CHEMICAL AND PHYSICAL FERTILITY INDICATORS OF A WEAKLY-STRUCTURED ULTISOL AFTER LIMING AND MULCHING

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ABSTRACT: In the humid tropic, chemical and physical soil properties that decrease soil's nutrient availability and increase oxygen deficiency are important as restrictions to crop growth. The objective of this study was to evaluate the relations between plant growth and chemical and physical fertility indicators of an Ultisol developed from sediments of the Itapecuru Formation in Central-Northern state of Maranhão, Brazil. An experiment was established with randomized block design, four replicates, and six treatments: 6.0 Mg ha^{-1} mulch with or without liming; 3.0 Mg ha^{-1} mulch with or without liming; bare soil with or without liming. Determinations in the plants included leaf area index, net assimilation rate, and the yield parameters: mean number and weight of ears, 100-kernel weight, harvest index, and total grain yield. Soil determinations consisted of bulk density variations on the surface and at 20 cm, effective porosity evolution after intentional flooding, and alterations in chemical indicators such as cation exchange capacity, bases saturation, organic carbon, and macronutrient contents. Mulching and liming were equivalent with regard to their influence on leaf area yield, but mulching was more important for corn productivity because of its greater effect on net photosynthesis.
Key words: *Zea mays* L., growth, yield, effective porosity

INDICADORES DE FERTILIDADE DE UM ARGISSOLO ESTRUTURALMENTE FRÁGIL SOB EFEITO DA CALAGEM E DA COBERTURA MORTA

RESUMO: No trópico úmido, os indicadores químicos e físicos, que diminuem a disponibilidade de nutrientes e aumentam a deficiência de oxigênio dos solos, são importantes para diagnosticar restrições ao crescimento das culturas. Avaliaram-se as relações entre o crescimento das plantas e os principais indicadores físicos e químicos da fertilidade de um Argissolo desenvolvido em sedimentos da Formação Itapecuru, no Centro-Norte do Maranhão. O experimento foi instalado em blocos casualizados, com quatro repetições e seis tratamentos: 6,0 Mg ha^{-1} de cobertura morta com e sem calagem; 3,0 Mg ha^{-1} de cobertura morta com e sem calagem; solo descoberto com e sem calagem. Nas plantas, foram determinados o índice de área foliar, a taxa de assimilação líquida e os parâmetros de produtividade: número e peso médio das espigas, peso de 100 grãos, índice de colheita e produção total de grãos. No solo foram avaliadas as variações nas densidades na sua superfície e a 20 cm, a evolução da porosidade efetiva após alagamento provocado e as alterações em indicadores químicos como capacidade de troca catiônica, saturação por bases, carbono orgânico e teores de macronutrientes. A cobertura morta e a calagem se equivaleram quanto à influência na produção da área foliar, mas a cobertura morta foi mais importante para a produtividade do milho, devido ao seu maior efeito sobre a fotossíntese líquida das plantas.
Palavras-chave: *Zea mays* L., crescimento, produtividade, porosidade efetiva

INTRODUCTION

Soil fertility has been referred, since as the soil's ability to provide water, air, nutrients, and spaces to the root environment of plants (Currie, 1962). In the humid tropics, the improvements in the plough layer conditions cannot be retained if porous structure deterioration is not prevented. Termed natural reconsolidation this process of soil porosity reduction occurs during wetting and drying cycles, due to the impact of rain droplets, matrix collapse or condensation, caused by its own weight, or by the dynamic forces resulting from water movement through the pores (Ahuja et al., 1998; Busscher et al., 2002).

Several studies confirm the influence of mulching on the reduction of the impact caused by rain on the soil surface (Adekalu et al., 2006). All plants' residues should be left or returned to the soils, to improve the physical properties of hard setting soil surfaces (Becher et al., 1997). Furthermore, the oxygen demand by the roots increases with temperature; in humid equatorial regions, the combination of high temperatures and low O_2 diffusion rates causes a negative additive effect on the growth and activity of cultivated plant's roots (Huang et al., 1996).

The Itapecuru Formation occupies approximately 60% of the total area state of Maranhão, Brazil, in its central and northern parts, and is characterized by a predominance of sandy or sandy loam soils, with high susceptibility to compaction; this, together with high rainfall index values, decreases the correlation between plant growth and improvements in chemical properties, as demonstrated by Moura et al. (2008). To better understand the relations between plant growth and chemical and physical fertility indicators of Ultisols of the Itapecuru Formation, this study sought to evaluate how mulching and liming doses in those soils affects corn growth and productivity.

