total C in fine roots, thick roots and aerial biomass of pasture and trees was estimated using the methodology of CATIE and the University of Guelph (2000) to estimate the C in silvopastoral systems, multiplying the dry matter/ha of each component by 0.35 (to estimate the C in pastures) and 0.42 (to estimate the C in roots and aerial biomass in silvopastoral systems). To compare the soil C level statistically among the different systems, C contents were corrected for apparent density and adjusted to a fixed soil weight using as reference value the sampling point of minimum weight in each ecosystem (Ellert, Janzen and Entz, 2002; Buurman, Ibrahim and Amézquita, 2004).

Socio-economic evaluations with producers

The economic benefit of investing in improved pasture and silvopastoral systems was evaluated by surveys and workshops with producers in all project ecosystems. Detailed research findings are not presented in this article. Gobbi *et al.* (2008) describe the methodology of socio-economic research. Ramírez *et al.* (2008) show socio-economic results. They show the economic benefit of producers from the Andean hillsides ecosystem in Colombia who adopted improved pasture and silvopastoral systems as a five times increase in farm income/ha/year, an increase in self-sufficiency from 30 to 40 percent, and life conditions increase from three to five (under a one to five scale).

RESULTS AND DISCUSSION

Tables 11 to 13 present the averages of accumulation of C in the soil (adjusted to a fixed soil weight), C in pasture biomass, C in fine roots, and C in thick roots, trunks and leaves, together with the percentage that the C of each component represents of the C total of the system in each land use under study. Table 11 presents the results obtained for Colombia's Andean hillsides, Table 12 those corresponding to the tropical rain forest of Colombia's Amazon region, and Table 13 those corresponding to Costa Rica's subhumid tropical rain forest. The tables present global descriptive statistics (N, mean, coefficient of variation [CV] (%), least significant difference [LSD_{10}]), and the results of the statistical comparison of soil C among the different land-use systems.

Data show that the C accumulated in the soil represents the total cumulative C in the system: 61.7 percent in a native tropical forest, 90 percent in a silvopastoral system of *Acacia mangium* + *Arachis pintoi* (Table 13), and 95–98 percent in pasture systems (Tables 11 to 13). The C accumulated in thick roots, trunks, and leaves in the silvopastoral system of *A. mangium* + *A. pintoi* accounts for 7 percent of the system's total (Table 13). The C accumulated in fine roots in pasture systems accounts for 3–8 percent and the cumulative in pasture biomass, 0.5–2.1 percent (Tables 11 to 13). The native forest shows the highest total cumulative C levels of the system (soil + biomass) of all ecosystems. However, differences in soil C were observed between ecosystems.

The data of the hillsides of Colombia's Andes (Table 11) suggest that at sites of higher altitude, lower temperature, steep slopes, and relatively more fertile soils, the forest shows the highest levels of C accumulated in the soil (231, 186, and 155 tonnes/ha/1meq at sites 1 and 2), these means being statistically higher than those of the improved *Brachiaria decumbens* pasture (147 and 136 tonnes/ha/1meq at sites 1 and 2), which, in turn, statistically surpassed those of a degraded pasture and a degraded soil (136 and 97 tonnes/ha/1meq at sites 1 and 2).

The data corresponding to the tropical rain forest of Colombia's Amazon region (Table 12) and to Costa Rica's subhumid tropical forest (Table 13) show a situation that differs from that of the Andean hillsides regarding levels of C accumulated in the soil. In the flat Amazon region, characterized by warm, humid lowlands with poor, extremely acid soils with a high nutrient recycling rate, the improved pasture systems of *Brachiaria humidicola* alone, *B. humidicola* + native legumes, *Brachiaria decumbens* alone and *B. decumbens* + native legumes show soil C levels (144, 138, 128, and 124 tonnes/ha/1meq) that are statistically higher than those of the native forest (107 tonnes/ha/1meq). On the rolling slopes of the Amazon region, improved pasture systems show soil C levels (172 and 159 tonnes/ha/1meq) statistically higher than those found in a degraded pasture (129 tonnes/ha/1meq). In Costa Rica's subhumid tropical forest (Table 13), located in the warm lowlands with a six-month rainy season and a six-month dry season and poor acid soils, the improved pasture and silvopastoral systems of *Brachiaria brizantha* + *Arachis pintoi*, *Ischaemum ciliare*, *Acacia mangium* + *A. pintoi*, and *B. brizantha* alone show levels of soil C accumulation (181, 170, 165, 138 tonnes/ha/1meq) statistically higher than those of the native forest (134 tonnes/ha/1meq) and to those of a degraded pasture (95 tonnes/ha/1meq).

