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Soil Quality of Very Fragile Sandy Soils From Southern Brazil

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ABSTRACT

Very fragile sandy soils have long been known to have high erosion susceptibility, low water retention, and low mineral storage with significant areas of such soils in Southern Brazil, where substitution of native grassland by grain production with conventional tillage (CT) caused an intense degradation reaching an extreme of non-vegetated sandy surfaces (NVSA). The study was carried out at a farm with about 400 ha of NVSA of Quartzipsamment soil with annual average precipitation of 1511 mm. Four land uses were evaluated: 1) eucalyptus forest; 2) native grassland; 3) NVSA; 4) CT. Soil physical and chemical indicators were studied. The physical attributes indicate an extreme state of degradation at NVSA with 96.8 g kg^{-1} of sand with low water holding capacity and very high saturated hydraulic conductivity. Wet aggregate stability, as ranked from highest to lowest, was eucalyptus > native grassland > CT > NVSA. The physical differences among the soils were closely related to total organic carbon (TOC) at the soil surface, which seems to be the driving force for resisting soil degradation. The eucalyptus forest was the best system for retaining soil TOC, with a carbon stock of 15.7 Mg ha^{-1} higher than NVSA at the 0-20 cm depth. The greater proportion of CEC of these soils is due to TOC, thus the low TOC of NVSA represented a significant loss of soil CEC causing bases leaching and high aluminum saturation. The later restricts plant growth and reduces soil cover, thus creating an environment prone to wind erosion.

INTRODUCTION

Soil quality can be defined as a soil functioning within a given ecosystem (Doran & Parkin, 1994). Among its functions, the ability to react to soil management and to resist degradation is of great agricultural importance. The later is closely related to the capacity of a soil recover from a stress condition or soil management change (Novaes & Smyth, 1998). Soils formed from sandstone parent material occupy a large area at the southwestern of Rio Grande do Sul (RS) state in Brazil and are naturally very susceptible to erosion (Souto, 1982), with low resilience. These soil properties produce an ecosystem with a high degree of fragility, the highest in the state, making it difficult to have sustainable agricultural systems.

In the 70's and 80's decades, there was an extensive agricultural use of sandy soils where native grasslands were replaced by conventional tillage (moldboard + disk operations) soybean, resulting in a severe soil and whole ecosystem degradation. In the most severely degraded areas, known as non-vegetated sand areas (NVSA), there are great limitations to plant growth and increased susceptibility to wind and water erosion. However, properly managed, sandy soils can improve in quality faster than clayey soils (Reinert, 1998) due its low resilience.

The degradation of fragile ecosystems, as in southwestern Rio Grande do Sul, is triggered when its resistance to anthropic disturbance is surpassed, however, as the last is very low any disturbance may be critical to the whole system. This shows the importance of evaluating the degree of degradation, for different land uses, as compared to native conditions. In this study, chemical and physical indicators of a sand soil were evaluated to access soil quality modification for different soil uses. The hypothesis is that soil organic carbon build up at different land use in very fragile soil is the driving force to resist a high degradation process. The main objectives of this research are: a) evaluate the stage of degradation of NVSA; b) evaluate the soil quality under different land uses; c) identify land uses that prevent soil degradation in a very fragile soil.

MATERIAL AND METHODS

The study was carried out at a farm in the county of São Francisco de Assis, RS, Brazil, selected because it has an expressive non-vegetated sand area (NVSA). The soil is classified as Quartzipsamment using soil taxonomy (USDA, 1975), with very low clay content, weak structure, and gentle slope. The mean annual rainfall is 1511 mm, with monthly rainfall over 95 mm. The mean annual evaporation is about 903 mm, 60% of total rainfall. The areas with this type of ecosystem are located at 29 and 31° latitude South and 54 and 58° West Gr. The climate is classified as cfa subtropical humid. The winter average temperature is from 13 to 14°C and summer average temperature is around 25°C. The annual average temperature is from 19 to 20°C.

