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Research article

Evaluación del efecto de obras de conservación en suelos forestales de Tlaxcala, México

Assessment of the effects of conservation works in forest soils of *Tlaxcala*, México

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Abstract

Soil conservation practices are widely used in Mexico to reduce soil erosion and to promote recovering of eroded soils. These practices are particularly important in the state of *Tlaxcala*, which has extensive areas with different levels of soil erosion. The study was carried out in 2020 in *Gustavo Diaz Ordaz*, *Zacapexco* and *San Bartolomé Matlalohcan*, sites with soil conservation practices (board-ditches and trench-ditches). The objective was to assess the effects of soil conservation practices through physical, chemical and biological soil properties at each location site. At the *Gustavo Díaz Ordaz* site, the values of soil properties did not significantly different from the control with the conservation practices after eight years of its establishment. At *Zacapexco*, after five years of the establishment of board-ditches, there is a positive impact on several chemical and biological soil properties, whereas, at *San Bartolomé Matlalohcan*, after more than 40 years of establishment of board-ditches, there were no significant effects on biological properties of the soil. A principal components analysis allowed us to identify that organic matter content (*OM*), cation exchange capacity (*CEC*), calcium, pH, total N and the proportion of clay and sand, are properties that significantly influence soil quality in the study sites, therefore, monitoring these variables is greatly useful in assessing the impact of conservation practices.

Key words: Soil quality, soil degradation, conservation practices, edaphic properties, board-ditch, trench-ditch.

Resumen

Las obras de conservación de suelos son muy utilizadas en México para disminuir la erosión y propiciar la recuperación de suelos erosionados. Estas obras son particularmente notables en Tlaxcala, estado que presenta grandes superficies con diferentes niveles de erosión edáfica. El estudio se llevó a cabo en 2020 en las localidades Gustavo Díaz Ordaz, Zacapexco y San Bartolomé Matlalohcan, Tlaxcala; sitios con obras de conservación de suelo (zanja bordo y zanja trinchera). El objetivo fue evaluar el impacto del establecimiento de las obras de conservación a través de propiedades físicas, químicas y biológicas del suelo. En el sitio Gustavo Díaz Ordaz, los valores de las propiedades del suelo no fueron significativamente diferentes respecto al testigo a ocho años de su implementación. En Zacapexco, a cinco años de la construcción de las zanjas bordo, se verificó un impacto positivo en varias propiedades químicas y biológicas del suelo. En San Bartolomé Matlalohcan, después de más de 40 años de la realización de las zanjas bordo, no se observaron cambios significativos en las propiedades biológicas del suelo. El análisis de componentes principales permitió identificar que la materia orgánica (*MO*), la capacidad de intercambio catiónico (*CIC*), calcio, pH, N total y la proporción de arcilla y arena son propiedades que influyen de manera importante en la calidad del suelo en los sitios de estudio, por lo que el monitoreo de estas variables es de gran utilidad en la evaluación del impacto de obras de conservación.

Palabras clave: Calidad del suelo, degradación del suelo, prácticas de conservación, propiedades edáficas, zanja bordo, zanja trinchera.

Introduction

In Mexico, socioeconomic factors and human activities (agriculture, livestock and deforestation) influence soil degradation by promoting wind and water erosion (Cotler *et al.*, 2022), particularly in rural areas (Espinosa *et al.*, 2011; Li and Fang, 2016), as is the case of the state of *Tlaxcala*, which presents this problem in 76.8 % of its territory (Semarnat and Colpos, 2002).

Due to this problematic situation, the construction of soil conservation works has been highly recommended to speed up the rehabilitation process, since they seek to improve and recover quality and minimize the process of soil erosion. Within the soil conservation works, in Mexico the trench stands out, which is implemented indistinctly in different geographical and ecological conditions (Cotler *et al.*, 2015), however, it has been argued that its construction can affect the conditions of water infiltration, increase the erosion process and decrease the organic carbon (*OC*) content in the soil, which affects biological activity (Cotler *et al.*, 2022).

In contrast, other studies have recorded positive results with some conservation works. For example, González-Romero *et al.* (2018) analyzed the functionality and the effect on the soil over time through physical, chemical and biological properties, after establishing silt control dams; the same authors describe that the works positively influenced the decrease in bulk density (*Bd*) and pH, increases in the *OM* concentration and the activity of the dehydrogenase enzyme (*DHS*).

