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Effects of land-use change on some properties of tropical soils — An example from Southeast Mexico

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ABSTRACT

We studied the effects of land-use and land-cover changes on physical and chemical properties of soil in tropical South-East Mexico. In the study area of about 5500 km^2, the dominant land use is pastureland (Pa seasonal agriculture (TA), fruit plantations (FP), sugarcane, (SC) secondary (SF) and primary forest (PF) and other not specified land-use types (undefined). From 1988 to 2003 severe deforestation took place and pastureland increased by 179% while primary forest decreased to 17% of the initial area.
Based on topographic and soil maps we selected 176 sampling sites covering the combinations of topography and soil type. In 2005, we took soil samples in each selected site from two soil depths (0–20 cm and 20–40 cm). We analyzed fertility parameters like pH, texture and contents of organic carbon, total nitrogen and available phosphorus. Furthermore, we measured soil resistance against penetration in layers of 5 cm down to a depth of 40 cm. We estimated land-use changes between 1988 and 2005 using digital land-use maps derived from satellite and aerial photography interpretation. We compared soil properties of different soil types, soils under different current land use and under the influence of land-cover changes.
Gleysols, Vertisols, Regosols, Luvisols and Leptosols showed clay to clay loam texture, whereas Cambisols were characterized by sandy clay loam texture. All soil groups in the study region were slightly acidic with pH (KCl) values between 5.3 and 6.2. Furthermore, they neither showed significant differences in available P content nor in C/N ratio. However, the investigated soil associations displayed different organic carbon and total nitrogen contents in the upper 20 cm depth.
Soils under different current land use did not show any significant differences with respect to available phosphorus, organic carbon, total nitrogen and C/N ratio whereas the pH value was significantly higher under seasonal agriculture than under pasture.
Land-use changes between 1988 and 2003 did not significantly influence the contents of available phosphorus and organic carbon or the C/N ratio. However, total nitrogen was significantly higher in soils which were changed from forest in 1988 to seasonal agriculture in 2003 (F-TA) than in soils changed from forest to pastureland (F-Pa) or from pasture to forestland (Pa-F). Furthermore, soils under land-use change F-TA were less acidic in both depths than soils under Pa-F, TA-Pa, or which remained pastureland over the whole time (Pa-Pa).
Soils in pastureland were significantly more compacted in all layers than soils used for seasonal agriculture. Soils that were used for pastureland already in 1988 showed significantly higher compaction than most of the other soils.
We conclude that land-use change in a period of 15 years did not lead to chemical soil degradation. However, permanent pastureland leads to a severe compaction of soils.

1. Introduction

In the last decades severe land-use changes occurred in tropical countries, due to increasing population and their demand for food resources (Houghton et al., 1991; Houghton, 1994; Ojima et al., 1994; Lambin et al., 2001). Forest land is rapidly converted into agriculture or pastureland. Land-use conversion may cause important changes in soil physical and chemical characteristics and can affect soil fertility, increase soil erosion or cause soil compaction (Neill et al., 1997; SEMARNAT, 2002a). The effect of the conversion of forest land into pastureland on soil organic matter is variable, in some cases an increase has been reported for certain locations (De Moraes et al.,

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1996; Lemenih et al., 2005), decreasing in others (Detwiler, 1986; Trumbore et al., 1995; Powers, 2004). Tiessen et al. (2003) observed that changes in organic carbon contents after deforestation strongly depend on soil type.

Increasing land conservation requires soil carbon and soil fertility management within a broader framework of sustainable development (Vergara-Sánchez et al., 2005; Smith, 2008). Furthermore, it is important to establish sustainable land-use systems while conserving soil fertility in the long term. However, concepts of soil quality under tropical conditions are still missing because these concepts were mainly developed for temperate climates and cannot be applied to tropical conditions (Sánchez et al., 2003).

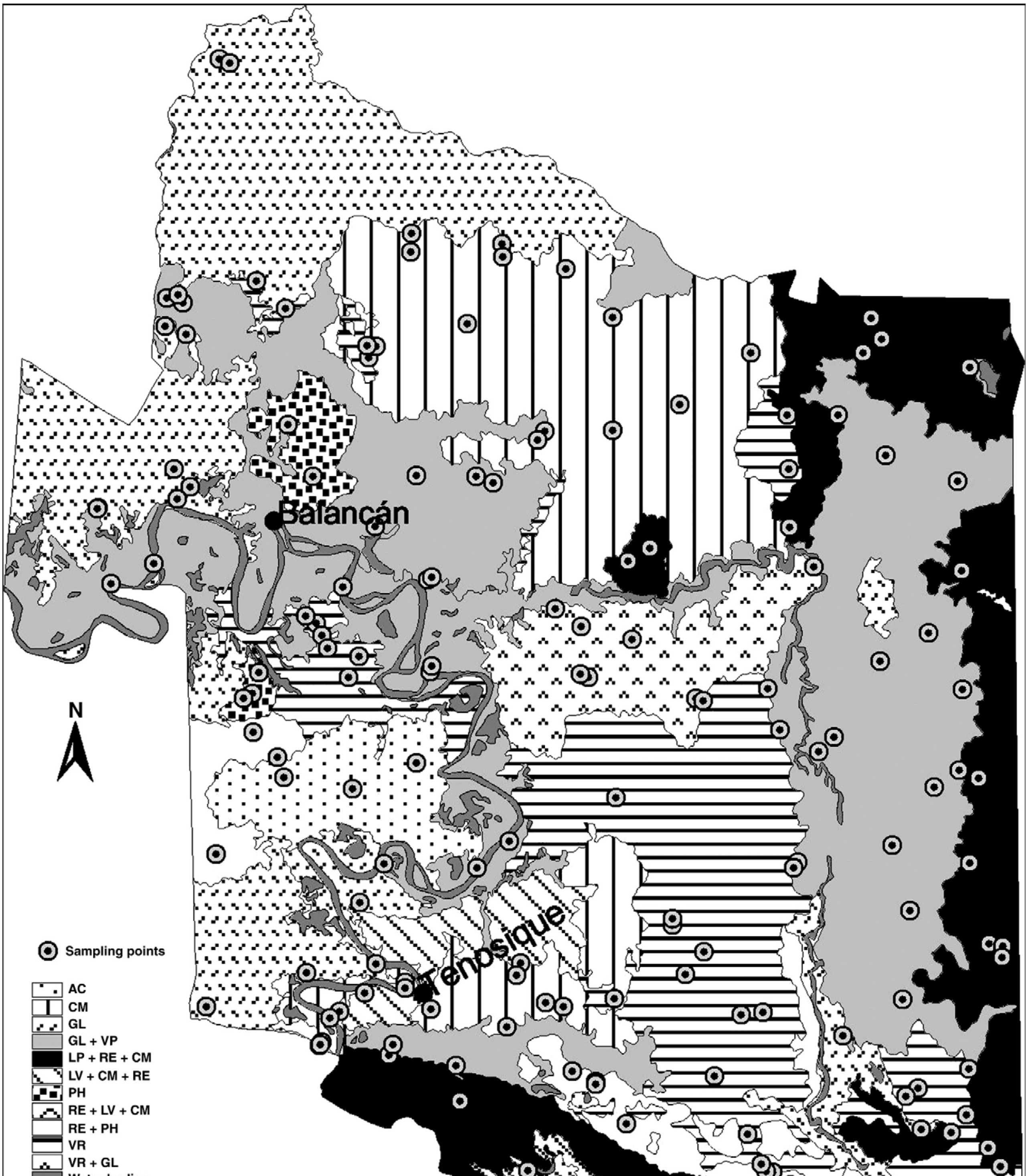


Fig. 1. Soil associations in the study area. (AC = Acrisol, GL = Gleysol, VR = Vertisol, CM = Cambisol, RE = Regosol, PH = Phaeosem, LP = Leptosol, LV = Luvisol).