MATERIAL AND METHODS

The experiment was carried out in the São Luís island (44º16'W; 2º30'S), State of Maranhão, Brazil. The rainfall regime in the region has a dry and a rainy seasons; annual rainfall ranges from 1900 to 2300 mm, of which more than 80% occur from February to May (Embrapa, 1986). The soil is a Typic Paleustult with an A horizon with the following characteristics: pH 4.6 (in $CaCl_2$); organic C: 12 g kg^{-1}; Al: 46 $mmol_c$ dm^{-3}; CEC: 55 $mmol_c$ dm^{-3}; Ca: 3, Mg: 5, K: 0.7 $mmol_c$ dm^{-3} respectively; P: 1 mg dm^{-3}; base saturation: 16%; coarse sand 260, fine sand 560, silt 80, clay 100 g kg^{-1}, respectively. Laboratory methods according to Raij et al. (1987).

The experiment was set as random blocks, with four replicates, in 4 × 5 m plots, with six of the following treatments: 6ML and 6M, soil covered with 6.0 Mg ha^{-1} dry matter with or without liming; 3ML and 3M, soil covered with 3.0 Mg ha^{-1} dry matter with or without liming; BL and B, bare soil with or without liming. 3.0 Mg ha^{-1} of lime (80% of calcium carbonate equivalent) was incorporated into the first 20 cm of the soil, to increase base saturation up to 60%. The native legume (sunn hemp - genus *Crotalaria incana)* selected as a soil cover plant was sown 60 d later. The legume was harvested, weighed, and applied uniformly onto the soil 90 d after sowing. Corn was seeded on 16 February 2003, after a fertilizer equivalent to 10-80-40 kg ha^{-1} N-P_2O_5-K_2O, ten days before the legume were harvested. Cultivar AG 405 was used at a row spacing of one meter, with eight seeds per meter. Corn was thinned to five plants per meter, or 100 plants per plot, 15 days after emergence; two top dressing fertilizations were performed, corresponding to 30 kg ha^{-1} N per application, at 30 and 45 days after emergence, using ammonium sulfate as a nitrogen source.

Crop growth dynamics was monitored by weekly evaluations of leaf area (LA) variation and dry matter (DM) with time (t). Estimations were made for leaf area index (LAI) and net assimilation rate (NAR) using the LA and DM variation values. To accomplish that, five plants were collected per plot at seven-day intervals, from the 25th day after emergence. Seven collections were performed; the last collection coincided with the corn milky grain stage. Leaf area was measured with a Licor device; dry matter was determined after drying the plants in a forced air circulation oven at 70°C.

Plants from the central 4.0 m^2 of the plots were yielded in May 25, and counted for number and weight of ears, 100-kernel weight, harvest index, biological yield, and grain weight. Harvest index and 100-kernel weight were determined from five plants selected randomly among those previously mentioned. Soil testing (Raij et al., 1987) was performed from samples taken at depth from 0 to 20 cm, with three replicates per plot, using duty auger at the corn planting term. For bulk density, the 0-20 cm-depth samples were taken at the end of the crop cycle with 100 cm^3 volumetric rings. Surface samples (0-3 cm) were taken with rings measuring 3 cm in height and 65 cm^3. The volumetric flask method was used to determine particle density (Embrapa, 1979). Effective porosity evolution through the profile was evaluated at a 10 cm depth, by following the method for soil moisture determination at field capacity (Embrapa, 1979), with three evaluations in the treatments: bare soil (B), soil covered with 6.0 Mg ha^{-1} (6M), and soil covered with 3.0 Mg ha^{-1} (3M). The sampling period lasted 48 h at 6-h intervals; however, the first interval was subdivided and samples were taken at 0, 2, 4, and 6 h after the soil was flooded. Total porosity was calculated by the equation :

$$\phi t = 1 - \frac{\rho s}{\rho p} \tag{1}$$

where: ψs is bulk density and ψp is particle density. Effective porosity was then calculated as: $\lambda e = (\lambda t - \chi v)$ where χv is soil water volume at the instant sampled.

Variance analyses were run using the SISTANVA software of Embrapa Trigo, and means were compared by Tukey test (ζ = 0.05), except for growth parameters whose indices were estimated and modeled with the ANACRES software, according to Portes & Castro Júnior (1991).

RESULTS AND DISCUSSION

Alterations in soil chemical and physical indicators

Liming produced changes in soil chemical properties, particularly acidity, sum of bases, and base saturation, which were modified to satisfactory levels in the limed plots, but underwent little changes in mulched only plots, remaining at critical, inadequate levels, according to Ribeiro et al. (1999).