On the other hand, in stone-based terraces as a conservation work, soil conditions were improved compared to sites without work, which provides positive effects on soil fertility and plant production (Welemariam *et al.*, 2018). Reyes *et al.* (2019) recorded that the board ditches favor the capture of water and with it the establishment of plant species. Grasses and other herbaceous plants establish more quickly in areas with conservation works, due to the increase in soil moisture (Doria *et al.*, 2022). Muscolo *et al.* (2014) point out that soil properties are sensitive to variations in climate and management; thus, their evaluation will allow identifying the impacts of degradation.

Therefore, under the different edaphic conditions of the sites and the intervention through conservation works and the establishment of vegetation, a positive change in the edaphic variables is possible. Therefore, the objective of this work was to evaluate the physical, chemical and biological properties of the soil with and without the presence of conservation works and to determine possible effects and relationships between said properties in each study area.

Materials and Methods

Study sites

Site 1. *Ejido Gustavo Díaz Ordaz* (GDO). Is located in the *Emiliano Zapata* municipality (19°32'31.6'' N and 98°08'58.0'' W) at 2 415 masl, with a total area of 470 ha. Subhumid temperate climate, 6.5-22.1 °C temperature, 6.8-140.8 mm rainfall, and predominant soil order Leptosol (30.11 %) (INEGI, 2010a). The dominant vegetation is pine-oak forest (*Pinus pseudostrobus* Lindl., *P. greggii* Engelm. ex Parl., *Quercus laurina* Bonpl. and *Q. rugosa* Née) (Conafor, 2012) and among the conservation works there is a notable presence of pastures.

In 2012, different conservation works were established in the *Peña del Chivo* area, whose soils show moderate degradation, due to deforestation and water erosion; in 30 ha, trench ditches and board ditches were built alternately, with a 40 ° slope (Conafor, 2012). The specific study area was 2.5 ha, including conservation works and the control (without conservation works).

Site 2. *Zacapexco* (ZAC). Private property within the *San Pedro Ecatepec* community, *Atlangatepec* municipality (19°32'31.6'' N and 98°08'58.0'' W) with an altitudinal interval between 2 480 and 2 600 m. Subhumid temperate climate with summer rains, 12-14 °C temperature, 600-700 mm rainfall, and Phaeozem soil order (54 %) (INEGI, 2010b).

In 2015, 40 ha of trenches and 50 ha of individual terraces were built. There are slopes of 15 to 20 % at the place and soil degradation was caused, mainly, by overgrazing and laminar water erosion (Conafor, 2015). The predominant vegetation is *Juniperus deppeana* Steud. Forests and where the conservation works were established, seedlings of *Pinus pseudostrobus* were planted.

Site 3. *San Bartolomé Matlalohcan* (SBM). Community located in the *Tetla de La Solidaridad* municipality (19°28'11.68" N and 98°07'16.65" W) at an average elevation of 2 516 masl. Subhumid temperate climate with rains in summer, 12-14 °C temperature, 600-900 mm rainfall, and soil order Phaeozem (61.8 %), with a slope of 15-20 % (INEGI, 2010c).

In this site, board-ditch and terraces were built in 7 ha between 1976 and 1978, as experimental plots of the National Institute of Forest, Agriculture and Livestock Research (*INIFAP*) to seek the rehabilitation of the *tepetate* (porous rocky soil). During sampling, the presence of introduced species such as eucalyptus (*Eucalyptus* L'Hér. spp.) and casuarina (*Casuarina equisetifolia* L.) was observed.

Soil sampling and sample preparation

At the GDO site, a grid with quadrats of 158 m×158 m was drawn on 2.5 ha of land, using the Schweizer´s systematic soil sampling method (2011). Two plots with a trench ditch (18 samples) and two with a board ditch (18 samples) were selected, in addition to six samples in a plot as a control (without conservation work). Within each quadrat, soil samples were collected between ditches at a depth of 0-30 cm. In ZAC, 3 ha were sampled with a trench (9 samples) and 1 ha as a control (without conservation work, 5 samples). For SBM, the sampling was in 1.5 ha with a ditch along the edge (9 samples) and in 0.5 ha without conservation work considered a witness (9 samples).