In the last 60 years rapid deforestation occurred in tropical Mexico. Along with the deforestation, there has been a drastic change in land use. The Tabasco State has experienced a rapid change in land use and can thus be considered as a case study for tropical countries. In 1940, 49% of Tabasco, SE Mexico was covered by forestland and only 21% with grassland (Palma and Triano, 2002). Governmental settlement programs encouraged extensive cattle ranching during the following 40 years. Consequently, nowadays only 5.6% of the area of Tabasco is covered by primary and secondary forests, while 53.8% is grassland for cattle management (Palma and Triano, 2002). Up to now very few investigations about the influence of different land-use types on soil fertility in tropical Mexico have been carried out (Garcia-Oliva et al., 1999; Palma and Triano, 2002; Geissen and Morales Guzman, 2006).

The aim of this study is to analyze the effects of 1) current land-cover and 2) land-use changes from 1988 to 2004 on physical and chemical properties of different soils in tropical Mexico. We expected that current land cover such as land-use changes have a strong influence on soil physical–chemical properties. The interpretation of our results is limited due to the fact that data about soil properties before land-use changes do not exist. We only studied soil properties after land-use changes.

2. Methods

2.1. Study area

The study was carried out in an area of 5474 km^2 in the eastern part of the state of Tabasco, SE Mexico. The region is characterized by a warm and humid climate with precipitation throughout the whole year. The average temperature is 26 °C and the mean annual precipitation is 1750 mm (INEGI, 2000a). The main part of the study region is located in a plain at an elevation of less than 20 masl, the hilly areas show elevations from 20 to 200 masl and the mountains are located in the southern part with elevations up to 640 masl (Fig. 1).

According to the soil map of INEGI (National Institute of Statistics, Geography and Informatics) (2000b) which is based on the soil classification of FAO (1989) the dominant soils in the plain are Gleysols over alluvial sediments. In the hilly areas Vertisols, Cambisols, Luvisols and Acrisols over Miocene or Oligocene sediments are dominant. In the mountain area the dominant soil types are Leptosols and Regosols over limestone. The main land use is pastureland, however there are areas with seasonal agriculture (corn, vegetable, melon, pineapple etc.), fruit plantations (papaya, citrus), sugar cane, secondary and primary forest (Isaac-Márquez, 2008).

2.2. Land-use change

We classified Landsat TM and ETM satellite images from 1988 and 2003 with a pixel size of 30 × 30 m (Isaac-Márquez, 2008). These were corrected geometrically with a polynomial model using IDRISI 32 (Eastman, 2001). We applied a supervised classification with maximum likelihood classifier to create maps of land use, and overlay procedures to detect land-use/cover changes from 1988 to 2003 in a scale of 1:50,000. Isolated pixels were eliminated using a filter median 3 × 3. To verify the accuracy of the maps with field points we generated a confusion matrix (Chuvieco, 1990). We distinguished the following land-use/cover classes: seasonal agriculture (TA), pastureland (Pa), fruit plantations (FP), sugarcane (SC), primary and secondary forest (PF, SF).

2.3. Selection of the sampling sites, soil sampling and soil analysis

Based on topographic (1:50,000) and soil maps (1:250,000, FAO 1989) we chose sites covering all potential combinations of the two factors (INEGI, 1985, 1994). Then we combined them with the land-use classes and land-use changes derived from satellite images (Isaac-Márquez, 2008). Based on this information we selected 176 sampling sites. From October 2004 to August 2005 soil sampling in the selected sites was carried out. Each sampling site was georeferenced using a GPS and their localization included in the digital maps. For each sampling site we annotated the current land use from field observation and land-use change between 1988 and 2003 using the land-use maps of Isaac-Márquez, R. (2008). We only selected sites which did not suffer a land-use change in the last 5 years due to farmers' information.

In each site we took three soil samples at two depths (0–20 cm, 20–40 cm) to determine soil chemical and physical properties. We selected soil physical and chemical parameters according to the land evaluation system of Landon (1984) and SEMARNAT (2002b) and that are important parameters to characterize soil fertility for plant production: Soil texture (Bouyoucos method)–important for soil water and air conditions–, pH(KCl)–characterizes soil acidity and is strongly correlated with base saturation and potential Aluminium toxicity–, organic carbon (Corg) (Walkley and Black), total nitrogen (Ntot) (Kjeldahl), available phosphorus (Pavail) (Olsen) and cation exchange capacity (CEC) (1 N CH_3COONH_4, pH 7, Sumner and Miller, 2007).

Soil resistance against penetration was determined in the field using a penetrometer which allowed us to determine the actual resistance (in MPa) in 5 cm layers from the depth 0–5 down to 35–40 cm. We applied this method in soils at field capacity. Furthermore, we determined the total depth of the solum.

