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THE EFFECT OF TIME OF USE OF TROPICAL PASTURES ON SOIL FERTILITY AND CATTLE PRODUCTIVITY

EL EFECTO DEL TIEMPO DE USO DE PASTIZALES TROPICALES EN LA FERTILIDAD DEL SUELO Y PRODUCTIVIDAD DE GANADO VACUNO

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ABSTRACT

Pastures in the neotropics at Los Tuxtlas, Mexico, were found to support a high density (2.8 animals ha^{-1}) of cattle. The cause of this was investigated doing a topsoil (10 cm) nutrient analysis in an undisturbed forest, and a 12-yr and 32-yr old pastures resulted from deforestation. Similarly to other locations elsewhere, soil pH, total nitrogen, phosphorus, sodium, calcium, hydrogen ion, and cation exchange capacity, decreased with increasing age of the pastures, but were all high probably because of the relatively recent volcanic replenishment. The top-soil of the 12-yr and 32-yr old pastures had a nearly neutral pH_{H2O} (7.2, 6.7), a high cation exchange capacity of 22.8 and 17.2 $cmol_c$ kg^{-1}, and appeared relatively rich in total nitrogen (0.365, 0.4%), extractable phosphorus (12.1, 1.12 µg g^{-1}), and exchangeable cations (K^+, 1.23, 0.33; Na^+, 0.46, 0.31; Ca^{2+}, 13.8, 7.6; Mg^{2+}, 7.1, 8.1 $cmol_c$ kg^{-1}). Soil bulk density increased in the older pasture to 1.0 g cm^{-3}. Owing to these high soil nutrients concentrations, it seems possible to support high stocking rates of cattle even in relatively old pastures.

Key words: land-use conversion, Los Tuxtlas, Mexico, pastures, soil nutrients, tropical rain forest, stocking rate

RESUMEN

En la región de Los Tuxtlas, México los pastizales soportan una alta densidad de ganado (2,8 animales ha^{-1}). Para investigar las posibles causas de esto, se realizó un análisis del suelo superficial (10 cm) del bosque no perturbado, y potreros de 12 y 32 años de edad. Al igual que la mayoría de las localidades en el trópico húmedo, con el aumento de la edad del potrero el suelo presenta una reducción del pH, nitrógeno total, fósforo, sodio, calcio, ión hidrógeno, y capacidad de intercambio catiónico; sin embargo, los valores se mantuvieron altos, posiblemente debido a aportes relativamente recientes de material volcánico. Los suelos de los pastizales de 12 y 32 años, presentaron un pH_{H2O} casi neutro (7,2, 6,7) y una alta capacidad de intercambio catiónico de 22,8 y 17,2 $cmol_c$ kg^{-1} respectivamente. Resultaron relativamente ricos en nutrimentos tales como nitrógeno total (0,365, 0,4%), fósforo extraíble (12,1, 1,12 µg g^{-1}), y bases intercambiables (K^+, 1,23, 0,33; Na^+, 0,46, 0,31; Ca^{2+}, 13,8, 7,6; Mg^{2+}, 7,1, 8,1 $cmol_c$ kg^{-1}). La densidad aparente del suelo fue mayor en el pastizal de 32 años (1,0 g cm^{-3}). Probablemente debido a estas concentraciones altas de nutrientes, los potreros relativamente viejos de esta localidad soportan una elevada carga animal.

Palabras clave: cambio de uso de suelo, Los Tuxtlas, México, pastizales, nutrientes del suelo, selva húmeda tropical, coeficiente de agostadero

INTRODUCTION

In the Neotropics, pasture establishment is the main consequence of the loss of lowland rain forest. When forests are burnt biomass nutrients are added to the soil as carbonates in the ash raising pH and soil nutrient pools (Ewel *et al*. 1981, Uhl *et al*. 1983, Werner 1984, Richards 1996). On old nutrient-poor tropical soils, there is evidence that soils are unable to maintain livestock production indefinitely owing to erosion and leaching of mineral nutrients (Sanchez 1976, Buschbacher 1987a,b; Jordan 1989). Some N, C and S are volatilised (Nye and Greenland 1960) and newly added nutrients lost by erosion and leaching (Sanchez 1976, Ewel *et al.* 1981, Richards 1996). The low availability of N, P and K^+ may soon limit pasture production (Serrão 1978, Uhl *et al.* 1983, Jordan 1989, but see Eden *et al.* 1994).