For the microbiological analysis of the soil, 100 g of each of the soil samples were taken and transferred to the Natural Resources Laboratory of the Genetics and Environment Research Center-UATx, cold, inside a Coleman® cooler with gel bags 250g POWERICE® coolant. Composite samples were made for each site using the quartering method, based on NOM-021-RECNAT-2000 (Semarnat, 2002). For GDO, 14 composite samples were obtained, in ZAC 7 and SBM 6, later stored at 4 °C in an Imbera® refrigerator to inhibit microbial activity. The rest of the soil from each sample was placed on Kraft paper to dry at room temperature and in the shade. The soil was sieved in a 2 mm mesh, all of the above following NOM-021-RECNAT-2000 (Semarnat, 2002).

Soil analysis

Each soil sample was determined texture, *Bd* (bulk density), *EC* (electrical conductivity); *OM* (organic matter); *OC* (organic carbon); *CEC* (cation exchange capacity), pH, total N, phosphorus, potassium, calcium and magnesium by methods established in NOM-021-RECNAT-2000 (Semarnat, 2002). Microbial respiration through the quantification of CO_2, the activity of the dehydrogenase enzyme and the bacterial biomass by the methods described by García *et al.* (2003).

Data analysis

Data were analyzed by site using one-way analysis of variance and a Tukey mean comparison test (p=0.05). Previously, the data were analyzed to verify compliance with the assumptions of normality (Kolmogorov) and homogeneity of variance (Levene). The model used for the analysis was the one described in Equation 1 (InfoStat, 2008).

$$Y_{ij} = \mu + \tau i + \varepsilon ij \qquad (1)$$

Where:

μ = General average

τi = Effect of the i^{-th} treatment

ε_{ij} = Experimental error

From the soil properties of the three sites with and without conservation works, a Pearson correlation analysis (p=0.05) and a principal component analysis (*PCA*) were carried out to determine their contribution to the total variation of the data. All of the above was done with the statistical software InfoStat free version 2020 (Balzarini *et al*., 2008).

Results and Discussion

Gustavo Díaz Ordaz

The soils between the board-ditch and trench-ditch treatments show significant differences (p<0.05) in bacterial biomass and total N with respect to the control. Based on the values observed in these two variables, it is clear that the soil conservation works and the vegetation present did not increase the values, since they are lower than the control (Table 1). The above agrees with Cotler *et al.* (2013), who report that the construction of trench-ditches did not allow an increase in the total N content, even with vegetation; they state that the mineralization of the litter to inorganic forms (ammonium and nitrates) will depend on the amount that can be converted by the microbial biomass, which in this case, was also lower with the conservation works, which suggests low effectiveness of the trench-ditch. Beltrán *et al.* (2018) point out that the establishment of plant species allows a greater diversity of microorganisms and microbial activity, in such a way that trophic relationships are established that contribute to the improvement of soil quality.

Table 1. Analysis of variance of physical, chemical and biological parameters of the soil with and without conservation work in GDO.

Parameter	*P* Value	Board-ditch	Trench-ditch	Control	Reference[†]
Sand (%)	0.1955	71.9±1.0 a	73.1±1.07 a	75.76±1.8 a	Sandy loam
Clay (%)	0.1846	5.94±0.62 a	6.61±0.64 a	4.28±1.07 a	
Silt (%)	0.3362	22.1±0.96 a	20.28±0.9 a	19.96±1.6 a	
Bd (g cm^{-3})	0.4839	0.94±0.02 a	0.92±0.02 a	0.91±0.02 a	<1
pH	0.4926	6.27±0.11 a	6.09±0.12 a	6.06±0.20 a	5.1-6.5
EC (dS m^{-1})	0.8187	0.06±0.0024 a	0.06±0.0042 a	0.06±0.002 a	<1
OM (%)	0.6423	5.10±0.42 a	4.53±0.44 a	4.87±0.80 a	4.1-6.0
OC (%)	0.6423	2.96±0.25 a	2.62±0.25 a	2.82±0.47 a	1.2-2.9
CEC [Cmol(+) kg^{-1}]	0.5700	45±4.01 a	38.9±4.12 a	43.2±6.94 a	2.9-4.6 >40 25-40
Total N (%)	≤0.0001	0.16±0.01 b	0.12±0.01 c	0.39±0.01 a	<0.30
P (mg kg^{-1})	0.8333	8.37±1.15 a	9.15±1.15 a	10.69±1.63 a	<15
Ca [Cmol(+) kg^{-1}]	0.0526	7.55±0.04 a	5.6±0.04 a	6±0.05 a	5-10
Mg [Cmol(+) kg^{-1}]	0.1250	2.4±0.14 a	1.8±0.14 a	2±0.2 a	1.3-3.0
K [Cmol(+) kg^{-1}]	0.6250	0.40±0.04 a	0.45±0.04 a	0.4±0.05 a	0.3-0.6