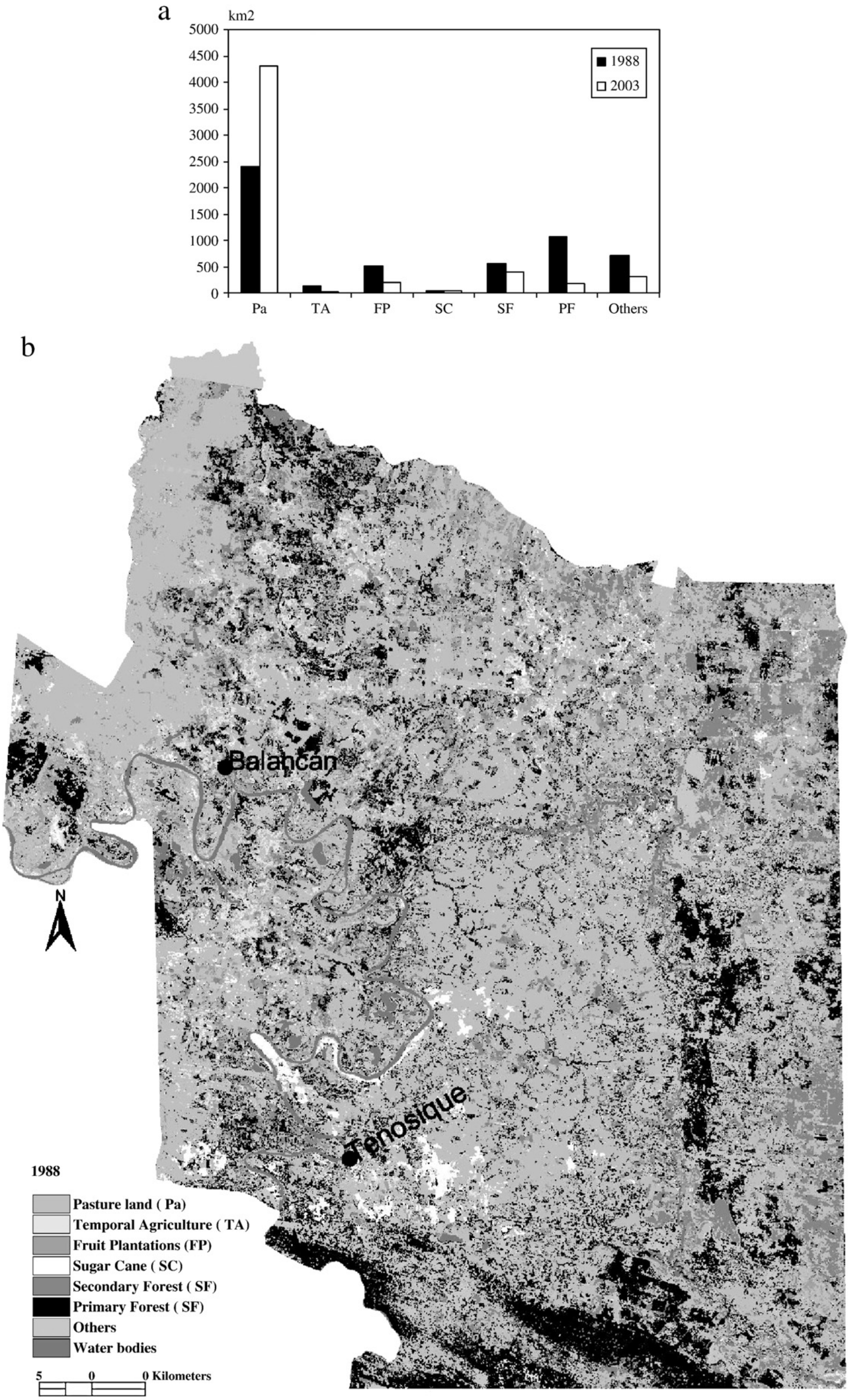
2.4. Data analysis

We analyzed data from the dominant soil groups or associations, which appeared with more than five replicate sites. We associated soil groups according to the WRB classification system (FAO, 1998) based on mapping units of soil maps of INEGI (2001b) (FAO, 1989). We verified the information of the soil maps with field observations. We used soil associations indicated by the original soil map (FAO, 1989) and changed the names due to actual terms of WRB (FAO, 1998).

We analyzed the data from the following soil groups and associations: Gleysols (eutric, humic, vertic) (GL, 20 sites), Gleysols (vertic, calcic, eutric)–Vertisols (pellic) (GL + VR, 35 sites)), Vertisols (pellic)–Gleysols (vertic) (VR + GL, 32 sites), Cambisols (eutric, calcic) (CM, 18 sites), Regosols–Cambisols (eutric)–Phaeosems (RE + CM + PH, 11 sites), Leptosols–Regosols–Cambisols (eutric) (LP + RE + CM, 20 sites), Regosols–Luvisols (calcic)–Gleysols (eutric) (RE + LV + CM, 8 sites), Luvisol (orchic, calcic)–Cambisols (eutric)–Regosol (LV + CM+ RE, 10 sites).

We analyzed data from the five common land-use classes: pastureland (Pa, 86 sites), seasonal agriculture (TA, 43 sites)) (annual crop such as corn, vegetable, melon, pine apple etc.), fruit plantation (FP, 8 sites) (papaya, citrus), sugar cane plantation (SC, 14 sites) and forest (F, 20 sites) (secondary and primary forest) and the changes of these 5 land-use forms from 1988 to 2003 such as: permanent pastureland (Pa-Pa, 50 sites), conversion from pastureland to seasonal agriculture (Pa-TA, 20 sites). conversion from pastureland to fruit plantations (Pa-FP, 14 sites), from pastureland to sugarcane (Pa-SC, 6 sites), from pastureland to forest (Pa-F, 12 sites), from forest to pastureland (F-Pa, 25 sites), from forest to seasonal agriculture (F-TA, 18 sites) and from seasonal agriculture to pastureland (Ta-Pa, 13 sites).

We used the Kolmogorov–Smirnov test to analyze whether the data followed a normal distribution. In case of normal distribution and homogeneity of variances, ANOVA followed by the Scheffé or Tukey test was carried out to estimate significant differences between the land-use systems and soil types. In case of non-homogeneity of the variances we applied the Dunnet T3 test. In case the data had no normal distribution, we applied the Kruskal Wallis and the Mann Whitney *U*-test ($p<0.05$).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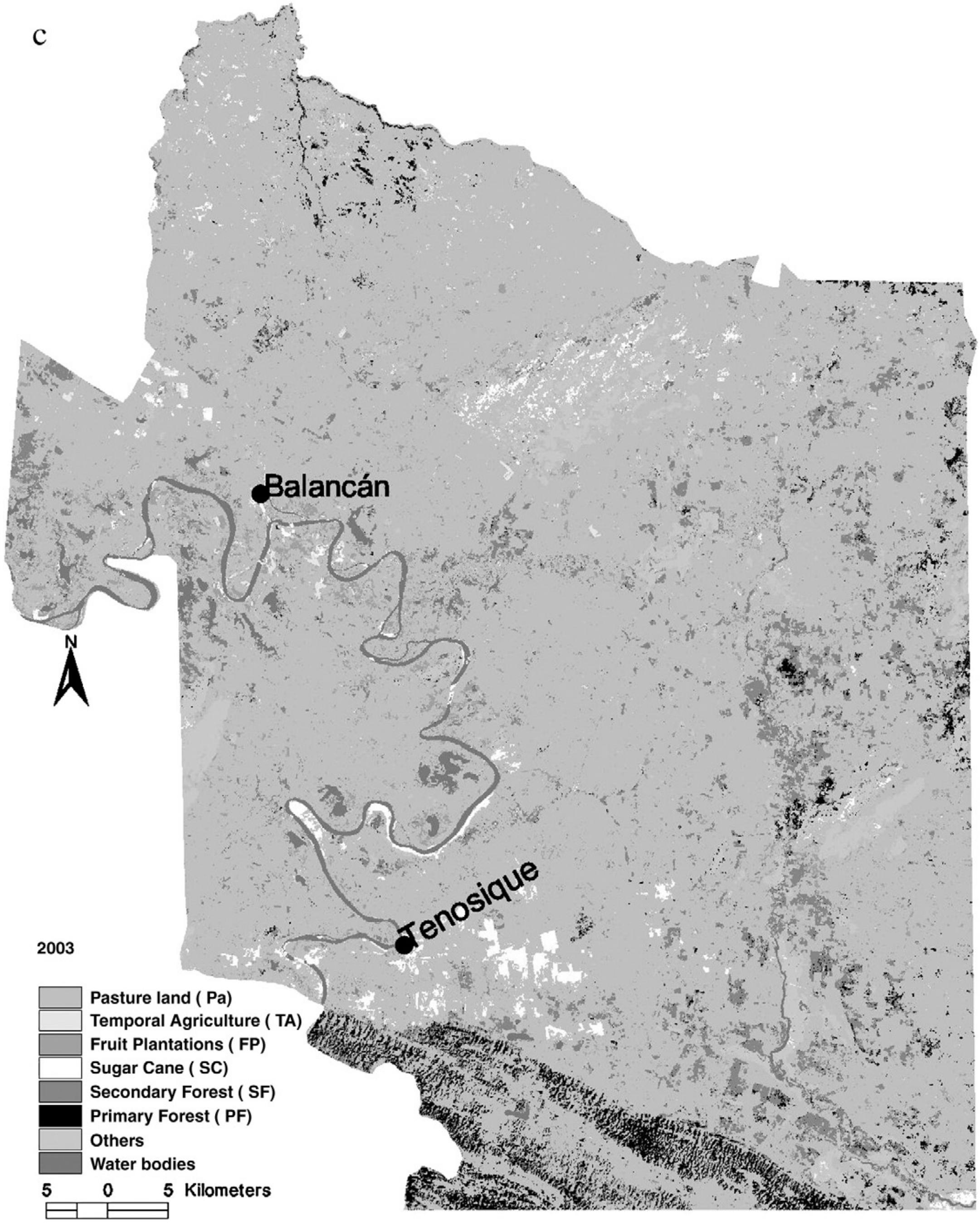

Fig. 2. a: Land-use change from 1988 to 2003 in the study area (Pa = pastureland, Ta = temporal agriculture, FP = fruit plantations, SC = sugar cane, SF = secondary forest, PF = primary forest). b: Land cover in 1988. c: Land cover in 2003.

We applied a principle component analysis to extract components from the variables soil type, land use, land-use change and soil physical–chemical properties (Greenacre, 1992).

