# SOIL RESPONSES TO RESTORATION OF A TROPICAL PASTURE IN VERACRUZ, SOUTH-EASTERN MEXICO

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**TOBÓN W, MARTÍNEZ-GARZA C & CAMPO J. 2011. Soil responses to restoration of a tropical pasture in Veracruz, south-eastern Mexico.** Investigations were carried out on litter nitrogen (N) and phosphorus (P), and soil carbon (C), N and P in an active pasture, a mature tropical rainforest, and two treatments of restoration (cattle exclusion alone and combined with planting of tree seedling) in Veracruz, Mexico. The aim was to outline how the two treatments of restoration affect the recovery of soil nutrient status in the short-term (one year). Thirty years of cattle ranching activities decreased the litter N and P pools by a factor of 72 in the former and 31 in the latter, largely reflecting differences in litter mass between pasture and mature forest. Pasture soils consistently had lower pools of organic C and total N and ammonium ($NH_4^+$) than forest soils. However, landuse did not affect the pool of soil nitrate ($NO_3^-$), and total and extractable P. Exclusion of grazing and exclusion of grazing plus planted tree seedlings increased N and P pools in the litter. In contrast, restoration treatments did not consistently affect soil C, N and P. The main response to restoration practices was a decrease of $NO_3^-$ and extractable P pools in soils. Overall, we observed that, subsequent to these practices, there were significant changes in the recovery of nutrient pools reaching levels similar to tropical forest soil.

Keywords: Soil fertility, soil restoration, tropical rainforest, cattle ranching, grazing

**TOBÓN W, MARTÍNEZ-GARZA C & CAMPO J. 2011. Gerak balas tanah terhadap pemulihan padang rumput tropika di Veracruz, tenggara Mexico.** Kajian dijalankan terhadap kandungan nitrogen (N) dan fosforus (P) sarap, serta kandungan karbon (C), N dan P tanah di sebuah padang rumput aktif, sebuah hutan hujan tropika yang matang dan dua rawatan pemulihan (satu melibatkan penyisihan lembu sahaja dan yang satu lagi digabungkan dengan penanaman anak pokok) di Veracruz, Mexico. Tujuannya adalah untuk melihat kesan amalan rawatan ini terhadap pemulihan status nutrien tanah dalam jangka masa pendek iaitu setahun. Aktiviti ternakan lembu selama 30 tahun mengurangkan kandungan takungan N dan P sarap masing-masing sebanyak faktor 72 dan 31. Ini jelas menunjukkan perbezaan antara padang rumput dengan hutan matang. Tanah padang rumput sentiasa mempunyai takungan C organik, jumlah N dan jumlah amonium ($NH_4^+$) yang lebih rendah berbanding tanah hutan. Bagaimanapun penggunaan tanah tidak memberi kesan terhadap takungan nitrat ($NO_3^-$) tanah, jumlah P dan jumlah P boleh ekstrak. Penyisihan aktiviti ragut serta gabungan penyisihan aktiviti ragut dengan penanaman anak pokok meningkatkan takungan N dan P dalam sarap. Sebaliknya, rawatan pemulihan tidak sentiasa memberi kesan terhadap kandungan C, N dan P tanah. Gerak balas utama dalam amalan pemulihan ialah pengurangan takungan $NO_3^-$ serta P boleh ekstrak dalam tanah. Secara keseluruhan, amalan ini menyebabkan perubahan signifikan dalam takungan nutrien yang menunjukkan pemulihan yang menyamai aras di tanah hutan tropika.

## INTRODUCTION

Tropical forests contain about 25% of the carbon available in terrestrial biosphere and account for roughly 33% of terrestrial annual C fixation (Sabine et al. 2004). The loss of tropical natural forests worldwide in the 1990s reached 152 000 $km^2$ $year^{-1}$ (Hassan et al. 2005). Clearing of tropical forests for agricultural expansion is the main cause of deforestation (Geist & Lambin 2002) and it is responsible for 12 to 26% of the total emission of carbon dioxide ($CO_2$) to the atmosphere (Houghton 2003). Agricultural expansion includes shifting cultivation, permanent agriculture and pasture creation for cattle ranching. Although there is considerable regional variation in the kinds of agricultural expansion affecting tropical forests, pasture creation for cattle ranching is the major direct driver of forest loss in Latin America (Ramankutty et al. 2008). A large proportion

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of these grazing lands have been degraded by excessive disturbance, erosion, loss of organic matter and other processes.

