STRUCTURAL SUSTAINABILITY OF CAMBISOL UNDER DIFFERENT LAND USE SYSTEM[1]

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SUMMARY

Incongruous management techniques have been associated with some significant loss of agricultural land to degradation in many parts of the world. Land degradation results in the alteration of physical, chemical and biological properties of the soil, thereby posing a serious threat to sustainable agricultural development. In this study, our objective is to evaluate the changes in a Cambisol structure under six land use systems using the load bearing capacity model. Sampling was conducted in Amazonas Region, Brazil, in the following land use: a) young secondary forest; b) old secondary forest; c) forest; d) pasture; e) cropping, and f) agroforestry. To obtain the load bearing capacity models the undisturbed soil samples were collected in those land use systems and subjected to the uniaxial compression test. These models were used to evaluate which land use system preserved or degraded the Cambisol structure. The results of the bulk density and total porosity of the soil samples were not adequate to quantify structural degradation in Cambisol. Using the forest topsoil level (0-0.03 m) as a reference, it was observed that pasture land use system was most severe in the degradation of the soil structure while the structure were most preserved under old secondary forest, cropping system and forest. At the subsoil level (0.10-0.13 m depth), the soil structure was most degraded in the cropping land use system while it was most preserved in young secondary forest and pasture. At the 0.20-0.23 m depth, soil structure degradation was most severe in the old secondary forest system and well preserved in young secondary forest, cropping and agroforestry.

Index terms: structure degradation, bulk density, precompression stress, Amazonas.

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RESUMO: SUSTENTABILIDADE ESTRUTURAL DE UM CAMBISSOLO SOB DIFERENTES SISTEMAS DE USO

Técnicas inadequadas de manejo têm sido associadas com a degradação de terras agricultáveis em muitas partes do mundo. A degradação do solo resulta em alterações das propriedades físicas, químicas e biológicas do solo, o que representa séria ameaça ao desenvolvimento agrícola sustentável. O objetivo deste estudo foi avaliar as alterações da estrutura de um Cambissolo sob seis sistemas de uso da terra por meio dos modelos de capacidade de suporte de carga. A amostragem foi realizada na região Amazônica, Brasil, nos seguintes sistemas de uso: a) floresta secundária nova; b) floresta secundária velha; c) floresta; d) pastagem; e) roça; e f) agrofloresta. Para obter os modelos de capacidade de suporte de carga, as amostras indeformadas foram coletadas nesses sistemas de uso da terra e submetidas ao ensaio de compressão uniaxial. Esses modelos foram usados para avaliar qual sistema de uso da terra preserva ou degrada a estrutura do Cambissolo. Os resultados da densidade do solo e porosidade total do solo não foram adequados para quantificar a degradação estrutural do Cambissolo. Utilizando a profundidade de 0-0,03 m da floresta como referência, observou-se que a pastagem foi o sistema de uso da terra que mais promoveu degradação da estrutura do solo, ao passo que a estrutura foi mais preservada na floresta secundária velha, roça e floresta. Na profundidade de 0,10-0,13 m, a estrutura do solo foi mais degradada no sistema de cultivo roça e mais preservada na floresta secundária jovem e pastagem. Na profundidade de 0,20-0,23 m, a degradação da estrutura do solo foi mais intensa na floresta secundária velha e mais preservada na floresta secundária nova, roça e agrofloresta.

Termos de indexação: degradação da estrutura, densidade do solo, pressão de pré-consolidação, Amazonas.

INTRODUCTION

The appropriate management of land resources is critical to sustainable agricultural production, as its inappropriate use could result in the alteration of the physical, chemical and biological properties of the soil thereby promoting degradation. It is therefore imperative to evolve a strategic land use and management systems and system mixes that would promote efficient utilization of this limited resource by preserving its structure and thereby prevent degradation and attendant compaction.

There been concerted efforts in the literature to investigate the effect of different land use system and management practices on soil physical, mechanical, hydrological and chemical and sometimes engineering properties (Silva et al., 2006; Dias Junior et al., 2007; Araujo Junior et al., 2008; Glab & Kulig, 2008). Most of these studies have been premised on the investigation of the indexes of structural sustainability or degradation. Some land use and soil management system have been reported to cause significant increase in bulk density and mechanical strength of soils (Taylor, 1971; Glab & Kulig, 2008; Abid & Lal, 2008; Severiano et al., 2008); decrease in total porosity, pore size and continuity of pores in soils (Glab & Kulig, 2008; Severiano et al., 2008), reduction in soil's nutrient absorption, infiltration and redistribution of water (Arvidsson, 2001; Ishaq et al., 2001; Lipiec et al., 2006), reduction of hydraulic conductivity (Arvidsson, 2001; Silva et al., 2006), reduction of gas exchange (Gysi, 2001) and increase in the soil's load bearing capacity and compactibility (Dias Junior et al., 2007; Silva et al., 2007; Araujo Junior et al., 2008; Dias Junior et al., 2008).