In the soils originally under cerrado, differences caused by liming alone would be sufficient to increase corn plant growth, as confirmed by Prado (2001) and Barros et al. (2007). Under humid tropics' conditions, other properties like a soil moisture exercises a fundamental role over the productivity of crops because it controls the principal factors that determine the nutrition and growth of roots, namely aeration, the volume of water available, and the level of resistance to penetration (Betz et al., 1998). Therefore, the success in the management of agroecosystems requires the formation of a surface layer where the soil bed raises the root hospitality factor, as described by Wong & Asseng (2007).

The mulching effects on physical indicators were observed both at mulching amount and depths sampled (Table 1). However, greater differences occurred on the surface, and the formation of surface crusts could be observed even visually at the end of the crop cycle on the bare plots, whereas high fauna activity and the formation of clods could be observed on the surface of the mulched soil. The differences in bulk density observed at 20 cm agree with results obtained by Khan (1983) in sandy loam soils and with observations by Franzen et al. (1994) on the mulch ability to prevent subsurface reconsolidation. These results reinforce also the fact that higher total porosity volume was maintained. Thus, 6.0 Mg ha^{-1} of mulch on the soil resulted in almost 8% more porous space in the root growth region at the harvest stage in comparison to bare plots.

Physical fertility parameters must be interpreted considering rainfall and soil water dynamics, which strictly define effective porosity and volume variation with time. Therefore, a knowledge about the contri-

Table 1 - Effects of mulching and liming on soil chemical and physical indicators.

Treatments	Chemical indicators										
	P	pH $CaCl_2$	K	Ca	Mg	Al	H+Al[2]	SB	CEC	V	OM
	g dm^{-3}		mmol$_c$ dm^{-3}							%	
6ML[1]	2.0 a	6.8 a	0.3 a	24.5 a	17.5 a	-	3.0 a	41.7 a	44.7 a	95 a	2.1 a
3ML	2.5 a	6.4 ab	0.3 a	19.2 b	18.5 a	-	15.0 b	38.5 a	53.5 a	73 a	1.2 b
BL	1.0 a	6.2 b	0.2 a	16.2 c	13.3 b	-	13.0 b	31.2 a	44.2 a	73 a	1.4 b
6M	1.0 a	4.5 c	0.4 a	9.7 d	9.0 c	1.5 a	37.5 c	19.5 b	57 a	33 b	2.2 a
3M	1.0 a	4.3 c	0.3 a	8.7 d	7.7 c	3.7 b	39.7 c	17.0 b	62.5 a	28 b	1.7 ab
B	2.0 a	4.4 c	0.3 a	4.7 d	7.2 c	3.7 b	37.0 c	12.7 b	49.7 a	25 b	1.2 b
CV%	75.8	4.4	25.6	27.3	26.5	54.8	24.9	23.8	17.5	14.9	33.2

	Physical indicators		
	Bulk density at two depths, kg dm^{-3}		Soil porosity, %
	0 - 3 cm	20 cm	
6ML	1,270 a	1,342 a	52.7 a
3ML	1,355 b	1,452 b	48.5 b
BL	1,520 b	1,425 b	45.2 c
6M	1,302 a	1,340 a	4.5 ab
3M	1,402 ab	1,317 a	50.0 a
B	1,522 b	1,422 b	45.5 c
CV %	5.41	5.23	5.62

Mean values followed by the same letters in the columns did not differ (Tukey test, $p < 0.05$). [1]6ML and 6M = soil covered with 6.0 Mg ha^{-1} dry matter with or without liming; 3ML and 3M = soil covered with 3.0 Mg ha^{-1} dry matter with or without liming; BL and B = bare soil with or without liming. [2]H+Al = Potential acidity; SB = Sum of bases; CEC = Cation exchange capacity; V = Base saturation percentage; OM = Organic matter bution of the increased volume of pores toward the increase in vertical water flow in mulched plots is more important than these absolute values (Thomasson, 1978; Jayawardane & Chan, 1994).

In bare plots, 6 h after a rain, the soil at a 20 cm depth still can be considered to be under anaerobic conditions (Figure 1); 48 hours later, it has not yet reached 20% effective porosity, a limit below the critical value for sandy soils to allow the development of a diffusion coefficient capable of attaining the O_2 requirements of the roots, according to Currie (1962) and Sallam et al. (1984). Conversely, plots mulched with 6.0 Mg ha^{-1} dry matter 24 hours after flooding had already reached the "around 30%"satisfactory level of effective porosity.