Microbial respiration (mg C-CO_2 kg^{-1} soil)	0.3725	23.35±1.34 a	21.39±1.38 a	23.93±2.33 a	-----
Dehydrogenase enzyme (*μ*g TTC g^{-1} soil)	0.7954	0.51±0.09 a	0.47±0.09 a	0.42±0.11 a	-----
Bacterial biomass (UFC×10³ g^{-1} soil)	0.0021	1 142±108.28 b	845±98.85 b	1 820±171.21 a	-----

*Equal letters per row indicate no significant differences ($p \geq 0.05$); Tukey´s Mean±*E.E*; †NOM-021-RECNAT-2000; *Bd* = Bulk density; *EC* = Electric conductivity; *OM* = Organic matter; *OC* = Organic carbon; *CEC* = Cation exchange capacity.

The establishment of trenches coupled with the vegetation did not modify the physical properties of the soil for eight years, the sand fraction predominates by 73 % on average and the bulk density without variation. On the other hand, even without significant differences, the chemical properties show that the presence of trees tends to increase the acidity of the soil (Khalaji *et al*., 2021). With the trenches on board, an increase in the content of *OM*, *OC*, Ca, Mg and *CEC* was observed, which is high [>40 Cmol ($^+$) kg^{-1}] based on NOM-021-RECNAT-2000 (Table 1). Vazquez-Alvarado *et al.* (2011) refer that soil conservation works and an adequate selection of plant species are important to obtain positive results, due to the fact that there is an increase in the *OM* content and, therefore, a greater retention of moisture and soil particles, as well as a greater number of microorganisms (Doria *et al.*, 2022). However, this was not observed in this site for bacterial biomass, which was significantly higher in the control soil.

Zacapexco

In the soil between the board-ditches, the sand and clay fraction, the pH, *OM*, *OC*, microbial respiration and the dehydrogenase enzyme presented significant differences ($p<0.05$) with respect to the control soil (Table 2). At this site, the construction of the board-ditches probably allowed an increase in soil moisture, which favors the presence of herbaceous plants and grasses associated with *J. deppeana* and *P. pseudostrubos*, which improves the chemical and biological properties of the soil.

Table 2. Analysis of variance of the physical, chemical and biological properties of the soil with and without conservation work in ZAC.

Property	*P* value	Board-ditch	Control	Reference†
Sand (%)	0.0118	78.86±2.07 a	68.58±2.78 b	Sandy loam
Clay (%)	0.0205	7.67±2.44 a	15.77±1.82 b	
Silt (%)	0.2185	13.47±1 a	15.65±1.35 a	
Bd (g cm^{-3})	0.0907	0.96±0.02 a	1.03±0.03 a	<1
pH	0.0319	7.55±0.16 b	8.24±0.12 a	7.4-8.5
EC (dS m^{-1})	0.6218	0.04±0.01 a	0.04±0.01 a	<1
OM (%)	0.0031	3.94±0.38 a	1.61±0.5 b	<4.0
OC (%)	0.0031	2.28±0.22 a	0.9±0.29 b	<1.2 1.2-2.9
CEC [Cmol($^+$) kg^{-1}]	0.1566	30.58±1.24 a	27.45±1.66 a	25-40
N total (%)	0.1613	0.23±0.04 a	0.27±0.05 a	<0.30
P (mg kg^{-1})	0.1000	0.3±0 a	0.4±0 a	0.3-0.6
Ca [Cmol($^+$) kg^{-1}]	0.3815	8.8±1.98 a	5.6±2.42 a	5-10
Mg [Cmol($^+$) kg^{-1}]	0.4086	2.8±0.66 a	1.8±0.81 a	1.3-3
K [Cmol($^+$) kg^{-1}]	0.1000	0.3±0 a	0.4±0 a	0.3-0.6
Microbial respiration (mg C-CO_2 kg^{-1} soil)	0.0045	23.77±1.46 a	15.29±1.95 b	-----
Dehydrogenase	0.0025	2.41±0.11 a	0.05±0.12 b	-----

enzyme (μg TTC g^{-1} soil)				
Bacterial biomass (UFC×10^3 g^{-1} soil)	0.7245	1 047.78±133.65 a	971.67±163.69 a	-----

