EFFECTS OF STILLAGE APPLICATION ON THE STRUCTURE OF TROPICAL CULTIVATED SOILS[1]

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ABSTRACT

The stillage generated in ethyl alcohol production from sugarcane, is now part of a routine practice in sugarcane cultivation. Besides solving the deposition and pollutant degradation problems when in contact to water streams, it adds nutritive elements and organic components to soil. The stillage, apart from chemical effects, interferes on soil physical characteristics: aggregation, porosity, density and water holding capacity. Although these physical effects are not very well known, the chemical effects have been better studied. The effects in tropical soils of stillage application were evaluated on the structure of a medium textured Latosol. The analytical and density parameters used were porosity and medium diameter of aggregates (MDA), under: sugarcane crop, "cerradão" and eucalyptus. The cultivated areas showed a certain struture degradation, with a change of its granular porous shape to a denser compact shape, by the increase in the density, lowering of the total porosity / increase on microporosity and lowering of MDA. The physical effects of stillage, although be not so evident as the chemical effects, were present up at a 65 cm depth, probably by high biodegradability degree, mainly in medium textured soils. Probably in clayey soils, with grater specific surface, these effects would have shown to be more effective.
Key Words: Stillage, soil, aggregation

RESUMO

EFEITOS DA APLICAÇÃO DE VINHAÇA NA ESTRUTURA DE SOLOS TROPICAIS CULTIVADOS.

A vinhaça gerada na produção de álcool etílico, a partir da cana-de-açúcar, veio incorporar-se como prática rotineira nessa exploração agrícola; além de resolver o problema da disposição e degradação de um material poluente, quando em contato com os mananciais de água, ela adiciona elementos nutritivos e componentes orgânicos ao solo, que, além do efeito químico, age sobre suas propriedades físicas, afetando a agregação, a porosidade, a densidade e a capacidade de retenção de água. Todavia, esses efeitos físicos ainda estão por ser adequadamente esclarecidos, enquanto que os químicos têm sido bem mais explorados pela pesquisa. Procurou se avaliar os efeitos da aplicação da vinhaça sobre a estrutura de um Latossolo de textura média, usando como parâmetros de análise a densidade, a porosidade e o diâmetro médio de agregados (DMP), sob condições de cultivo com cana-de-açúcar, sob cerradão e sob eucalipto. Constatou-se certa degradação da estrutura nas áreas cultivadas, traduzida pela transformação da sua forma granular porosa em maciça adensada, pelo aumento da densidade, diminuição da porosidade total/aumento da microporosidade e diminuição no DMP. Os efeitos físicos da vinhaça, embora não tão evidentes quanto os de natureza química, fizeram-se presentes até cerca de 65 cm de profundidade, provavelmente em razão de seu alto grau de biodegrabilidade, notadamente nesses solos de textura média; possivelmente em solos argilosos, com maior superfície específica, esses efeitos se mostrassem mais efetivos do que os observados.
Palavras-chave: vinhaça, solo, agregação

INTRODUCTION

When a soil under native vegetation is submitted to agricultural cultivation, several modifications, usually of negative character, start appearing. This may have chemical (nutrient and organic matter taxes, exchangeable complex saturation, pH, acidity, etc.), biological (microbiological modifications) and physical (structure deformation, porosity lowering, increases in bulk density) natures.

In the specific case of the structure and its associated aspects, like porosity (total, macro and micro), this degradation uses to assume high proportions in soils of humid tropical regions. In these regions the amounts of organic matter are expressively lower than in temperate climate (BENNEMA, 1963). This aspect associated to the usual cultivation practices, where the presence of heavy machines is common, has as a consequence compacting processes. The compacting can promote virtual lowering of total soil porosity, with a correlative increase of micropores and lowering of macropores.

In sugarcane exploration, the compacting problem has been frequent due to the intensity of agricultural practices. The aggregate stability of these cultivated soils have already been investigated in Brazilian soils (CARON et al., 1993), in places where sugarcane represents an important role in sugar and ethyl alcohol fabrication.

In this industrial process stillage is produced, in a proportion of 13 liters for each alcohol liter produced. This by-product has as its constituents mainly water (96 to 98%), and organic matter and mineral salts (2 to 4%). It has also a highly pollutant potential when in contact with water streams, because of its high Biological Demand of Oxygen - BDO (12 to 20 thousand ppm. of oxygen).