Few authors refer to the change in soil nutrients concentrations with the time of use of the pasture. For nutrient-poor soils in the tropics, Bruce (1965) reported a decrease in total N in the upper 15 cm from 0.37% to 0.27% during 22 yr of pasture use in Australia. In Brazil, after forest clearing, soil extractable P, K^+, Ca^{2+}, and Mg^{2+} were higher in a pasture of 0.5 yr and less in one of 4.5 yr, whereas N remained high (Buschbacher 1987b, Buschbacher *et al.* 1987). In a semi-evergreen seasonal forest in Brazil, Falesi (1976) reported a steady increase of pH, K^+, Ca^{2+} and Mg^{2+} from a forest stand to a 13-yr pasture, while extractable P, which had its highest value in a 3-yr pasture, subsequently decreased with age. Al^{3+} decreased consistently with age. In nutrient-rich soils, conversion of forest to pastures in a volcanic soil in Costa Rica resulted in a decline in soil organic matter, pH, N, Ca^{2+}, and Mg^{2+} and an increase in Al^{3+} through time (Krebs 1975).

At Los Tuxtlas, southeastern México, pastures seem very productive. In South America animal production is generally low; one animal requires 5 to 25 ha of grassland, and 4 to 5 yr to attain a market-size weight of 400 to 450 kg (Sanchez 1976). Less than 0.5 cows ha^{-1} are common in Brazil (Eden *et al.* 1994). In few regions with Ultisols (*e.g.* Peru), a carrying capacity of one animal ha^{-1} is possible. In México average stocking rate in the humid tropics is 1.3 cows ha^{-1} (INIFAP 1999). At Los Tuxtlas, Barrera *et al.* (1993) indicated a stocking rate of 2.8 cows ha^{-1} and 2 yr are required on average to attain 400 kg of body weight.

The aim of this study was to analyse the soil physical and chemical properties of a tropical rain forest, and two pastures of 12-yr and 32-yr old, and to relate to cattle productivity.

STUDY SITE

The study was located in the State of Veracruz, México, in and around the Biological Station 'Estación de Biología Los Tuxtlas' (18° 34' - 18° 36' N, 95° 04' - 95° 09' W) (henceforth referred to as LT) which is a natural forest reserve belonging to the Universidad Nacional Autónoma de México. The LT is inserted into a mosaic of forest fragments and pastures of different ages established since the decade of 60's.

The Los Tuxtlas volcanic field (18° 11' - 18° 41' N, 94° 38' - 95° 26' W), including the highest volcano of San Martin Tuxtla (1650 m), lies over basaltic rocks erupted in two series. The older series dates from 1 and 3 million yr ago and the younger series from about 800,000 yr ago (Nelson and González-Caver 1992). There are considerable sampling problems associated with the selection of pastures for research. It is very difficult to find pastures which differ only in the age factor. Most of the LT lies on the younger series of basaltic rocks, and the 12-yr and 32-yr pastures on the older series. However, soil genesis and fertility may had been influenced by the relatively recent volcanic activity and the climate. The last eruptions of Volcán San Martin were in 1664 and 1793 (Friedlaender and Sander 1923 in Martin-Del Pozzo 1997). Eruptions have been mostly of the strombolian type, producing significant quantities of ash and a small volume of lava flows (Nelson and González-Caver 1992). Soils in the region are classified as well drained, coarse textured, vitric Andosols mixed with volcanic ash (FAO/UNESCO 1975).

Climatic data (> 2100 d) were available at LT (110 m altitude). The mean annual temperature is 25.1 ºC, with a mean maximum of 32.2 ºC (May) and a mean minimum of 18.7 ºC (January and February). Mean annual rainfall from 23 years data from 1972 to 1997 was 4,487 mm, being 157.4 rainless (0 mm) days per year on average. Evaporation at Sontecomapan (*c.* 10 km SE from the LT) from 1976 to 1997 had an annual mean of 1,390 mm.

The forest

The forest is a Tropical Lowland Evergreen Rain Forest with a canopy height of 30 - 35 m (Bongers *et al.* 1988). It has a relatively low species richness (81 species 0.75 ha^{-1}), low density (306 trees 0.75 ha^{-1}) and low basal area (24.9 m^2 0.75 ha^{-1}) for trees $\geq$ 10 cm dbh, and a preponderance of mesophyll leaves (Martínez-Sánchez 1999).

