

Baseline Soil Characteristics of a Humid Tropical Silvopastoral System and Changes in Selected Soil Properties¹

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ABSTRACT

We established fast-growing leguminous trees (*Erythrina berteroana* Urban) in native grass pastures in Costa Rica's Atlantic region to determine the effects of tree pruning and cattle grazing on soil phosphorus availability and pasture biomass production. The field experiment included a randomized complete block of four treatments which were replicated on five farms: grazing and trees, grazing-no trees, trees-no grazing, and no trees-no grazing (the control). In 1987, we conducted a complete baseline characterization of the study soil's chemical, physical and mineralogical properties (andic humitropept, series Neguev). Three years later, we remeasured exchangeable bases and acidity, soil pH, carbon and nitrogen contents, phosphorus forms and bulk density to evaluate both farm and treatment effects over time. The Neguev soil series is acid (pH 4.8 - 5.2), low in exchangeable bases (sum of bases ~2.3 cmol_c/kg), high in exchangeable Al (>25% of ECEC), low in available P (2.8 mg P/kg modified Olsen extractable), yet high in total P (1385 mg P/kg). Soil bulk density was relatively low (0.84 - 0.91 g/cm³) and moisture retention capacity high (53% by volume at field capacity). The soil's mineralogy, dominated by kaolinite, gibbsite and iron oxides, is consistent with the oxic-andic nature exhibited by both chemical and physical properties. Over the three-year study period, soil organic C increased in the two no-grazing treatments and soil bulk density decreased in the no-grazing no tree control. Short-term changes in these parameters reflect the fallow-like status incurred from no grazing. There were also significant declines in soil pH and exchangeable monovalent cations along with increases in exchangeable Al and Fe at the farm level. Concurrently, organic P reserves declined and NaHCO₃-EDTA extractable P increased. Such changes may represent either gradual soil chemical changes associated with post-deforestation equilibrium shifts or normal fluctuations in the pasture ecosystem's inherent dynamic equilibrium.

Key words: Andic humitropept, leguminous tree, labile soil P, silvopastoral system.

RESUMEN

Se sembraron árboles leguminosos de rápido crecimiento (*Erythrina berteroana* Urban) en pasturas naturalizadas en la región atlántica de Costa Rica, para evaluar los efectos de la poda de los árboles y el pastoreo del ganado vacuno sobre la disponibilidad de P del suelo y la producción de biomasa de la pastura. El experimento incluyó los tratamientos: pastoreo y árboles; pastoreo sin árboles; árboles sin pastoreo; pasturas sin pastoreo y sin árboles (control). Los tratamientos se plantaron en forma aleatoria en un bloque en cinco fincas diferentes. Las características químicas, físicas y mineralógicas básicas de estos suelos (andic humitropept, serie Neguev) se determinaron en 1987. Tres años más tarde, se midieron nuevamente las siguientes variables: bases intercambiables y acidez, pH, contenidos de C y N, diferentes formas de P, y densidad aparente. El objetivo fue determinar los cambios en los estados de estas variables en el tiempo, a nivel de la finca como de diferentes tratamientos. Los suelos de la serie Neguev son ácidos (pH 4.8 - 5.2), pobres en bases intercambiables (la suma de bases es 2.3 cmol_c/kg), ricos en Al intercambiable (> 25% del CICE) y bajos en P disponible (2.8 mg P/kg, según Olsen modificado) a pesar de los elevados niveles de P total (1385 mg P/kg). La densidad aparente del suelo es relativamente baja (0.84 - 0.91 g/cm³) y una elevada capacidad de retención de humedad (53% por volumen con el suelo a capacidad de campo). Las propiedades físico-químicas de estos suelos son una mezcla de rasgos de oxisoles y andosoles. Su mineralogía, dominada por caolinita, gibbsite y óxidos de hierro, es congruente con estos órdenes de suelos. Al cabo de tres años, la cantidad de C orgánico del suelo aumentó en los dos tratamientos sin pastoreo, mientras que la densidad aparente del suelo disminuyó en el control (sin árboles y sin pastoreo). El barbecho de la pradera, una vez excluido el pastoreo, produjo cambios significativos en estos parámetros del suelo, aun en el corto período del estudio. A nivel de finca, se detectaron descensos significativos en el pH y en los cationes monovalentes intercambiables, y aumentos en el Al intercambiable y en hierro. Las reservas de P orgánico disminuyeron y el P que podría extraerse por Olsen modificado aumentó. Estos cambios se atribuirían a la dinámica natural de estos suelos después de la eliminación del bosque o a fluctuaciones normales en el equilibrio dinámico de la pradera.

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INTRODUCTION

In the Costa Rican Atlantic coastal plain, improper pasture management practices such as continuous grazing, overstocking and lack of inputs often result in declines in soil fertility and pasture productivity. Over time, the common end-product is degraded pasture; i.e., an increase in undesirable forage species such that it is no longer economically or ecologically viable to maintain livestock (Serrao *et al.* 1979). Degraded pasture lands are subsequently abandoned and more forests are cleared to maintain livestock production. Soils with inherently low fertility (low nutrient levels, acid, aluminum toxicity, high phosphorus retention) exacerbate this problem and accelerate the process of degradation (Sánchez y Benites 1987; Sollins *et al.* 1988). Phosphorus, in particular, is considered the major nutrient limiting plant growth in highly weathered soils or those derived from volcanic materials (Parfitt *et al.* 1989).

In an attempt to improve and sustain existing pasture land productivity on inherently infertile soils, we planted fast-growing leguminous trees (*E. berteriana* Urban) in native grass pastures in an acid, high P-retaining soil of Costa Rica's Atlantic coastal plain. The study's overall objectives were to: 1) investigate the dynamics of bioavailable soil P as a function of leguminous tree pruning and cattle grazing in this silvopastoral system; and 2) determine the effects of leguminous trees, tree pruning and cattle grazing on pasture biomass production. In this paper, we present the baseline characterization of the study soil's chemical, physical and mineralogical properties and evaluate changes in selected chemical and physical properties over a three-year-period.

