Soil carbon stocks under improved tropical pasture and silvopastoral systems in Colombian Amazonia

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Abstract
Soil carbon stocks of primary forest, degraded pasture, and four improved pasture systems in Colombian Amazonia were compared in a flat and a sloping landscape. The improved grasslands were *Brachiaria humidicola*, and *B. decumbens*, both in monoculture and in combination with a legume (*Arachis pintoi*). The age of the treatments was 30 years for degraded pasture and 10 or 15 years for each of the improved pastures. Carbon fractions were Total C, Oxidizable C, and Stable C. Stocks were compared using a fixed soil mass base. Although forest soils reputedly have the highest C stocks, this is not necessarily true if the forest is on poorly drained soil. The degraded pasture in the flat landscape was abandoned and dominated by weeds, while that in the sloping area was overgrazed. The latter has much lower C stocks than the former. *B. humidicola* monoculture had the highest stocks in both areas, while the effect of the other three treatments varied. The effect of improved pastures, although they tend to increase soil C stocks, depends strongly on both soil and management practices.

Key Words
Soil carbon, land use, Amazonia.

Introduction
Since the studies by Lugo and Brown (1993) and Fisher *et al.* (1994) it has been recognized that soils of well-managed tropical pasture systems may contain amounts of soil organic carbon (SOC) equal or even superior to those under native tropical forest. To understand the major cycles that influence soil organic matter under cleared lands is vital for predicting the consequences of continued conversion of tropical forest to cattle pastures and agriculture (Cerri *et al.* 2007) and for devising management technologies that enhance the sustainability of these areas slowing down further deforestation. This work presents differences in soil carbon stocks related to changes in land use.

Materials and methods
Field experiments were carried out on three farms in the Amazonian humid tropical forest, both on flat and mildly sloping topography, at 800 m.a.s.l., 1.8^o N, 75.7^o W, with an annual precipitation of 3500-4000 mm. Soils of the region are acid (pH<5) and have low phosphorus content and high aluminum saturation. The soils of the flat areas are Haplic Acrisols, while those in the mild slope areas are Haplic Ferralsols.

Blocks of different land uses were chosen at experimental farms where the history of land use had been documented. These were La Guajira and Santo Domingo for the flat area, and Los Balcanes and Pekin for the sloping landscape. The different land uses were Natural Forest, degraded pasture, and four improved pastures, i.e., *Brachiaria humidicola* in monoculture; *Brachiaria decumbens* in monoculture; *Brachiaria humidicola* + legume; *Brachiaria decumbens* + legume. The improved pastures were all established in previously degraded pasture. The age of the various systems was different. Within each topography, there were three replications in each land use and four soil sampling depths (0-10; 10-20; 20-40, and 40-100 cm). Litter was also sampled in triplicate.

Carbon determinations were carried out in the Analytical Services Laboratory at CIAT (Centro Internacional de Agricultura Tropical) Cali, Colombia. Oxidizable Carbon was determined spectrometrically according to Walkey-Black modified by Kurmies (Temminghof *et al.* 2000). Total Carbon was also determined spectrometrically but after a digestion time of two hours at 120 degrees. For a valid comparison of C stocks between land uses, the calculations were based on fixed soils mass (Ellert *et al.* 2002; Amezquita *et al.* 2008), and not on fixed soil depth. The results are given in t/ha.m/equiv (m-equiv is the soil mass of the

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profile that had the lowest mass to 1 m depth). Data were statistically analysed by SPSS 11.5. An Anova was done to determine statistical differences between treatments.

Results and discussion

Separate calculations were made for total, oxidizable, and stable C. Stocks of Stable C are obtained by subtracting stocks of Oxidizable C from those of Total C. In both areas there are wide differences between stocks under the various treatments. In the flat area, stocks range from 104 to 137 and in the sloping area from 94 to 152 t/ha/meq (Table 1). In the flat topography, the degraded pastures belong to the group with the highest C stocks, while it belongs to the lower group in the sloping area. This is mainly due to the fact that 'degraded pasture' is a varying concept. In the flat area, it denotes a pasture that is largely colonized by shrubs, while in the sloping area it is still dominated by grasses and over grazed.