Four soil uses, already existing on the farm, were selected to reduce natural soil variation. These uses were: 1) eucalyptus forest, nine years old (40 g clay kg^{-1} soil); 2) native grassland (40 g clay kg^{-1} of soil); 3) non-vegetated sand area (NVSA) susceptible to high degradation (20 g clay kg^{-1} clay); and 4) conventionally tilled corn, five years old (30 g clay kg^{-1} soil). Conventional tillage was performed by one operation of moldboard followed by two disking. To evaluate soil chemical attributes, soil samples were taken from a 0.4x0.3x0.2 m pit wall, at 0-2.5, 2.5-5, 5-7.5, 7.5-10, and 10-20 cm depths. Soil analyses included total soil carbon using wet digestion (Nelson & Sommers, 1982), total soil nitrogen by micro-Kjeldahl distillation (Tedesco et

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al., 1995), available soil P and K (Mehlich-I), exchangeable Ca, Mg and Al were extracted by KCl 1M (Tedesco et al., 1995). Aluminum saturation and effective CEC were calculated from the data.

Soil cores (5.3 cm diameter by 3 cm height) from 0-3, 5-8, and 10-13 cm depths were extracted using a core-pushing device to measure saturated hydraulic conductivity and water retention. The hydraulic conductivity was measured as described in Klute (1965) in soil cores, previously saturated. Thereafter the cores were weighed and then taken to tension table and Richards apparatus (Richards, 1965). The water retention curve was constructed determining soil water content at matric potentials of -1, -6, -33, -100, and -500 kPa. The soil cores were oven dried, weighed, and soil bulk density and porosity were calculated. The volumetric water content retained at -6 kPa was considered as microporosity and the difference between total porosity and microporosity was considered as macroporosity.

Soil samples with partially disturbed structure were sampled at the 0-5 cm depth to measure water aggregate stability (Kemper & Chepil, 1965) using two strategies: (1) initial sample with aggregate size between 8 and 4.7 mm; and (2) initial sample using whole sample passed through a 8 mm sieve. Dry aggregate size distribution was also measured on samples < 8 mm.

The statistical analyses were done using a complete random design with one factor, four treatments, and four replications. The data were analyzed by depth and the means compared by Duncan's (P=0.05) test, using SAS package (SAS, 1985).

RESULTS AND DISCUSSION

Total organic carbon (TOC), due to its multiple functions, is the main indicator of soil quality (Larson & Pierce, 1991). TOC contents at the study sites were low with only small changes with depth, except for forest soil (Figure 1). The eucalyptus forest soil had 15.7 t ha^{-1} more TOC, at 0 to 20 cm depth, than the non-vegetated sand area (NVSA). The TOC contents for native grassland were similar to those for conventional tillage corn. The main reason for the similarity was probably due to low biomass production, high biomass exportation by beef cattle grazing, and natural low soil fertility of the native grassland. By contrast, fertilization with nitrogen, phosphorus, potassium, calcium and magnesium increased the biomass production by conventional tillage corn increasing biomass left over. The NVSA showed lower TOC with a greater difference from the original condition (native grassland), implying a high degree of land degradation.

For this soil, as for most sandy soils, there was a close relationship between TOC and cation exchange capacity (CEC) (Fig. 2). Thus, the great proportion of CEC is due to organic matter. The remarkable decrease in TOC content in the NVSA is accompanied by large decrease in CEC and in cation storage (Fig. 3).

The leaching potential for these soils is high and most available cations are replaced by Al, causing high Al saturation and toxicity to plants. Al saturation is an indicator of poor environment for plant growth, and results in low soil biomass, thus providing less surface protection against climatic factors (wind and rain), which accelerate land degradation. The comparison between forest and NVSA soils allows the evaluation of the severity of degradation in these sand soils, clearly indicating the fragility of this ecosystem. The forest system showed high potential to cycling nutrients and prevents the negative effect of Al concentration, apparently by improvement of bases cycling.

The soil physical indicators for the NVSA reflect the degree of soil degradation. The soil at this site has 98% sand and, at sampling time, the water content was extremely low, due to its low microporosity and high macroporosity (Table 1). For the other land sites the differences, seen at the 0 to 3 cm depth, included higher microporosity and total porosity and lower macroporosity for the eucalyptus forest, native grassland and conventional tillage corn in decreasing order. For all but the NVSA, the bulk density and total porosity were similar for studied depth below 3 cm.

Table 1 – Bulk density, porosities and water content of a sandy soil, in 3 depths, under different management systems in Southern Brazil.