The pastures

Accurate information about the history of the Los Tuxtlas pastures is difficult to obtain while increasing in age and number of owners, but some was gleaned from the present owner Luis Juan Argüelles at Balzapote. The pasture sites were of a known history and of two times of use after forest clearance: 12, and *c*. 32 yr. *Cynodon plectostachyus* was planted and dominated along with the native species *Paspalum conjugatum* and *Hyptis atrorubens*. In the 32-yr pasture *Mimosa pudica* was conspicuous. Livestock was mostly a mixture of Swiss and Zebu races used for milk and beef production. Flat sections of the pastures are sometimes cultivated with crops depending on the wealth of the owner. No fertiliser was ever applied.

12-yr old pasture

The pasture was located between 1.5 and 2 km NE of the LT (Figure 1) on the SW side of a hilly terrain and was 15 ha in total. The forest was cut and burned in 1985. During 1985 and 1986 maize was grown and then left fallow from 1987 to 1989. In 1990 and 1991 more maize was obtained after burning the fallow and in 1992 the land was planted with grass. Overall, the site remained for 6 yr in cultivation and fallow, and for 6 yr as a pasture. Differences in soil nutrients between cultivation and fallow, and a pasture are difficult to assert, but in general, soil erosion, nutrient leaching and crop removal are greater in cultivation stands, then in pastures, and then in fallow sites owing to differences in plant cover. Given that the study site remained for similar periods of time in the extreme conditions of cultivation and fallow, it was considered that overall, the effects on nutrient concentrations were overweighed, and finally giving a no striking difference from being a pasture 12 years. Then the site has been referred to as a 12-yr pasture. Herbicides were used during maize cultivation. Cattle density in the pasture was between 1.0 (dry season) and 3.0 (wet season) animals ha^{-1}.

32-yr old pasture

The pasture was around 3.5 km N of the LT and *c*. 750 m from the rough road to Montepio (Figure 1). This pasture was 20-ha in size and located on a mostly level landscape at 30 m altitude. When the forest was cut and burned, the site was cultivated with maize for 2-3 years, and then left to pasture. One plot (see Methods) was cultivated with three-month lasting crops. One crop of peanuts (*Arachis hypogaea*) and another of chilli (*Capsicum annuum*) were harvested three times

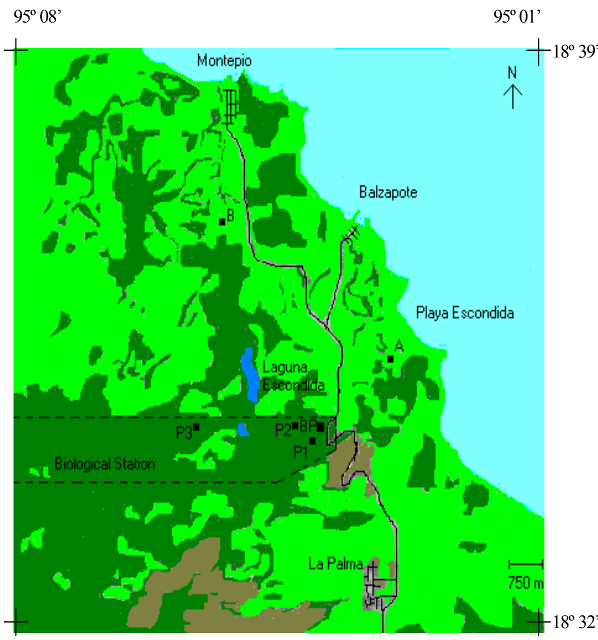

Figure 1. Location of forest plots (P1, P2, P3), 12-yr old pasture (A), and 32-yr old pasture (B). Forest (dark grey), pasture (light grey), rough road (solid line).

at 10-yr intervals, and two of peanuts and maize in the last five years. In the wet season an average of 2 to 3 t ha^{-1} of maize was obtained and about 700 - 800 kg ha^{-1} during 'winter'. The pasture has around 4.0 animals ha^{-1} in the rainy season (June to October) and 1.0 animal ha^{-1} in the dry, and 'winter' season (November to February) where *P. conjugatum* grows. Where *C. plectostachyus* is present, it has around 5.0 animals ha^{-1} in the rainy season and 2.0 to 3.0 animals ha^{-1} in the dry and 'winter' season. Cattle need 3 yr to reach the market weight of 380 - 600 kg depending on the race. Milk production was 3 - 4 l day^{-1} cow^{-1}.