In Brazil agricultural system, the study of soil compaction which has the most degenerative effect on soil structure has been hinged mainly on the determination of precompression stress. The precompression stress separates the region of recoverable deformation from the non-recoverable deformation and thereby defines the point where soil structure degradation may occur (Silva et al., 1999; Dias Junior & Pierce, 1996; Silva et al., 2007; Severiano et al., 2008; Ajayi et al., 2010; Severiano et al., 2010a,b; Araujo Junior et al., 2011; Pacheco & Cantalice, 2011; Figueiredo et al., 2011). It has been used as a parameter to evaluate the susceptibility and vulnerability of soil structure to compaction under varying management scenarios (Jones et al., 2003; Spoor et al., 2003; Arvidsson & Keller 2004; Ajayi et al., 2010). Since it has been established that soil structure degradation may occur at any moisture content (Dias Junior & Pierce, 1995), it is important that any study designed to monitor soil structural changes must measure soil properties that would highlight these deformations at various moisture level.

Reviewing the published studies on Brazilian and some other sub-tropical regions agriculture systems, it was noted that there are very few studies that takes into account, the measurement of soil precompression stress as a function of water content to diagnose changes in soil structure for the different land use system. Considering the rate of development of mechanized agriculture in the Amazon Region of Brazil due to the productive nature of Cambisol soil widely found in the region, this study was designed with the objective of evaluating the changes in a Cambisol structure under six different land use systems using the load bearing capacity model.

MATERIAL AND METHODS

Soil samples were collected in the Benjamin Constant County (4° 26' S and 69°36' W), North Western State of Amazon. This region commonly referred to as the Upper Amazon lies within the triangular border between Brazil, Colombia and Peru. The dominant soil class in the region is Cambisol (Ustox) (Coelho et al., 2005). The climate of the upper Amazon, by the criteria of Köppen, is tropical humid or super humid (Af), with no significant dry season and an annual average temperature of 25.7 °C. Mean annual rainfall is 2,562 mm. The total rainfall of the driest month is greater than 100 mm, with higher rainfall concentrated in the months from December to April (Coelho et al., 2005).

The studied area represents a discontinuous surface of approximately 218,400 m^2 and was divided into six windows for standardized sampling under the project Biosbrasil (http://vsites.unb.br/ib/zoo/bios/indexe.html). The windows were also selected to ensure that the practices are very similar in each the identified land use systems, indicating there are no accentuated differences in terms of intensity of use in each system. The approximate area of each window is 3.64 ha, divided into 100 x 100/50 m sampling grids. These windows were divided to reflect the various land use system and the dominant soil types (Fidalgo et al., 2005). The predominant land use systems in agricultural production system in the study area are based on a cycle of deforestation and burning of secondary vegetation to grow crops over a given period. In some instances, agroforestry resulting from the spontaneous regeneration of secondary forest species is practiced. Interviews with farmers in the region revealed that most of the areas used in agroforestry systems were deforested between 1979 and 1983 and were planted with banana and cassava. The use for agroforestry began soon after the first few cycles of cultivation, between 1980 and 1984 (Fidalgo et al., 2005). 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[6], the land use system are classified as forest - areas with original forest type, with no evidence of the removal of timber (Windows 1 and 4); old secondary forest - 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 - 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); agroforestry - 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 - includes areas planted to annual crops (cassava, maize, sugarcane and pineapple) and perennial crop (banana) (Windows 2, 3, 4.5 and 6); and pasture - includes areas for livestock production, covered by grasses (Window 6). These land use systems were compared using the load bearing capacity models to identify which one preserves or degrades the Cambisol structure.