3. Results

3.1. Land-use change in the study area

Severe land-use changes took place between 1988 and 2003 (Fig. 2a–c). While pastureland almost doubled in extent (increase by 79%), primary forest decreased to 17% of its original cover. Areas with seasonal agriculture and fruit plantations showed a decrease to 56% and 49% respectively of its original cover whereas the area cultivated with sugarcane did not change.

3.2. Soil properties

3.2.1. Soil association and soil properties

The soil groups/associations did not differ with respect to pH values, silt and available phosphorus content (Table 1). All soils were slightly acidic with pH(KCl) values between 5.3 and 6.2. Phosphorus contents varied between 9.77 and 15.9 mg kg^{-1} in the upper 20 cm and between 6.81 and 13.6 mg kg^{-1} between 20 and 40 cm. While C/N ratios did not differ significantly between the different soil types

Table 1
Soil properties of different soil types (layer 1: 0–20 cm, layer 2: 20–40 cm; GL = Gleysol, VR = Vertisol, CM = Cambisol, RE = Regosol, PH = Phaeosem, LP = Leptosol, LV = Luvisol; Corg = organic carbon, Ntot = total nitrogen, Pavail = plant available phosphorus, CEC = cation exchange capacity) (ns = no significant differences ($p<0.05$), sign. differences: a<b<c).

Soil association	N	Total depth (cm)	Layer	pH(KCl)	Corg (g 100 g^{-1})	Ntot (g 100 g^{-1})	C/N	Pavail. (mg kg^{-1})	CEC (cmol kg^{-1})	Sand (%)	Clay (%)	Silt (%)
GL	20	72.3 ± 25.6	1	5.47 + 1.03	1.38 + 0.81 a	0.11 + 0.07 ab	13.4 + 2.88	14.67 + 7.64	24.5 + 15.5 ab	44.6 + 23.6	32.6 + 19.8	22.2 + 10.8
			2	5.35 ± 1.15	1.02 + 0.67	0.05 + 0.02	20.0 + 13.7	9.33 ± 7.12	21.9 + 10.0 a	44.4 + 24.2	34.7 + 22.2	20.9 + 11.2
GL + VR	35	69.3 ± 30.0	1	5.62 + 1.13	1.58 + 0.96 a	0.13 + 0.07	13.4 + 5.13	12.89 + 8.79	34.3 + 20.9 abc	45.4 + 23.2	34.1 + 19.5	20.5 + 13.9
			2	5.53 ± 1.07	1.20 + 0.68	0.08 + 0.05	20.14 + 12.2	8.95 ± 5.31	33.6 + 20.0 ab	40.0 + 24.4	39.1 + 21.1	21.0 + 13.2
VR + GL	32	53.4 + 20.3a	1	5.74 + 0.88	2.19 + 0.99 b	0.18 + 0.09 bc	13.0 + 5.63	13.0 + 10.1	36.1 + 15.9 bc	40.8 + 18.5	38.5 + 17.3	20.7 + 8.35
			2	5.76 ± 0.87	1.37 + 0.73	0.10 + 0.06b	17.4 + 15.45	9.98 + 7.65	40.3 + 16.0 b	40.1 + 17.9	41.5 + 16.3 b	18.4 + 10.0
CM	18	79.3 + 23.9b	1	5.33 + 0.96	1.19 + 0.74 a	0.10 + 0.06 a	14.4 + 13.8	15.9 + 8.11	15.2 + 13.3 a	55.2 + 17.7 b	26.7 + 15.6 a	18.1 + 8.52
			2	5.46 ± 1.09	0.97 + 0.76	0.05 + 0.03 a	23.1 + 13.8	13.62 + 9.19	21.7 + 11.6 a	62.8 + 22.0 b	21.3 + 14.5 a	16.0 + 9.8
RE + CM + PH	11	50.5 + 24.8	1	5.76 + 1.22	2.20 + 1.06	0.18 + 0.06	12.1 + 5.13	14.9 + 7.96	30.8 + 16.5 abc	33.3 + 10.1 a	44.6 + 10.6 b	22.1 + 11.6
			2	6.06 + 1.30	1.29 + 0.59	0.10 + 0.04	13.18 + 2.90	10.75 + 5.76	46.2 + 14.8 b	36.8 + 14.0 a	42.9 + 17.0	20.3 + 14.7
LP + RE + CM	20	50.1 + 19.1a	1	5.71 + 0.69	2.87 + 0.91 b	0.20 + 0.07 c	15.0 + 1.73	7.75 + 3.71	45.0 + 10.5 cd	34.2 + 11.9 a	44.0 + 14.4 b	21.7 + 11.4
			2	5.71 + 0.87	1.67 + 0.93	0.12 + 0.06 b	17.3 + 17.9	6.61 + 1.92	41.7 + 11.6 b	25.9 + 13.8 a	53.3 + 20.1 b	20.7 + 14.5
RE + LV + GL	8	51.4 + 16.3	1	6.05 + 0.73	2.54 + 0.82 b	0.20 + 0.06	12.6 + 1.45	14.94 + 8.42	55.9 + 7.36 d	40.8 + 15.6	41.2 + 15.6	17.9 + 4.41
			2	5.95 + 0.67	1.78 + 0.61	0.11 + 0.04b	16.7 + 4.28	7.99 + 2.10	52.1 + 6.6 c	33.8 + 11.0 a	48.8 + 11.2 b	17.4 + 6.30
LV + CM + RE	10	54.0 + 30.5	1	6.25 + 0.97	4.87 + 3.19	0.31 + 0.20	15.8 + 1.88	9.77 + 5.94	33.1 + 25.1	37.2 + 19.2	37.6 + 19.2	25.1 + 18.6
			2	6.16 + 0.97	2.51 + 1.86	0.20 + 0.15	12.9 + 1.77	6.81 + 2.57	44.6 + 17.6	27.3 + 15.5 a	45.6 + 22.7	27.0 + 22.9
				ns	ns		ns	ns				ns

(12.1 to 15.8 in the first layer and 12.9 to 23.1 in the lower layer), organic carbon content was significantly higher in 0–20 cm in VR + GL, LP + RE + CM and RE + LV + CM than in GL, GL + VR and CM (Table 1). Between 20 and 40 cm there were no significant differences between the soil groups with respect to organic carbon content.

Total nitrogen content was lowest in CM in both layers and significantly higher in VR + GL and RE + LV + CM. Cambisols were characterized by a sandy clay loam texture presenting a significantly higher sand and lower clay content that the other soil types with a clayey or loamy clayey texture (Table 1). Consequently, the CEC was lower in Cambisols than in the main part of the other soils.

Considering the resistance against penetration as a characteristic of soil compaction we did not find any significant difference between the soil types in all measured depths (0–40 cm) (Fig. 3, shown for 4 depths). In the first 20 cm all soils showed a resistance against penetration below the critical value for undisturbed root growth of 3 MPa (De León-González et al., 1998). However, in the lower depths of Cambisols soil resistance were higher than 3 MPa.

3.2.2. Current land use and soil properties

Only a few soil properties were significantly different in soils under different land use. The contents of available phosphorus, total nitrogen as well as CEC and C/N ratio were comparable in both investigated depths and independent from land-use types (Table 2).

In 0–20 cm the organic carbon content was significantly higher under seasonal agriculture (2.23 g 100 $g^{-1)}$ than under fruit plantations (1.16 g 100 g^{-1}). Organic carbon content in the other land-use types did not show significant differences and ranged from 1.85 (sugarcane SC) to 2.70 g 100 g^{-1} (forest F) in the upper layer and from 1.08 (FP, fruit plantations) to 1.47 g 100 g^{-1} (temporal agriculture TA) below 20 cm (Table 2).

In general, the soils under the different land-use types were all slightly acidic with pH values between 5.2 and 6.0, soils with Pa being significantly more acidic (5.2) than soils with TA (6.1) in the layer below 20 cm (Table 2).