METHODS

Three 50 x 50 m plots were placed in the undisturbed forest and in each of the pasture sites. The plots were placed on apparently representative areas of structure and composition in each of their vegetation types and easily to reach to. They were divided into 25 subplots (10 x 10 m) and the slope of the terrain was obtained at each intersection (36 measures per plot). The forest plots were located in the LT (Figure 1) at 120 - 200 m altitude with maximum slopes of 25° - 30°. Pasture site replication was impossible. In agreement with Hurlbert (1984) the plots were treated as statistically independent samples, relying on plot replicates within the same type of forest and pasture (pseudoreplication). In the 12-yr pasture, the plots were set up on a hill top (30° max. slope), steep slope (44°) and depression (23° max. slope). In the 32-yr pasture two plots were located on flattish ground (3° and 4° max. slope) and one on a small hill slope (24°).

During May and October 1996, ten soil samples (0 - 10 cm deep) were collected in a stratified random way in each of the nine plots for chemical and physical analyses, with a 8-cm diameter soil corer. For soil nutrient analyses, the samples were immediately air-dried and passed through a 1.2-mm mesh. Samples were kept in polythene bags at 20 °C until the laboratory analyses. Soil bulk density was calculated drying the samples at about 95 °C in the oven to a constant weight and then weighing to obtain the dry weight per unit volume (g cm^{-3}). During August 1997, soil profiles (- 110 cm) were described following the method of Siebe *et al*. (1996) which is mostly qualitative: three in the forest, and one in each pasture.

Soil analyses were made in the Instituto de Geología of the Universidad Nacional Autónoma de México. Analyses were all made in duplicate and checked with international standards. Soil texture was determined by a hydrometry technique (Bouyoucos 1963) and the soils were not completely dried according to the method for Andosols. For texture classification the United Kingdom system was used. The pH was determined in H_20 (1:2.5) and in a 1 M KCl (1:2.5) solution. For total N analyses the samples were digested with sulphuric acid, distilled in boric acid and determined by titration with 0.1 M sulphuric acid (the Kjeldahl method). P was extracted by 0.025 M HCl and 0.03 M NH_4F and determined by photocolorimetry at 660 mm. Exchangeable cations were extracted by 1 M ammonium acetate (pH 7) and by centrifugation for 5 min at 2500 rpm. Ca^{2+} and Mg^{2+} were determined by atomic absorption spectophotometry in 0.5% lanthanum chloride solution, and K^+ and Na^+ by flame photometry in a $CaCl_2$ solution. Exchangeable Al^{3+} and H^+ ions were determined by titration with 0.01 M NaOH in a solution of 1 M KCl. Cation exchange capacity (CEC) was assessed by the summation of exchangeable cations.

Statistical analyses were made with Minitab release 11.12. One-way ANOVA was applied. Log_e transformations were applied when necessary (Zar 1984). A Tukey means comparison test was applied to the ANOVA results. When data did not match the assumptions for a parametric test, a non-parametric Kruskal-Wallis test for three or more samples were used. In the latter, a Tukey medians comparison test was applied (Zar 1984).

RESULTS

The forest soil presented only two horizons, the 12-yr pasture, four, and the 32-yr pasture, three (Appendix). The forest soil had more stones (10% of the soil volume) than the 12-yr (0%) and 32-yr (1%) pastures. Subangular structure of the soil with weak to medium aggregations, and good density and size of pores predominated in the tree sites. The 32-yr pasture had the highest root density of the three sites, and was in the first horizon (Appendix). The forest soil was almost equally composed by silt, clay and sand, the 12-yr pasture had a major proportion of silt, and the 32-yr pasture a major proportion of silt and clay (Table 1). The soil of the forest had a lower (median = 0.75 g cm^{-3}) bulk density than the soil of the pastures where there were no changes with increasing age of the sites (Table 1). The forest soil had the highest values of total N, Na^+, Ca^{2+} and CEC. The soil of the 12-yr pasture had the highest values of pH, P and K^+, and the lowest values of N and Al^{3+}. The soil of the 32-yr pasture had the lowest values of pH, P, K^+, Na^+, Ca^{2+} and CEC, and the highest of Al^{3+}. Mg^{2+} did not show differences (Table 1).