To obtain the load bearing capacity models, in March 2008, undisturbed soil samples were collected at depths 0-0.03, 0.10-0.13, and 0.20-0.23 m from field within the different six land use systems. In each land use system, 10 undisturbed soil samples were collected in 6.5 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. (six land use systems x three 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 uniaxial compression 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 initial 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 1 mol L^{-1} NaOH (Day, 1986) (Table 1). Particle density was determined using 95 % hydrated alcohol with 20 g of air-dried soil material in a 50 mL pycnometer (Blake & Hartge, 1986b). The total porosity (TP) was calculated from the expression:

$$TP = \left(1 - \frac{BD}{PD}\right)$$

where DB is bulk density (Mg m^{-3}) and PD is particle density (Mg m^{-3}).

[6] Project BiosBrasil/Conservation and sustainable management of below ground biodiversity (CSM-BGBD) implemented by the Global Environment Facility of the "United Nations Program (UNEP)" and executed in seven countries: Brazil, Ivory Coast, India, Indonesia, Kenya, Mexico and Uganda. In Brazil, GF2715/02.

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 h. 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. For the test, the undisturbed soil samples were kept within the coring cylinders, which were placed into the compression cell, and afterward submitted to pressures of 25, 50, 100, 200, 400, 800 and 1,600 kPa. Each pressure was applied until 90 % of the maximum deformation was reached (Taylor, 1948) and then the pressure was increased to the next level following the procedures described in Dias Junior & Pierce, (1995) and Dias Junior et al. (2008).

The precompression stress (s_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 & 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 8.0 (Sigma Plot, 2002) and comparisons of the regression lines were performed using the procedure described in Snedecor & Cochran (1989). The results of the bulk density (Blake & Hartge, 1986a) and total porosity (Table 1) were analyzed for variance and comparison of means was implemented with Scott-Knott ($p<0,05$) procedure.

RESULTS AND DISCUSSION

The particle size distribution, silt/clay ratio and textural classes of the Cambisol at different depths and land use systems are presented in table 1. The high silt/clay ratio is peculiar for this soil class and this trend is maintained in almost all the different land use systems. The variability of this ratio is in agreement with the low pedogenic development of the Cambisol class (Kämpf & Curi, 2012).

The values of the initial field bulk density and total porosity (Table 1) did not differ among the six different land use systems and in the various depths considered in this study. This indicates that bulk density and total porosity may not be appropriate to accentuate the effect of the various land use systems on the Cambisol structure. These results agree with that of Martins (2009) which concluded that not all variation in the initial bulk density and total porosity may not be sufficient as indexes of soil structure degradation. However, it should be noted, that the insignificance in the variation of the initial bulk density does not imply that there is no soil structure deformation as a consequence of the various land use systems, rather it implied that most of the deformations occur within the region of the secondary compression curve, wherein they would be elastic and recoverable (Figure 1); suggesting that changes in these properties will not be adequate to characterize the soil structure degradation. Degradation of soil structure occurs only when the deformation (inducing variations in these properties) occur within the region of plastic deformation, wherein the deformations are not recoverable, being bounded by preconsolidation pressure. From that initial observation, it was concluded that soil structure degradation in this study would be analyzed using the load bearing capacity models (a variation of precompression stress against moisture content) of the soil samples at the various depths under the different land use systems.

It was observed that for the three depths and different land use systems considered, the precompression stress (σ_p) decreases exponentially with volumetric water content (θ), as similarly observed in previous other studies (Mosaddeghi et al., 2003; Peng et al., 2004; Severiano et al., 2009; Ajayi et al., 2011). Using the model proposed by Dias Junior & Pierce (1995) $\sigma_p = 10^{(a + b\theta)}$, where σ_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 for the different land use systems for the various depth were constructed (Figures 2 to 4).

At 0-0.03 m depth, when compared, the load bearing capacity models for old secondary forest, cropping and forest were not statistically different. Similarly the load bearing capacity model of the young secondary forest and agroforestry were not different (Table 2). In the land use systems that were not statistically different, a single equation was then fitted to all values of precompression stress and volumetric water content, therefore generating a single and representative load bearing capacity model for these mixes of land use systems (Figure 2).