*Equal letters per row indicate no significant differences ($p≥0.05$); Tukey´s Mean±*E.E.*
ᵻNOM-021-RECNAT-2000; *Bd* = Bulk density; *EC* = Electric conductivity; *OM* = Organic matter; *OC* = Organic carbon; *CEC* = Cation exchange capacity.

Five years after the establishment of the conservation works, there is a decrease in pH, an increase in *OM* and *OC*, in *CEC*, phosphorus, calcium and magnesium, as well as a notable improvement in biological activity. This highlights the importance of maintaining and incorporating plant cover with the correct species together with conservation works, since plants supply *OC* as an energy source for soil organisms to carry out their metabolic activity, which will depend on the type of soil, time of year, climate, nutriments, topographic conditions of the site and the type of vegetation (Yáñez *et al.*, 2017; Khalaji *et al.*, 2021; Doria *et al.*, 2022).

San Bartolomé Matlalohcan

The average values of *Bd*, *EC*, *CEC*, the content of Ca, Mg and K were significantly different ($p<0.05$) between the treatments (Table 3). On the other hand, the values of the content of *OM*, *OC* and of the biological properties, although without significant differences, reflect a slight increase. At this site, conservation works were complemented by reforestation with eucalyptus trees. It has been indicated that although eucalyptus trees are fast growing, they have an allelopathic effect that negatively impacts the soil (Murillo *et al.*, 2005), because they modify their characteristics and decrease the biodiversity of fungi, lichens, and herbaceous plants. In the same way, the functioning of the ecosystem is altered in processes such as the decomposition of litter, due to the decrease in soil microorganisms (Munguía *et al.*, 2004; García-Osorio *et al.*, 2020; Solís-Vargas *et al.*, 2021), what is observed in this particular site.

Table 3. Analysis of variance of the physical, chemical and biological properties of the soil with and without conservation work in SBM.

Property	*P* value	Board-ditch	Control	Reference†
Sand (%)	0.1886	77.71±1.87 a	81.62±2.12 a	Sandy loam
Clay (%)	0.0559	8.38±1.18 a	4.66±1.34 a	
Silt (%)	0.9417	13.91±1.66 a	13.72±1.88 a	
Bd (g cm^{-3})	0.0004	0.91±0.02 b	1.03±0.02 a	<1
pH	0.6790	5.68±0.18 a	5.79±0.18 a	5.1-6.5
EC (dS m^{-1})	0.0051	0.03±0.0028 a	0.01±0.0028 b	<1
OM (%)	0.4433	1.62±0.24 a	1.14±0.24 a	<4.0
OC (%)	0.4433	0.94±0.14 a	0.66±0.14 a	<1.2
CEC [Cmol($^+$) kg^{-1}]	0.0086	26.00±1.51 a	11.25±1.85 b	5-15 25-40
N total (%)	0.2629	0.1±0.3 a	0.15±0.3 a	<0.30
P (mg kg^{-1})	0.8580	7.41±0.3 a	7.33±0.3 a	<15
Ca [Cmol($^+$) kg^{-1}]	0.0032	8.93±0.6 a	3.6±0.6 b	2-5 5-10
Mg [Cmol($^+$) kg^{-1}]	0.0008	3.07±0.13 a	1.33±0.13 b	1.3-3.0 >3
K [Cmol($^+$) kg^{-1}]	0.0003	0.67±0.03 a	0.13±0.03 b	<0.2 >0.6
Microbial respiration (mg C-CO_2 kg^{-1} soil)	0.3459	17.66±1.51 a	15.18±1.51 a	-----
Dehydrogenase enzyme (μg TTC g^{-1} soil)	0.6704	0.09±0.05 a	0.03±0.07 a	-----

Bacterial biomass (UFC×10^3 g^{-1} soil)	0.5776	350±26.26 a	328.89±26.26 a	-----

*Equal letters per row indicate no significant differences ($p \geq 0.05$); Tukey´s Mean±*E.E*; †NOM-021-RECNAT-2000; *Bd* = Bulk density; *EC* = Electric conductivity; *OM* = Organic matter; *OC* = Organic carbon; *CEC* = Cation exchange capacity.