MATERIALS AND METHODS

Site description

The field experiment was located in the Atlantic coastal plain of Costa Rica (10° N 83° W). The area receives 3630 mm rainfall annually and the ecological lifezone is lowland humid tropical rainforest. The field experiment, a silvopastoral system, was a 2 x 2 factorial design with cattle (grazing) and trees as the two independent variables; resultant treatments included: grazing and trees (GT), grazing-no trees (G), trees-no grazing (T) and no trees-no grazing (the

experimental control C). We planted *E. berteriana* (a tropical leguminous tree) from 2.6 m cuttings (stakes) in native grass pastures on five farms, all within a 6 km radius (all inside the Neguev settlement, Siquirres Canton, Limon Province). All farms were located on the Neguev soil series upon which we established the randomized block of four treatments (farms were considered as experimental replicates). Grazed treatment plots were 900 m² and non-grazed treatments 400 m². We planted trees one year prior to the experiment's initiation to allow sufficient time for establishment.

The study soil (series Neguev) is classified as an andic humitropept, family very fine, kaolinitic, isohyperthermic according to U.S. soil taxonomy (USDA Soil Survey Staff 1990). The soil formed from fluvio-laharic materials on the high flat ridges and slopes of the dissected landscape (Wielemaker and Lansu 1991). The Neguev series is the penultimate in a soil chronosequence typical of the region. It is deep to very deep (>150 cm), well-drained, clayey, acid, dark brown to dark yellowish brown (hue 10YR) with slightly weathered gravels at depths greater than 120 cm (de Bruin 1991). Soil texture is classified as clay with approximately 60% < 2 µm diameter particles.

Baseline soil characterization

We took composite soil samples (1-2 kg) to characterize baseline soil chemical, physical and mineralogical properties on all five farms. After treatments were demarcated, we collected at least 10 random subsamples per composite sample. We included treatment and soil depth as the two main factors in the sampling design: four treatments (GT, G, T and C) and two soil depths (0 -15 cm and 15 - 30 cm). For the two larger grazed plots (900 m²), we took two composite samples per depth, and one composite sample per depth for the smaller, non-grazed plots (400 m²). The samples were mixed, air-dried and sieved through a 2-mm mesh sieve for subsequent chemical, physical and mineralogical analyses. We undertook composite soil sampling as well as other baseline measurements in August 1987 before trees were planted and conducted final characterization sampling, in the same manner, in November-December 1990.

Soil chemical methods

General characteristics

The following soil chemical parameters were measured according to conventional procedures: 1) soil pH in water and 1 M KCl (1:1 soil:solution ratio; (McLean 1982); 2) exchangeable cations (Ca, Mg, K) in pH 4.8 ammonium acetate and exchangeable acidity via unbuffered KCl (Thomas 1982); 3) total Kjeldahl nitrogen (TKN); for initial soil characterization, we used a modification of Lachat's QuickChem method No. 10-107-06-2-G (Lachat Instruments Co. 1990b) in which 0.5 g of air-dried, sieved soil was digested for 3 h at 350°C with 2.5 ml concentrated H₂SO₄ and a mercuric oxide catalyst; an aliquot of the digest was then run on the Lachat QuickChem Automatic Flow Injection Ion Analyzer using the salicylate colorometric test for NH₃; for end of the study period, we followed the method according to Bremner and Mulvany (Bremner and Mulvany 1982); 4) organic carbon via dry combustion (USDA Soil Survey Staff 1972); 5) total P; for initial characterization, we followed the Lachat QuickChem method No. 10-115-01-1-H for PO₄-P in Kjeldahl digests (Lachat Instruments Co. 1990a); at the end of the study period, we used the conc. HNO₃/HClO₄ digestion method (Olsen and Sommers 1982); 6) organic P via ignition method (Olsen and Sommers 1982); 7) NaHCO₃-EDTA extractable or modified Olsen P (Diaz-Romeu and Hunter 1978). We devised a multivariate ANOVA model using the SYSTAT MGLH procedure (Wilkinson 1990) including farm, treatment, soil depth and sampling time as main effects and all corresponding 2-, 3- and 4-way interactions.

Post tests were performed (either least significant differences, LSDs or Tukey's HSD multiple comparisons test) for those effects with a significant F-statistic ($P < 0.05$).

Anion Exchange Resin (AER) P

Anion exchange resin P (AER-P), considered to be correlated with the most labile soil P fraction, was determined *in situ* only at the beginning of the study. AER-P was determined using the buried bag technique (Gibson *et al.* 1985) with Dowex 1 x 8 anion exchange resin, and 20 - 50 µm mesh. Approximately 1 g was sewn into very fine mesh (< 20 µm) permeable polyethylene bags, 3 cm x 3

cm. We buried bags randomly in each treatment plot in the surface horizon only (0 - 7.5 cm depth): 18 bags each in G and GT treatments, 8 in the T treatment and 6 in the C treatment, for a total of 50 bags per farm. We left these bags in the soil at all five farms for one week in August 1987. We extracted resin from each bag twice with 25 ml of 0.5 M HCl and determined AER-P according to the ascorbic acid-reduced phosphomolybdate method (Olsen and Sommers 1982). We conducted MGLH analyses of variance on the data for both farm and treatment effects using the SYSTAT MGLH ANOVA procedure (Wilkinson 1990).

Phosphorus sorption isotherm

We determined P sorption isotherms for the 0 - 15 cm (surface) and 15 - 30 cm (subsurface) horizons. We took composite samples for each depth from the five farms and shook duplicate, air-dried, sieved soil samples at a soil:solution ratio of 1:100 with six P levels (0, 5, 10, 15, 25, 50 mg/l) in 0.05 M NaCl for 72 h. Total dissolved Al was determined for a subset of the samples via the ferron-phenanthroline method (Barnhisel and Bertsch 1982). Dissolved organic C (DOC) was also measured directly in the equilibrium solution with a Dohrmann-Xertex Carbon Analyzer. Using pH, Al, DOC and PO₄ and the Geochem program (Sposito and Mattigod 1980), Al-P ion activity products (IAP) were calculated for all P levels. These were then compared to IAPs for variscite and amorphous aluminum phosphate to determine whether the major mechanism for soil P retention was sorption and/or mineral precipitation.

Soil physical analyses

Bulk density was determined via the core method for oven-dried (105°C) soil (Blake and Hartge 1986). After field treatment plots were established and before trees were planted, we took 10 cores from the 900 m² plots and five cores from the 400 m² plots from the surface soil horizon (0 - 10 cm). For final characterization, we stratified sampling in tree treatments. We took six cores from each of the four treatments.

From the tree treatments, we stratified the six cores into three next to trees and three from tree row interspaces. The statistical analysis included: 1) an

MGLH ANOVA on the end sampling (t_e) data set including farm, treatment (only analyzed the two tree treatments) and distance from tree; and 2) a second ANOVA on the beginning (t_0) and t_e data sets including farm, treatment and sampling time as main effects. We used an incomplete factorial design because farm 4 was not sampled at the end of the study.