Table 1. Soil carbon stocks (t/ha) of 1m equivalent depth under various land covers. Recalculated from Amezquita *et al.* (2008) omitting bad data and with new measurements of C content in degraded pasture samples.

	Total C stocks		Oxid C stocks		Stable C stocks		
	Mean	SD	Mean	SD	Mean	SD	*N*
FLAT Forest	104.0 ^{d}	12.6	55.0 ^{c}	10.9	49.0 ^{d}	6.5	27
Br. humidicola	137.2 ^{a}	10.5	73.5 ^{a}	10.4	63.6 ^{a}	5.7	27
Br. decumbens	114.2 ^{c}	10.0	55.1 ^{c}	9.2	59.1 ^{b}	5.3	9
Br. Hum+Leg.	131.1 ^{a}	12.8	76.1 ^{a}	9.8	55.0 ^{c}	5.2	27
Br. dec+Leg.	121.6 ^{b}	8.7	64.5 ^{b}	7.9	57.0 ^{bc}	2.8	25
Deg. Pasture	132.5 ^{a}	9.3	76.8 ^{a}	16.0	55.7 ^{bc}	13.3	15
SLOPE Forest	151.5 ^{a}	23.8	74.4 ^{a}	19.6	64.6 ^{b}	8.6	8
Br. humidicola	141.1 ^{a}	10.9	72.0 ^{a}	9.1	58.0 ^{c}	7.7	9
Br. decumbens	102.0 ^{b}	12.0	61.5 ^{bc}	11.4	40.4 ^{d}	5.2	9
Br. Hum+Leg.	93.9 ^{b}	9.5	56.1 ^{c}	5.4	37.8 ^{d}	7.9	9
Br. dec+Leg.	153.4 ^{a}	7.5	80.2 ^{a}	9.0	73.2 ^{a}	4.9	9
Deg. Pasture	103.8 ^{b}	18.5	60.7 ^{bc}	15.2	43.1 ^{d}	15.2	12

*Different letters denote statistically significant differences between land uses ($p<0.05$) within one topography.

In the flat landscape, the primary forest had the lowest total Carbon stocks, while the degraded pasture and both improvements with *B.humidicola* had the highest. As long as the soils are not permanently water-logged, poorly drained soils may have lower C contents than better drained ones close by, as also found for grassland soils invaded by shrubs in the US (Albrecht and Kandji**.** 2003). In the sloping area, highest stocks were found under forest, *B.decumbens*+legumes and *B.humidicola* in monoculture. Stocks under both *B.decumbens* monoculture and *B.humidicola*+legumes attained only 2/3 of those of the former group and were not different from those under the degraded pasture. Stable carbon stocks are between 42 and 52 % of total stocks in the flat area and between 40 and 48% in the sloping area. The level of the stable stocks therefore increases with the total stocks.

There seems not to be a clear tendency on the stocks when comparing landscapes. In flat areas the *Brachiaria humidicola* treatments showed the highest Total C content and were different from the other treatments. The Forest treatment showed the lowest content. In sloping areas however, Forest showed the highest total C content and *B. humidicola*+legumes and *B. decumbens*, the lowest. As far as the stable C contents, in flat landscape Brachiaria humidicola showed the highest contents and Forest the lowest but in the sloping landscape Degraded pastured and *B. humidicola* +Legumes showed the lowest and Forest and *B. decumbens*+legumes the highest.
Comparing the total C stocks of the improved pastures with those of the Degraded Pasture, it is encouraging to find that in sloping areas Brachiaria humidicola and Brachiaria decumbens+legumes, show increases of 40 to 50 t/ha. This difference was obtained in (less than) 15 years. In flat areas, improved pastures did not increase C stocks when compared with degraded pasture.

