Environtropica, July 2012, Vol 8, 150-160 ISSN 1597-815X

Land Use System and Degradation Potential: Example from Brazil Amazon

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Accepted on June 10, 2012

Abstract
Inappropriate management techniques have been associated with some significant loss of agricultural land to degradation in many parts of the world. In this study, our objective is to evaluate the changes in structural attributes of a Cambisol soil structure under six different management practices using the load bearing capacity (LBC) models. Samples were collected from representative plot at 3 depths. The samples were analysed and subjected to uniaxial compression test to evaluate the effects on soil structure. Our result showed that the initial bulk density and porosity of the soil samples were not adequate to quantify structural degradation in Cambisol. In the topsoil we observed that pasture land use system was most severe in the degradation of the soil structure while the structure were most preserved in old secondary forest and cropping systems. At the subsoil level (10-13 cm depth), the soil structure was most degraded in the cropping land use system while it was most preserved in young secondary forest and pasture system. At the 20-23 cm depth, soil structure degradation was most severe in the old secondary forest system and well preserved in young secondary forest, cropping and agro forestry. Considering the soil structure degradation that was observed in virgin forest in the 20-23cm layer, and the 10 – 13 cm layer for re-forested farm, it is encouraged that researchers take a closer look on these land use systems, such that we can understand their contribution and dynamics in the estimation of global warming potential. Our conclusions in this study will be a good decision tool in the selection of system mix that could enhance continuous productivity on agricultural land in the sub-tropical and tropical regions of the world and particularly in the agricultural development process in the Amazonas agricultural belt in Brazil.

Keywords*: Structure degradation, precompression stress, Amazonas*

Introduction

Inappropriate management of land resources has been linked to the degradation of agricultural soil in several parts of the world. Oldeman (1994) estimated the extent of degraded land at about of 6.8×104 km^2 world-wide, of which 3.3×104 km^2 is located in Europe. This has adversely affected crop production as well as environmental quality in agricultural production system (Soane and Van Ouwerkerk, 1995). Land degradation results in the alteration soil's physical, chemical and biological properties, thereby reducing productivity from the land (Taylor, 1971; Glab and Kulig, 2008, Abid and Lal, 2008; Severiano *et al.*, 2008). Considering the significant influence of soil degradation to agricultural productivity, there has been concerted efforts in the literature to investigate the effect of different land use system and management practices on soil properties (Silva *et al.* 2006; Dias Junior *et al.*, 2007, Araujo Junior, *et. al.* 2008; Glab and Kulig, 2008). These studies have been premised on the investigation of the indexes of structural sustainability or degradation.

The study of soil compaction which is the most degenerative soil structure has been hinged on the determination of precompression stress (Berli *et al.*, 2004; Rucknagel *et al.*, 2010, Ajayi *et al.*, 2011). The precompression stress separates the region of recoverable deformation from the non-recoverable deformation, thereby defining the point where soil structure degradation may occur (Silva *et al.*, 1999, Dias Junior and Pierce, 1995 Silva *et al.*, 2007; Severiano *et al.*, 2008). It has been used as a tool to evaluate the susceptibility and vulnerability of soil structure to compaction under varying management scenarios (Jones *et al.*, 2003; Spoor *et al.*, 2003; Arvidsson and Keller 2004; Ajayi *et al.*, 2010; Ajayi *et al.*, 2011).

In this study, our objective was to evaluate the structural sustainability of Cambisol soil structure under six different land use systems using the load bearing capacity model.

Material and Methods

The study was carried out in Benjamin Constant County (4° 26' S and 69°36' W), Amazonas State, NW Brazil. The region is commonly referred to as the Upper Amazon and lies in the tri-podal border between Brazil, Colombia and Peru. Cambisol (Ustox – USDA *classification*) was the dominant soil class in the region and thus was the focus in this study (Coelho *et al.* 2005). According to Köppen criteria, the climate is tropical humid or super humid (Af), with no significant dry season and an average annual temperature of 25.7°C. The mean annual rainfall is 2562 mm with the total rainfall of the driest month exceeding 100 mm. Higher rainfall are concentrated in the months between December and April (Coelho *et al.*, 2005).