Soils with sugar cane (SC) and seasonal agriculture (TA) showed significantly higher clay content than soils used for fruit plantations (FP) in both depths, whereas sand content was significant lower under TA than under Pa between 20 and 40 cm. Silt content did not differ between the land-use types.

Considering soil compaction, the only significant difference was found between pastureland and seasonal agriculture, with significantly higher resistance against penetration in Pa at each soil depth (Fig. 4).

3.2.3. Relationships between land-use change and soil properties

We compared the land-use changes with more than five replicates such as Pa-Pa (is no change), Pa-TA, Pa-FP, Pa-F, Pa-SC, TA-Pa, F-TA, F-Pa, F-TA (Table 3).

As already described for soils under current land use, there were only a few significant differences between properties of soils that passed different land-use changes. Available phosphorus and organic carbon contents as well as C/N ratios did not differ in both investigated depths (Table 3). However, total nitrogen contents in the upper layer of soils with a land-use change F-TA (0.22 g 100 g^{-1}) was significantly higher than after the changes Pa-F (0.11 g 100 g^{-1}) and Pa-F (0.14 g 100 g^{-1}).

In both depths, soils under the influence of land-use change F-TA showed significantly higher pH(KCl) values (6.4, 6.5) than soils under permanent pastureland (Pa-Pa) (5.5, 5.5), or were changed from TA to Pa (5.8, 5.8). from Pa to F (5.4, 5.5) and from F to Pa (5.5, 5.4) (Table 3).

Clay content in the depth of 20–40 cm was significantly lower and sand content significantly higher in soils under permanent pasture (Pa-Pa) and Pa-F than under F-TA. Consequently, CEC was significantly lower in soils with permanent pasture and with land-use change Pa-F than under F-TA.

Permanent pastureland showed significant higher resistance in all depths than nearly all other soils after different land-use changes, with maximum values of 10 Mpa (Fig. 5). Furthermore, soils actually used as pastureland had a significantly higher resistance against mechanical penetration than TA, independent of the soil type.

3.2.4. Relations between the different variables

We extracted three main components from the variables land use, land-use change, chemical soil properties and resistance against mechanical penetration. The components extracted were the same for the two studied soil depths (Fig. 6a, b) and explained 57 and 59% of the variance, respectively. The first component is the soil component which is related to the soil association and the soil properties organic carbon, total nitrogen, clay content and depth of solum. The second component is related to land us and land-use change as well as to phosphorus content and resistance against mechanical penetration. The third extracted component was mainly explained by clay content and solum depth.

4. Discussion

4.1. Soil chemical properties

We compared physical and chemical properties of tropical soils under different current land use and under the influence of different

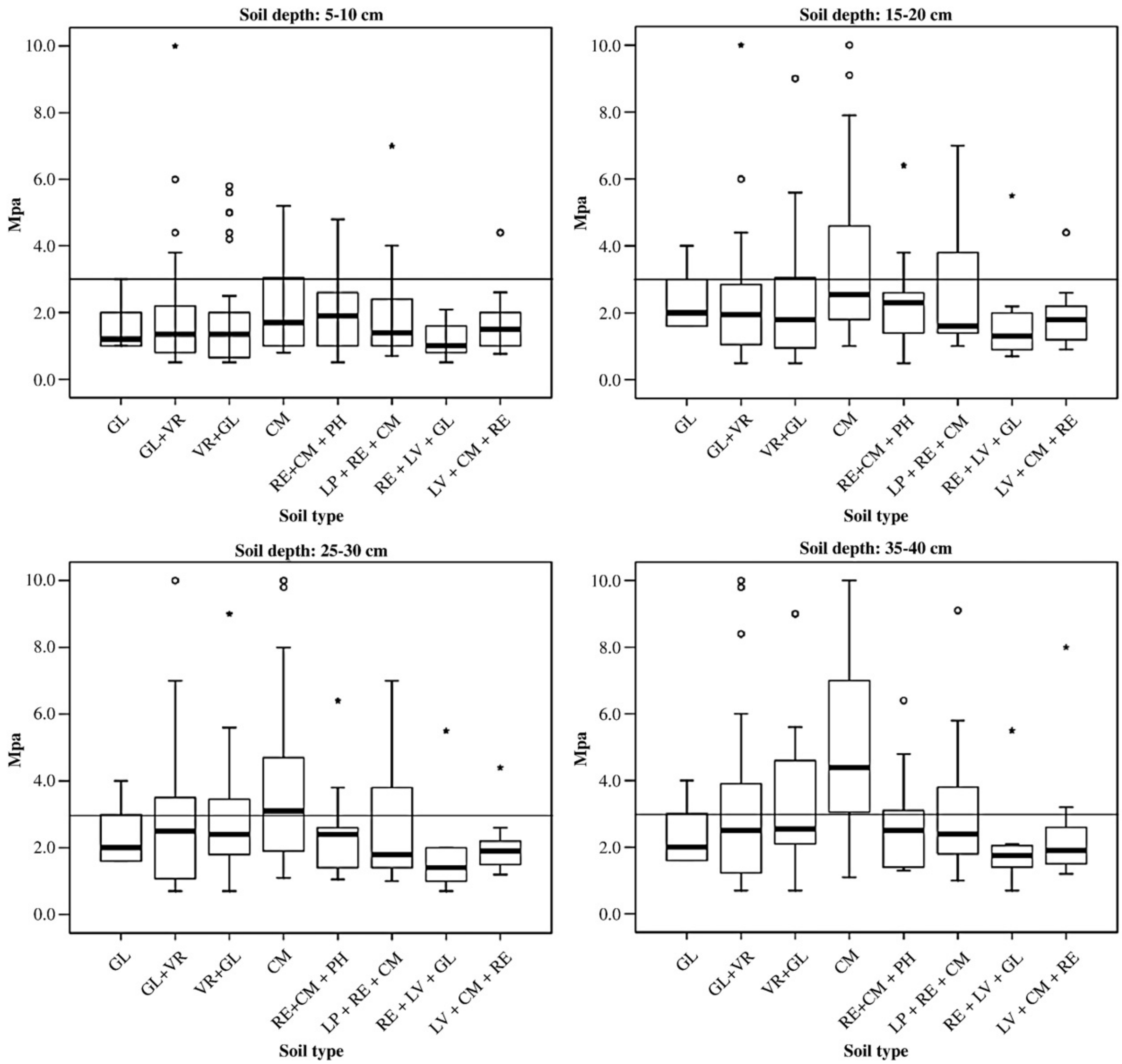

Fig. 3. Resistance against penetration (MPa) in different soil associations in four depths (trigger value (Leon 1998): 3 MPa) sign. differences (p<0.05); (GL = Gleysol, VR = Vertisol, CM = Cambisol, RE = Regosol, PH = Phaeosem, LP = Leptosol, LV = Luvisol).

land-use changes in a period of 15 years using soil chemical and physical properties as indicators, as proposed by Landon (1984), SEMARNAT (2002b) and Sánchez et al. (2003). We assume that properties such as soil texture and depth of solum may influence the selection of land-use forms and would only change in a period of 15 years in case of severe soil erosion which was not observed in the study area. In contrary, with respect to soil chemical properties and compaction we postulate a possible influence of different land-use types.

All soils already used in 1988 as pastureland – except those changed to seasonal agriculture – were acidic with pH values below 5.5 which

Table 2
Soil properties under different land use (Pa = pastureland, TA = temporal agriculture, FP = fruit plantations, SC = sugarcane, F = primary and secondary forest; Corg = organic carbon, Ntot = total nitrogen, Pavail = plant available phosphorus, CEC = cation exchange capacity, (ns = no significant differences (p<0.05), sign. differences: a<b<c).