The data obtained in the tropical rain forest and subhumid tropical ecosystems (Tables 12 and 13) suggest that in the warm, humid lowlands, with poor acid soils, with high nutrient recycling rates, the improved pasture and silvopastoral systems, adapted to these environments and well managed by producers, play an important role in the recovery of degraded pasture areas because of their high C sequestration potential. On the other hand, the high level of C accumulated by the native forest in its biomass of roots, trunks, and leaves makes it possible to estimate the potential loss of C when a native forest in these ecosystems is felled.

CONCLUSIONS

The findings of these five years of research (2002–07) on target tropical ecosystems suggest, first, that in terms of C accumulated in the total system (soil + plant biomass), the native forest presents the highest levels of all land uses in all ecosystems, followed by improved pasture, a silvopastoral system, natural regeneration of degraded pastures and, finally, degraded pasture or degraded soils. The C accumulated in the soil accounts for a very high percentage of the total C of the system (61.7 percent in native forest, 90 percent in a silvopastoral system of *Acacia mangium* + *Arachis pintoi*, and 95–98 percent in pasture systems). Second, in terms of C accumulated in the soil, improved, well-managed pasture and silvopastoral systems show comparable or even higher levels than the native forest, depending on local climatic and environmental conditions. Research results indicate that improved and well-managed pasture and silvopastoral systems should be regarded as attractive alternatives from the economic and environmental viewpoints, especially because of their capacity to recover degraded areas and their C sequestration potential.

BIBLIOGRAPHY

Amézquita, M.C., Ibrahim, M. & Buurman, P. 2004. Carbon sequestration in pasture, agro-pastoral and silvo-pastoral systems in the American tropical forest ecosystem. In *Proc. 2nd Intl. Congress in Agroforestry Systems*, pp. 61–72. Mérida, Mexico, February.

Amézquita, M.C., Buurman, P., Murgueitio, E. & Amézquita, E. 2005a. C-sequestration potential of pasture and silvo-pastoral systems in the tropical Andean hillsides. *In* R. Lal *et al*., eds. *C-sequestration in soils of Latin America*, pp. 267–284. New York, The Haworth Press, Inc.

Amézquita, M.C., Ibrahim, M., Llanderal, T., Buurman, P. & Amézquita, E. 2005b. Carbon sequestration in pastures, silvo-pastoral systems and forests in four regions of the Latin American Tropics. *J. Sustainable Forestry,* 21(1): 31–49.

Amézquita, M.C., Putten, B. van, Ibrahim, M., Ramírez, B.L., Giraldo, H. & Gómez, M.E. 2006. Recovery of degraded pasture areas and C-sequestration in ecosystems of tropical America. *WSEAS Transactions on Environment and Development,* 2(8): 1085–1091.

Amézquita, M.C., Amézquita, E., Casasola, F., Ramírez, B.L., Giraldo, H., Gómez, M.E., Llanderal, T., Velásquez, J. & Ibrahim, M.A. 2008a. C stocks and sequestration. *In* L.'t Mannetje, M.C. Amézquita, P. Buurman & M.A Ibrahim, eds. *Carbon sequestration in tropical grassland ecosystems*, pp. 49–67. Wageningen, Netherlands, Wageningen Academic Publishers. ISBN 978-90-8686-026-5.

Amézquita, M.C., Chacón, M., Llanderal, T., Ibrahim, M.A., Rojas, J.M.M. & Buurman, P. 2008b. Methodology of bio-physical research. *In* L.'t Mannetje, M.C. Amézquita, P. Buurman & M.A Ibrahim, eds. *Carbon sequestration in tropical grassland ecosystems*, pp. 35–47. Wageningen, Netherlands, Wageningen Academic Publishers. ISBN 978-90-8686-026-5.

Buurman, P., Amézquita, M.C. & Ramírez, H.F. 2008. Factors affecting soil C stocks: a multivariate analysis approach. *In* L.'t Mannetje, M.C. Amézquita, P. Buurman & M.A Ibrahim, eds. *Carbon sequestration in tropical grassland ecosystems*, pp. 91–101. Wageningen, Netherlands, Wageningen Academic Publishers. ISBN 978-90-8686-026-5.

Buurman, P., Ibrahim, M. & Amézquita, M.C. 2004. Mitigation of greenhouse gas emissions by silvopastoral systems: optimism and facts. In *Proc. 2nd Intl. Congress in Agroforestry Systems*, Mérida, Mexico, February.

CATIE & University of Guelph. 2000. *Evaluaciones de carbono en sistemas silvopastoriles*. Internal Publication. Tropical Agroforestry Project. CATIE. December.

CIAT (Centro Internacional de Agricultura Tropical). 1999–2005. *Tropical Forages Project Annual Reports*. Cali, Colombia.

Ellert, B.H., Janzen, H.H. & Entz, T. 2002. Assessment of a method to measure temporal change in soil carbon storage. *Soil Sci. Soc. Am. J.*, 66: 1687–1695.