DISCUSSION

The upper 10 cm of the soil at Los Tuxtlas have a texture composition sufficient to give good structural properties and high aggregate stability (Table 1). Scott (1978) mentioned that in the long term, grassland soils are likely to have less sand, similar silt, and more clay with increasing depth as a result of erosion and eluviation, and that soil compaction can also produce textural differences. At Los Tuxtlas soil bulk density in the forest was lower than in the pastures and did not increase with increasing age of the pasture. In an Ultisol, bulk density increased with pasture age (1.36 for 2 – 4 yr pastures, and 1.52 for 6 – 25 yr pastures) and were also higher than in the forest (1.20 g cm^{-3})

Table 1. One-way ANOVA (mean ± S.D.) and Kruskal-Wallis* (medians) tests for soil variables of the forest and pastures of different ages. *n* = 30 except where indicated between parenthesis. Different superscript letters indicate a significant difference within a row (Tukey test, p = 0.05).

	Forest	**12-yr old**	**32-yr old**
Bulk density (g cm^{-3})*	0.75 ^{a}	0.98 ^{b} (25)	1.00 ^{b}
Clay (%)	33.8 ^{ab} ± 9 (26)	28.3 ^{a} ± 9 (22)	36.6 ^{b} ± 9 (23)
Silt (%)	31.9 ^{a} ± 5 (26)	40.1 ^{b} ± 4 (22)	37.2 ^{b} ± 6 (23)
Sand (%)	34.3 ^{a} ± 8 (26)	31.5 ^{ab} ± 9 (22)	26.2 ^{b} ± 8 (23)
pH_{H2O} (1:2.5)	6.9 ^{a} ± 0.27	7.2 ^{b} ± 0.23	6.7 ^{c} ± 0.23
pH_{KCl} (1:2.5)	5.5 ^{a} ± 0.26	5.8 ^{b} ± 0.33	5.2 ^{c} ± 0.27
Total N (%) *	0.495 ^{a}	0.365 ^{b}	0.40 ^{b}
P (µg g^{-1})	4.1 ^{a} ± 3.1	12.1 ^{b} ± 10.5	1.12 ^{c} ± 0.74
K^{+} ($cmol_c$ kg^{-1}) *	0.51 ^{a}	1.23 ^{b}	0.33 ^{a}
Na^{+} ($cmol_c$ kg^{-1})	0.54 ^{a} ± 0.4	0.46 ^{a} ± 0.4	0.31 ^{b} ± 0.29
Ca^{2+} ($cmol_c$ kg^{-1})	14.2 ^{a} ± 4.1	13.8 ^{a} ± 3.1	7.6 ^{b} ± 2.2
Mg^{2+} ($cmol_c$ kg^{-1})	8.6 ^{a} ± 2.52	7.1 ^{a} ± 2.18	8.1 ^{a} ± 2.6
H^{+} ($cmol_c$ kg^{-1}) *	0.28 ^{a}	0.19 ^{b}	0.19 ^{b}
Al^{3+} ($cmol_c$ kg^{-1}) *	0.11 ^{a}	0.06 ^{b}	0.15 ^{a}
CEC ($cmol_c$ kg^{-1})	24.3 ^{a} ± 6.8	22.8 ^{a} ± 5.9	17.2 ^{b} ± 4.3

(Eden *et al.* 1994). In the primary forest, Reiners *et al.* (1994) found a lower soil density (0.69 g cm^{-3}) at 5-10 cm depth than in a 20-36 yr old pasture (0.84 g cm^{-3}) as a result of cattle soil compaction. Values for Los Tuxtlas pastures, measured in the wet season, were around 1.0 g cm^{-3}.

At Los Tuxtlas the soil pH in particular is high and the proximity to the sea does not seem to influence it, since surface pH and Na^{+} concentrations from the nearest pasture (12-yr) to the sea was not higher than in the most distant pasture (32-yr), and pH did not decrease consistently down through the soil profiles up to 1 m. Bongers *et al.* (1988) had previously determined a pH_{H2O} of 6.3 at a 15 cm depth in the same undisturbed forest.

