

IMPROVEMENT OF PROPERTIES, AND WATER AND CLAY MOVEMENT IN VERTISOL-AMENDED SAND COLUMNS¹

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ABSTRACT - Clay amendments may improve agricultural productivity of sandy soils by increasing nutrient- and water-holding capacities. The objective of this research was to determine the effect of Vertisol amendments on infiltration rate, available water capacity, cation exchange capacity, and clay and carbon migration in sandy soil columns. Acid-washed quartz sand was packed into PVC columns and covered with 10 cm of a Vertisol-sand mixture that contained 50, 100, 200, or 400 g kg⁻¹ of the Ap horizon of a Vertisol (fine, montmorillonitic, thermic Typic Chromoxererts). Water was applied every other day. Leachate volume and dissolved organic carbon were measured biweekly. After 10 weeks, columns were sectioned into four layers, and chemical and physical properties were measured in each layer. Water retention, available water capacity, and cation exchange capacity increased with increasing Vertisol content. Dissolved organic C in column leachates also increased with increasing Vertisol concentration and decreased with time. The 400 g kg⁻¹ Vertisol mixture had extremely low infiltration rate, possibly because of surface crusting. The results of this study suggest that the 200 g kg⁻¹ Vertisol mixture had the overall physical and chemical properties most conducive to improved agricultural productivity with reasonable infiltration rate.

Index terms: water retention capacity, sandy soils, Vertisols.

MELHORIA DE PROPRIEDADES E MOVIMENTO DE ÁGUA E ARGILA EM AREIA COM ADIÇÃO DE VERTISSOLO

RESUMO - Adição de argila pode melhorar a produtividade agrícola de solos arenosos, por aumentar a capacidade de retenção de água e nutrientes. O objetivo deste trabalho foi determinar o efeito da adição de material de Vertissolo na taxa de infiltração, teor de água disponível, capacidade de troca de cátions e migração de argila e carbono em colunas de areia. Areia de quartzo lavada foi colocada em colunas de PVC e coberta com 10 cm de mistura de Vertissolo-areia contendo 50, 100, 200 ou 400 g kg⁻¹ do horizonte Ap de um Vertissolo. As colunas foram irrigadas a cada dois dias. O conteúdo de água nas colunas, volume de água drenada e o teor de carbono na água foram medidos a cada duas semanas. Após 10 semanas, as colunas foram seccionadas em 4 camadas para determinação das propriedades físicas e químicas. A capacidade de retenção de água, o teor de água disponível e a capacidade de troca de cátions aumentaram com a concentração de Vertissolo na mistura. A quantidade de carbono na água de drenagem também aumentou com a concentração de Vertissolo e diminuiu com o tempo. A mistura de 400 g kg⁻¹ causou extremo decréscimo na taxa de infiltração, possivelmente devido ao encrustamento. A mistura de 200 g kg⁻¹ apresentou, de forma geral, melhorias nas propriedades químicas e físicas capazes de melhorar a produtividade das culturas, mantendo ainda razoável taxa de infiltração de água.

Termos para indexação: retenção de água, solos arenosos, Vertissolos.

¹ Accepted for publication on November 13, 1997.

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INTRODUCTION

In sandy soils, crop yields are limited by low water-holding capacity, high permeability, and low cation exchange capacity (CEC). High agronomic production in such soils requires large inputs of irrigation water and fertilizer, much of which is lost by rapid percolation. Several methods have been proposed to minimize

water and nutrient leaching. Asphalt barriers were installed below the root zone to decrease water movement, but such barriers are expensive and do not improve soil chemical and physical properties (Erickson et al., 1968). Organic amendments such as manure or sewage-sludge composts add nutrients and increase available water capacity (Tester, 1990; Bauer & Black, 1992).

In some areas, sandy soils on eroded hillsides or terraces are found adjacent to Vertisols or smectite-rich, fine-textured sediments in flood plains. Vertisols are spread over a significant range of Northeast region in Brazil, mainly in the dry zone and Reconcavo Bahiano (Embrapa, 1981) and in the area of Imperatriz, Maranhão State (Oliveira et al., 1992). This region also has large areas of sandy soils (Quartzous Sands) close to the sea shore in Bahia, Paraíba, and Piauí States (Embrapa, 1981), and in the continental region in the North of Bahia State and in the States of Maranhão, Piauí, and Pernambuco (Oliveira et al., 1992).