Leaf litter is the most important source of nutrients. Particularly, the decomposition of eucalyptus leaves releases a greater amount of K (0.96 %) than P (0.06 %) and N (0.89 %), which depends on soil conditions (Munguía *et al*., 2004). The cation exchange capacity was verified, mainly, by the clay content, which was higher with the presence of the board-ditch, since the organic matter is low, from the slow decomposition of the litter (Welemariam *et al.*, 2018; García-Osorio *et al*., 2020).

Relationship between soil properties

In this part of the results, bulk density (*Bd*) is negatively correlated with *OM*, potassium, calcium and microbial respiration, which means that if *Bd* decreases, there will be less compaction; this will increase the pore space and, consequently, there will be an increase in the water storage capacity, which, in turn, will impact the functions of soil microorganisms (Notaro *et al.*, 2018; Rosero *et al.*, 2019; Barajas *et al.*, 2020). Cotler (2015) evaluated the construction of trench-ditches and reported that *Bd* increased, and explained that this material which is deposited undergoes an alteration that is reflected in *OM* and microbial activity, as observed in GDO.

The *OM* content is a measure of soil quality since it is considered a source of energy and a reserve of nutriments, contributes to the resilience of the soil-plant system, favors *CEC*, improves the availability of phosphorus, influences the increase in water retention capacity and attenuates thermal variations in the soil, in addition to microbial diversity and activity (Fischer and Dubis, 2019; Frugoni *et al.*, 2020). This situation was reflected in GDO and ZAC with the establishment of the board-ditch and the vegetation, and there was an improvement in the chemical and biological properties of the soil. On the other hand, *OM* also had a positive influence on *EC*, P, K and Ca. Total N with bacterial biomass and *CEC*, which was higher in the three sites, is positively associated with Mg, but negatively with K and Ca (Table 4).

Table 4. Pearson correlation of soil properties with and without conservation work in three sites in *Tlaxcala*.

	Sand	Clay	Silt	*Bd*	pH	*EC*	*OM*	*OC*	N	P	*CEC*	Mg	K	Ca	*RM*	*BB*	*DHS*
Sand	1																
Clay	-0.80*	1															
Silt	-0.4	-0.21	1														
Bd	-0.35	0.75	-0.63	1													
pH	-0.64	0.85*	-0.24	0.63	1												
EC	-0.42	-0.11	0.89*	-0.66	0.01	1											
OM	0.13	-0.57	0.68	-0.89*	-0.27	0.83*	1										
OC	0.12	-0.57	0.69	-0.89*	-0.27	0.83*	1.00*	1									
N	-0.51	0.49	0.21	0.18	0.62	0.23	0.01	0.03	1								
P	-0.4	0.04	0.69	-0.62	0.05	0.82*	0.65	0.65	0.37	1							
CEC	-0.1	0.61	-0.76*	0.63	0.64	-0.55	-0.56	-0.56	0.17	-0.2	1						
Mg	0.09	0.38	-0.7	0.47	0.2	-0.65	-0.61	-0.62	-0.13	-0.21	0.86*	1					
K	-0.16	-0.45	0.95*	-0.78*	-0.4	0.89*	0.83*	0.83*	-0.01	0.62	-0.85*	-0.78*	1				
Ca	-0.14	-0.47	0.95*	-0.8*	-0.38	0.87*	0.84*	0.85*	0.08	0.63	-0.82*	-0.76*	0.99*	1			
RM	0.42	-0.58	0.26	-0.84*	-0.32	0.46	0.79*	0.79*	-0.1	0.6	-0.12	-0.06	0.41	0.46	1		
BB	-0.34	0	0.67	-0.43	0.19	0.69	0.57	0.59	0.78*	0.7	-0.36	-0.56	0.57	0.64	0.33	1	
DHS	0.28	-0.1	-0.28	-0.21	0.36	0.15	0.43	0.42	0.1	0.19	0.39	0.07	-0.12	-0.1	0.62	0.15	1