In addition to soil bulk density, a moisture retention curve was determined for the study soil. For the low tensions, we used undisturbed soil cores from the surface horizon placed on a sand-filled tension table (points determined include: saturated, pF 1.7, 2.0, 2.3) (Klute 1986). For the intermediate tensions (pF 2.7 and 3.0), we used cores equilibrated on ceramic pressure plates. We took two cores per treatment plot per farm for a total of 60 cores. For high tensions, we used disturbed samples equilibrated on ceramic pressure plates (3 and 15 bar or pF 3.48 and 4.18). The soil samples used were the bulk composite samples collected in 1987. We converted gravimetric moisture content to volumetric and plotted pF against volumetric moisture content. We also calculated the percentage of total pores drained at each suction pressure. Soil moisture retention was determined for baseline characterization only.

Soil mineralogy

Most of the mineralogical analyses were performed on the clay fraction only. For the oxalate-Al and -Fe (McKeague *et al.* 1971; Searle and Daly 1977) and citrate-bicarbonate-dithionite (CBD)-Fe extractions (Jackson 1975), we used samples composited from all five farms for both the 0 - 15 cm and 15 - 30 cm horizons. Whole soil was used for oxalate extraction, whereas the clay fraction was used for CBD. A composite 0 - 15 cm sample was used for x-ray diffraction of which the clay fraction (< 2 μm) was separated, Mg-saturated, and freeze-dried according to standard procedures (Jackson 1975).

Parallel-oriented aggregate specimens were prepared for XRD by pipetting 2 ml of Mg-saturated dispersed clay suspensions (containing approximately 30 mg clay) onto glass slides and allowing to air-dry (Brady *et al.* 1986). We used a Philips XRG-3100 generator, PW 1316/90 wide-range goniometer (using CuK radiation) fitted with a theta-compensat-

ing slit diffractometer and DMS-41 control panel to generate the diffraction patterns with the following instrument parameters: initial $2\theta = 10^\circ$, final $2\theta = 65^\circ$, $2\theta = 0.1^\circ$, $T = 40$ s and number of data points = 551.

We also performed a rapid test for presence of halloysite (Churchman *et al.* 1983). An XRD spectrum was run on an untreated clay specimen as described previously. The same slide was then sprayed with formamide, allowed to dry for 20 - 30 min and the XRD spectrum rerun. If halloysite was present, a peak at 1.04 nm d-spacing would appear. Spectra were also compared with those of halloysite and kaolinite standards.

RESULTS AND DISCUSSION

Soil chemical parameters

Exchangeable bases and pH

Consistent with the general characteristics of the study soil, bases extracted in pH 4.8 NH_4 -acetate were low (mean sum of bases for five farms was 2.29 cmol_e/kg) and unbuffered KCl-exchangeable acidity was high (mean for the five farms was 1.45 cmol_e/kg ; Table 1). Overall, exchangeable bases were significantly lower in the subsoil than the surface soil (mean is 0.94 cmol_e/kg) while exchangeable Al and acidity did not differ appreciably with depth. Exchangeable Al dominated both total acidity and ECEC. Both exchangeable Al and percent ECEC present as Al increased substantially from beginning to end of the study.

Soil pH in H_2O and KCl were low (5.17 and 4.00 respectively for the surface horizon), and there was a significant decrease in H_2O pH with depth (5.17 to 4.88). Both pH in water and in 1 M KCl appeared to decrease significantly over time for all farms (from 5.17 to 4.80 H_2O pH; from 4.00 to 3.84 KCl pH; Table 2). This decrease was probably regulated by increases in exchangeable Al. H_2O pH did not change significantly over time in the 15 - 30 cm horizon, but it did decrease significantly for KCl pH (from 4.03 to 3.85). The difference between the H_2O pH and KCl pH ($\bar{\Delta}$ pH) was always positive (ranges from 0.72 - 1.23 across both soil depths), indicating a net CEC for both soil horizons. While pH decreased over time, the Δ pH did not change.

Table 1. Cation exchange properties of study soil at two depths from the beginning and end of study.

| Farm | Ca | | Mg | | K | | Sum | | Bases | | Al | |
|------------------------|------------|------|------------|------|------------|------|------------|------|-------|------|-----|-----|
| | beg | end | beg | end | beg | end | beg | end | beg | end | beg | end |
| molc/kg ⁻¹ | | | | | | | | | | | | |
| 0 - 15 cm | | | | | | | | | | | | |
| 1 | 1.33 | 1.63 | 1.01 | 0.93 | 0.40 | 0.32 | 2.73 | 2.88 | 0.92 | 1.63 | | |
| 2 | 0.66 | 0.67 | 0.84 | 0.65 | 0.33 | 0.23 | 1.83 | 1.55 | 0.69 | 1.19 | | |
| 3 | 0.76 | 0.83 | 0.81 | 0.71 | 0.51 | 0.32 | 2.08 | 1.85 | 1.40 | 2.12 | | |
| 4 | 0.92 | 0.83 | 1.17 | 1.00 | 0.63 | 0.46 | 2.73 | 2.30 | 0.89 | 1.52 | | |
| 5 | 0.69 | 0.62 | 0.91 | 0.85 | 0.49 | 0.32 | 2.09 | 1.79 | 1.31 | 2.36 | | |
| 15 - 30 cm | | | | | | | | | | | | |
| 1 | 0.48 | 1.13 | 0.40 | 0.42 | 0.24 | 0.19 | 1.13 | 1.74 | 0.90 | 1.99 | | |
| 2 | 0.21 | 0.36 | 0.29 | 0.28 | 0.18 | 0.14 | 0.69 | 0.79 | 0.59 | 1.24 | | |
| 3 | 0.30 | 0.76 | 0.27 | 0.37 | 0.27 | 0.21 | 0.84 | 1.33 | 1.45 | 2.20 | | |
| 4 | 0.45 | 0.45 | 0.44 | 0.48 | 0.42 | 0.28 | 1.31 | 1.20 | 1.07 | 1.79 | | |
| 5 | 0.27 | 0.28 | 0.27 | 0.34 | 0.20 | 0.16 | 0.74 | 0.79 | 1.63 | 3.33 | | |
| | LSD = | 0.22 | LSD = | 0.08 | LSD = | 0.07 | LSD = | 0.27 | LSD = | 0.15 | | |
| cmolc/kg ⁻¹ | | | | | | | | | | | | |
| 0 - 15 cm | | | | | | | | | | | | |
| 1 | 0.56 | 0.26 | 1.48 | 1.88 | 4.21 | 4.76 | 21.6 | 34.0 | | | | |
| 2 | 0.31 | 0.22 | 1.00 | 1.41 | 2.83 | 2.96 | 25.1 | 40.1 | | | | |
| 3 | 0.45 | 0.28 | 1.85 | 2.40 | 3.94 | 4.25 | 36.0 | 50.1 | | | | |
| 4 | 0.31 | 0.31 | 1.21 | 1.83 | 3.93 | 4.13 | 22.8 | 36.9 | | | | |
| 5 | 0.57 | 0.38 | 1.70 | 2.74 | 3.79 | 4.53 | 30.0 | 51.9 | | | | |
| 15 - 30 cm | | | | | | | | | | | | |
| 1 | 0.41 | 0.26 | 1.32 | 2.25 | 2.44 | 3.99 | 36.9 | 49.7 | | | | |
| 2 | 0.24 | 0.22 | 0.83 | 1.46 | 1.51 | 2.25 | 39.2 | 55.5 | | | | |
| 3 | 0.37 | 0.27 | 1.81 | 2.47 | 2.65 | 3.80 | 54.3 | 59.9 | | | | |
| 4 | 0.24 | 0.26 | 1.31 | 2.05 | 2.63 | 3.26 | 41.0 | 54.9 | | | | |
| 5 | 0.56 | 0.39 | 2.19 | 3.73 | 2.93 | 4.51 | 55.9 | 73.8 | | | | |
| | LSD = 0.14 | | LSD = 0.15 | | LSD = 0.35 | | LSD = 5.51 | | | | | |