The study area represents a discontinuous surface of approximately 54,000 m^2 divided into six windows for standardized sampling protocol in project Biosbrasil (http://vsites.unb.br/ib/zoo/bios/indexe.html). These windows were selected and divided to reflect the various land use system and the dominant soil types (Fidalgo *et al.*, 2005), indicating no accentuated differences in terms of intensity of use in each system. The approximate area of each window is 3.64 Ha, which was divided into 100m x 100/50m sampling grids. The agricultural land use systems in the study area were based on a cycle of deforestation and burning of secondary vegetation to grow crops over a given period. In some instances, agro-forestry resulting from the spontaneous regeneration of secondary forest species is practiced. The secondary forest system was further divided into young secondary forest and old secondary forest according to their stage of regeneration.

Thus, within the scope of this study, the land use systems were classified as Forest (FR)- areas with original forest type with no evidence of the removal of timber (Windows 1 and 4); Old secondary forest (OSF) - includes secondary forest areas in advanced stages of regeneration with more than five years of formation after being used for cropping (Windows 3, 4 and 5); Young secondary forest (YSF) - includes secondary forest areas in early stages of regeneration with less than five years of formation after being cropped (Windows 2, 3, 4 and 5); Agro-forestry (AFR)- includes areas where much of the vegetation is formed by the spontaneous regeneration of secondary forest species and is also planted to annual crops for economic interests (Windows 2 and 5);Cropping (CRP)- includes areas planted to annual crops (cassava, maize, sugar cane and pineapple) and perennial crop (banana) (Windows 2, 3, 4.5 and 6); and Pasture (PST)- includes areas for livestock production, covered by grasses (Window 6).

In March 2008, undisturbed soil samples were collected at depths 0 -3 cm, 10 – 13 cm; and 20 – 23 cm within the different 6 land use systems. In each system and depth, 10 undisturbed soil samples were collected in 6.5 cm x 2.5 cm aluminum rings, using Uhland undisturbed soil sampler. The sampling device was pushed carefully into the soil using a falling weight. Thus a total of 180 samples were collected i.e. (6 Land Use Systems x 3 depths x 10 samples per depth). At each point of sample collection, the ring filled with soil was removed from the Uhland sampler, and wrapped with plastic materials and paraffin wax until compressibility and other tests were performed.

In the laboratory, the soil samples were carefully trimmed to the size of their respective rings, whose inner diameter, height and weight had been pre-measured. This was used to determine the field bulk density of each sample. The disturbed soil samples scraped near the intact soil cores were air-dried and passed through a 2 mm sieve and stored in plastic bags prior to other analyses. Basic soil characterization of the samples was performed according to Brazilian standard procedures as described in Embrapa (2006). Particle-size-distribution was determined using the pipette method after dispersing with 1N NaOH (Day 1986). Particle density was determined using 95% hydrated alcohol with 20 g of air-dried soil material in a 50 ml pycnometer (Blake and Hartge, 1986). The total porosity was calculated from the expression $TP = (1 - Ds/Dp)$ (Vomocil, 1965).

For the uniaxial compression test, some prepared soil cores samples held in the aluminum rings, from each land use system and at the various depths, were initially saturated in a tray filled with water up to 2/3 of the samples height, for 24 hours. The saturated samples were later air-dried in the laboratory to obtain the water content levels between 0.28 to 0.66 $m^3 m^{-3}$ and then subjected to uniaxial compression test (Bowles, 1986) using a Boart Longyear consolidometer in which the pressures were applied by compressed air. The prepared undisturbed samples were subjected to pressures 25, 50, 100, 200, 400, 800 and 1600 kPa until 90% of the maximum deformation was reached (Taylor, 1948; Dias Junior and Pierce, 1995).

The precompression stress (σ_p) for each of the samples were obtained from the corresponding soil compression curves constructed from the applied stress versus bulk density data (Dias Junior and Pierce, 1995, Ajayi *et al.*, 2010). The precompression stresses were thereafter plotted as a function of volumetric water content. Regression analyzes were performed to obtain the mathematical equations that corresponds to the load bearing capacity models using the software Sigma Plot 10.0 (Jandel Scientific, PO Box 7005, San Rafael, CA, USA) and comparisons of the regression lines were performed using the procedure described in Snedecor & Cochran (1989). The results of the bulk density and total porosity were analyzed for variance and comparison of means was implemented with Scott-Knott ($p < 0{,}05$) procedure.

Results and Discussion

The soil physical properties including initial field bulk density and total porosity are presented in Table 1. There were no significant differences in the bulk densities of the soil for the different land use systems and at the various depths studied. This indicates that field bulk density may not be sufficient to accentuate the effect of the various land use systems on the Cambisol structure. Differences along profile were expected due to the nature of the studied soil cambisol.