Na^{+}, Ca^{2+} and CEC showed a steady decrease from the forest to the 32-yr pasture (Table 1). pH, total N and P also had higher values in the forest than in the 32-yr pasture; pH, P and K^{+} had their highest values in the 12-yr pasture, probably an aftermath of burning (Table 1). The trends were similar to those reported in similar young pastures in a nutrient-poor soil in Brazil (Falesi 1976) and in a nutrient-rich soil in Costa Rica (Krebs 1975). In contrast to the 32-yr pasture in Los Tuxtlas, Reiners *et al.* (1994) did not find lower pH, K^{+}, Na^{+} and Ca^{2+} until 36 years after forest conversion in Costa Rica with a mean rainfall of 3,962 mm. For Mg^{2+} values were similar in the forest and pasture in both locations. Similar to Krebs (1975), Al^{3+} increased with increasing age of pastures, and together with H^{+} showed opposite trends to P, K^{+}, and Ca^{2+}. Like most volcanic soils, Al^{3+} was in low concentrations in the pastures, giving a high pH and free P (Nye and Greenland 1960, León and Hammond 1985). Reiners *et al.* (1994) did not find differences in concentrations of Na^{+}, Ca^{2+}, and Mg^{2+} among a forest, two pastures within 20-31 yr old and one of 36-yr old in Costa Rica, but they found more K^{+} in the A horizon (0 - 15 cm depth) and a higher base saturation in the B horizon of the pastures than in the forest.

The decline of total N, P (after 12 yr), and

Table 2. Soil pH and nutrient concentrations (on a mass basis) in some tropical undisturbed forests (-, no data).

Location	Soil	Depth (cm)	pH_{H2O}	Total N(%)	Ext. P (µg g^{-1})	K^+ (meq $100g^{-1}$)	Na^+ (meq $100g^{-1}$)	Ca^{2+} (meq $100g^{-1}$)	Mg^{2+} (meq $100g^{-1}$)	CEC (meq $100g^{-1}$)	Author
Brazil	Grossaneric Paleudult	0-10	4.4	0.022	0	-	-	0.11	0.14	1.26	Nortcliff & Robinson (1989)
Costa Rica	Alluvial	0-10	4.5	0.40	3.6	0.22	0.13	0.75	0.35	7.0	Werner (1984)
Costa Rica	Entisol	0-15	3.7 [a]	-	2.2	0.17	0.11	1.09	0.29	34.3	Grieve *et al.* (1990)
Ghana	Ochrosol	0-23	6.5	-	-	0.36	-	8.48	1.9	12.04	Charter (1955)
Ghana	Oxisol-Ochrosol	0-23	5.3	-	-	0.26	-	4.02	1.0	9.5	Charter (1955)
Malaysia	Alluvial	0-10	4.4	0.54	-	0.24	0.08	5.3	0.53	38.0	Proctor *et al.* (1983)
Malaysia	Ultisol	0-10	4.1	0.51	-	0.25	0.06	0.04	0.18	37.0	Proctor *et al.* (1983)
México	Andosol	0-10	6.9	0.50	4.11	0.62	0.54	14.25	8.56	24.4	This study
Perú	Typic Paleudult	0-10	4.1	0.11	8.0	0.08	-	0.2	0.13	3.4	Alegre *et al.* (1988)
Venezuela	Oxisol	-	-	0.27	-	3.5	-	1.8	-	-	Uhl *et al.* (1983)

[a] pH_{CaCl2}.

exchangeable cations at Los Tuxtlas, may have several causes. The uptake by cattle and leaching explains decreasing cations in the pastures. Because of their lower leaf area than forest, pastures have less evapotranspiration and a larger fraction of the soil solution may be leached (Weischet and Caviedes 1993). A partial depletion of N is accounted for by the grasses. Grasses remove large quantities of N annually and cattle return 80% via excrement and urine (Vicente-Chandler *et al.* 1964), but only 40% of the original amount is incorporated into the soil owing to volatilisation and leaching (Parsons 1976).

At Los Tuxtlas, 12 years after forest conversion, it was still possible to see the effect of adding nutrients (P and K^+) from forest biomass, and then decreased, though not in a striking way. pH had high values, even in the 32-yr pasture. Similar to Reiners *et al.* (1994), the original nutrient input into pastures by deforestation may have been

Table 3. Soil nutrient pools (kg ha^{-1}) in tropical mature forests (-, no data).