Actual land use	N	Total depth (cm)	Layer	pH(KCl)	Corg (g 100 g^{-1})	Ntot (g 100 g^{-1})	C/N	Pavail. (mg kg^{-1})	CEC (cmol kg^{-1})	Sand (%)	Clay (%)	Silt (%)
Pa	86	62.1 ± 27.6	1	5.56 ± 0.91	1.95 ± 1.14	0.14 ± 0.08	13.9 ± 5.23	11.8 ± 7.38	31.8 ± 18.2	45.5 ± 20.6	33.7 ± 17.8	20.7 ± 10.7
			2	5.19 ± 0.77 a	1.32 ± 0.75	0.08 ± 0.05	18.2 ± 11.9	8.95 ± 5.47	32.8 ± 17.3	43.5 ± 22.6 b	37.0 ± 20.5 ab	19.6 ± 12.6
TA	43	56.9 ± 23.9	1	6.0 ± 0.84	2.23 ± 1.11 b	0.19 ± 0.09	12.2 ± 3.17	14.0 ± 8.46	37.3 ± 17.2	35.5 ± 15.9	43.0 ± 15.8 b	21.5 ± 12.5
			2	6.06 ± 0.82 b	1.47 ± 0.81	0.10 ± 0.05	17.1 ± 12.5	8.80 ± 3.88	40.7 ± 15.5	31.6 ± 17.4 a	47.0 ± 16.0 c	21.4 ± 12.0
FP	8	87.1 ± 27.9	1	5.19 ± 0.77	1.16 ± 0.72 a	0.12 ± 0.10	11.9 ± 4.32	17.0 ± 7.53	20.8 ± 15.4	54.4 ± 21.4	23.5 ± 12.2 a	22.1 ± 12.7
			2	5.24 ± 1.01	1.08 ± 0.84	0.08 ± 0.07	24.0 ± 20.3	14.0 ± 11.7	22.0 ± 14.6	57.3 ± 19.2	21.8 ± 12.9 a	20.8 ± 8.0
SC	14	53.6 ± 13.1	1	5.61 ± 1.31	1.85 ± 1.03	0.15 ± 0.08	12.7 ± 2.27	15.7 ± 13.7	43.8 ± 18.3	34.9 ± 12.0	42.7 ± 12.2 b	22.4 ± 11.2
			2	5.73 ± 1.33	1.16 ± 0.47	0.07 ± 0.03	16.1 ± 5.55	14.5 ± 11.5	40.1 ± 17.2	36.4 ± 17.6	44.1 ± 16.0 bc	19.5 ± 12.5
F	20	72.4 ± 31.5	1	5.74 ± 1.11	2.70 ± 3.01	0.20 ± 0.19	13.2 ± 3.81	12.3 ± 4.89	29.3 ± 21.5	48.9 ± 23.1	28.4 ± 22.7	22.6 ± 12.4
			2	5.47 ± 1.23	1.60 ± 1.63	0.09 ± 0.05	21.3 ± 15.1	7.57 ± 2.24	31.4 ± 21.9	47.8 ± 25.8	30.2 ± 24.7	22.0 ± 17.6
		ns				ns	ns	ns	ns			ns

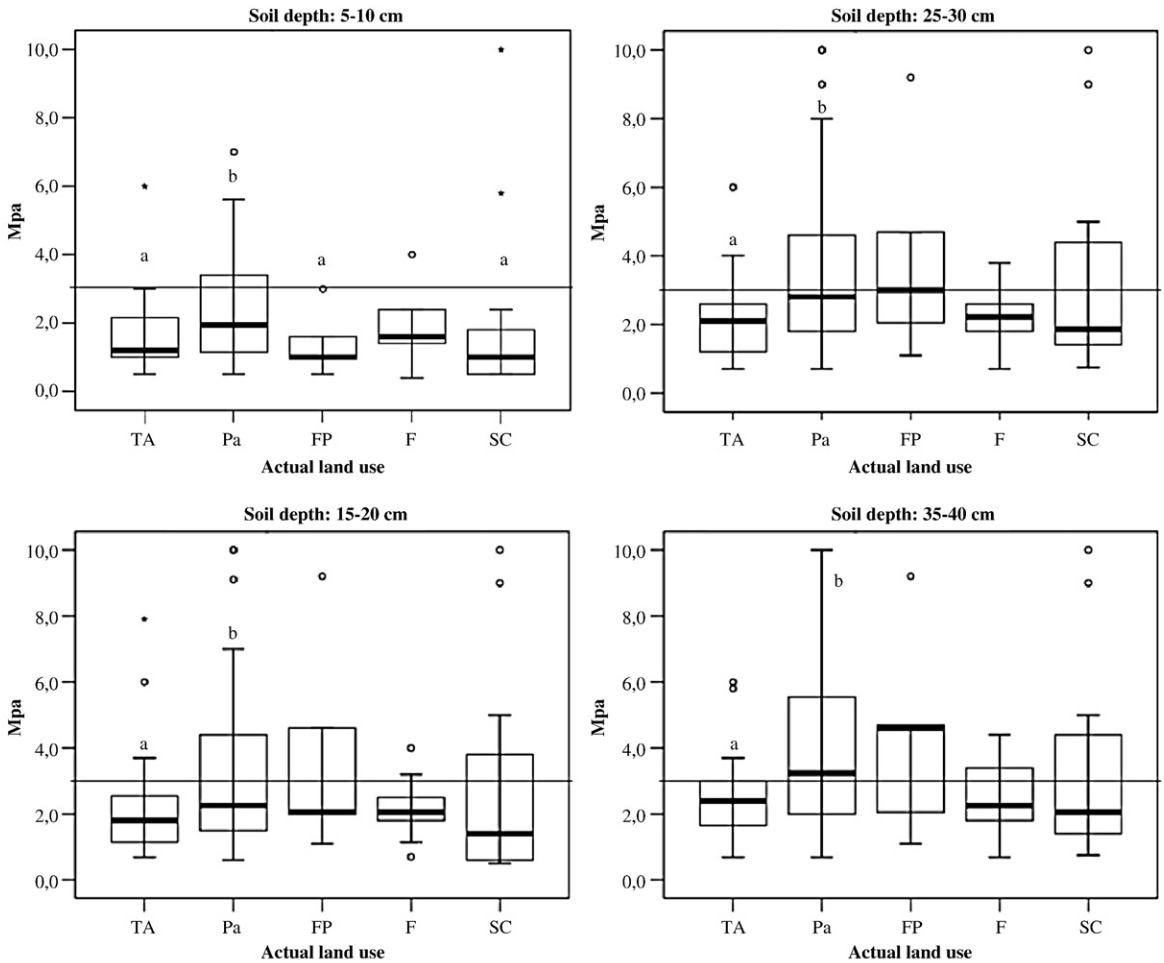

Fig. 4. Resistance against penetration (MPa) in soils under different current land use in four soil depths (trigger value (Leon 1998): 3 MPa) (Pa = pastureland, TA = seasonal agriculture, F = forest, FP = fruit plantations, SC = sugar cane) (sign. differences (p<0.05) a<b).

might cause Al toxicity for crops (Sánchez et al., 2003). This acidification was independent from soil association. The observed acidification of pastureland coincides with results of Rasiah et al. (2004) for tropical soils. However, land-use change from pastureland to seasonal agriculture seems to cause an increase pH value probably due to management activities such as liming and fertilization.

All soils showed a medium (0.9–2.0 g 100 g^{-1}) to high organic carbon content (2.0–3.4 g 100 g^{-1}) in the upper layer and a medium organic carbon content in the lower layer according to the classification of SEMARNAT (2002b). The only significant difference of organic carbon content was found between the actual land-use forms TA and FP. However, there were no differences between the organic carbon

Table 3
Soil properties under different land-use changes from 1988 to 2003 (Pa = pastureland, TA = temporal agriculture, FP = , fruit plantations, SC = sugarcane, F = primary and secondary forest; Corg = organic carbon, Ntot = total nitrogen, Pavail = plant available phosphorus, CEC = cation exchange capacity), (ns = no significant differences (p<0.05), sign. differences: a<b<c).