The stillage application to explored soils with sugarcane has turned up to be an additional practice, which solves the problem of this potential pollutant material deposition. This practice also increases certain nutrient contents in the soil (mainly K) and also organic matter, being rapid and efficiently biodegraded. The stillage *in natura* also passes through a biodigesting process, producing one biogas (methane) and microbial protein (biomass) and other stillage *biodigested*, with less organic and mineral components.

The first studies developed with stillage application to agricultural soils showed the increase in water holding capacity and in the total porosity of sugarcane cultivated soils (RANZANI, 1956). Other authors noticed some increase in the aggregation, which was explained by the addition of the organic component, followed by microorganisms' metabolism, for various years after its application (CAMARGO et al., 1983). This authors also found some elevation in the plasticity limit of the soil, although its particle size was not altered. AGUIAR et al. (1992) noticed, though, that certain application doses can lead to an increase of clay contents in the treated soil.

In the present study the effects of stillage *in natura* and *biodigested* application were evaluated on the porosity (total, macro and micro) and on the aggregate size (pondered mean diameter) in a mean texture soil. Comparisons were also established among cultivated soils with sugarcane in natural vegetation conditions - "cerradão" and eucalyptus.

MATERIALS AND METHODS

The study area is located in São João da Boa Vista (SP), in one important agricultural area, in São João distillery. Its climate type is Cwa from Köepen classification (dry and hot winter), with a median annual precipitation of 1450 mm, potential mean evapotranspiration of 870 mm and mean monthly temperature of 20.2^{0}C (SETZER, 1966).

Different uses and management situations in a mean texture soil, very deep, under slight undulating landscape were studied:

Profile 1 - soil with natural vegetation ("cerradão")
Profile 2 - soil with eucalyptus (*Eucaliptus citrodora*)
Profile 3 - soil with sugarcane + stillage *in natura*
Profile 4 - soil with sugarcane + stillage *in natura* + *biodigested* stillage
Profile 5 - soil with sugarcane without stillage for the last 4 years.

Morphological descriptions were done to each profile following recommendations in "Manual de Descrição e Coleta de Solo no Campo" (LEMOS & SANTOS, 1996). Although most of other morphological characteristics were much alike, field tests reveled that Profile 5 had heavier texture than the other profiles. It can still be included in the mean texture range (15 to 35% of clay), though. Because there was no other area in the property without stillage applications, we had to use this area to compare among the different land uses and managements. In this area, stillage was not applied for four years. In the other cases, stillage has been applied for more than 10 years. The applied stillage composition is presented in Table 1.

Table 1. Mean composition of stillages applied to soils

DESIGNATION	IN	BIODIGESTED
Organic matter	9.76	3.52
Total carbon	5.42	1.96
Total nitrogen	0.20	0.16
Total mineral residue	4.72	3.63
Insoluble mineral residue	0.29	0.52
Soluble mineral residue	4.43	3.11
Phosphorous	27/1	12/1
Potassium	0.14	0.10
Calcium	1.95	1.10
Magnesium	0.21	0.28
Sulfur	0.22	0.11
C / N	0.26	0.08
pH	3.50	4.70

The fertility control of soils was done continually, with applications of calcareous and chemical fertilizers, apart from the stillage applied by truck (*in natura*) or in irrigation channels (mixture of *in natura* + biodigested).

From each soil profile, horizons were sampled. Because of the impossibility of opening a higher number of pits to each situation of use and management, a minimum of four repetitions were made, to determine the following characteristics:

a) Particle size analysis

Pipette method (KILMER & ALEXANDER, 1949), using sodium hexametophosphate (calgon) as disperser, having the fractions sand (2 - 0.05 mm), heavy silt (0.05 -0.02 mm), fine silt (0.02 - 0.002 mm) and clay (< 0.002 mm).

b) Soil density

Global density or bulk density (Bd) was determined with a volumetric ring of 100 cm^3, and the particle densitiy (Pd) was determined by the picnometer method, taking care with that referred in "Manual de Métodos da Análise do solo", from EMBRAPA (1979).

c) Soil porosity

The Total Calculated Porosity (P) was obtained with the density values, through the following equation: $P = 1 - Gd / Pd * 100$.