Location	Soil	Depth (cm)	Total N	Ext. P	K^+	Na^+	Ca^{2+}	Mg^{2+}	Author
Brazil	Oxisol	-	1,300	50	100	-	600	200	Buschbacher *et al.* (1987)
Brazil	-	0-10	578	-	36	-	60	28	Thompson *et al.* (1992)
Malaysia	Alluvial	0-30	7,800	-	95	30	1,600	69	Proctor *et al.* (1983)
Malaysia	Ultisol	0-30	6,000	-	95	24	4.6	22	Proctor *et al.* (1983)
México	Andosol	0-10	3,750	3	18.2	9.3	427.5	156	This study
Venezuela	Ultisol	0-30	2,500	25	20	-	-	5	Buschbacher (1987b)
Venezuela	Oxisol	0-30	1,450	3	35	-	30	-	Saldarriaga (1987)
Venezuela	Oxisol	-	1,951	-	22.7	-	6.9	5.2	Jordan (1989)

Table 4. Soil pH and nutrient concentrations of some pastures of similar age and their original undisturbed forests in various tropical locations (-, no data).

Location	Site	Soil	Depth (cm)	pH_{H2O}	Total N (%)	Ext. P ($\mu g\ g^{-1}$)	K^+ ($cmol_c\ kg^{-1}$)	Na^+ ($cmol_c\ kg^{-1}$)	Ca^{2+} ($cmol_c\ kg^{-1}$)	Mg^{2+} ($cmol_c\ kg^{-1}$)	CEC ($cmol_c\ kg^{-1}$)	Author
Brazil	Pasture 6-25 yr	Ultisol	0-10	5.9	0.13	-	0.16	0.08	3.64	0.59	4.67	Eden *et al*. (1994)
México	Pasture 32-yr	Andosol	0-10	6.7	0.40	1.12	0.33	0.31	7.6	8.1	17.2	This study
Costa Rica	Pasture 36-yr	Ultisol	0-15	4.2	-	-	0.6	0.2	0.7	0.6	2.1	Reiners *et al*. (1994)
Brazil	Forest	Ultisol	0-10	5.4	0.16	3.8	0.13	0.03	2.63	1.57	5.0	Eden *et al*. (1994)
Costa Rica	Forest	Ultisol	0-10	3.5	-	-	0.1	0.1	0.5	0.6	1.3	Reiners *et al*. (1994)
México	Forest	Andosol	0-10	6.9	0.50	4.11	0.62	0.54	14.25	8.56	24.4	This study

sufficient to maintain higher pH and nutrient concentrations even in relatively old pastures. The pastures had a higher soil bulk density than the forest, thus reducing infiltration and nutrient leaching.

Comparison of Los Tuxtlas soil with the soil from other locations elsewhere

Most tropical forests around the world and particularly from South America have nutrient-poor soils (Nye and Greenland 1960, Sanchez 1976, Richards 1996). Proctor *et al.* (1983) listed soil characteristics from different soil types from a range of tropical rain forests around the world (Malaysia, Australia, Ghana, Venezuela, Peru and Brazil). Values ranged as follows: pH (3.0 - 6.6), total N (0.02 – 1%), K^+ (0.03 - 1.6 $cmol_c\ kg^{-1}$), Na^+ (0 - 0.57 $cmol_c\ kg^{-1}$), Ca^{2+} (0 – 29 $cmol_c\ kg^{-1}$), Mg^{2+} (0 - 4.6 $cmol_c\ kg^{-1}$), and CEC (2.5 – 43 $cmol_c\ kg^{-1}$). From these ranges and Table 2 it is possible to see that Los Tuxtlas values are in the mid and high ranges, with pH and Mg^{2+} being the highest values. Table 3 shows that the amount of soil nutrients at Los Tuxtlas when expressed on a volume basis are also in the high range. pH and nutrient concentrations of the pastures soils at Los Tuxtlas are also high (Table 4). Owing to the soil type, soils occupied by pastures for about 32 yr are more fertile at Los Tuxtlas than at Costa Rica and Brazil (Table 4).