Table 1. Physical characteristics of the Cambisol samples at depths 0-3, 10-13 and 20-23 cm under different land use systems.

Land Use Systems	Sand[1] ($g\ kg^{-1}$)	Silt ($g\ kg^{-1}$)	Clay ($g\ kg^{-1}$)	Ds[1] ($Mg\ m^{-3}$)	Dp[2] ($Mg\ m^{-3}$)	TP[1] ($m^3\ m^{-3}$)
			0-3 cm			
YSF	170	520	310	1.09 a	2.44	0.55 a
OSF	300	410	290	1.15 a	2.50	0.54 a
FR	150	540	310	1.06 a	2.41	0.56 a
PST	460	320	220	1.04 a	2.44	0.57 a
CRP	270	250	480	1.02 a	2.44	0.58 a
AFR	170	470	360	1.07 a	2.47	0.57 a
			10-13 cm			
YSF	240	370	390	1.23 a	2.53	0.51 a
OSF	180	440	380	1.26 a	2.53	0.50 a
FR	200	450	350	1.23 a	2.53	0.51 a
PST	160	440	400	1.20 a	2.41	0.50 a
CRP	160	440	400	1.23 a	2.56	0.52 a
AFR	120	430	450	1.27 a	2.41	0.47 a
			20-23 cm			
YSF	160	470	370	1.30 a	2.50	0.48 a
OSF	160	410	430	1.23 a	2.56	0.52 a
FR	180	380	440	1.28 a	2.60	0.51 a
PST	320	370	310	1.26 a	2.50	0.50 a
CRP	80	440	480	1.28 a	2.60	0.51 a
AFR	150	330	520	1.24 a	2.50	0.50 a

Ds = Initial bulk density, Dp = particle density, TP = total porosity, 1 = Average of 10 replications, 2 = Average of 3 replications. Average in columns and the same depth with the same letter did not differ by Scott-Knott at 5% probability. Forest – FR, Old secondary forest-OSF, Young secondary forest-YSF, Agro-forestry –AFR, Cropping –CRP, Pasture (PST)-

Using the model proposed by Dias Junior and Pierce (1995) $\sigma_p = 10^{(a+b\theta)}$, where $\sigma_p$is the precompression stress, "a" and "b" are empirical parameters of the adjustment of the model, and θ is the volumetric water content; representative load bearing capacity models (LBC) for the different land use systems for the various depth were constructed (Figures 2 to 4). For all the LBC, it was observed that the precompression stress (σ_p) decreases exponentially with volumetric water content (θ), in the different land use systems considered.

To compare the effects of different land use systems on the Cambisol structure, at the different depths the bearing capacity models were compared statistically according to the procedure described in Snedecor and Cochran (1989) (Tables 2 - 5) for the studied depth.

At 0-3 cm depth, the bearing capacity models for OSF, CRP and FR were not statistically different when compared. Similarly the bearing capacity model of the YSF and AFR were not statistically different (Table 2). In the land use systems that were not statistically different, the data were combined and a single equation was then fitted to all values of precompression stress and volumetric water content, thereby generating a representative LBC for the land use systems mix (Figure 1).

Table 2. Comparison of the bearing capacity models $\sigma_p = 10^{(a+b\theta)}$ of the Cambisol samples for different land use systems at 0-3 cm depth

Land Use Systems	Homogeneity	Intercept "a"	Slope "b"
OSF x CRP	H	ns	ns
OSF & CRP x FST	H	ns	ns
OSF, CRP & FR x YSF	H	*	**
OSF, CRP, & FR x AFR	H	**	**
OSF, CRP & FR x PST	H	**	**
YSF x AFR	H	ns	ns
YSF & AFR x PST	H	**	ns
YSF & AFR x OSF, CRP & FR	H	**	**

*H = Homogeneous, NH = not homogeneous, * = F test significant at 5% level, ** = F test significant at the 1% level and ns = not significant.*

Using the bearing capacity model of the forest land use system in the 0-3 cm depth as a reference for structural preservation (Figure 1), we observed thatPST land use system had the highest bearing capacity indicating a deterioration of the Cambisol structure at this depth due to cattle trampling. This corroborates the conclusions of Muller *et al.* (2001) and Correa and Reicherdt (1995) on the effect of animal trampling on soil structure in the topsoil zone. At this depth, the OSF, CRP and FR land use systems were observed to preserve the Cambisol structure. However, it should be noted that the more preserved the soil structure is, the more susceptible it is to soil compaction due to its lower bearing capacity. The higher susceptibility to compaction of these use systems (OSF, CRP & FR) may be related to the continuous formation of biopores and the steady incorporation of organic matter from the decomposition of roots and leaves (Muller *et al.*, 2001; Muller *et al.*, 2004). Similarly, the loosening of soil particles during tillage operations is significant at this depth (Arkin and Taylor, 1981).