LSDs = are differences among all independent variables for each dependent variable

ECEC = effective cation exchange capacity = sum of bases + exchangeable acidity

Table 2. Study soil pH in water, 0.1 M KCl and their difference for two depths at the beginning an end of study.

| Farm | pH H ₂ O | | pH KCl | | Delta pH | |
|----------|---------------------|------|------------|------|-----------|------|
| | beg | end | beg | end | beg | end |
| 0-15 cm | | | | | | |
| 1 | 5.25 | 4.80 | 4.01 | 3.73 | 1.23 | 1.08 |
| 2 | 5.32 | 4.83 | 4.10 | 3.94 | 1.22 | 0.89 |
| 3 | 5.06 | 4.79 | 3.89 | 3.83 | 1.17 | 0.96 |
| 4 | 5.08 | 4.86 | 3.97 | 3.94 | 1.11 | 0.93 |
| 4 | 5.12 | 4.74 | 4.04 | 3.74 | 1.08 | 1.00 |
| 15-30 cm | | | | | | |
| 1 | 4.94 | 4.81 | 4.03 | 3.76 | 0.91 | 1.05 |
| 2 | 4.96 | 4.86 | 4.16 | 3.94 | 0.80 | 0.93 |
| 3 | 4.93 | 4.80 | 3.91 | 3.88 | 1.02 | 0.93 |
| 4 | 4.79 | 4.89 | 4.01 | 3.96 | 0.78 | 0.93 |
| 5 | 4.78 | 4.86 | 4.06 | 3.73 | 0.72 | 1.14 |
| | LSD= 0.80 | | LSD= 10.05 | | LSD= 0.10 | |

LSDs: area differences among all independent variables for each dependent variable

The extremely low values obtained for exchangeable Ca, Mg and K for the study soil are typical of highly leached volcanic-material derived soils, and they corroborate results obtained by de Bruin (1991) and Lansu (1988) for the Neguev soil series. In a survey of soils from Central America, Müller *et al.* (1968) found notably fewer exchangeable bases in acid Costa Rican soils than in other less acid Central American soils. In general, Al dominates both the exchangeable acidity and effective CEC of the Neguev soil series. The importance of free Al hydroxide is further evidence for the soil's advanced stage of weathering (van Dooremolen *et al.* 1990a).

Organic C and TKN

Total organic C did not change significantly over the three-year study and ranged from 3.17 - 3.85% in the 0 - 15 cm horizon and 1.92 - 2.73% in the 15 - 30 cm horizon (Table 3). In contrast, TKN decreased over time among farms for both soil depths (from 0.38 to 0.29% and 0.23 to 0.19% in the surface and

subsurface horizons, respectively). The two grazed treatments, G and GT, exhibited higher C:N ratios (11.52, 12.35) than the non-grazed treatments T, C (8.14, 8.84) in the subsurface horizon only (Table 4). By the end of the study, however, there were no significant differences among treatments or depths, suggesting that either organic C increased for all treatments at both depths or TKN decreased (except in the two grazed treatments' subsurface horizons).

The Neguev soil had a slightly higher than average OC content when compared with a survey of Central American soils (Fassbender *et al.* 1968), yet its organic C content was much lower than soils of more recent volcanic deposition. Alvarado (1984) cites 9.2% OM or 5.4% OC for volcanic ash-derived soils in Guatemala and Costa Rica. The literature on volcanic-ash soils also reports C:N ratios ranging from 9 - 12; again, the Neguev soil falls within this range. Relative to other non-volcanic soils of the tropics, the C:N ratio is low, probably due to the relatively higher TKN values (Lal 1989a).

Table 3. Organic carbon, total Kjeldahl N and C:N ratio for two depths at the beginning and end of study.

| Farm | Organic C (%) | | TKN (%) | | C:N ratio | |
|------------|---------------|------|------------|------|------------|-------|
| | beg | end | beg | end | beg | end |
| 0 - 15 cm | | | | | | |
| 1 | 3.17 | 3.12 | 0.31 | 0.27 | 10.49 | 11.51 |
| 2 | 3.17 | 3.20 | 0.33 | 0.27 | 10.15 | 11.78 |
| 3 | 3.19 | 3.68 | 0.50 | 0.31 | 6.45 | 12.04 |
| 4 | 3.85 | 3.26 | 0.42 | 0.31 | 9.25 | 10.45 |
| 5 | 3.50 | 3.18 | 0.33 | 0.29 | 10.65 | 10.85 |
| 15 - 30 cm | | | | | | |
| 1 | 2.18 | 2.02 | 0.17 | 0.17 | 12.69 | 12.25 |
| 2 | 2.06 | 1.99 | 0.26 | 0.17 | 8.44 | 11.88 |
| 3 | 2.25 | 2.49 | 0.28 | 0.21 | 8.33 | 11.91 |
| 4 | 2.73 | 2.14 | 0.25 | 0.20 | 11.00 | 10.81 |
| 5 | 1.92 | 2.01 | 0.19 | 0.19 | 10.61 | 10.85 |
| | LSD = 0.42 | | LSD = 0.05 | | LSD = 2.54 | |