In general, decreases of soil carbon stocks occur when forests are converted to other land uses, but there are contrasting reports on the effects of forest to pasture conversion. Powers and Veldkamp (2005) found that mean values of soil C storage were similar in primary forest (80.5 Mg C ha^{-1}) and pasture (76.7 Mg C ha^{-1}) across a large region in Costa Rica (1400 km^2), though variation was high within the region and best explained by topographic features and soil mineralogy. Whether pasture soils are a net sink or a net source of carbon depends on their management, but an approximation of the fraction of pastures under 'typical' and

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‘ideal' management practices indicates that pasture soils in Brazilian Amazonia are a net carbon source, with an average release of 12.0 t C/ha. (Fearnside and Barbosa, 1998). However, a study of the 0–30 cm layer in soils in Rondônia, Brazil by Moraes, cited by Fearnside and Barbosa**,** 1998, indicated that, over the long term, there is an increase in the stock of soil carbon in well-managed pasture as compared to nearby primary forest. In a soil under very well-managed pasture at an agricultural station near Manaus, carbon in the top 20 cm returned to approximately the level of the original forest, eight years after clearing (90 t C/ha under forest vs. 96 t C/ha under pasture, without correction for soil compaction), following a decline by 21.4% reached two years after clearing. Trumbore *et al.* (1995) compared C budgets for forest and pastures in the eastern Amazon. In a rehabilitated and fertilized pasture of *Brachiaria brizantha*, they estimated gains, relative to forest soil C stocks, of over 20 Mg soil C/ha in the top 1 m of soil and a loss of about 0.5 Mg C/ha in the 1–8 m soil depth interval during the first 5 years following pasture rehabilitation. These contrasting patterns are suggestive of variable soil C dynamics following land use change and/or the partitioning of soil C between active and passive pools across soil types and ecosystems.

In our case, *Brachiaria humidicola* monoculture had highest stocks in both topographies. *B. decumbens* did not perform well in the flat area, but in combination with legumes, it had stocks as high as that under forest in the sloping area. In the sloping area, *B. humidicola* and *B decumbens*+legume showed an increase of 37 and 50 t/ha C with respect to the degraded pasture.

Conclusions

Although improved pastures tend to have carbon stocks that are superior to those in degraded pastures, the differences are sometimes obscured by variation in the concept of *degraded pasture*. If pastures are overgrazed, they tend to have the lowest carbon stocks, but if they are abandoned or undergrazed, weeds tend to establish and carbon stocks can go up considerably.

Of the four improved systems investigated here (*Brachiaria humidicola* and *B. decumbens* in monoculture and in combination with the legume *Arachis*), only the *B. humidicola* monoculture increased C contents and stocks both in the flat and the sloping landscape. The other combinations had varying success, but the variation is partly due to different time from establishment and different management.

References

Albrecht A, Kandji ST (2003) Carbon sequestration in tropical agroforestry systems. *Agriculture, Ecosystems and Environment* **99,** 15-27.

Cerri CEP, Easter M, Paustian K, Killian K, Coleman K, Bernoux M, Falloon P, Powlson DS, Batjes NH, Milne E, Cerri CC (2007) Predicted soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030. *Agriculture, Ecosystems and Environment* **122,** 58-72

Ellert BH, Janzen HH, Entz T (2002) Assessment of a method to measure temporal change in soil C storage. *Soil Science Society of America Journal* **66,** 1787-1695.

Fearnside PM, Barbosa RI (1998) Soil carbon changes from conversion of forest to pasture in Brazilian Amazonia. *Forest Ecology and Management* **108,** 147-166

Fisher MJ, Rao IM, Ayarza MA, Lascano CE, Sanz JI, Thomas R, Thomas J, Vera RR (1994) C storage by introduced deep-rooted grasses in the South American savannas. *Nature* **371,** 236-238.

Lugo AE, Brown S (1993) Management of tropical soil as sinks or sources of atmospheric carbon. *Plant and Soil* **149,** 27–41.

Mannetje Lt*,* Amezquita MC, Buurman P, Ibrahim MA (2008) ‘Carbon sequestration in tropical grassland ecosystems’. (Wageningen Academic Publishers: The Netherlands).

Powers JS, Veldkamp E (2005) Regional variation in soil C and d^{13}C in paired forests and pasture of Northeastern Costa Rica. *Biogeochemistry* **72,** 315-336.

Temminghoff, E.J.M., Houba, V.J.G., van Vark, W. And Gaikhorst, G.A. 2000. Soil and Plant Analysis Part 3. *Plant Analysis Procedure*. Wageningen University, Wageningen 195 pp.

Trumbore, S.E., Davidson, E.A., Camargo, P.B.de, Nepstad, D.C. and Martinelli, L.A. 1995. Belowground Cycling of Carbon in Forests and Pastures of Eastern Amazonia, *Global Biogeochem. Cycles* **9**, 515–528