Soil use	Depth cm	Bulk density g cm-3	Microporosity dm3dm-3	Macroporosity dm3dm-3	Total porosity dm3dm-3	Moisture at sampling g g-1
Eucalyptus	0-3	1.22	0.231	0.284	0.515	0.113
	5-8	1.44	0.169	0.280	0.449	0.053
	10-13	1.47	0.156	0.284	0.440	0.061
Native grassland	0-3	1.40	0.175	0.285	0.460	0.069
	5-8	1.54	0.163	0.250	0.413	0.065
	10-13	1.54	0.162	0.247	0.409	0.072
Non-vegetated	0-3	1.52	0.078	0.346	0.424	0.014
sand area	5-8	1.55	0.073	0.338	0.410	0.021
	10-13	1.54	0.078	0.334	0.412	0.030
Conventional	0-3	1.40	0.143	0.315	0.458	0.044
tillage corn	5-8	1.56	0.155	0.243	0.399	0.055
	10-13	1.51	0.156	0.266	0.422	0.063

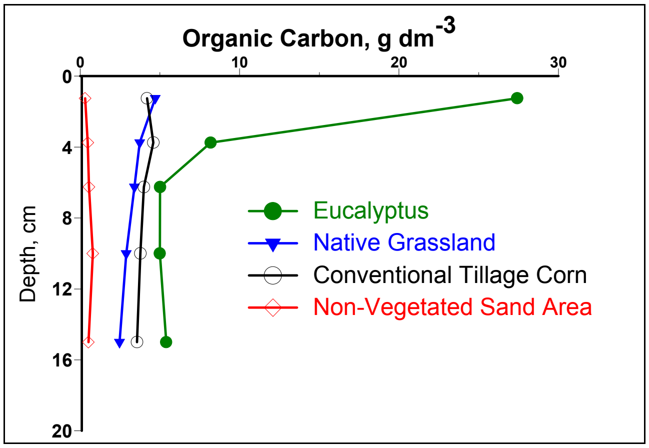

Figure 1. Total organic carbon at 0 to 20 cm depth of a sandy soil for different land uses.

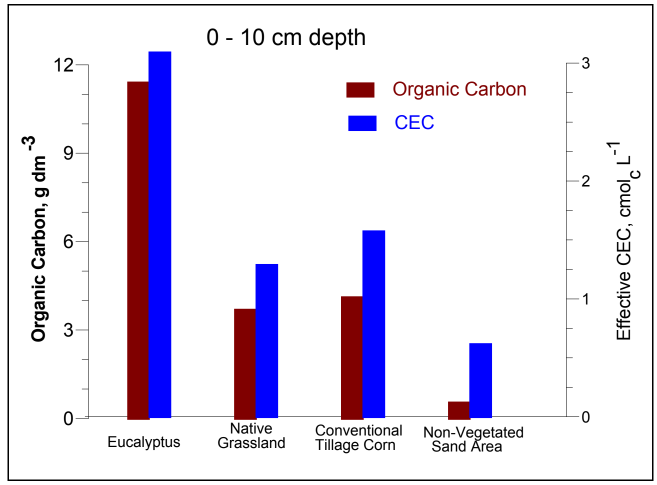

Figure 3. Exchangeable bases and aluminum saturation for a sandy soil at 0 to 2.5 cm depth under different land management in Southern Brazil.

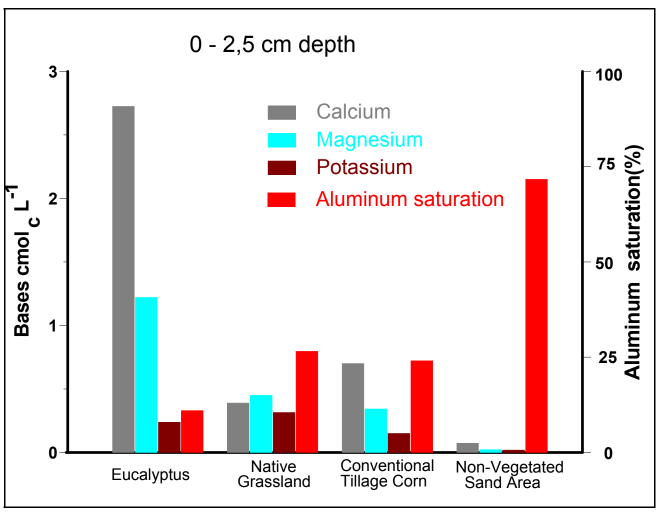

Figure 2. Organic carbon and effective CEC at the 0 to 10 cm depth for different land uses.