Using the load bearing capacity model of the forest land use system as a reference for structural preservation at the 0-0.03 m depth (Figure 2), it was observed that, at any water content, the pasture 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 & Reicherdt (1995) on the effect of animal trampling on soil structure in the topsoil zone. At this depth, the old secondary forest, cropping and forest land use systems were observed to preserve the Cambisol structure. It is noteworthy 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 land use

Table 1. Particle size distribution, silt/clay ratio, textural classes and physical characteristics of the Cambisol samples at three depths under different land use systems

Land use system	Sand(1)	Silt	Clay	Silt/Clay	Textural class	BDi(2)	PD(1)	TP(2)
	g kg^{-1}					Mg m^{-3}		m^3 m^{-3}
					0 - 0.03 m			
Young secondary forest	170	520	310	1.68	Silty clay loam	1.09 a	2.44 c	0.55 a
Old secondary forest	300	410	290	1.41	Clay loam	1.15 a	2.50 a	0.54 a
Forest	150	540	310	1.74	Silty clay loam	1.06 a	2.41 d	0.56 a
Pasture	460	320	220	1.45	Loam	1.04 a	2.44 c	0.57 a
Cropping	270	250	480	0.52	Clay	1.02 a	2.44 c	0.58 a
Agroforestry	170	470	360	1.31	Silty clay loam	1.07 a	2.47 b	0.57 a
					0.10 - 0.13 m			
Young secondary forest	240	370	390	0.95	Clay loam	1.23 a	2.53b	0.51 a
Old secondary forest	180	440	380	1.16	Clay loam	1.26 a	2.53b	0.50 a
Forest	200	450	350	1.29	Clay loam	1.23 a	2.53b	0.51 a
Pasture	160	440	400	1.10	Clay	1.20 a	2.41c	0.50 a
Cropping	160	440	400	1.10	Clay	1.23 a	2.56a	0.52 a
Agroforestry	120	430	450	0.96	Silty clay	1.27 a	2.41c	0.47 a
					0.20 - 0.23 m			
Young secondary forest	160	470	370	1.27	Silty clay loam	1.30 a	2.50 c	0.48 a
Old secondary forest	160	410	430	0.95	Clay	1.23 a	2.56 b	0.52 a
Forest	180	380	440	0.86	Clay	1.28 a	2.60 a	0.51 a
Pasture	320	370	310	1.19	Clay loam	1.26 a	2.50 c	0.50 a
Cropping	80	440	480	0.92	Silty clay	1.28 a	2.60 a	0.51 a
Agroforestry	150	330	520	0.63	Clay	1.24 a	2.50 c	0.50 a

(1) and (2): Average of three and 10 replications, respectively, BDi: Initial bulk density; PD: particle density; TP: total porosity. Average in columns and the same depth with the same letter did not differ by Scott-Knott at 5 %.

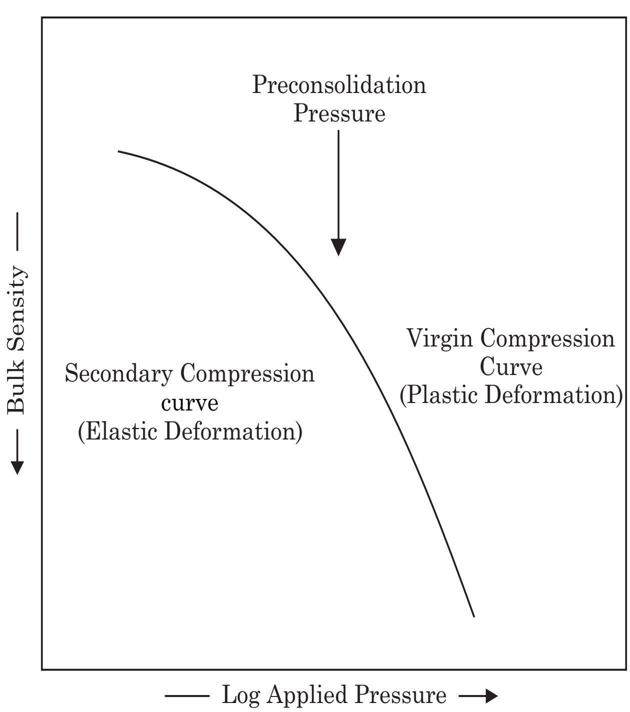

Figure 1. Soil compression curve.

systems may be related to the formation of biopores and the steady incorporation of organic matter from the decomposition of roots and leaves (Muller et al., 2001, 2004). Similarly, the loosening of soil particles during tillage operations is significant at this depth (Arkin & Taylor, 1981).

For the 0.10-0.13 m depth, the load bearing capacity models for young secondary forest and pasture were not different. Those of the old secondary forest and forest land use systems were also not different (Table 2). Therefore the respective data were of the land use systems that were not statistically different were fitted with a single equation generating a single load bearing capacity model for these land use systems (Figure 3).