Because smectites have very high CEC and high water-holding capacity, the nutrient-and water-holding capacity properties of sandy soils may be improved by incorporating Vertisol material into sandy surface horizons. Laboratory studies have shown that properties such as sand-to-clay ratio, type of clay, and particle size significantly affect hydraulic properties of clay-sand mixtures (Alperovitch et al., 1985). Unger (1975) reported that plant-available water increased with increasing clay content. Numerous studies have investigated the hydraulic properties of pure clay-sand mixtures with or without added Al and Fe hydrous oxides (Alperovitch et al., 1985; Keren & Singer, 1990, 1991), but little research has been done to determine the effect of clay-rich soil material amendments upon sandy soil chemical properties and water retention.

The objective of this research was to determine the effect of Vertisol amendments on infiltration rates, leaching, available water capacity, cation exchange capacity, and clay and carbon migration through sandy soil columns.

MATERIAL AND METHODS

Columns were made from PVC tubes (7.6-cm diameter x 50-cm length) that were cut in half longitudinally and rejoined using duct tape. This design allowed the columns to be opened with little disturbance at the end of the experiment so that different layers could be sampled easily. The bottom of each column was sealed with a PVC end cap that contained a 0.5-cm diameter drainage tube. The bottom 1 cm of each column was filled with very coarse (1 - 2 mm) acid-washed quartz sand, and the next 39 cm was filled with medium and coarse (0.25 - 1.0 mm) acid-washed quartz sand. The upper 10 cm of each column was filled with a mixture of the <0.5-mm fraction of Vertisol Ap horizon and medium and coarse (0.25 - 1.0 mm) acid-washed quartz sand. The <0.5 mm Vertisol size fraction was used so that the soil could be mixed easily with the 0.25 - 1.0 mm sand. The Vertisol-sand surface layers contained 50, 100, 200, and 400 g kg⁻¹ (w/w) Vertisol. Triplicate columns of each Vertisol treatment were arranged in a completely randomized design in a greenhouse.

The <0.5-mm fraction of the Vertisol contained 470 g kg⁻¹ clay, 190 g kg⁻¹ silt, 340 g kg⁻¹ sand, and 19 g kg⁻¹ organic C. The CEC was 348 mmol_c kg⁻¹, and pH was 6.2 (1:2.5 soil:water). Smectite was the dominant component of the Vertisol, although kaolinite and mica were also present.

Time-domain reflectometry (TDR) probes were installed horizontally at 5-cm intervals from the top to the bottom of the columns so that volumetric water contents (θ_v) could be measured in different layers. The TDR probes, which were 3 mm in diameter and 6.3 cm long, were installed in only one column of each Vertisol concentration. An empirical third-order equation was used to calculate θ_v from measured values of the apparent dielectric constant (Topp et al., 1980).

Water was applied to the surface of each column at a 16-mm pulse once every two days, except that an 80-mm pulse was applied biweekly, beginning in the first day of the experiment. Column leachate was collected continuously and volume was measured biweekly. Leachate organic C was quantified by high-temperature combustion with a Dohrmann DC-190 TOC analyzer (Rosemount, Santa Clara, CA). To determine the effect of Vertisol concentration on *in situ* water retention and redistribution in the columns, TDR readings were taken at 1 and 72 h after the third 80-mm water pulse, four weeks after the start of the experiment.

After the ten-week period, water contents at each depth were measured by TDR and used to calculate the total amount of water in each column. The amount of waterlost by evaporation during the experiment was calculated as the difference between total applied water (720 mm) and the sum of final water content plus total drained water.

The effect of Vertisol concentration on infiltration rate was determined after the final water contents were measured. To measure infiltration rates, a 10-cm head of water was applied to each column. The change in height (h_w) of the water column was measured as a function of time (t), until dh_w/dt attained a constant value. That constant value of dh_w/dt was equated with the infiltration rate. Suspended solids in the infiltration leachates were measured to give information about the amount of clay translocated under strong leaching conditions. Leachates were filtered through pre-weighed 0.22- μ m filter membranes, which were dried and re-weighed to determine the mass of suspended solids. The dry filter membranes were taped to glass slides and X-rayed (2 to 32 °2 θ) CuK α in order to identify clay minerals in the leachates.