In the southern state of Tabasco, on low to medium fertility soils like Gleysol, Acrisol, Fluvisol, Luvisol and Vertisol, average stocking rate is 1 – 2.5 cows ha^{-1} depending on the type of grass and grazing management (INIFAP 1998). Recommended stocking rate is 1.0 cows ha^{-1}. Most Amazon pastures are only productive for 4 to 8 yr (Serrão and Homma 1982), whereas at Los Tuxtlas it is possible to have 3.0 to 4.0 animals ha^{-1} for more than 50 yr with moderate fertilisation in a flat terrain (Martínez-Sánchez 1999). On native savannas in Brazil, annual live weight gains are in the order of 20 to 50 kg ha^{-1}; 100 to 300 kg ha^{-1}, on improved grass-legume mixtures with minimum fertiliser inputs; and 500 to over 1000 kg ha^{-1}, on intensively fertilised pastures (Sanchez 1976). At Los Tuxtlas, cattle production is about 400 to 800 kg ha^{-1} yr^{-1} with no fertilisation.

As Baillie (1996) mentioned, pastures appear to be viable in the long term only on fertile soils like Andosols, clays over limestones and alluvial soils. It is necessary to analyse more pastures of different ages to estimate how long the nutrients could remain high in the pastures under the traditional management at Los Tuxtlas, but a 52-yr pasture studied by Martínez-Sánchez (1999) showed that with moderate fertilisation it can be kept at a high level of production. Further investigations are necessary at this location to see if the nutrient-rich soils are really productive in grass and animal biomass.

CONCLUSIONS

Pastures in the neotropics at Los Tuxtlas, México, were found to support a high density of cattle. Similarly to other locations elsewhere, pH, total nitrogen, phosphorus, sodium, calcium, hydrogen ion, and cation exchange capacity of the soil, decreased with increasing time of use of the pastures, but were all high. It seems that the local volcanic eruptions, the higher soil compaction in pastures, the high CEC which counteracts nutrient leaching (Bouwman 1990), and perhaps the high root density (Appendix), could be the main factors maintaining high soil nutrient concentrations and hence cattle production at this location.

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Appendix. Description of three typical soil profiles at Los Tuxtlas, following Siebe *et al*. (1996).

		Profile		
	Horizon	Forest	12-yr pasture	32-yr pasture
Depth (cm)	1	0 – 50	0 - 30	0 – 15
	2	50 – 120	30 – 60	15 – 30
	3		60 - 90	30 – 100
	4		90 - 120	
Texture	1	Clay loam	Silty clay loam	Clay loam
	2	Sandy clay	Silty clay loam	Clay loam
	3		Silty clay loam	Sandy clay
	4		Sandy clay	
Color (wet)	1	7.5 YR 3/2	10 YR 2/1	7.5 YR 3/2
	2	7.5 YR 3/4	5 Y 3/1	7.5 YR 3/3
	3		2.5 Y 4/2, 5 Y 3/1	5 YR 3/3
	4		5 Y 3/1	
Stones (mm)	1	10% (>20 - 63)	1% (>20 - 63)	1% (>63 - 200)
	2	5% (>20 - 63)	0%	1% (>63 - 200)
	3		0%	1% (>6.3 - 20)
	4		0%	
Structure	1	Subangular in medium blocks with weak aggregation	Subangular in medium blocks with weak aggregation	Granular in small blocks with weak aggregation
	2	Subangular in medium blocks and medium aggregation	Subangular in medium blocks and medium aggregation	Subangular in small blocks and weak aggregation
	3		Subangular in small blocks and weak aggregation	Subangular in small blocks and weak aggregation
	4		Subangular in medium blocks and strong aggregation	
Pores (shape, abundance, size)	1	Vesicular, 51 - 200 dm^{-2}, 0.075 - 1 mm	Vesicular, 51 - 200 dm^{-2}, 0.075 - 1 mm	Vesicular, 51 - 200 dm^{-2}, 0.075 - 1 mm
	2	Vesicular, 1 - 51 dm^{-2}, 0.075 - 1 mm	Vesicular, 51 - 200 dm^{-2}, 0.075 - 1 mm	Vesicular, 1 - 51 dm^{-2}, 0.075 - 1 mm
	3		Vesicular, 1 - 51 dm^{-2}, 0.075 - 1 mm	Vesicular, 1 - 51 dm^{-2}, 0.075 - 1 mm
	4		Vesicular, 1 - 51 dm^{-2}, 0.075 - 1 mm	
Roots (< 2 mm diam.) density (dm^{-2})	1	6 – 20	11 – 20	20 -50
	2	6 – 10	6 – 20	6 - 10
	3		6 – 10	1