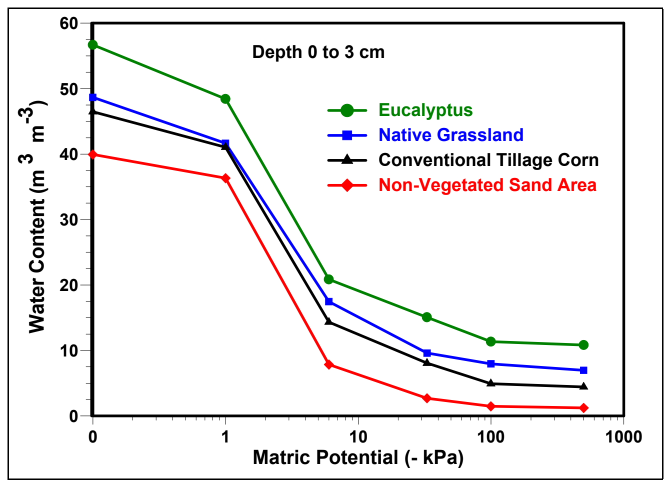

Figure 4. Water retention curve for a sandy soil at the 0-3 cm depth under different land managements in Southern Brazil.

Table 2. Aggregate stability for 0 to 5 cm depth of a sandy soil under different land managements in Southern Brazil.

Aggregates classes and indexes (mm)	Method of Kemper & Chepil (25 g of aggregates from 4.76 to 8 mm)			Modified method of Kemper & Chepil (50 g of aggregates smaller than 8 mm)		
	Forest	Native grass	CT[‡] corn	Forest	Native grass	CT corn
8.00 to 4.76	37.7 a	32.5 b	12.0 c	21.4 a	12.5 b	6.3 c
4.76 to 2.00	6.9 b	10.2 a	7.8 ab	12.1 a	11.6 a	6.1 b
2.00 to 1.00	1.2 b	0.9 b	2.4 a	4.9 ab	6.1 a	4.6 b
1.00 to 0.21	1.7 b	3.3 b	15.3 a	7.0 b	12.0 ab	14.7 a
< 0.21	52.3 b	52.9 b	62.5 a	55.1 b	57.6 b	68.2 a
GMD[†] wet	0.68 a	0.62 a	0.32 b	0.49 a	0.38 b	0.25 c
MWD[§] wet	2.7 a	2.5 a	1.2 b	1.93 a	1.40 b	0.83 c
GMD dry	---	---	---	0.95 a	0.61 b	0.4c
2.00 to 8.00	44.6 a	42.7 a	19.8 b	33.5 a	24.1 b	12.4 c

[†]GMD = geometric mean diameter; [§]MWD = mean weight diameter. [‡]CT= Conventional-tillage corn
Means followed by the same letter, in the row, do not differ significantly according to the Duncan mean test (P<0.05).

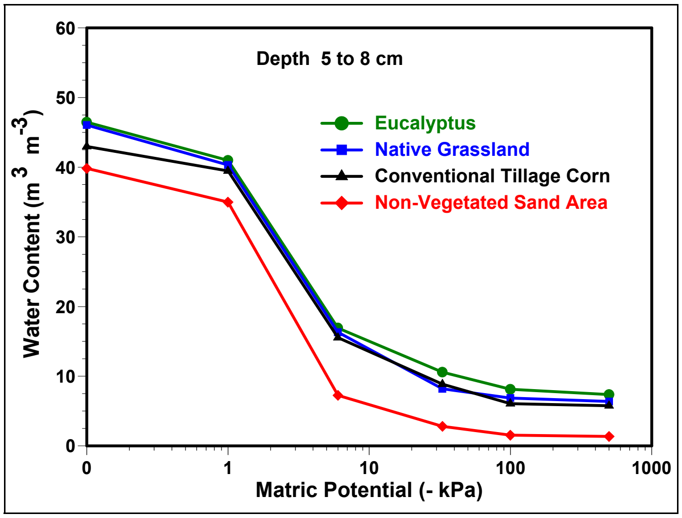

Figure 5. Water retention curve for a sandy soil at the 5-8 cm depth under different land managements in Southern Brazil.