Tropical ecosystems of Mexico showed one of the highest deforestation rates in the world (FAO 2007); deforestation rate was 2.6% between 1976 and 1993, and 1.3% between 1993 and 2002 (Challenger & Dirzo 2009). In the state of Veracruz for example, only 20% of the original tropical rainforest area remains; the majority of the area was converted for planting of food crops or cattle ranching (Masera et al. 1997). Pastures for livestock area increased threefold from 15 000 km$^2$ in 1940 to 45 000 km$^2$ in 1990 (Dirzo & García 1992). Unfortunately, overgrazing is one of the most significant factors that contribute to elevated rates of deforestation and soil erosion, producing further effects on global biogeochemistry (Neill et al. 2001).

The presence of livestock reduces the aboveground biomass and incorporation of organic matter into the soil but increases the density of soil (Feldpausch et al. 2004). This increase in soil density in turn affects the stability of soil aggregates (Lal 1996) and decreases water infiltration (Trimble & Mendel 1995) and soil fertility (Buschbacher et al. 1988).

The change in landuse from tropical rainforest to pasture for cattle ranching limits the incorporation of organic matter into the soil, which causes negative effects on the cycling of carbon (C). In contrast, the presence of cattle raises the amount of nitrogen (N) and phosphorus (P) extractable for plants, reducing the C:N ratio of soil organic matter (SOM) and improving its mineralisation and the release of nutrients (Singer & Schoenecker 2003). However, increased nutrient concentration in the soil solution raises nutrient leaching, which is augmented especially in humid ecosystems, as plants cannot compensate their nutrient assimilation rates to the elevated nutrient income (Matson et al. 1987).

The reduction of soil fertility and changes in the biogeochemical cycles caused by livestock limit the establishment and growth of vegetation (McLauchlan 2006). Thus, ecological restoration is often associated with the exclusion of livestock which may improve the quantity and quality of plant biomass, SOM and nutrients. Also restoration favours the recovery of soil physical properties; this recovery assists the establishment and development of vegetation in disturbed areas. Often, storage of C and nutrients can be restored by reforestation (Post & Kwon 2000) or nutrient manipulation (Gamboa et al. 2010). In addition, the introduction of native plants is a useful strategy for the restoration of the ecosystem structure and function (Singh et al. 2002).

In this study, we report the effects of the change in landuse based on comparisons between soil properties of a tropical rain forest and cattle pasture in Veracruz, Mexico. We evaluated short-term effects of cattle exclusion and the introduction of native species in the active pasture, which was adjacent to the mature forest. Our goal was to understand how restoration practices affect the soil nutrient status in one year. Finally, we compared soil properties of the areas to establish suitable baselines for examination of restoration success.

## MATERIALS AND METHODS

### Study area

The study was conducted for one year from mid-October 2006 till mid-October 2007 in a 12-ha active pasture in the agricultural colony of Adolfo Ruíz Cortinez (18° 30' and 18° 40' N, 95° 03' and 95° 10' W) located just east of the Los Tuxtlas Biological Station (LTBS) in the Los Tuxtlas Biosphere Reserve in the state of Veracruz, south-east Mexico. Los Tuxtlas Biosphere Reserve is covered with highly diverse lowland tropical rainforest. The forest has a closed canopy about 35 m high. *Nectandra ambigens* (Lauraceae) is the most common species in the canopy, while *Pseudolmedia oxyphyllaria* (Moraceae) and *Astrocaryum mexicanum* (Arecaceae) are most common in the mid-canopy and understorey respectively (Bongers et al. 1988).

Annual mean temperature is 27 °C and annual mean precipitation is 4900 mm. The region receives more than 90% of annual rainfall during the rainy season between June and February. Soil parent material in LTBS is determined by the past activity of the San Martín volcano. The altitude of the area ranges from 150 to 530 m and its topography is mountainous with 10 to 30% of slopes.