After the infiltration measurements, columns were opened along their longitudinal seams and cut into horizontal layers at 10, 20, 30, and 45 cm below the surface. Selected chemical and physical properties were measured in each layer. Since

properties in the sand subsurface layers were independent of Vertisol concentration in the surface layer, only data for the sand-Vertisol layers are reported. Cation exchange capacity was determined by Ca saturation and ammonium acetate extraction. Organic C was determined by high temperature combustion using a Dohrmann DC-190 TOC analyzer with a boat sampler attachment (Rosemount, Santa Clara, CA). Particle-size distribution was measured by the sieve and pipet method (Gee & Bauder, 1986). Water retention at 0.01 and 1.5 MPa was measured using a pressure plate apparatus (Klute, 1986).

Available water capacity was calculated as the difference between the 0.01 and 1.5 MPa water contents (Cassel & Nielsen, 1986). Water-stable macroaggregates (1 - 2 mm and > 2 mm) were quantified by a wet-sieving method similar to that described by Kemper & Rosenau (1986). Briefly, dry sand-Vertisol mixture from the surface layer was sieved to obtain 4- to 8-mm aggregates. Twenty-five g subsamples of aggregates were pre-wetted by spraying with water and transferred to a sieve nest, which was placed in a home-built aggregate stability apparatus that raised and lowered the sieve nests in water at approximately 35 strokes per minute. Larger than 0.5-mm aggregates were used so that only newly formed sand-Vertisol interparticle associations, not aggregates dominated by the original Vertisol material, would be measured.

The relationships between Vertisol concentration and properties of the sand-Vertisol surface layer were determined by linear regression analysis (Steel & Torrie, 1980).

RESULTS AND DISCUSSION

Available water capacity (AWC), an estimate of plant-available water, is defined as the difference between the water content at the field capacity [0.01 MPa for coarse-textured soils (Rivers & Shipp, 1972)] and the water content at the permanent wilting point [1.5 MPa (Cassel & Nielsen, 1986)]. Both 0.01 and 1.5 MPa water contents increased linearly with increasing Vertisol concentration within the range of Vertisol concentrations used in this experiment ($P \leq 0.001$), but 0.01 MPa water contents increased at a greater rate than did water retention at 1.5 MPa (Fig. 1). Consequently, AWC increased as Vertisol concentration increased. Within experimental error, AWC increased linearly as Vertisol concentration increased from 0 to 400 g kg⁻¹ ($P \leq 0.001$). Both organic matter and clay contributed to the increase in water stable aggregates and CEC (Table 1) with increasing Vertisol concentration. *In situ* water contents in Vertisol-sand surface layers (measured by TDR) also increased with Vertisol amendments at the surface (Fig. 2). Because only one column of each treatment was instrumented with TDR probes, it was not possible to perform statistical analyses of *in situ* water contents.

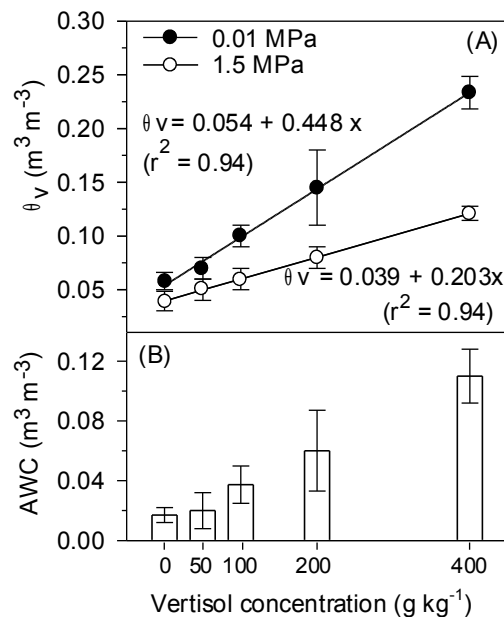


FIG. 1. A) Water retention (θ_v) as a function of Vertisol concentration. Data points and error bars represent mean and standard deviation of triplicate measurements. B) Available water capacity (AWC) calculated for triplicate water retention measurements. Error bars represent standard deviation $S_{AWC} = (S_{0.01MPa}^2 + S_{1.5MPa}^2)^{0.5}$.

As a consequence of increased water retention, the volume of leachate (drainage water) decreased with increasing Vertisol concentration (Fig. 3); no water drained from the 400 g kg⁻¹ Vertisol column during the first two weeks of the experiment. Calculated evaporation increased with increasing Vertisol concentration (Fig. 3). Alizai & Hubert (1969) also reported an increase in evaporation with increasing clay content. Decreased leaching could improve crop productivity by minimizing nutrient losses, but increased evaporation could cause salt accumulation and crusting at the soil surface, particularly in the 400 g kg⁻¹ Vertisol.