LSDs: area differences among all independent variables for each dependent variable

Table 4. Changes in C:N ratio among treatments from beginning to end of study.

| Treatment | Beginning | End |
|-------------------------|-----------|-------|
| 0 - 15 cm | | |
| Trees alone (T) | 8.51 | 11.36 |
| Grazed-no trees (G) | 9.33 | 11.18 |
| Grazed-trees (TG) | 9.51 | 11.00 |
| No grazing-no trees (C) | 10.25 | 11.77 |
| 15 - 30 cm | | |
| Trees alone (T) | 8.14 | 11.60 |
| Grazed-no trees (G) | 11.52 | 11.56 |
| Grazed-trees (TG) | 12.35 | 11.45 |
| No grazing-no trees (C) | 8.84 | 11.55 |

Overall LSD = 2.54

Phosphorus forms
and P adsorption isotherm

Both AER-P and modified Olsen (NaHCO_3 -EDTA) extractable P were low while total P was

very high (Table 5). The percent of total P as organic was also quite high, ranging between 60 - 75%. Modified Olsen P increased for all farms over time in both soil depths, but dramatically on farms 3 and 4 (3.28 to 11.7 and 4.05 to 15.12 mgP/kg). Organic P decreased significantly over time (from 882.5 to 671.6 mg/kg in the surface horizon), while the percent of total P in organic form marginally increased for some farms. Both, however, remained high relative to other, non-volcanic soils (Fassbender and Bornemisza 1987). Over time, total P increased significantly for farms 1, 2 and 5 in the surface horizon and farms 3, 4 and 5 in the subsurface.

The P retention capacity for the study soil was high; approximately 2000 mg P/kg soil and higher for the surface and subsurface horizons (Fig. 1). Changes in Al-P ion activity products (IAP) with increasing P addition showed that all P levels were undersaturated with respect to variscite (Fig. 2). However, the Geochem model suggested that, at the four highest P additions, the soil was supersaturated with respect to amorphous Al-phosphate. As such, we could not conclude that the P retention characteristics of this soil series resulted solely from adsorp-

Table 5. Phosphorus forms in study soil at two depths from the beginning and end of study.

| Farm | AE# | NaHCO ₃ extr. P | | Organic P | | Total P | | Org. P (% total) | | |
|---------------|-------|----------------------------|-------|-------------|--------|-------------|---------|------------------|-------|-----|
| | | Resin P | beg | end | beg | end | beg | end | beg | end |
| (mgP/kg soil) | | | | | | | | | | |
| 0 - 15 cm | | | | | | | | | | |
| 1 | 0.325 | 1.95 | 3.63 | 900.21 | 615.47 | 1310.55 | 821.25 | 68.70 | 74.93 | |
| 2 | 0.179 | 2.20 | 3.34 | 716.43 | 480.55 | 1091.41 | 662.11 | 65.35 | 72.54 | |
| 3 | 0.378 | 3.28 | 11.69 | 893.06 | 705.73 | 1507.06 | 1196.67 | 59.26 | 59.21 | |
| 4 | 0.503 | 4.05 | 15.12 | 1055.29 | 853.44 | 1731.84 | 1452.19 | 60.79 | 58.96 | |
| 5 | 0.578 | 2.47 | 6.12 | 847.28 | 702.58 | 1284.07 | 967.27 | 65.99 | 72.67 | |
| 15 - 30 cm | | | | | | | | | | |
| 1 | nd | 2.09 | 3.27 | 779.69 | 503.75 | 1199.59 | 701.25 | 64.93 | 71.81 | |
| 2 | nd | 2.00 | 2.90 | 764.98 | 383.67 | 1104.81 | 567.74 | 69.09 | 67.64 | |
| 3 | nd | 3.01 | 10.16 | 730.14 | 677.62 | 1359.76 | 1161.99 | 53.62 | 58.65 | |
| 4 | nd | 3.63 | 14.68 | 940.71 | 790.00 | 1606.79 | 1384.22 | 58.44 | 57.11 | |
| 5 | nd | 2.28 | 5.75 | 788.39 | 612.50 | 1258.21 | 872.34 | 62.63 | 70.33 | |
| LSD = 0.087 | | LSD = 0.52 | | LSD = 167.4 | | LSD = 95.21 | | LSD = 9.68 | | |

LSDs = are differences among all independent variables for each dependent variable.

Anion exchange resin extractable P in mg P/g resin measured at beginning of study only.

tion; rather, precipitation of amorphous Al-phosphate minerals may contribute substantially to the soil's high P retention capacity. Parfitt (Parfitt 1989) concurs that Al-phosphates are likely to precipitate at high levels of P addition in soils containing large amounts of reactive Al. Indeed, several studies have shown that the sesquioxide constituents of andosols

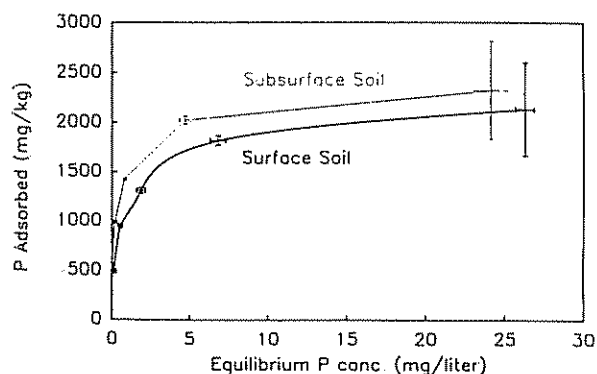


Fig. 1. P adsorption isotherm for the surface (0-15 cm) and subsurface (15-30 cm) horizons.

(e.g., gibbsite) contribute as much to the soils' high P retention capacities as the poorly-crystallized minerals like allophane and imogolite (Shoji and Ono 1978; Daage 1987; Saunders 1965).