Soils in the study region are classified as Entisols, from typic ustorthents to lithic ustorthents. Soil depth (lithic contact) vary from 50–60 cm in upper and medium slope positions to 105 cm in lower slope position. Rocks (as % of soil volume) range from 25–40% in the upper 20 cm of soil profile to 80–92% in the 20–50 cm depth; in more deeper portion of the profile (50–100 cm), rock contents are about 80%. Soil pH ranges from 5.6 to 5.9 and its clay contents are 14–18%, silt 14–22% and sand 62–72%. Soil organic C (SOC) is concentrated in the upper 5 cm soil profile (roughly 30% of the total soil C in 1 m depth) and ranges from 30 to 50 g C $kg^{-1}$ soil. Soil cation exchange capacity values range from 9 to 22 $cmol_{(+)}$ $kg^{-1}$ in upper and medium slopes, and from 21 to 33 $cmol_{(+)}$ $kg^{-1}$ in lower slope (Sommer-Cervantes et al. 2003).

The study site is a hillside gradient from 180 to 260 m above sea level (asl) in a broad valley facing north-east to the Gulf of Mexico. Forest at the site was cleared more than 30 years ago. The remaining vegetation was burned and corn was planted for one season together with exotic (*Cynodon plectostachyus*, *C. dactylon*, *Brachiaria decumbens* and *B. brizantha*) and native (*Axonopus compressus*, *Panicum* spp., *Paspalum conjugatum*) grasses. Herbicides were applied every three months in the first year and later, as often as necessary. Due to the decrease in productivity of grasses, stocking rates decreased from three to two cows $ha^{-1}$ (M de la Peña, personal communication).

## Plot layout

In the active pasture area, a 3 × 8 grid of 24 fenced plots (30 × 30 m with 35-m wide buffer spaces between them) were established between August and October 2006. The plots were within 500 to 1200 m to the edge of the LTBS. Sixteen plots (i.e. upper, middle and lower parts of the slope) were planted with 24 native trees species in September 2006. Details of this plantation plots are reported in Martínez-Garza et al. (2011). The other eight plots along the slope were maintained as control plots, i.e. with cattle exclusion and without trees planted. Another 24 plots were established in the closest mature rainforest 90 m from the south-west corner of the grid, also along the slope.

## Soil sampling and analysis

Soil samples were collected from the active pasture and mature forest in October 2006 (one-month after plantations were established; n = 24 plots each) and October 2007 (n = 8 each). Four samples each were taken from the litter layer and superficial soil (0–5 cm depth) of each plot and their properties were evaluated. Soil properties were also investigated and for this purpose, three samples of litter and soils were taken from three slope positions, namely, upper (260 m asl), medium (220 m asl) and lower (180 m asl) in October 2006. Prior to analysis, soil samples were air dried and sieved (2-mm mesh). The fine fraction was used to determine concentrations of SOC, total and mineral N (i.e. $NO_3^- + NH_4^+$), and total and extractable P. Soil organic C was analysed using an automated C-analyser. Mineral N was extracted using 2 M potassium chloride (Robertson et al. 1999) and extractable P, using Bray solution (Lajtha et al. 1999). Nitrogen and P concentrations were determined using the NP elemental analyser. All concentrations were transformed into area units (kg $ha^{-1}$) according to the bulk density of each plot from each landuse or treatment.

## Statistical analysis

An ANOVA was used to determine differences between lower, medium and upper plots at the pasture site. Non-parametric Kruskall-Wallis analysis was used to determine differences between the pasture and the mature forest. A second ANOVA was run with three categories of sites, comparing the active pasture, planted plots and control plots. Soil chemistry differences in 2007 were evaluated to determine variations in soil chemistry across the different treatments in 2006. Analysis of normality of variance for all ANOVAs was done with a Shapiro-Wilk test. In all ANOVAs, where significant differences ($p < 0.05$) were found, further analyses of differences were evaluated using a post hoc Tukey's (HSD) test. All statistical analyses were performed with STATISTICA 7.0.

# RESULTS

## Topographic effects on pasture soils

Litter mass and its N and P concentrations and pools were very consistent along the slope (Table 1). In addition, SOC, total N, $NO_3^-$, $NH_4^+$ and total P pools did not show significant differences along slopes. However, soils from lower plots had the greatest pools of extractable P among this set of slope positions.