Land-use change	N	Total depth (cm)	Layer	pH(KCl)	Corg (g 100 g^{-1})	Ntot (g 100 g^{-1})	C/N	Pavail. (mg kg^{-1})	CEC (cmol kg^{-1})	Sand (%)	Clay (%)	Silt (%)
Pa-Pa	50	67.1 + 31.3	1	5.50 + 0.95 a	1.99 + 1.66	0.15 + 0.11	13.8 + 4.82	13.1 + 8.24	28.3 + 17.4 a	47.0 + 22.1	31.3 + 18.0	21.6 + 12.2
			2	5.54 + 0.87 a	1.26 + 0.73	0.07 + 0.05	19.4 + 13.7	9.35 + 5.92	31.0 + 18.0	43.3 + 22.5 bc	34.9 + 19.7 a	21.8 + 14.7
Pa-TA	20	61.9 + 30.0	1	5.93 + 0.83	1.73 + 1.11	0.15 + 0.07	11.8 + 3.50	12.5 + 6.74	33.3 + 16.3	41.2 + 17.9	38.8 + 16.5	20.0 + 7.58
			2	5.92 + 0.90	1.18 + 0.49	0.07 + 0.04	16.3 + 6.40	7.70 + 2.14	32.6 + 14.3	33.0 + 21.0 a	43.5 + 16.5	23.5 + 13.6
Pa-FP	14	61.3 + 28.3	1	5.45 + 0.86	2.19 + 1.30	0.16 + 0.10	13.8 + 1.98	10.4 + 5.70	33.3 + 18.3	38.5 + 17.1	39.1 + 16.8	22.4 + 12.6
			2	5.48 + 1.09	1.60 + 0.91	0.10 + 0.05	21.5 + 19.0	9.02 + 8.11	39.6 + 19.2	36.7 + 17.9	41.5 + 19.3	21.9 + 12.8
Pa-SC	6	51.2 + 9.5	1	5.01 + 1.53	1.76 + 0.50	0.15 + 0.05	12.6 + 2.32	24.0 + 17.6	46.1 + 16.1	40.8 + 11.6	40.5 + 12.0	18.6 + 2.53
			2	4.94 + 1.35	0.97 + 0.47	0.07 + 0.04	13.3 + 2.10	19.52 + 11.69	38.3 + 18.7	45.0 + 17.7	36.6 + 15.4	18.3 + 7.70
Pa-F	12	84.9 + 29.5	1	4.97 + 0.83 a	1.42 + 0.89	0.11 + 0.08 a	17.7 + 15.4	12.1 + 4.52	20.2 + 12.8 a	55.0 + 25.22	22.2 + 21.1	22.8 + 11.5
			2	5.05 + 0.83 a	1.08 + 0.90	0.06 + 0.08	25.7 + 16.7	7.11 + 1.75	20.5 + 13.7 a	61.8 + 20.2 c	21.2 + 18.3 a	17.0 + 10.3
F-Pa	25	64.0 + 23.6	1	5.51 + 0.88 a	2.02 + 1.14	0.14 + 0.07 a	14.4 + 6.66	11.38 + 7.83	38.2 + 20.2	45.5 + 20.4 ab	36.0 + 19.4	18.5 + 7.20
			2	5.44 + 0.93 a	1.43 + 0.73	0.09 + 0.05	17.9 + 8.70	8.25 + 5.02	35.5 + 17.8	43.2 + 20.5	39.0 + 20.2	17.8 + 10.6
F-TA	18	53.4 + 17.4	1	6.44 + 0.68 b	2.70 + 0.81	0.22 + 0.06 b	12.4 + 2.02	17.79 + 9.58	49.4 + 12.2 b	28.4 + 12.6	45.3 + 14.4	26.2 + 17.7
			2	6.55 + 0.58 b	1.47 + 0.68	0.12 + 0.05	14.7 + 9.30	10.30 + 5.17	48.4 + 8.6 b	20.7 + 11.4 a	53.6 + 11.7 b	20.7 + 10.4
TA-Pa	13	53.1 + 18.7	1	5.76 + 0.99 a	1.94 + 1.33	0.17 + 0.11	12.7 + 4.66	11.7 + 4.20	35.8 + 20.1	38.8 + 15.6	36.5 + 15.1	24.7 + 12.7
			2	5.79 + 1.18	1.42 + 0.95	0.10 + 0.08	16.2 + 7.90	13.07 + 8.56	33.6 + 15.5	41.7 + 24.1	40.2 + 23.4	18.1 + 9.50

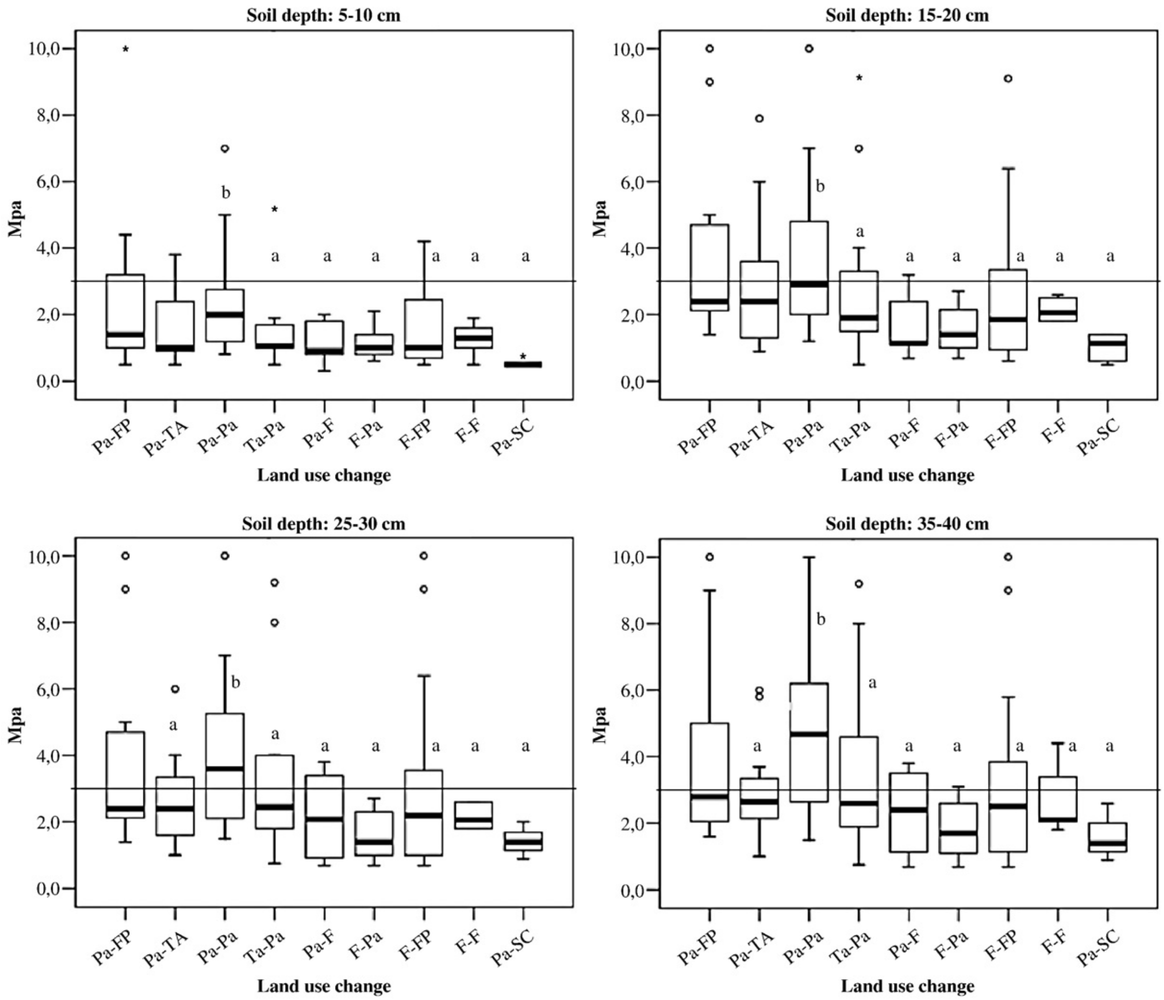

Fig. 5. Resistance against penetration (MPa) in soils under different land-use changes from 1988 to 2005 in four depths (trigger value (Leon 1998): 3 MPa) (Pa = pastureland, TA = seasonal agriculture, F = forest, FP = fruit plantations, SC = sugar cane) (sign. differences (p<0.05) a<b).