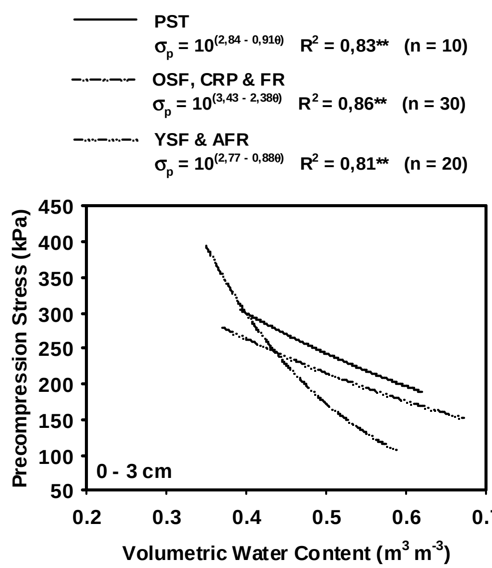

Figure 1. Load Bearing Capacity models for the Cambisol sample collected at 0-3 cm depth under different land use systems.

For the 10-13 cm depth data, the LBC models for YSF and PST were found not to be statistically different. Those of the OSF and FR land use systems were also not statistically different (Table 3). Therefore the respective data of the land use systems that were not statistically different were fitted with an equation generating a LBC model for these systems (Figure 2).

Table 3. Comparison of the bearing capacity models [$\sigma_p = 10^{(a + B\theta)}$] of a Cambisol samples for different land use systems in the 10-13 cm

Land Use Systems	Homogeneity	Intercept "a"	Slope "b"
YSF x PST	H	ns	ns
YSF & PST x AFR	H	*	ns
YSF & PST x OSF	H	**	ns
YSF & PST x FR	H	**	ns
YSF &PST x CRP	H	**	**
OSF x FR	H	ns	ns
YSF& PSTx OSF& FR	H	**	ns
OSF & FR x CRP	H	ns	**
OSF & FR x AFR	H	**	ns
CRP x AFR	H	**	**

*H = Homogeneous, NH = not homogeneous, * = F test significant at 5% level, ** = F test significant at the 1% level and ns = not significant.*

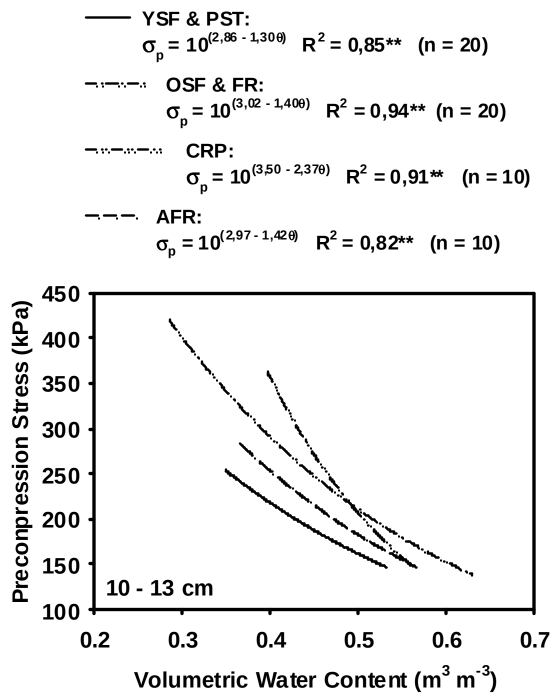

Figure 2.Bearing capacity models for the Cambisol at 10-13 cm depth under different land use systems.

The result showed that at this depth (10-13 cm), CRP system degraded most the soil structure, while YSF and PST were best in preserving the soil structure (Figure 3). The high bearing capacity of the CPR system is indicative of the Cambisol structure degradation that may have been induced by the hard pan created by tillage implement used in initial land preparation (Arkin and Taylor, 1981).