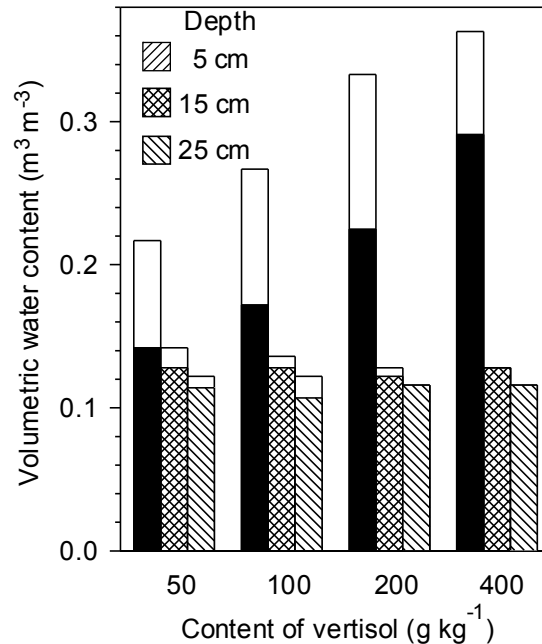


FIG. 2. Effect of Vertisol concentration on volumetric water content at three depths at 1 and 72 h after applying an 80-mm water pulse. Combined bar length is 1-h water content; stippled bar is 72-h water content.

Previous research has shown that smectite addition to sandy material reduces its hydraulic conductivity by increasing water retention and clay swelling (Alperovitch et al., 1985; Keren & Singer, 1991). In the amended sand columns, infiltration rates decreased from 980 to 380 mm h⁻¹ as Vertisol concentration increased from 50 to 200 g kg⁻¹, then decreased to 30 mm h⁻¹ as Vertisol concentration doubled from 200 to 400 g kg⁻¹ (Fig. 3). The moderate decreases in infiltration rates measured for 100 and 200 g kg⁻¹ Vertisol columns would probably improve crop growth because of decreased water and nutrient leaching. In the 400 g kg⁻¹ Vertisol columns, however, surface crusts were visible and probably caused the drastic reduction in infiltration rates shown in Fig. 3. Extremely slow infiltration may cause increased runoff and erosion or may inhibit germination in areas where ponding occurs; surface crusting could inhibit seedling emergence.

Concentrations of >0.22- μ m solids in column leachates did not vary systematically with Vertisol concentration ($P < 0.5$) and were very low (0.8 ± 0.2 mg L⁻¹). Smectite was the only mineral group detected in the leachates (Fig. 4). The total amount of clay and organic matter available for transport increased with increasing Vertisol concentration, but leaching and infiltration rates decreased, so less energy was available to cause clay translocation at high Vertisol concentrations, although the 200 and 400 g kg⁻¹ Vertisol mixtures showed the better peaks in the X-ray patterns (Fig. 4).

Particle-size analyses also suggested that very little clay was eluviated from the surface horizon: no clay was detected in subsurface layers at the end of the experiment, and clay contents in surface layers at the end of the experiment (Table 1) were identical to those predicted by multiplying the Vertisol clay content by the Vertisol concentration of each sand-Vertisol mixture. Over a longer time, though, it is likely that more clay would be translocated and retained in subsurface layers, thereby improving their CEC and water-holding capacity.

The concentration of aggregated particles >1 mm in diameter increased with increasing Vertisol concentration (Table 1; $P \leq 0.001$). These water-stable “aggregates” were sand grains held together by clays

and organic matter from the Vertisol. For the 50 and 100 g kg⁻¹ Vertisol treatments, concentrations of water-stable aggregated-particles were extremely variable: some subsamples contained no stable aggregated particles, whereas others contained 10 or 20 g kg⁻¹ water-stable aggregated particles (>1-mm aggregated units). This result suggests that low clay concentrations did not cause a uniform increase in water-stable interparticle associations. The 200 and 400 g kg⁻¹ Vertisol mixtures, however, produced consistent increases in “aggregation”. Thus, there may be a threshold Vertisol concentration (near 200 g kg⁻¹) required to bind sand grains together.

TABLE 1. Selected chemical and physical properties of Vertisol-sand mixtures at the end of 10-week column experiment¹.