The result showed that at 0.10-0.13 m depth, cropping was found to degrade most the soil structure, while young secondary forest and pasture preserved the soil structure (Figure 3). The high bearing capacity of the cropping land use 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 & Taylor, 1981). The lower bearing capacity presented by young secondary forest and pasture may be indicative of a

Table 2. Comparison of the load bearing capacity models[1] [$\sigma_p = 10^{(a + b\theta)}$] of a Cambisol samples for different land use systems at 0 - 0.03, 0.10 - 0.13 and 0.20 - 0.23 m depths

Land use system	Homogeneity	Intercept "a"	Slope "b"
		0 - 0.03 m	
Old secondary forest x cropping	H	ns	ns
Old secondary forest and cropping x forest	H	ns	ns
Old secondary forest, cropping and forest x young secondary forest	H	*	**
Old secondary forest, cropping and forest x agroforestry	H	**	**
Old secondary forest, cropping and forest x pasture	H	**	**
Young secondary forest x agroforestry	H	ns	ns
Young secondary forest and agroforestry x pasture	H	**	ns
Young secondary forest and agroforestry x old secondary forest, cropping and forest	H	**	**
		0.10 - 0.30 m	
Young secondary forest x pasture	H	ns	ns
Young secondary forest and pasture x agroforestry	H	*	ns
Young secondary forest and pasture x old secondary forest	H	**	ns
Young secondary forest and pasture x forest	H	**	ns
Young secondary forest and pasture x cropping	H	**	**
Old secondary forest x forest	H	ns	ns
Young secondary forest and pasture x old secondary forest and forest	H	**	ns
Old secondary forest and forest x cropping	H	ns	**
Old secondary forest and forest x agroforestry	H	**	ns
Cropping x agroforestry	H	**	**
		0.20 - 0.23 m	
Forest x pasture	H	ns	ns
Forest and pasture x old secondary forest	H	**	**
Forest and pasture x cropping	H	ns	**
Forest and pasture x young secondary forest	H	**	**
Forest and pasture x agroforestry	H	**	**
Young secondary forest x old secondary forest	H	**	**
Old secondary forest x cropping	H	**	**
Old secondary forest x agroforestry	H	**	ns
Young secondary forest x cropping	H	ns	**
Young secondary forest x agroforestry	H	ns	**
Cropping x agroforestry	H	ns	**

[1] According described in Snedecor & Cochran (1989). H: Homogeneous, *and **: F test significant at 5 and 1 % level, respectively; ns: not significant.

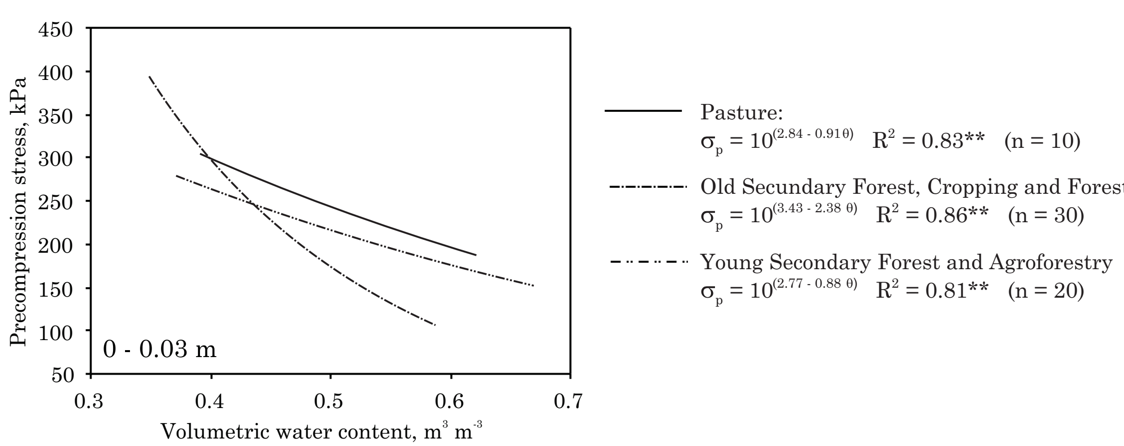

Figure 2. Load bearing capacity models for the Cambisol at 0 - 0.03 m depth under different land use systems.

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, 2004).

A comparison of the precompression stress data for the various land use systems at 0.20-0.23 m depth indicated that the load bearing capacity models for forest and pasture land use systems were not different (Table 2). Thus, a representative load bearing capacity model was generated for these mix of land use systems (Figure 4).