FAO. 2002. *Food balance sheets*. Rome.

Gobbi, J., Ramírez, B.L., Muñoz, J. & Cuellar, P. 2008. Methodology of socio-economic research. *In* L.'t Mannetje, M.C. Amézquita, P. Buurman & M.A Ibrahim, eds. *Carbon sequestration in tropical grassland ecosystems*, pp. 103–111. Wageningen, Netherlands, Wageningen Academic Publishers. ISBN 978-90-8686-026-5.

Kaimowitz, D. 1996. *Livestock and deforestation in Central America in the 1980s and 1990s: a policy perspective*. Jakarta, Center for International Forestry Research (CIFOR), Special Publication.

Llanderal, T. & Ibrahim, M. 2004. Biophysical analysis: advancement report on subhumid and humid tropical forest, Costa Rica. In *Six-months Report No. 5*. Internal Document No. 11. Carbon Sequestration Project, Cali, Colombia, The Netherlands Cooperation CO-010402.

Mannetje, L.'t, Amézquita, M.C., Buurman, P. & Ibrahim, M.A., eds. 2008. *Carbon sequestration in tropical grassland ecosystems.* Wageningen, Netherlands. Wageningen Academic Publishers. 221 pp. ISBN 978-90-8686-026-5.

Ramírez, B.L., Cuellar, P., Gobbi, J.A. & Munoz, J. 2008. Socio-economic results. *In* L.'t Mannetje, M.C. Amézquita, P. Buurman & M.A Ibrahim, eds. *Carbon sequestration in tropical grassland ecosystems*, pp. 113–142. Wageningen, Netherlands, Wageningen Academic Publishers. ISBN 978-90-8686-026-5.

Rodríguez-Becerra, M. 2008. In search of new horizons in socio-environmental policies. *In* L.'t Mannetje, M.C. Amézquita, P. Buurman & M.A Ibrahim, eds. *Carbon sequestration in tropical grassland ecosystems*, pp. 21–27. Wageningen, Netherlands, Wageningen Academic Publishers. ISBN 978-90-8686-026-5.

Toledo, J.M. 1985. Pasture development for cattle production in the major ecosystems of the tropical American lowlands. In *Proc. of the XV Intl. Grasslands Congress*, pp. 74–81. Kyoto, Japan.

UNFCCC COP13. 2007. United Nations Framework Convention on Climate Change, Conference of the Parties at its thirteenth session, Paris, France. April.

UNFCCC COP11. 2005. United Nations Framework Convention on Climate Change, Conference of the Parties at its eleventh session, Montreal, Canada, 28 November–2 December.

UNFCCC COP10. 2004. United Nations Framework Convention on Climate Change, Conference of the Parties at its tenth session, Buenos Aires, Argentina, 6–17 December.

UNFCCC COP9. 2003. United Nations Framework Convention on Climate Change, Conference of the Parties at its ninth session, Milan, Italy, 1–12 December.

UNFCCC COP8. 2002. United Nations Framework Convention on Climate Change, Conference of the Parties at its eighth session, New Delhi, India, 23 October–1 November.

UNFCCC COP7. 2001. United Nations Framework Convention on Climate Change, Conference of the Parties at its seventh session, Marrakech, Morocco, 29 October– 9 November.

UNFCCC COP6. 2000. United Nations Framework Convention on Climate Change, Conference of the Parties at its sixth session, The Hague, Netherlands, 13–24 November.

UNFCCC COP5. 1999. United Nations Framework Convention on Climate Change, Conference of the Parties at its fifth session, Bonn, Germany, 25 October–5 November.

UNFCCC COP4. 1998. United Nations Framework Convention on Climate Change, Conference of the Parties at its fourth session, Buenos Aires, Argentina, 2–13 November.

UNFCCC COP3. 1997. United Nations Framework Convention on Climate Change, Conference of the Parties at its third session, Kyoto, Japan, 1–10 December.

USDA (United States Department of Agriculture). 1996. *Soil survey laboratory methods manual*. Soil Survey Investigations Report No. 42, Version 3. Washington, DC, United States Department of Agriculture. 693 pp.

Van Putten, B. & Amézquita, M.C. 2008. Reflections on modeling and extrapolation in tropical soil carbon sequestration. *In* L.'t Mannetje, M.C. Amézquita, P. Buurman & M.A Ibrahim, eds. *Carbon sequestration in tropical grassland ecosystems*, pp. 143–169. Wageningen, Netherlands, Wageningen Academic Publishers. ISBN 978-90-8686-026-5.

Veldkamp, E. 1994. Organic carbon turnover in three tropical soils under pasture after deforestation. *Soil Sci. Soc. Am. J.,* 58: 175–180.