Table 4. Comparison of the bearing capacity models [$\sigma_p = 10^{(a + B\theta)}$] of a Cambisol samples for different land use systems in the 20-23 cm depth

Land Use Systems	Homogeneity	Intercept "a"	Slope "b"
FR x PST	H	ns	ns
FR & PST x OSF	H	**	**
FR & PST x CRP	H	ns	**
FR & PST x YSF	H	**	**
FR & PST x AFR	H	**	**
YSF x OSF	H	**	**
OSF x CRP	H	**	**
OSF x AFR	H	**	ns
YSF x CRP	H	ns	**
YSF x AFR	H	ns	**
CRP x AFR	H	ns	**

*H = Homogeneous, NH = not homogeneous, * = F test significant at 5% level, ** = F test significant at the 1% level and ns = not significant.*

The lower bearing capacity presented by the YSF and PST may be indicative of a recovery of the Cambisol structure due to formation of biopores and organic matter incorporation from decomposing roots associated with these land use systems (Muller *et al.*, 2001; Muller *et al.*, 2004).

A comparison of the precompression stress data for the various land use systems in the 20-23 cm depth indicated that FR and PST data were not statistically different (Table 4). Thus, a representative LBC was generated for these mix of land use systems (Figure 3).

For this depth, the OSF system degraded most the Cambisol structure, while the YSF , CRP and AFR systems preserved the soil structure. The observed degradation in this layer in the OSF may be related to the natural consolidation of the Cambisol structure associated with compression of the soil by thick roots that is trying to occupy the spaces previously occupied by air and water when the soil was deforested (Arkin and Taylor, 1981; Araújo *et al.*, 2004). It was observed that the extent of degradation of the soil is related to the stage of regeneration of the secondary forest.

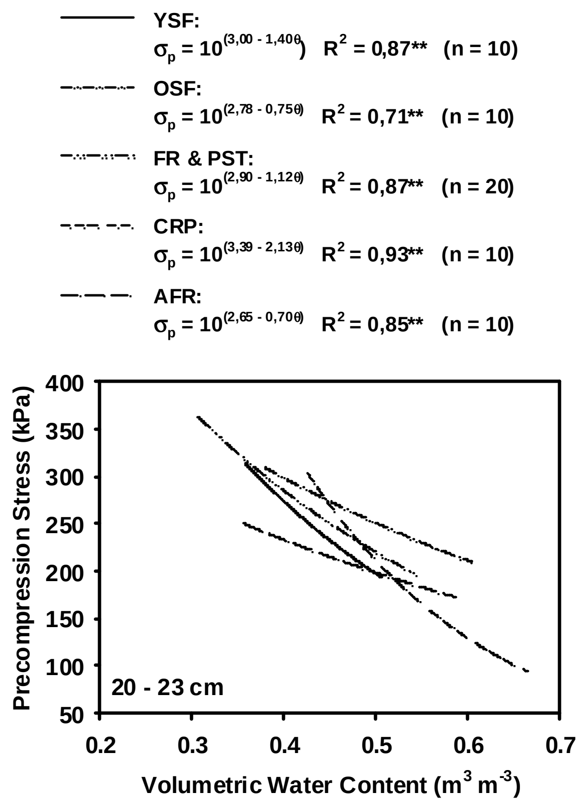

Figure 3.Bearing capacity models for a Cambisol at 20-23 cm depth under different land use systems.

The homogeneity test on the precompression stress data at all the depth under study showed consistent homogeneity for all the land use system. This is an interesting observation that underscores the need for an appropriate methodology in trying to decipher structural change in this soil type. Cambisol are relatively young compared to most soil types and as such the horizon differentiation is weak. The intensity of its cultivation is high due to its good nutrient level, therefore careful examination is necessary to avoid structural degradation moreso, the soil type is highly susceptible to erosion.

Conclusion

On a general note, environmentalist often clamors for the complete avoidance of deforestation, and propose re-afforestation for deforested area, however this study have shown the possibility of soil structure degradation in virgin forest soil, while indicating that afforestation / reforestation program must be effectively monitored in order to avoid land degradation. This observation is very critical considering the recent linkage of soil structure degradation to significant contribution to Global warming potential (Teepe *et al.*, 2004; Simojoki *et al.*, 2008; Horn and Peth, 2009). Considering the soil structure degradation that was observed in virgin forest in the 20-23cm layer, and the 10 – 13 cm layer for re-forested farm, it is encouraged that researchers take a closer look on these land use systems, such that we can understand their contribution and dynamics in the estimation of global warming potential.

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