**Table 1** Litter nitrogen and phosphorus concentrations and pools, and soil organic carbon, nitrogen and phosphorus pools along a slope of an active pasture in Los Tuxtlas, Mexico

| Nutrient | Upper plot 260 m asl | Medium plot 220 m asl | Lower plot 180 m asl | F | p |
|---|---|---|---|---|---|
| Litter | | | | | |
| Dry mass (kg $ha^{-1}$) | 34.6 ± 4.8 a | 37.8 ± 4.1 a | 59.6 ± 10.6 a | 1.98 | 0.161 |
| N (mg $g^{-1}$) | 1.51 ± 0.11 a | 1.59 ± 0.17 a | 1.42 ± 0.13 a | 0.36 | 0.700 |
| P (mg $g^{-1}$) | 0.83 ± 0.12 a | 0.99 ± 0.16 a | 0.79 ± 0.11 a | 1.01 | 0.352 |
| N (g $ha^{-1}$) | 52.2 ± 7.8 a | 60.1 ± 7.1 a | 84.6 ± 18.0 a | 1.10 | 0.381 |
| P (g $ha^{-1}$) | 28.7 ± 4.9 a | 37.4 ± 4.8 a | 47.1 ± 10.7 a | 0.58 | 0.573 |
| Soil | | | | | |
| Organic C (Mg $ha^{-1}$) | 17.9 ± 1.1 a | 18.2 ± 0.7 a | 16.8 ± 1.5 a | 0.59 | 0.562 |
| Total N (Mg $ha^{-1}$) | 1.60 ± 0.09 a | 1.64 ± 0.11 a | 1.42 ± 0.11 a | 1.70 | 0.211 |
| C:N | 12 ± 0.6 a | 11 ± 0.4 a | 12 ± 0.5 a | 1.26 | 0.303 |
| $NO_3^-$ (kg $ha^{-1}$) | 9.06 ± 0.53 a | 7.96 ± 0.55 a | 8.34 ± 1.71 a | 0.68 | 0.525 |
| $NH_4^+$ (kg $ha^{-1}$) | 1.23 ± 0.22 a | 1.75 ± 0.17 a | 1.66 ± 0.39 a | 2.11 | 0.141 |
| $NO_3^-$:$NH_4^+$ | 7.4 ± 1.8 a | 4.6 ± 0.4 a | 5.0 ± 0.7 a | 2.03 | 0.123 |
| Total P (kg $ha^{-1}$) | 108 ± 10 a | 110 ± 6 a | 112 ± 6 a | 0.43 | 0.523 |
| Extractable P (kg $ha^{-1}$) | 2.19 ± 0.19 b | 2.18 ± 0.17 b | 2.62 ± 0.09 a | 5.29 | 0.014 |

All values are averages of three replicates ± 1 SE; within rows, different letters indicate significant difference ($p < 0.05$); F and p are ANOVA test and probability values respectively.

## Landuse effects

Thirty years of cattle ranching activities significantly altered nutrient concentrations and pools in the litter (Table 2). Active pasture showed 61 times less litter mass compared with mature forest. In addition, changes in landuse significantly increased litter P concentration but not N. Litter N and P pools differed considerably between active pasture and mature forest (by a factor of 72 in the case of N and 30 for P), largely reflecting differences in litter mass. Pasture soils had lower pools of SOC, total N and $NH_4^+$ than mature forest soils. However, landuse did not significantly affect the pools of soil $NO_3^-$ and total and extractable P.

## Effects of restoration activities

Litter mass also showed differences between active pasture and treatments of restoration (Table 3). Both exclusion of grazing alone and combined with planting of tree seedlings increased the litter mass by twofold compared with the active pasture. These restoration activities (i.e. exclusion of grazing alone and combined with plantations) increased the concentration of N in the litter compared with the active pasture but the treatments did not have any effect on litter P concentration. Nitrogen and P pools in the litter were greater in the control and planted plots than in active pasture plots. Planted and control plots constituted a statistically homogeneous group (i.e. without significant differences between them, $p > 0.05$) in litter mass, nutrient concentrations and nutrient pools.