content of the soils under the influence of land-use change. This is contradictory to results of McGrath et al. (2001) and Powers (2004) who described organic carbon reduction in tropical soils after deforestation and the establishment of continuous cropping as well as a organic carbon reduction after the conversion of pasture into crops. Furthermore, our results do not coincide with Dominy et al. (2002) who described a large decline of soil organic matter after conversion of undisturbed forest and grassland into sugarcane plantations. We suppose that organic carbon losses after land conversion in our study area probably did not occur due to the high clay content of the soils. The absorption of organic molecules onto clay mineral surfaces provides a mechanism of organic carbon stabilization against microbial attack (Ladd et al., 1996). Furthermore, another important mechanism for C stabilization may be the inhibition of aerobic respiration during periods of anaerobic conditions which occur over several periods in the year. Therefore, we assume that the organic matter in the soils of the study area is well protected against mineralization. This view may be supported by Garcia-Oliva et al. (1999) who described that only the labile organic carbon associated in macroaggregates was destructed by forest burning, whereas the other organic carbon fractions were not affected. We conclude that there was no quantitative organic carbon change caused by land conversion, as also found by Shrestha et al. (2006). Furthermore it is possible, that organic carbon changes after land conversions may need more than 15 years in similar conditions as in our study site. Further studies are needed to show whether qualitative organic carbon changes in our study area took place after conversion from forest to pastureland, as described by Singh and Singh (1995) in India.

Total nitrogen content in the first depth of all soils were medium (0.10–0.15 g 100 g^{-1}: SEMARNAT, 2002b) to high (0.15–0.25 g 100 g^{-1}: SEMARNAT, 2002b). We did not observe nitrogen losses after conversion of pastureland to TA as described by Powers (2004) nor lower (Rasiah et al., 2004) or higher nitrogen content (Neill et al., 1997) under pastureland than under forest. This may be due to the low C/N ratio in all land-use classes. Furthermore, high annual rainfall leads to a high water saturation of the soils during the main part of the year, which may decrease N mineralization in all sites. The observed increase of total nitrogen content in soils converted from forest to TA is probably caused by the routinely N fertilization of the agricultural sites.

Available P content in all soils was medium (5.5–11.0 mg kg^{-1}, SEMARNAT, 2002b) to high (>11 mg kg^{-1} SEMARNAT, 2002b). This means that P fixation by Fe- and Al-oxides, as often described for tropical soils, did not occur (Sánchez et al., 2003). We did not observe any P limitation as described for other tropical soils (Agele et al., 2005).

Concerning soil chemical properties, the soils under all land-use types can be characterized as fertile according to SEMARNAT (2002b). Land-use changes in the study area did not affect principle soil chemical properties that characterize soil fertility such as organic carbon, total nitrogen, available P and CEC.

We assume that in our study area we did not observe strong effects of land use or land-use changes on soil chemical properties due to the

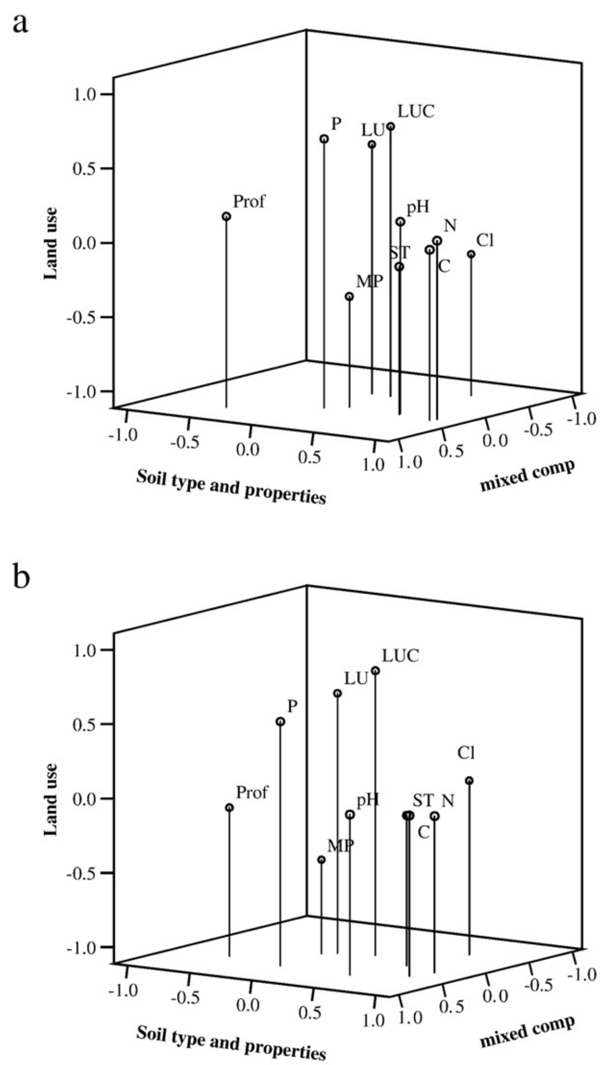

Fig. 6. a: Three main components (soil component, land-use component and a mixed component) extracted from land use and soil data (soil depth: 15–20 cm). b: Three main components (soil component, land-use component and a mixed component) extracted from land use and soil data (soil depth: 25–30 cm). (LU = land use, LUC = land-use change, P = Pavailable., C = Corg, N = Ntot, MP (=MPa), Cl = clay, ST = soil association, prof = depth of solum).

fact that in the study area flooding is common over several periods in the years. This leads to reductive conditions in the soils and inhibits mineralization processes. Therefore, the influence of water is overlapping the possible influence of land use on soil chemical properties.

4.2. Resistance against penetration

The permanent use of pastureland in the study area led to severe soil compaction. This negative effect of pastureland on soil structure was already described by Rasiah et al. (2004) and Sharrow (2007), who reported significant increase in bulk density in soil with livestock. De León-González et al. (1998) estimated an optimal soil resistance against penetration for root growth in tropical soils between 1 and 3 MPa. The soils under pastureland in this study exceeded this trigger value in 35–40 cm depth. The resistance against penetration exceeded the trigger value in some pasture sites more than three times with maximum values of 10 MPa. This leads to the conclusion that permanent pasture leads to decreasing soil fertility due to soil compaction for all soil types in the study region, which in turn inhibits sufficient root growth (De León-González et al., 2007).

5. Conclusions

We conclude that land-use change did not lead to significant changes in soil chemical parameters, however, soils used as pastureland showed acidification and soil compaction. In the study area, the influence of water which leads to reductive conditions in several periods of the years is overlapping the possible influence of land use on soil chemical properties.

We recommend the conversion of pastureland to other land-use forms such as fruit plantation, agroforestry systems or reforestation that do not show these effects. Further studies are required to test if there are differences in the quality of the organic matter between the various land-use types.

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