The Determined Total Porosity was also obtained, in laboratory, with the known volume in the volumetric ring (100 cm^3). Macro and microporosity were obtained through one tension table, with a water column of 60 cm height (6.0 Kpa), and its values expressed in percentage in relation to total determined porosity, expressed in $m^3{*}m^{-3}$.

d) pH and organic matter

These attributes were obtained as analytic indicators of possible stillage effects on soil aggregation. The pH was determined with a potentiometer, in a proportion of soil and water of 1:2.5. The organic matter was obtained by determination of organic carbon contents by a humid via (NELSON & SOMMERS, 1986).

f) Aggregate size

One of the most representative indices from aggregation soil conditions is the Pondered Mean Diameter (MPD), which allow comparisons among different uses and managements in soil conditions. The method of evaluation of percentage aggregations by a humid via, treated with water and ethyl alcohol (HENIN, 1976), was used. The samples were passed through different sieves (6.35 - 2.0 - 1.0 - 0.5 - 0.25 - 0.125 mm). This method is, basically, the traditional one proposed by YODER (1936), with adaptations recommended by KEMPER & CHEPIL (1965).

The Aggregation indice (MPD) is determined by the percentage of weights of aggregates that remained in the sieves through the equation proposed by Youker & Mcginness (1956). This equation gives a representative diameter to aggregates in each sample. This indice allows comparisons of aggregations among horizons in the same soil, or among different profiles, because it works with only one number, instead of a collection of numbers (KIEHL, 1979).

RESULTS AND DISCUSSION

Morphological observations showed that all profiles have one moderate A horizon above one Latosol (Bw) B horizon from the Brazilian classification being developed (EMBRAPA, 1988). This leads to the taxonomic unity of mean texture Red-Yellow Latosol. The correspondent nouns in the international classification from FAO/UNESCO (1991), are ochric (superficial) and B ferralic (subsurface), making possible the taxonomic correlation with the Xantic Ferralsols.

The mean texture identified in the field is confirmed by the particle size analysis expressed in Table 2, beside the data from organic matter and pH. The clay contents of Profile 5 (< 18%) are clearly inferior to the other profiles, as already noted in field tests. Yet, the other characteristics conform to maintain it in the same taxonomic class (mean texture Red-Yellow Latosol).

Table 2. Analytical data from soil profiles.

PROFILE	HORIZONT	DEPT	SAND	SILTE	CLAY	ORGANIC MATTER	pH
		(cm)			(%)		H_2O
	A11	0-7	76	4	20	7.5	4.3
CERRADÃO	A12	7-36	74	2	24	5.6	4.5
	AB	63-75	74	2	24	1.8	4.5
	B1	75-115	70	2	28	1.8	4.5
	B2	115-170	72	2	26	1.1	4.7
	A1	0-20	76	1	23	4.5	4.4
EUCALYPTUS	ÀB	20-40	75	1	24	1.7	4.6
	BA	40-77	78	1	21	1.3	4.4
	B1	77-127	69	2	29	1.1	4.3
	B2	127-170	69	2	29	0.9	4.5
	Ap1	0-13	75	2	23	4.5	6.8
SUGGARCANE	Ap2	13-32	74	3	22	1.8	5.9
+ IN NATURE	AB	32-65	73	3	24	1.2	5.3
STILLAGE	B1	65-115	71	1	28	1.1	4.4
	B2	115-160	70	2	28	0.9	4.2
	Ap	0-20	70	2	28	2.0	7.4
SUGGARCANE	AB	20-45	69	1	30	1.7	7.2
+BIDIGESTED	BA	45-85	70	2	28	1.5	7.3
STILLAGE	B1	85-130	67	1	32	1.2	6.3
	B2	130-170	66	1	33	1.2	5.5
	Ap	1-20	79	3	18	1.5	5.8
SUGGARCANE	AB	20-45	79	2	19	1.4	4.6
(no stillage for	BA	45-85	78	4	18	1.2	5.9
four years)	B21	85-130	77	3	20	1.0	4.0
	B22	130-170	78	4	18	0.8	4.1

The higher organic matter content in the superficial horizon of Profile 1 (cerradão) is reflected in the organization of its organic-mineral constituents, leading to a structure described as large granular highly developed. In Profile 2 (eucalyptus) its shape is still granular, but with smaller size (mean) and with less degree (moderate). In the other profiles, with sugarcane, its structure presents more compact aspect, which, manipulated, is reduced to smaller parts with subangular and granular shapes. This may be a consequence of the cultivation operations, which can deform the structure.