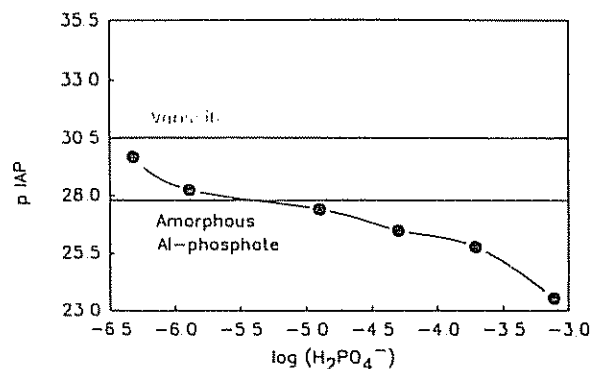


Fig. 2. Calculated ion activity products (IAP) in adsorption isotherm equilibrium solutions compared with solubilities of variscite and amorphous Al phosphate (AlOHPO₄). Activities estimated with the Geochem speciation model (Sposito and Mattigod 1980).

In summary, the Neguev soil's chemical properties do not fit neatly in either typical andisol or oxisol soil orders. The high P retention capacity is more characteristic of volcanic ash-deposited soils, whereas the low pH, low CEC and high exchangeable Al are more reminiscent of highly weathered soils. Organic C and N levels are intermediate when placed along an andisol-oxisol continuum. As van Dooremolen *et al.* (van Dooremolen *et al.* 1990a) indicate, the Neguev series falls along the older end of the spectrum of volcanic-derived soils.

Soil physical parameters

Soil bulk density

The no grazing-no tree experimental control (C) was the only treatment with a significant decrease in bulk density over the three-year study (from 0.89 to 0.83 g/cm³; Table 6).

Table 6. Soil bulk density via core method presented as means by farm and by treatment for the beginning and end of study.

| Farm | beg | end |
|------------|-----------------------|------|
| | (g cm ⁻³) | |
| 1 | 0.85 | 0.85 |
| 2 | 0.86 | 0.86 |
| 3 | 0.84 | 0.83 |
| 4 | 0.90 | nd |
| 5 | 0.91 | 0.88 |
| LSD = 0.03 | | |
| Treatment | beg | end |
| | (g cm ⁻³) | |
| T | 0.87 | 0.85 |
| G | 0.87 | 0.87 |
| IG | 0.87 | 0.88 |
| C | 0.89 | 0.83 |
| LSD = 0.03 | | |

Bulk density not measured for farm 4 at end of study.
Treatment T = trees alone; G = grazed-no trees;
IG = grazed-trees; C = no grazing-no trees.

This probably resulted from the sustained absence of animals along with no trees. The presence of trees may have slowed the rebound effect from lack of grazing in the trees-no grazing treatment. Among farms, the soil bulk density ranged between 0.84 - 0.91 g/cm³; typical of soils with andic properties and high clay content (El Swaify 1980; Shoji and Ono 1978; Wielemaker and Lansu 1991).

Moisture retention characteristics

Soil moisture retention changed little from saturated conditions to tensions close to 1 bar (Fig. 3). Saturated moisture content was approximately 63% by volume and decreased gradually to around 48% at 1 bar (pF 3). Field capacity, which several researchers suggest is more appropriately represented by pF 1.7 (Maeda *et al.* 1977), was 53% by volume. The greatest decrease in soil moisture retention occurred between 1 and 3 bar (pF 3 and 3.5) and coincided with the break between measurements made on intact soil cores and those made with disturbed soil samples. Even at 15 bar tension (pF 4.2), volumetric moisture content still hovered around

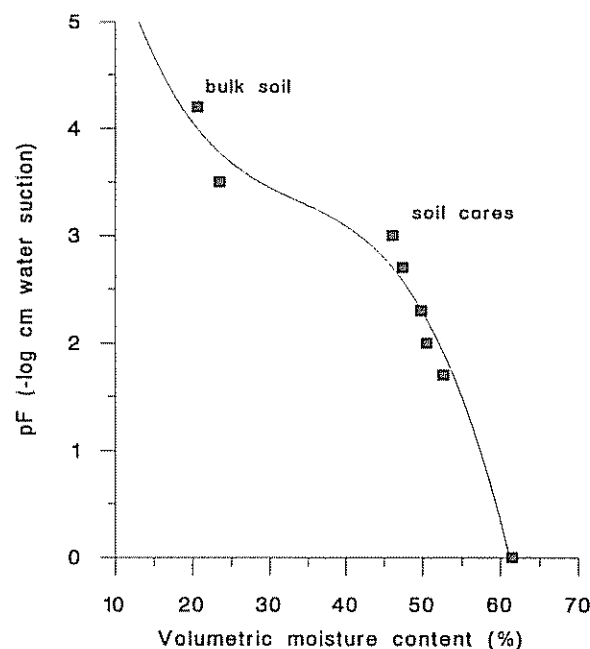


Fig. 3. Moisture retention characteristics of the Neguev soil surface (0-15 cm) horizon. Each point on the curve represents the mean value of the five study farms.

20%. This relatively high moisture retention at such high tensions was most likely a function of the soil's high clay content (Warkentin and Maeda 1980). In addition, the high 15 bar water content is another indication of the andic nature of the Neguev soil series (Maeda *et al.* 1977).

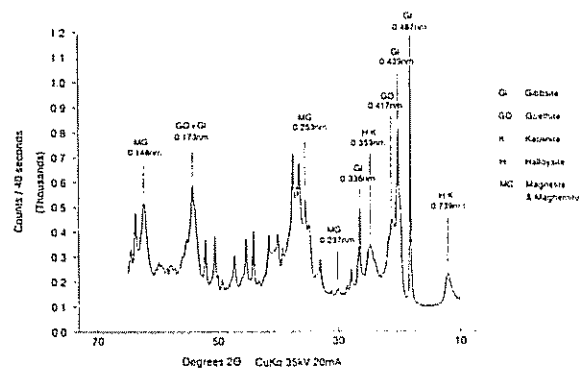


Fig. 4. Percent total pores drained over the range of pore size diameters from macropores to micropores. Pore size diameters correspond to the difference between successively increasing suction pressures.

Plant available water, calculated as the difference in water content between pFs 1.7 and 3.5 was 29.2% by volume. The total porosity, averaged over all farms, was 64%. The high percentage of micropores (~52%) was most likely a function of the soil's high clay content (El Swaify 1980; Gavande 1968), whereas the low percentage of macropores (~20%) suggested soil compaction (Lal 1989b). In general, the shape of the moisture release curve was similar to those for soils with high allophane content; i.e., an S-shaped curve with a linear portion between 0.01 - 1 bar or pF 1.5 - 3.0 (Warkentin and Maeda 1980; Maeda *et al.* 1977; Gavande 1968). Although the Neguev soil has no allophane, the high clay and moderate organic matter contents coupled with high total porosity contribute to the soil's andosol-like moisture retention characteristics.

