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Comparisons of land use effects on soil bulk density in the Amazon Basin

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Understanding the processes that lead to degradation is an essential element to define suitable land use systems for these soils. Declining productivity of tropical soils under continuous cultivation, even with supplementary fertilisation, is well documented. Nowadays, with the development of models for simulating plant growth or transport of solutes in soils, the concept of a static and qualitative description of soil structure is changing into the concept of finding ways of adjusting and optimising structure to achieve maximum yields or reduced leaching rates. Bulk density (ρ) measurement is proposed as a rough indicator of the ideal structure for a land use system, and a simple statistical approach is proposed for comparing different scenarios of soil structure, using average weighted values of ρ as indicator parameter.

The study was carried out on the research station of Embrapa Amazônia Ocidental near Manaus. The land use systems investigated were described in Table 1. Undisturbed soil samples were collected at ≈ 40 cm from the trunk of the respective species as well as under the cover crop (Table 1). The experimental design for statistical analysis was a randomised block design (RBD) with three subsamples within each treatment. The estimation of the weights of the spot areas are based on the area of influence of a specific specie, proportional to the entire of the land use system. The domain of influence of a specific plant is a “disc” centred at the stem. These discs were calculated based on: the crown area of the plants at that stage of growth and management practices. These specific areas of influence of each species were then multiplied by the number of individuals. The remaining areas predominant effect of the cover crop were calculated by subtraction. After estimating the radius of influence of these spots around a stem and calculating their relative means, plant species and whole land use systems can be compared using contrast analyses, and hypotheses of practical interest can be formulated in terms of the ρ-weighted values.

An exploratory analysis of the data is shown in Table 1. Table 2 shows differences between the ρ evaluated near the different plant species ($\alpha < 0.05$) and does not indicate a variation between the blocks. The computation of the subsample variance, with three samples per position, shows that the sampling error contributes with 0.003 to the error variance of 0.010. The analysis of subsampling was computed as an indication of the adequacy of the sampling scheme adopted in this study. It seems to be appropriate, because, if the number of samples were doubled, the sampling error contribution would be halved. Therefore, the main source of the variance is not from a presumed inadequate number of samples, and the reduction of the variance with increasing sampling (in this example, as well in many other situations) may not be worthwhile. The mean values of ρ observed in Table 1 lie in the small range of 0.82 – 1.01 Mg m^{-3}, with a mean of 0.91 Mg m^{-3}. This range is not typical, considering that this Ferralsol has clay content at the surface of more than 600 g kg^{-1} and the organic carbon content is not very high. The reason for this is that the clay particles in these soils are flocculated in microaggregates (intra-aggregate) and a secondary pore system (inter-aggregates) was established as a result from an intense biological activity and fissures. The only significant difference in Table 1 is between the ρ near bacabas in the primary forest and the position between the cupuaçus in monoculture covered by grasses and pueraria. The higher values of ρ found between the cupuaçus growing in the monoculture are due to inadequate growth of the cover crop in this land use system, resulting, presumably, in compaction of the soil structure owing to direct impact of the tropical rain drops on the soil, and the more intensive cycles of heating and drying. In the monoculture of peach palm for fruit and palm heart, the sample positions between the plants tend to show higher ρ values than the values near the trunks (Table

1). This agrees with observation of ponded water, for short periods, after intense rainfalls in those positions. The high number of roots (with a low density) per volume maintains the soil ρ values low.

The results and discussion of comparison within and between the whole land use systems was divided in the three land use systems evaluated and some results concerning the agroforestry system are presented below. The complete study is presented by Teixeira, 2001 However, within the agroforestry system the bulk density (ρ) near the peach palms and under the pueraria tends to show lower values of ρ none significant difference between the six plants growing within the agroforestry system were found (Table 1). The effect of pueraria to recuperate the porosity of the soil and to maintain the soil structure quality in a good level confirms the results found in early experiments carried out in the Ferralsols in Manaus. Practical hypotheses and its statistical formulation concerning the agroforestry system as a whole system are shown in Equations 1, 2 and 3.

Is there a significant difference in ρ between on the agroforestry and the primary forest?

$$H_1: 0.04\ \mu_1 + 0.11\ \mu_2 + 0.18\ \mu_3 + 0.02\ \mu_4 + 0.03\ \mu_5 + 0.62\ \mu_6 - 0.50\ \mu_{14} - 0.50\ \mu_{15} = 0 \qquad [1]$$

Is there a difference in ρ between on the agroforestry and the secondary forest?

$$H_1: 0.04\ \mu_1 + 0.11\ \mu_2 + 0.18\ \mu_3 + 0.02\ \mu_4 + 0.03\ \mu_5 + 0.62\ \mu_6 - 1\ \mu_{13} = 0 \qquad [2]$$

Is there a difference in ρ between on the agroforestry and the monoculture of cupuaçu?

$$H_1: 0.04\ \mu_1 + 0.11\ \mu_2 + 0.18\ \mu_3 + 0.02\ \mu_4 + 0.03\ \mu_5 + 0.62\ \mu_6 - 0.07\ \mu_7 - 0.93\ \mu_8 = 0 \qquad [3]$$

Here, μi are mean values of ρ and the coefficients are the estimated weight factors for each mean in relation to the whole system.