The situation was even more serious since the precipitation data collected near the experiment indicated a total of 1,300 mm during the 90-d corn cycle, with eight occurrences of rains greater than 50 mm day^{-1}. From the 55th to the 70th day, a critical period for reproductive organ development, it rained 240 mm, without any interval greater than 24 hours without rains and the rainfall rate was 85 mm day^{-1} (data not shown).

Effects of liming and mulching on corn growth and yield

The leaf area index data show the effects of lime and mulch on photosynthetic surface development in corn. The intermediate position (Figure 2A) of the treatment containing 3.0 Mg ha^{-1} mulch plus liming (3ML) may indicate that there was no interaction between the practices. In addition, with regard to leaf production, some observations are pertinent: first, the substantial dependence on leaf area index, both in relation to chemical and physical soil properties. This is demonstrated by the differences between treatments with the highest amounts of mulching and liming (6ML) and all other treatments, especially in relation to the control (B). Next, the similarities between the almost identical results achieved in the treatments with the highest amount of mulching (6M) and liming alone

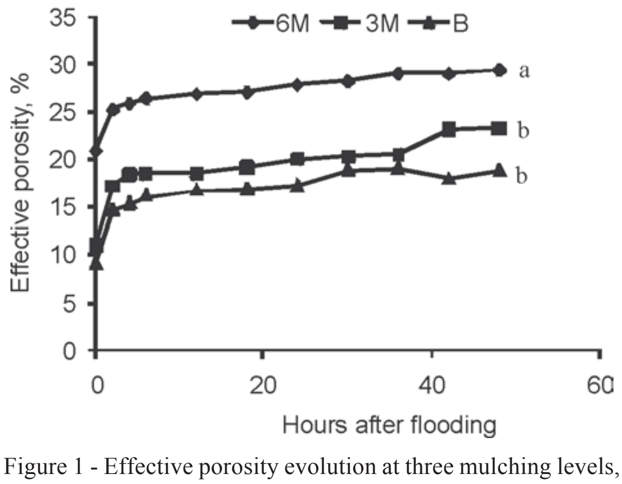

Figure 1 - Effective porosity evolution at three mulching levels, after flooding. (Mean values followed by the same letters did not differ (Tukey test, $p < 0.05$), only for the last measure. (6M = soil covered with 6.0 Mg ha^{-1} dry matter without liming; 3M = soil covered with 3.0 Mg ha^{-1} dry matter without liming; B = bare soil without liming).

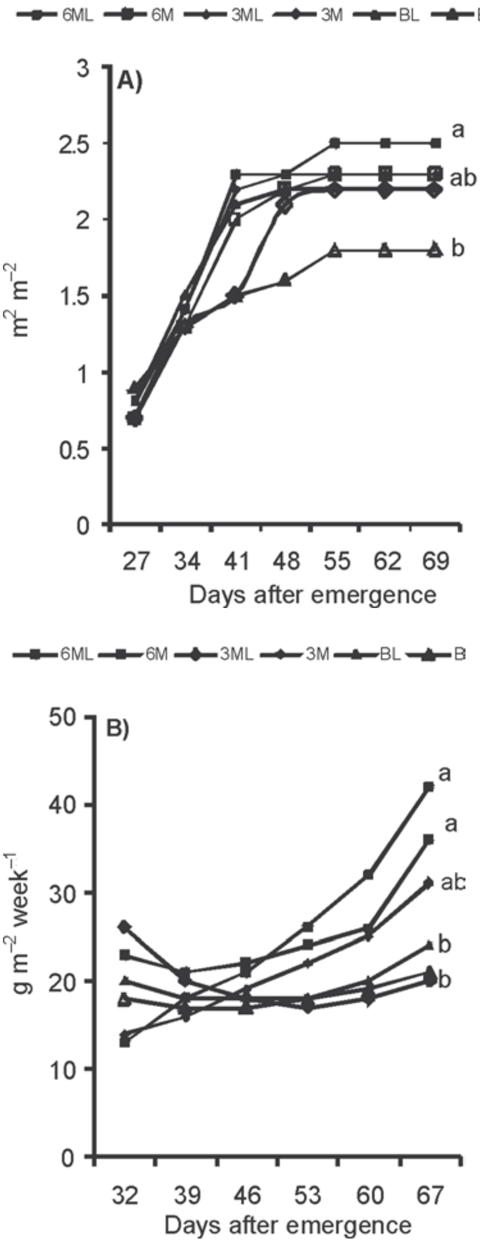

Figure 2 - Growth parameters for treatments with 6.0 and 3.0 Mg ha^{-1} mulch and bare soil. A) Leaf area indices and B) Net assimilation rate, in grams dry matter m^{-2} of leaf area week^{-1}. (Mean values followed by the same letters did not differ (Tukey test, $p < 0.05$), only for the last measure. 6ML and 6M = soil covered with 6.0 Mg ha^{-1} dry matter with or without liming; 3ML and 3M = soil covered with 3.0 Mg ha^{-1} dry matter with or without liming; BL and B = bare soil with or without liming).