Soil mineralogy

Mineral oxide characteristics

Oxalate extractable Fe and Al were high (1.64% Fe, 0.94% Al), but were consistent with other soil chemical and mineralogical analyses which characterized the soil series as a highly weathered andisol.

There was no significant difference between the surface and subsurface horizons (1.64 vs. 1.48% for Fe; 0.94 vs. 1.04% for Al). Although oxalate is believed to extract poorly crystallized Fe forms, the high values obtained may be an overestimate of this fraction due to the presence of magnetite (J. Bigham, Ohio State University, pers. comm., 1991).

The percent Fe extracted with citrate bicarbonate dithionite (CBD) in the < 2 μm fraction was also high (9.8%) and most closely correlated with the soil's crystallized Fe oxide content (goethite, magnetite, maghemite). The ratio of oxalate-Fe:CBD-Fe, a measure of percent poorly crystallized Fe, was considered high relative to oxisols (15% - 17%) but was probably representative of volcanic material-derived soils (Bigham *et al.* 1978). The ratio should be viewed with some caution, however, since the oxalate-Fe was probably not an accurate estimate of the soil's amorphous fraction.

X-ray diffraction and the formamide test for halloysite

The dominant minerals were poorly crystallized kaolinite or halloysite, gibbsite and iron oxides (Fig. 5). The differential pattern of untreated and

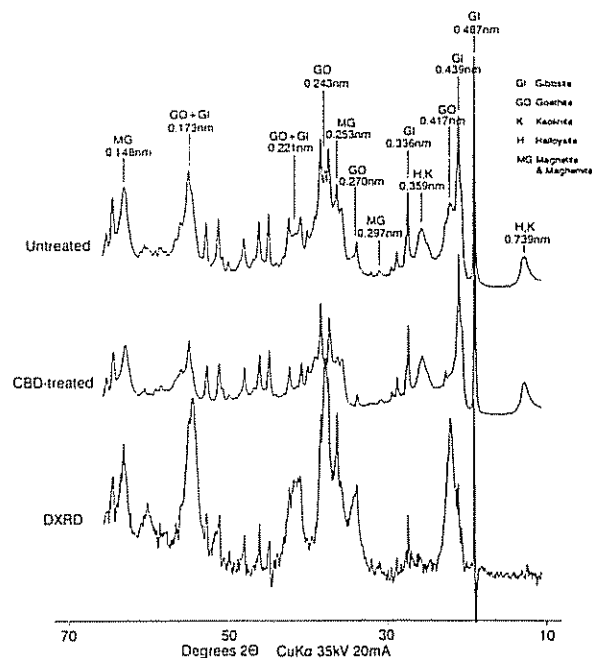


Fig. 5. X-ray diffractogram of the Neguev surface (0-15 cm) horizon clay (< 2 μm) fraction.

CBD-treated samples showed sharp peaks for gibbsite, goethite, magnetite and maghemite (Fig. 6). The asymmetry and breadth of the two kaolinite/halloysite peaks (0.74 and 0.36 nm) fostered doubts regarding the exact mineralogy of the 1:1 aluminosilicate present. X-ray diffractograms for both formamide-treated surface and subsurface <math> < 2 \mu\text{m}</math> study soil samples did not show the shift associated with halloysite (Fig. 7). Previous work has shown that kaolinites in oxic materials are largely poorly crystallized, and that poor crystallinity is often exhibited as broad XRD peaks which can be confused further if oxide coatings are present (Haynes and Swift 1986).

Nonetheless, the van Dooremolen *et al.* (van Dooremolen *et al.* 1990a) survey of the Atlantic coastal region's soils provides conclusive XRD evidence for the dominance of kaolinite, gibbsite and goethite in the older volcanic deposits like the Neguev series.

Characterization of the dominant minerals explained the somewhat-oxic, somewhat-andic nature of the Neguev soil series. For example, CBD-extractable Fe for oxisols ranges between 7% - 14% (Bigham *et al.* 1978); the Neguev soil's CBD-Fe (9.8%) fell squarely within this range.

However, the Neguev soil had almost twice the amount of oxalate extractable Al typical of oxisols (0.94% - 1.04%), suggesting that there is still a significant amorphous Al component. As Blume and Schwertmann (1969) suggest, the soil's low pH coupled with some downward movement of organic matter may actually retard the crystallization process, resulting in high relative and absolute amounts of poorly crystallized Fe and Al oxides.

Changes in selected soil chemical and physical properties over the study period

The silvopastoral system of *E. berteriana* and native grass pasture underwent notable changes at the farm level over the 40-month study. However, there were no significant treatment-induced changes in any of the soil chemical parameters measured. The significant declines in soil pH and exchangeable