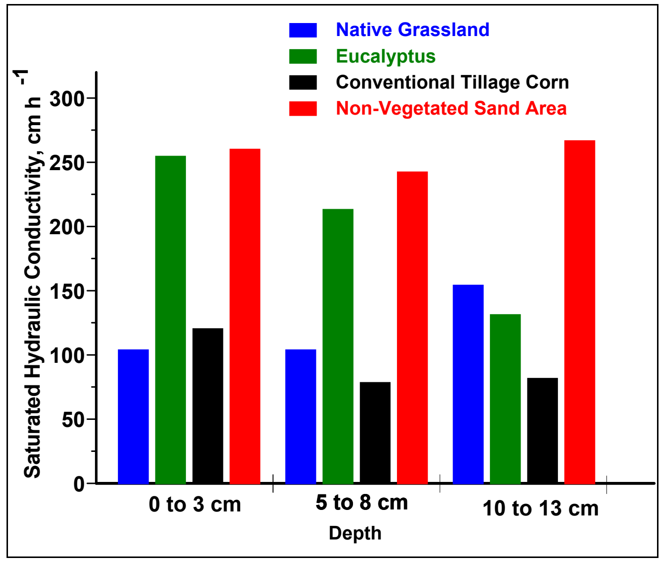

Figure 7. Saturated hydraulic conductivity for a sandy soil at 0 to 13 cm depth under different land managements in Southern Brazil.

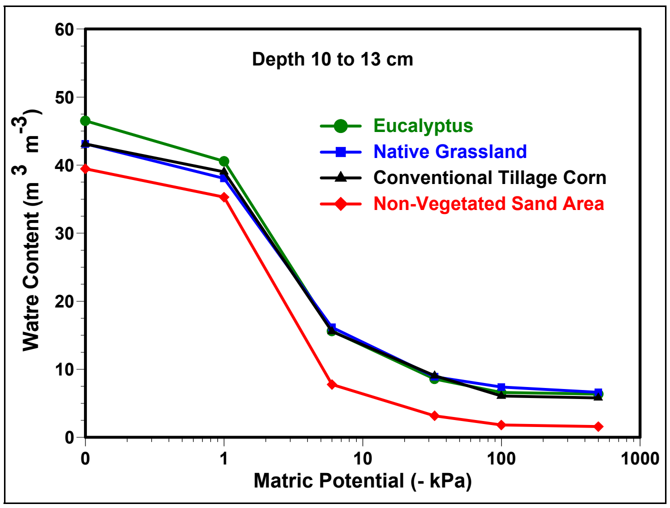

Figure 6. Water retention curve for a sandy soil at the 10-13 cm depth under different land managements in Southern Brazil.

The water retention in each pore size class for the NVSA explains the great difference in water content observed at soil sampling (Table 1)**.** The total water retained at –6 kPa for this site was almost half as the others and implies very low water storage even right after abundant rainfall. The water retention curve for NVSA at all depths, was less than the other soil managements. The eucalyptus forest, at the soil surface (0-3 cm) had higher water retention, but was similar to native grass and conventional tillage corn for the 5-8 and 10-13 cm depths. The proportion of various soil pores classes were similar for all sites; however, the pore class between 288 µm (-1 kPa) and 48 µm (-6 kPa) was responsible for most of the water storage in this soil (Figures 4, 5 and 6).

The high macroporosity observed for NVSA induced high-saturated hydraulic conductivity (Ksat) (Figure 7). The other land uses also had high Ksat values always greater than 75 cm h^{-1}. The eucalyptus forest, which had higher TOC and aggregation, had Ksat values similar to NVSA, implying similar, high water fluxes in this soil type for both management systems, clearly showing that this soil physical property have small valuable to evaluate soil structure of sandy soils.

There was no aggregation in the NVSA, where the soil mass was formed by single grains impregnated by clay and oxides. For other soil management systems, aggregation was differentiated, decreasing from the eucalyptus forest < native grass < conventional tillage corn (Table 2). However, when the aggregation was measured on all the soil sample that passed on 8-mm sieve there was better separation between treatments. Despite of some differences, all aggregation measurements showed similar trends and had a close association with the TOC content.

In conclusion, the management of sandy soils should avoid soil disturbance to increase TOC content.

Soil quality restoration in the non-vegetated sandy areas should emphasize increasing the base saturation and CEC, reducing in the aluminum saturation, and increasing the soil organic matter. Greater soil physical changes occur at the soil surface and are closely related to the soil organic matter content, which, in turn, affects aggregate stability, pore size distribution and water flux.

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