The low pH found (< 4.7 in Profiles 1 and 2, both under natural vegetation) is typical to these Latosols without bases, which correction with calcareum, together with fertilization, alter soil chemical conditions. This can be seen in the pH observations taken from the three first layers of profiles with sugarcane, up to the inferior limit of BA horizon. The deep layers, Latosols (Bw) tend to keep, in the cultivated soils, the same characteristics of soils under natural vegetation.

Although stillage application has not substantially altered the organic matter contents in the soil, Longo *et al.* (1996) have observed expressive increases in the sum of bases, cations exchange capacity and base saturation, with stillage use. These chemical aspects were not investigated in the present study. The organic matter has special interest by being a constituent in aggregates. The small effect of stillage on organic matter contents is probably due to the instability of organic constituents of that material (ALMEIDA, 1952).

Observing Table 3 it can be clearly seen that the density values are in agreement with use and management of soil conditions. The smallest values of particle densities (Pd) occur in surface horizons under "cerradão", where organic matter is more intensely accumulated. This correspondence is also found in Profiles 2 and 3, which superficial layers richer in organic matter, as shown in Table 2 (in Profile 3 this increase is due to the stillage action). Through the profile, as a whole, distributions of density values are also in agreement with soil textures, with slightly higher values in Profile 5, where sand content is higher.

The more elevated global density (bulk density) values in AB and BA horizons from cultivated soils, or up to an average of 70 cm surface, are certainly because of the mechanical effects of compacting by agricultural machines. This is not easily detectable by usual methodological techniques, needing, sometimes, more specialized studies, such as micromorphology (FERNANDES & SPÍNDOLA, 1993). In many cases, though, the morphological description can show the presence of these compact layers. These layers result in a more compact structure, with porous space reduction and density increase (MIELNICZUK, 1993), as can be also seen in this study.

The percentage of total porosity calculated through density values, clearly show the effects of sugarcane cultivation, with virtual lowering of its values in AB and BA horizons. The minimum value obtained (44%) is found in Profile 5 (sugarcane without stillage for 4 years), though this soil is also more sandy. This may lead to a smaller value of total porosity compared to the porosity in soils with finer texture. In the surface layers (A horizon) the constant ploughing the soil makes the porosity values to increase, apart from the already analyzed effect of accumulated organic matter. In Profile 4, where the biodigested stillage is utilized, the lesser matter content is followed by a lower value of porosity compared to Profile 3, where stillage *in natura* was utilized.

Curiously, the soil with eucalyptus (Profile 2) showed also AB and BA horizons with total porosity diminution, in relation to the other horizons in the profile. This compacting probably may have occurred when the wood was substituted by this vegetation, which is maintained until today.

The data of determined porosity, macro and microporosity come to confirm our suppositions. In general, the highest values of macroporosity are found in Profile 1, under "cerradão". It is still high in the soil with eucalyptus (Profile 2) up to AB horizon the macroporosity is higher than the microporosity. In soils with sugarcane the AB horizon always shows greater disequilibrium in macro and microporosity distribution, to confirm the generalized tendency of increase in microporosity with cultivated operations. With micromorphology it is possible to note that cultivation can make changes in size, type, amount and distribution of pores, in clayey and sandy soils (COSTA LIMA & COSTA LIMA, 1993).

It is noteworthy the effect of different stillages in regard to macro and microporosity. While the stillage *in natura* showed a great favorable action to the macropores distribution (Profile 3), the biodigested seems to have behaved contrariously (Profile 4), at least to the 45 cm depth of AB horizon. In Profile 5, in sugarcane without stillage for four years, in this same AB horizon (same depth) the microporosity increase is also expressive, certainly as an effect of mechanical compacting. In this specific case it would be interesting to analyze the behavior of stillage *in natura*, if it had been used.

From these constatations, it is interesting to observe the aggregation problem with the aggregate sizes, which values for MPD shown in Table 3. The size of the aggregate is virtually higher in soils under natural vegetation, or without cultivation. In "cerradão" (Profile 1) the highest values for MPD are found. In soils with sugarcane there is a subtle lowering in MPD through the profile (Profiles 3 and 4). To the soil without stillage for four years (Profile 5) the least value for MPD was found, in AB horizon (20-45 cm), coinciding with its higher values for microporosity and global density (bulk density).