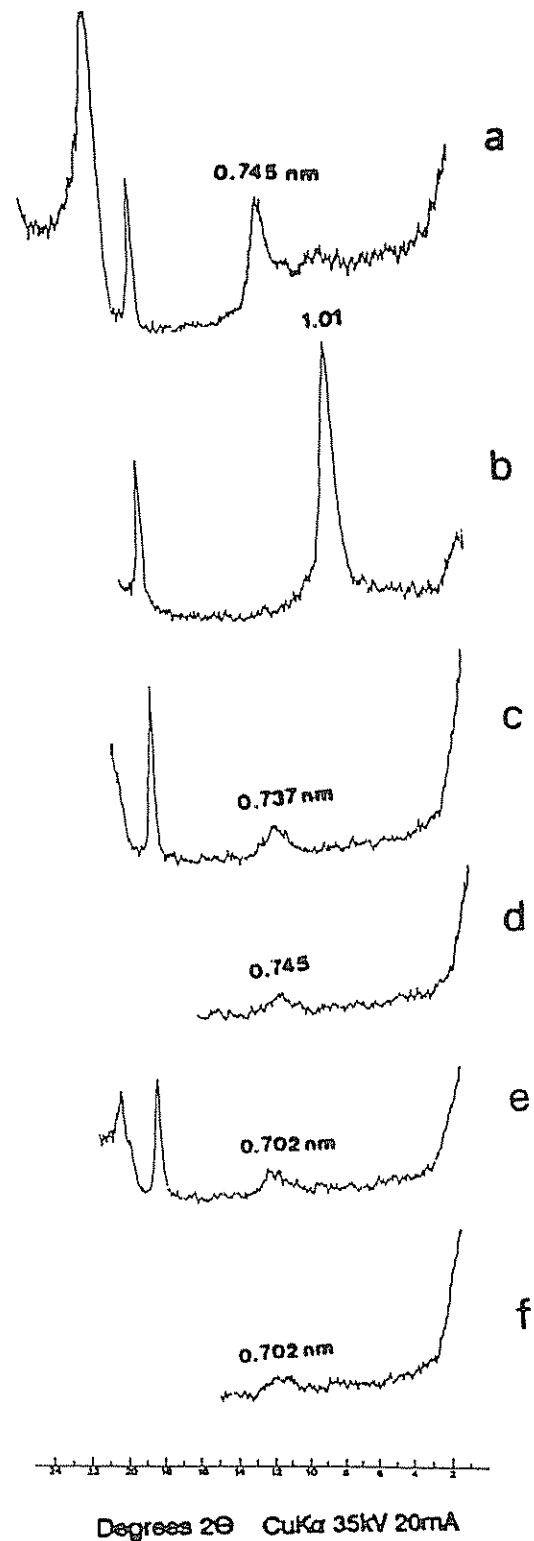


Fig. 6. Differential x-ray diffractogram for untreated and CBD-treated <math> < 2 \mu\text{m}</math> fraction, surface horizon.

monovalent cations with concurrent increases in extractable Al and Fe suggest that the soil system was still undergoing an equilibrium shift from forest to pasture ecosystems, even 15 - 20 years after rain forest clearing (Herbillon 1980). Alternatively, the observed changes in soil chemical properties, when viewed in a longer time-scale context, may merely represent normal fluctuations associated with the pasture ecosystem's own dynamic equilibrium.

The significant increase in soil C relative to N in only the non-grazed tree treatment implies that organic C accumulated to a greater extent than N. Since there is no nutrient or organic matter export from the non-grazed system, one should expect organic C accumulation over time. In addition, N may not have accumulated as much as C because N mineralized from decomposing *Erythrina* leaves may have stimulated mineralization of soil organic N reserves, resulting in a temporary decrease in TKN (Bornemisza 1966). The presence of leguminous trees and tree pruning increased the C:N ratio in the surface soil to a greater extent than recycling from pasture grass clippings alone (control treatment). The increase in the C:N ratio in the non-grazed tree treatment relative to the grazed treatments supports the hypothesis that the lack of grazing is analogous to fallow conditions and that leguminous trees enhance the fallow status of the system.

In contrast with organic C, organic P reserves decreased among all farms regardless of treatment. Simultaneously, available P (NAHCO₃-EDTA extractable) increased. With treatment means pooled by farm, there was an increase in P mineralization from the experiment's initiation to its end. Bertsch and Cordero (Bertsch and Cordero 1984) also found that when inorganic P was added to P-deficient soils, mineralization of organic P and N reserves increased. This increased mineralization may reflect enhanced nutrient turnover associated with changes in pasture management from continuous to rotational or no grazing (Wielemaker and Lansu 1991; Sollins and Radulovich 1988).

Soil bulk density decreased significantly only in the control treatment after three years. When compared with the Neguev series' bulk density under forest (0.63 g/cm³), the control treatment bulk density was still relatively high. Nonetheless, it appeared to

be rebounding from the compaction incurred from previous continuous grazing (Humphreys 1991). In comparison, the non-grazed tree treatment did not undergo such a significant decline in soil bulk density, which suggests that the tree roots are slowing the rate of decline. The possible ameliorative tree effect in a grazed system may not have developed yet at this early stage in the silvopastoral system's establishment.

CONCLUSIONS

—The study soil, an andic humitropept (series Neguev), exhibits chemical, physical and mineralogical properties reflective of both oxisols and andisols; i.e., it is acid, high in exchangeable Al, dominated by kaolinite, gibbsite and iron oxides (properties characteristic of oxisols), yet it has a very high P retaining capacity, low bulk density and high water holding capacity (properties akin to andisols).

—Over the three-year study period, there were few changes in soil chemical or physical properties resulting from treatment imposition. However, soil organic C increased in the two non-grazed treatments and soil bulk density decreased in the no-grazing no tree control. Short-term changes in these parameters reflect the fallow-like status incurred from no grazing.

—There were significant changes in selected soil chemical properties at the farm level. These may either represent gradual chemical changes associated with post-deforestation agro-ecosystem equilibrium shifts, or simply reflect normal fluctuations in the pasture ecosystem's inherent dynamic equilibrium.

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RESEÑA DE LIBROS

BRIGHMAN, J.M.; CIOLKOSZ, E.J. (EDS.).
1993. **Soil color.** Madison, WI, **Soil Science Society of America. Special Publication no. 31. 159 p.**

La utilización del color del suelo y la teoría del color son los temas centrales del libro, contribución de la Sociedad Americana de la Ciencia del Suelo. A pesar de que este tema es relevante en la ciencia del suelo, debe mencionarse que los problemas relacionados son motivo de preocupación para otras disciplinas científicas (ver *Hortscience* 27(12) 1992)

El color del suelo en su forma natural presenta una gran variabilidad espacial, debido a que este parámetro se ve afectado por factores que influyen en su formación (p.e. material parental, edad, clima, otros) y los procesos que lo modifican (p.e. gleización, laterización, otros). Por esta razón, el color se emplea como criterio de clasificación en casi todos los sistemas taxonómicos.

Los ocho capítulos que conforman el documento incluyen los aspectos históricos del desarrollo del concepto teórico, las metodologías empleadas para su determinación, las correlaciones entre mediciones de campo y de laboratorio, las relaciones entre color

y óxidos de hierro, el efecto de la materia orgánica sobre el color del suelo, la coloración de los suelos ácidos con sulfatos y la perspectiva geológica del color de las capas sedimentarias rojas.

La publicación resume y analiza el conocimiento actual sobre el origen y la medición del color del suelo, y cada capítulo fue preparado por distinguidos profesionales en el tema, de los Estados Unidos de América, Alemania y España. La edición del documento es impecable, incluyéndose varias figuras en colores nítidos.

Por lo especializado del tema, el libro tendrá una audiencia muy seleccionada pero es sobre todo recomendable para quienes laboran en programas de cartografía de suelos. Es también una obra de consulta para estudiantes de posgrado en el área de suelos. El documento puede adquirirse por US\$25.00 escribiendo a Soil Science Society of America, Attention Book Order Dept., 677 South Segoe Road, Madison, WI 52711-1086.

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