Table 2 - Effects of liming and mulching on corn yield parameters.

Yield parameters	Treatments						CV
	6ML[1]	3ML	BL	6M	3M	B	%
No. ears per plot	20.2 a	20.7 a	19.5 a	19.5 a	20.0 a	18.5 a	10.6
Mean ear weight (g)	134.0 a	106.5 b	89.9 c	112.3 b	99.6 b	79.5 c	11.6
100-kernel weight (g)	26.2 a	25.5 ab	21.6 b	24.9 ab	26.3 a	20.7 b	14.3
Biological yield (kg ha^{-1})	8,854 a	7,203 b	6,121 b	7,070 b	6,401 b	4,674 c	13.7
Harvest Index (%)	47.8 a	48.7 a	46.6 a	49.5 a	46.9 a	47.8 a	8.8
Grain yield (kg ha^{-1})	4,281 a	3,510 b	2,837 c	3,501 b	2,982 bc	2,238 c	13.6

Mean values followed by the same letters in the row did not differ (Tukey test, $p < 0.05$). [1]6ML and 6M = soil covered with 6.0 Mg ha^{-1} dry matter with or without liming; 3ML and 3M = soil covered with 3.0 Mg ha^{-1} dry matter with or without liming; BL and B = bare soil with or without liming.

(BL), with a small positive difference toward the first only in the final samplings, indicate that the soil chemical and physical restrictions are practically equivalent for growth of the corn photosynthetic apparatus.

With respect to yield per leaf area (Figure 2B), the positive effects of mulching were enhanced, especially after the 50th day from emergence. The net yield difference shown by plants in the treatment with the highest amount of mulching (6M) as compared with plants that received lime alone (BL) was determinant for the comparison of the importance of effective soil porosity in relation to the chemical indicators of corn photosynthetic effectiveness and soil fertility. Soil oxygen deficiency determines net assimilation rate and decreases corn leaf production, under excess rainfall and high temperature conditions (Evans, 1990).

Economic yield parameters

Economic yield was primarily affected by mean ear weight, followed by grain weight (Table 2), which leads to the conclusion that yield differences mainly occurred due to greater or smaller development capacities of the reproductive organs. Since the treatments did not significantly affect the harvest index, these variations in economic yield were more related to differences in biological yield. By comparing the bare soil plus liming treatments (BL) and the one of the highest amount of mulching (6M), whose photosynthetic surfaces was practically identical, differences in grain yield can be noticed: a 23% variation in favor of mulched plots without liming (6M), a result of the higher efficiency of the photosynthetic surface. The combination between the highest mulching level and liming in treatment 6ML produced differences in relation to all other treatments, with a yield value 1.9 time higher than the control. In this case, in addition to a larger leaf area and higher leaf efficiency, physiological processes such as the absorption of nutrients during the pre-anthesis may have also played a role toward those differences. These process increases ear length and the number of fertile spikelets, and the transport of nutrients into the grain which is highly sensitive to soil O_2 deficit (Schreiber et al., 1988; Evans et al., 1990).

The economic yield results must be interpreted in the light of the relative differences obtained, since even in plots involving liming and 6.0 Mg of mulch corn yield did not reach as much as one half of their potential as reported by Boyer (1982). In this case, to decrease the stress associated with physical properties, the recommendation can be made for an advanced planting date, to prevent the critical aeration deficit stage from occurring together with the period of highest precipitation, which in that region occurs during March-April.

CONCLUSIONS

In the studied humid tropic Ultisols with predominance of a fine sand fraction, physical and chemical soil fertility indicators can be regarded as equivalent to the influence on leaf area yield; both are important for biological yield, but physical indicators have a greater impact on the net photosynthesis of corn.

In the rainy period, the mulch applied onto this humid tropic Ultisol decreases plough layer compaction, via an increase in aeration capacity. This was attained by maintaining effective porosity at higher levels, which encourages corn growth and yield.

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