Restoration practices did not affect the SOC, total N and total P contents in the soil in this short-term study (Table 3). However, soil C:N ratio decreased in plots with tree seedling plantations compared with active pasture. Cattle exclusion (alone or combined with tree seedling plantations) consistently decreased soil $NO_3^-$ and extractable P pools relative to active pasture plots but did not have significant effects on soil $NH_4^+$ pool and $NO_3^-$:$NH_4^+$ ratio.

# DISCUSSION

## Landuse effects

Future deforestation is estimated to remain high in the tropics in the short and long terms (Satahaye et al. 2007). Its effects on tropical

**Table 2** Litter nitrogen and phosphorus concentrations and pools, and soil organic carbon, nitrogen and phosphorus pools under pasture and mature forest in Los Tuxtlas, Mexico

| Nutrient | Active pasture | Mature forest | H | p |
|---|---|---|---|---|
| Litter | | | | |
| Dry mass (kg $ha^{-1}$) | 24.9 ± 3.2 b | 1530.3 ± 152.0 a | 12.1 | < 0.001 |
| N (mg $g^{-1}$) | 1.49 ± 0.04 a | 1.75 ± 0.05 a | 3.81 | 0.051 |
| P (mg $g^{-1}$) | 0.73 ± 0.06 a | 0.42 ± 0.06 b | 4.11 | 0.043 |
| N (g $ha^{-1}$) | 37.3 ± 4.8 b | 2677.1 ± 265.7 a | 11.9 | < 0.001 |
| P (g $ha^{-1}$) | 18.4 ± 3.5 b | 556.5 ± 60.1 a | 12.0 | < 0.001 |
| Soil | | | | |
| Organic C (Mg $ha^{-1}$) | 18.7 ± 0.7 b | 56.6 ± 6.2 a | 13.4 | < 0.001 |
| Total N (Mg $ha^{-1}$) | 1.35 ± 0.03 b | 3.17 ± 0.33 a | 13.5 | < 0.001 |
| C:N | 14 ± 0.3 b | 19 ± 3.0 a | 4.17 | 0.041 |
| $NO_3^-$ (kg $ha^{-1}$) | 4.32 ± 0.21 a | 4.45 ± 0.29 a | 0.72 | 0.412 |
| $NH_4^+$ (kg $ha^{-1}$) | 2.87 ± 0.23 b | 6.25 ± 1.12 a | 7.00 | 0.011 |
| $NO_3^-$:$NH_4^+$ | 1.7 ± 0.1 a | 0.7 ± 0.2 b | 5.49 | 0.019 |
| Total P (kg $ha^{-1}$) | 116 ± 9 a | 148 ± 34 a | 0.76 | 0.414 |
| Extractable P (kg $ha^{-1}$) | 3.77 ± 0.19 a | 4.00 ± 0.53 a | 0.98 | 0.331 |

All values are average of 24 replicates ± 1 SE; within rows, different letters indicate significant difference ($p < 0.05$); H and p are Kruskall and Wallis non-parametric test and probability values respectively.

ecosystems show great spatial and temporal variabilities depending on soil characteristics, weather conditions, elevation, topographic position and landuse history.

Our study showed that the change in landuse from mature rainforest to active pasture affected the litter accumulation which caused changes in litter nutrient pools and soil nutrient cycling. In addition, changes in landuse also decreased SOC and total N pools. As a consequence of losses in aerial biomass and litter accumulation, the pasture site could be more vulnerable to soil erosion, leading to predictable patterns of impoverishment in soil fertility.

## Effects of restoration activities

Despite biogeochemical variation in soils of Los Tuxtlas (Table 1), restoration treatments generated responses in terms of dynamics of litter and soil N and P pools that indicated nutrient cycling changes in the direction towards its characteristics in natural tropical rainforest (e.g. in litter stoichiometry). The mean N:P mass ratio in litter increased from 1.4 in active pasture to 1.8 in control and planted plots (Table 3). In spite of this trend, N:P ratios for litter in both restoration plots were low in comparison with the value obtained in litter from mature forest (N:P = 4.2; Table 2). N:P values obtained in this study were very low compared with reported mean stoichiometric ratio for senesced litter in tropical forests worldwide (N:P = 28; McGroddy et al. 2004) and balanced plant nutrient requirements (N:P = 9–14; Koerselman & Meuleman 1996). These differences suggested that P was the limitation factor for the productivity of plants (grasses and trees) at Los Tuxtlas. This hypothesis that tropical rainforest and pasture land are P-limited systems can be verified with a study of primary production at the ecosystem level, analysing the way in which P-limited forest and active pasture respond to a release of such limitation (i.e. by an experimental increase in soil P availability).