It is interesting to observe that the alcohol action as a first treatment for aggregates before immersion in water makes passing through micropores easier and lowers the action of present cations (HÉNIN, 1976). The MPD values were superior with this first treatment, compared, in general, to all conditions of use and management of soils. The effect of the kind of stillage is less evident on MPD values. Although stillage *in natura* seems to have favored the upper layers (Profile 3), in relation to these layers treated with biodigested stillage (Profile 4), in the treatment with alcohol, the situation inverts. Anyway, in the soil without stillage for four years (Profile 5) the values of MPD are, in general, lower than in all other cases, although this soil may present a heavier texture. This characteristic may exert a great influence.

Table 3. Density, porosity and pondered medim diameter of aggregates.

PROFILE	HORIZONT	DENSITY g.cm^{-1}			DETERMINID POROSITY (%)			AGGREGATE S ((MDA)	
		Part	Glob		TOTAL	MACRO	MICRO	WATER	ALCOHOL
	A11	2.69	1.16		45	26	19	3.44	3.36

CERRADÃO	A12	2.69	1.39		50	28	22	1.78	2.78
	AB	2.73	1.33		50	27	23	2.75	3.08
	B1	2.74	1.29		50	27	24	2.79	3.16
	B2	2.72	1.28		50	25	25	2.57	2.72
	A1	2.74	1.34		48	27	21	3.0	3.11
EUCALYPTUS	AB	2.75	1.43		47	24	23	1.94	2.67
	BA	2.75	1.40		48	24	24	2.31	2.62
	B1	2.78	1.29		52	27	25	2.40	2.39
	B2	2.78	1.27		54	25	29	1.81	2.51
	Ap1	2.75	1.36		50	28	22	0.89	1.01
SUGGARCANE	Ap2	2.78	1.48		46	21	25	1.16	1.05
+ IN NATURE	AB	2.76	1.54		43	19	24	0.78	1.09
STILLAGE	B1	2.76	1.36		47	23	24	0.93	1.41
	B2	2.74	1.26		51	29	22	1.04	1.58
	Ap	2.76	1.47		46	49	27	0.75	1.37
SUGGARCANE	AB	2.78	1.51		45	49	26	0.80	1.63
+BIDIGESTED	BA	2.77	1.36		50	26	24	0.99	1.99
STILLAGE	B1	2.78	1.25		52	26	26	1.11	2.24
	B2	2.71	1.28		54	28	26	1.38	2.11
	Ap	2.77	1.61		42	21	21	0.91	0.73
SUGGARCANE	AB	2.79	1.57		40	18	22	0.43	0.84
(no stillage for	BA	2.81	1.49		43	21	22	0.67	1.05
four years)	B21	2.79	1.45		46	23	23	0.79	0.92
	B22	2.80	1.40		45	21	24	0.90	1.14

CONCLUSIONS

The expression of field structure (morphological description), density, porosity (total, macro and micro) and the sizes of aggregates (pondered mean diameter) are some characteristics affected by the mean texture of soils with sugarcane cultivation. This may confirm certain soil degradation, from comparisons with natural soils (without cultivation). The results confirm previous observations to clayey Latosols (FERNANDES & ESPINDOLA, 1994), which are more subject to compacting, increase in density, and lowering of microporosity and permeability.

The use of stillage in management of soils treated with sugarcane solves the important problem of matter deposition, which suffers rapid biodegradation. Besides, it can alter chemical characteristics and increase soil fertility. In the case of physical characteristics the effects are less evident, although positive (especially up to the average of 65 cm depth) in density, porosity and aggregate sizes. These effects may be mainly linked to the organic fraction of stillage, which has, although, a high degree of biodegradability (MINHONI et al., 1990). This biodegrability maybe insufficient to promote a more effective aggregation of these mean texture soils. Finer soils (clay) have more elevated specific surfaces, where the interactions between the organic fraction and mineral fraction are intensified. It is possible that in these soils physical effects are more notable. Although the stillage *in natura* has a higher organic matter content than the biodigested one, it is less used than the second one, because of methane parallel production and the utilized residue as a fertilizer.

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