It was observed that at 0.20-0.23 m depth, the old secondary forest land use system degraded most the Cambisol structure, while the young secondary forest, cropping and agroforestry systems preserved the soil structure. The observed degradation in this layer by the old secondary forest 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 & 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.

CONCLUSIONS

1. The results of the bulk density and total porosity of the soil samples were not adequate to quantify structural degradation in Cambisol.

2. Using the forest topsoil level (0-0.03 m) as a reference, it was observed that pasture land use system was most severe in the degradation of the soil structure while the structure were most preserved under old secondary forest, cropping system and forest.

3. At the subsoil level (0.10-0.13 m depth), the soil structure was most degraded in the cropping land use system while it was most preserved in young secondary forest and pasture.

4. At the 0.20-0.23 m depth, soil structure degradation was most severe in the old secondary forest

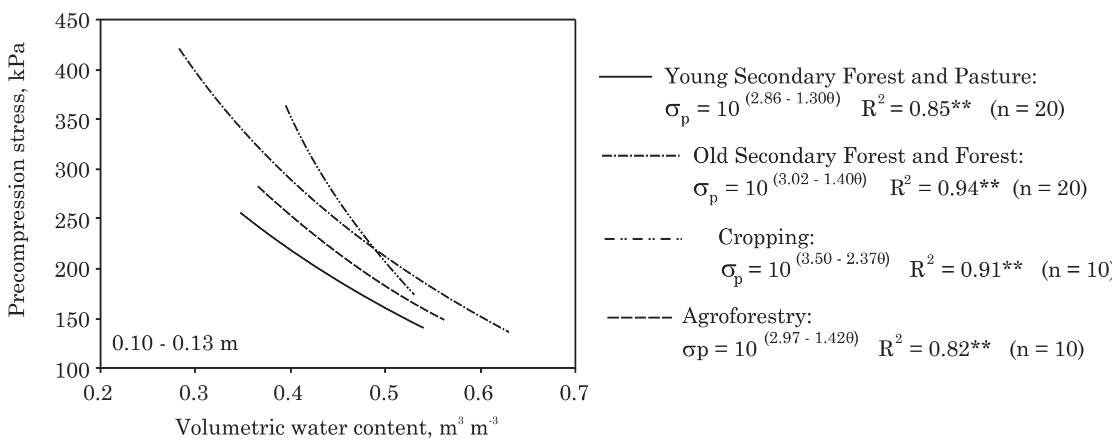

Figure 3. Load bearing capacity models for a Cambisol at 0.10 - 0.13 m depth under different land use systems.

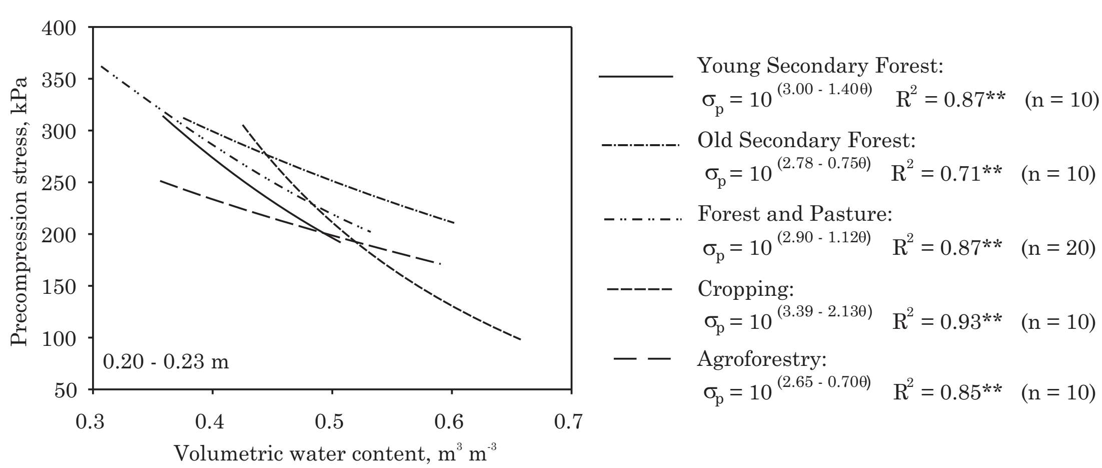

Figure 4. Load bearing capacity models for a Cambisol at 0.20 - 0.23 m depth under different land use systems.

system and well preserved in young secondary forest, cropping and agroforestry.

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