Vertisol concentration	Clay content	Stable aggregates		Organic carbon	CEC (mmol _c kg ⁻¹)	Bulk density ² (Mg m ⁻³)
		>2 mm (g kg ⁻¹)	1- 2 mm			
50	28±11	0	0	1.9±0.2	33±2	1.52±0.07
100	60±13	7±11	3±6	2.7±0.1	54±5	1.46±0.02
200	119±38	15±14	19±5	5.0±0.03	103±2	1.3±0.09
400	190±41	116±48	40±8	8.3±0.4	175±7	1.18±0.03

¹ Mean ± standard deviation (n=3).

² Bulk densities of samples used for water retention calculations.

Dissolved and colloidal organic carbon (DOC) concentrations in column leachates increased with increasing Vertisol concentration and decreased with time; leachate DOC appeared to approach steady state after 6 to 8 weeks. The high initial DOC concentrations suggest that sieving the Vertisol material to separate the <0.5-mm fraction may have released a large amount of dissolved and colloidal organic C; it is possible that tillage may produce a similar flush in organic C release and subsequent leaching. The very large standard deviations in DOC (Table 2) were caused by variability among leachates from triplicate columns; coefficients of variation were as high as 25% for replicate leachates, but were less than 2% for duplicate measurements on a single solution. Dissolved and colloidal OC concentrations in final leachate samples were similar to DOC values typically reported for soil solutions.

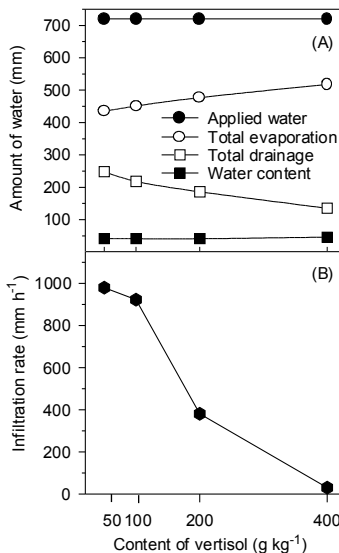


FIG. 3. A) Effect of Vertisol concentration on final column water contents, total drainage, and total evaporation. Applied water was identical for all treatments and does not include water added to measure infiltration rates. Infiltration rates (B) were measured after total leachate volume and final column water contents were measured.

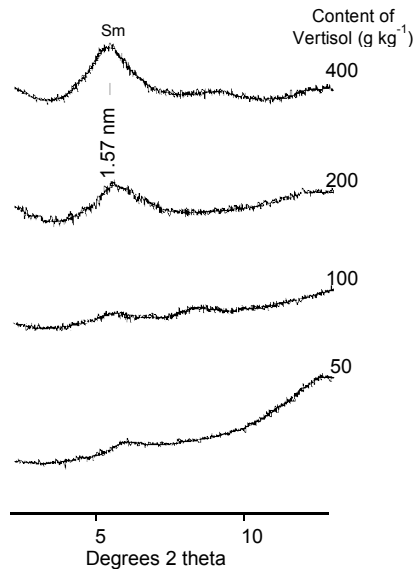


FIG. 4. X-ray diffraction patterns of the solids migrated during the infiltration rate measurements in the columns. Sm: Smectite.

TABLE 2. Organic C in column leachates collected biweekly for eight weeks¹.

Vertisol concentration (g kg ⁻¹)	Time (weeks)			
	2	4	6	8
	(mg L ⁻¹)			
50	60±1	37±2	23±0.6	24±8
100	93±11	53±3	36±9	36±13
200	93±1	93±9	86±24	52±23
400	0 ²	174±21	86±11	81±23

¹ Mean ± standard deviation (n=3).

² No water drained from column.

CONCLUSIONS

1. Vertisol material increases water- and nutrient-retention in sandy columns.
2. Water retention at field capacity (0.01 MPa) and at the permanent wilting point (1.5 MPa) increases linearly with increasing Vertisol concentration.
3. Available water capacity also increases with increasing Vertisol concentration.
4. Concentration of water stable aggregates increases with increasing Vertisol concentration from 200 to 400 g kg⁻¹.
5. Surface crusts that formed in the 400 g kg⁻¹ Vertisol column cause infiltration rates to decrease much more than predicted by a simple linear dependence upon Vertisol concentration.
6. Vertisol amendments may be a practical method to improve sandy soils productivity since the distance between the Vertisol source and the area to be applied is within limits of economical viability. The 200 g kg⁻¹ Vertisol treatment seems to provide the best combination of water retention, available water capacity, and adequate infiltration rates.

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