The exclusion of cattle increased the accumulation of litter (i.e. organic horizon layer) by three times as a consequence of the lack of grazing. In contrast, the exclusion of cattle did not affect the SOC pool. Without nutrient fertilisation, restoration of SOC levels can only be expected in the long term but not in the short term (Gamboa et al. 2010).

## CONCLUSIONS

Changes in landuse in the tropical rainforest region of Veracruz, Mexico allowed us to conclude that N and P cycles in the soil were markedly

**Table 3** Litter nitrogen and phosphorus concentrations and pools, and soil organic carbon, nitrogen and phosphorus pools in active pasture, planted (cattle exclusion combined with mixed seedling plantations) and control plots (cattle exclusion alone) in Los Tuxtlas, Mexico

| Nutrient | Active pasture plot | Planted plot | Control plot | F | p |
|---|---|---|---|---|---|
| Litter | | | | | |
| Dry mass (kg ha$^{-1}$) | 21.9 ± 4.6 b | 55.3 ± 8.9 a | 53.5 ± 7.5 a | 12.9 | 0.003 |
| N (mg g$^{-1}$) | 1.19 ± 0.02 b | 1.58 ± 0.08 a | 1.60 ± 0.08 a | 7.75 | 0.018 |
| P (mg g$^{-1}$) | 0.87 ± 0.13 a | 0.85 ± 0.08 a | 0.90 ± 0.07 a | 0.14 | 0.948 |
| N (g ha$^{-1}$) | 26.0 ± 5.8 b | 87.4 ± 15.7 a | 85.6 ± 10.5 a | 80.4 | < 0.001 |
| P (g ha$^{-1}$) | 19.0 ± 3.1 b | 47.0 ± 9.3 a | 48.1 ± 9.4 a | 70.1 | < 0.001 |
| Soil | | | | | |
| Organic C (Mg ha$^{-1}$) | 18.1 ± 1.0 a | 17.5 ± 0.6 a | 17.9 ± 2.5 a | 0.27 | 0.615 |
| Total N (Mg ha$^{-1}$) | 1.45 ± 0.07 a | 1.62 ± 0.07 a | 1.55 ± 0.04 a | 1.27 | 0.273 |
| C:N | 13 ± 0.4 a | 11 ± 0.2 b | 12 ± 0.3 ab | 6.75 | 0.017 |
| $NO_3^-$ (kg ha$^{-1}$) | 10.46 ± 0.74 a | 8.16 ± 0.25 b | 7.33 ± 0.53 b | 16.4 | < 0.001 |
| $NH_4^+$(kg ha$^{-1}$) | 1.87 ± 0.27 a | 1.42± 0.16 a | 1.56 ± 0.32 a | 2.99 | 0.099 |
| $NO_3^-$:$NH_4^+$ | 5.6 ± 0.7 a | 5.3 ± 0.3 a | 4.9 ± 0.6 a | 0.46 | 0.508 |
| Total P (kg ha$^{-1}$) | 120 ± 13 a | 116 ± 7 a | 113 ± 11 a | 0.35 | 0.561 |
| Extractable P (kg ha$^{-1}$) | 3.21 ± 0.13 a | 1.98 ± 0.07 b | 2.23 ± 0.16 b | 16.4 | < 0.001 |

All values are averages of eight replicates ± 1 SE; within rows, different letters indicate significant difference (p < 0.05); F and p are ANOVA test and probability values respectively.

affected by deforestation for cattle ranching. Our study also suggested that exclusion of cattle or its exclusion combined with mixed seedling plantations might serve as important practices for short-term restoration of biogeochemical cycles in the soil. Overall, we observed that, subsequent to these practices, there were significant changes in the recovery of nutrient pools reaching levels similar to tropical forest soil.

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