Table 3 shows a significant difference ($\alpha' > 0.01$) between the agroforestry system and the cupuaçu monoculture. The other agricultural land use systems do not show significant differences at $\alpha' > 0.05$ in relation to the agroforestry. It should be emphasised that the agroforestry system had been installed in the field only 3 to 4 years before these measurements. Thus, it did not yet represent a stabilised land use system. Therefore, much free space existed between the plants. At the time of evaluation, the space between the trees was covered by pueraria, which in the agroforestry system was growing well, and this is one reason for the relative good performance of the agroforestry system analysed as a whole system. Simulations of two hypothetical scenarios were calculated and statistically compared. In the first simulation, the remaining areas between the trees in the agroforestry system, instead of being covered by pueraria, were covered by grasses (the mean and variance of the ρ for grasses, in this simulation were those found in the positions between the cupuaçu in monoculture), whereas the other means and the weight factors remained the same. An opposite hypothetical situation, where a better structure was conceptualised, was the second scenario. In this theoretical land use system, the soil of the monoculture of cupuaçu was covered by pueraria instead of being covered by grass. The results in Table 3 show that for the first scenario the agroforestry system shows a significant difference from the primary forest caused by the increased values of ρ when the soil is not well covered. In the second scenario, an opposite effect was found with the improvement of the average soil structure in a hypothetical monoculture of cupuaçu system well covered by pueraria. In this scenario, the monoculture of cupuaçu would not show significant difference from the primary forest. The bulk density is an appropriate physical indicator for the quality of the soil structure, or a mosaic of different soil structures within an agroforestry system. Plant growth, yields and leaching rates may be used as indicators of the efficiency of the ideal structure for the suitability of a land use system. A simple and useful tool to compare different combinations of plants or temporal scenarios are statistical models that combine contrast analysis with weighted means that represent the different spots within a land use system. This technique may be incorporated in land use planning as an additional tool to define a suitable combination of plants and management practices.

Table 1 Exploratory analysis of bulk density [Mg m^{-3}] evaluated on different land use system.

Land use system and specie	Mean	St. Error. 10^{-2}	Minimum	Maximum
Agroforestry System				
Cupuaçu – *Theobroma grandiflorum*	0.93 ab	2.05	0.84	1.02
Annatto – *Bixa orellana*	0.90 ab	2.47	0.74	0.99
Brazil nut- *Bertholletia excelsa*	0.96 ab	2.21	0.88	1.07
Peach palm – *Bactris gasipaes* – Fruits	0.88 ab	2.29	0.80	1.00
Peach palm – Palm heart	0.88 ab	3.55	0.67	0.98
Pueraria	0.88 ab	1.19	0.84	0.94
Monoculture				
Cupuaçu	0.93 b	1.96	0.84	0.99
Cover crop in Cupuaçu	1.00 ab	8.47	0.97	1.05
Peach palm – Fruits – near plants	0.86 ab	3.00	0.70	0.98
Peach palm – Fruits -between palms	0.98 ab	2.12	0.86	1.08
Peach palm - Palm heart – near palms	0.91 ab	3.31	0.79	1.07
Peach palm –Palm heart – between palms	0.97 ab	1.54	0.88	1.03
Adjacent areas covered with natural vegetation				
Secondary forest – Vismia *Vismia s*	0.90 ab	2.90	0.78	1.01
Primary forest – Matá-matá –*Escheweleira sp*	0.87 ab	1.92	0.77	0.94
Primary forest – Bacaba *Oenocarpus bacaba*	0.82 a	3.08	0.65	0.95
Average	0.91	7.32	0.65	1.08

Means followed by the same letters within the column, do not differ by Tukey's test ($\alpha < 0.05$).

Table 2 Analysis of variance using complete randomised block design with subsampling for bulk density

Source	Sum-of-Squares	df	Mean-Square	F-ratio	P
Land use and plant	0.341	14	0.024	2.465	0.020
Block	0.028	2	0.014	1.394	0.265
Error	0.277	28	0.010		
Subsampling	0.328	90	0.003		
subsampling	[0.009]	[2]	0.004	1.290	0.283
vs. land use and plant	[0.120]	[28]	0.004	1.271	0.220
vs. block	[0.010]	[4]	0.003	0.758	0.557
Error of subsampling	[0.189]	[56]	0.003		
Total	0.697	134			

Table 3 Analysis of variance for the hypothesis concerning agroforestry system.

Source of Variation	Sum of squares	Degrees of freedom	Mean Square	F	P
Agroforestry vs. primary forest	0.0100	1	0.0100	3.0038	0.0923
Agroforestry vs. secondary forest	< 0.0000	1	< 0.0000	0.0021	0.9640
Agroforestry vs. cupuaçu	0.0245	1	0.0245	7.4278	0.0109
Agroforestry vs. peach palm	0.0109	1	0.0109	3.3184	0.0792
Error	0.0922	28	0.0033		
Analysis of variance for hypothesis concerning hypothetical land use systems					
Agroforestry^{+} vs. primary forest	0.0585	1	0.0585	17.7518	0.0002
Cupuçu ¶ vs primary forest	1.8092×10^{-5}	1	1.8092×10^{-5}	0.0055	0.9414
Error	0.0922	28	0.0033		

The adjusted level (α'). See Sokal R. R and Rolf F J. Biometrics. New Yourk, Freeman, 1995. 887p.

Referência

Teixeira, W. G. Land use effect on soil physical and hydraulic properties of a clayey Ferralsol in the Central Amazon. Bayreuther Bodenkunde Berichte, Bayreuth. Band 72. 255p.