Bd = Bulk density (g cm^{-3}); *EC* = Electric conductivity (dS m^{-1}); *OM* = Organic matter (%); *OC* = Organic carbon (%); N = Total Nitrogen (%); P = Phosphorous (mg kg^{-1}), *CEC* = Cation exchange capacity [Cmol($^{+}$) kg^{-1})]; Mg = Magnesium

[(Cmol($^+$) kg^{-1}]; K= Potasium [Cmol($^+$) kg^{-1}]; Ca = Calcium [Cmol ($^+$) kg^{-1}]; *RM* = mg CO_2 kg^{-1} soil; *BB* = UFC×10^3, *DHS* = Dehydrogenase enzyme (μg TPF g^{-1}). *Significant values (p<0.05).

The principal component analysis (*PCA*) (Figure 1) showed that 74.5 % of the total variability of the data is explained by the PC1 (52.1 %) and PC2 (22.4 %) components. The variables with the greatest weight in CP1 were cation exchange capacity (0.32), calcium (0.32), organic carbon (0.32) and organic matter (0.31), which presented significant correlations (Table 4) and influence the biological activity of the soil. Similar results were reported by Rosero *et al.* (2019), who through a *PCA* recognized that in forest, grassland and silvopastoral system soils, PC1 explains that 48.48 % of the variability is determined by *CEC* (0.97) and calcium (0.86), while, in PC2 (21.69 %), the sand and clay particles, the pH and total N stood out.

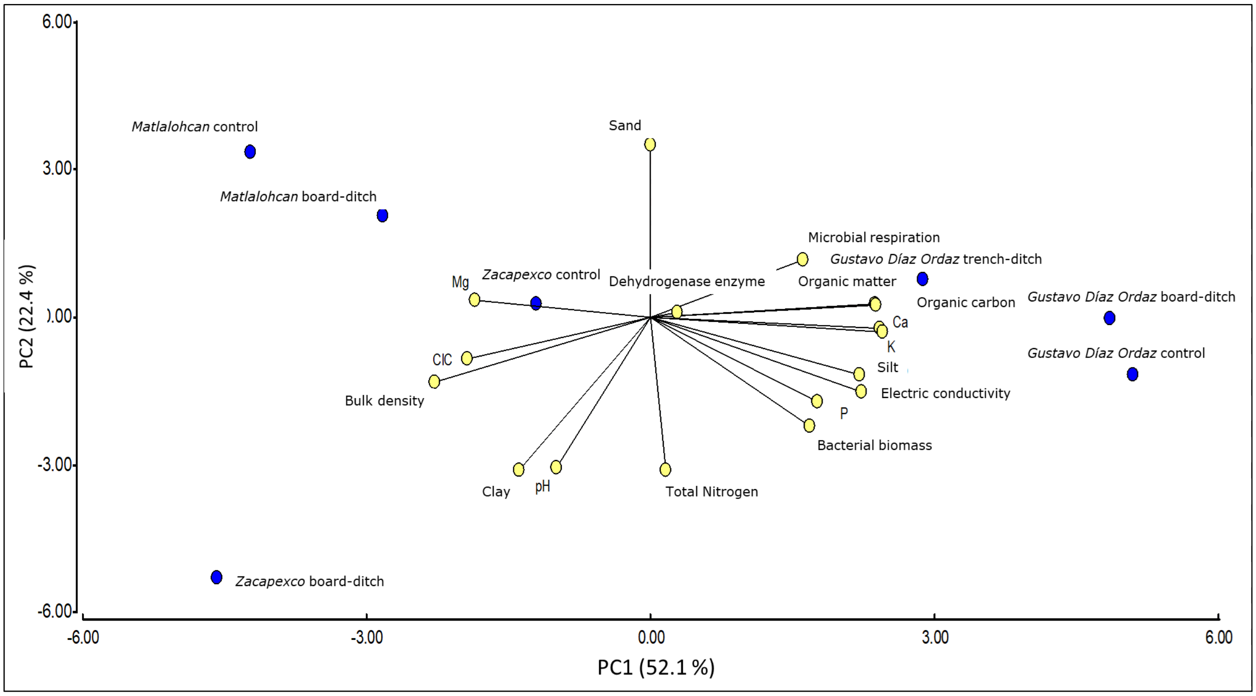

Figure 1. Biplot graph of soil properties in three sites in the state of *Tlaxcala*.

On the other hand, in forest soils with native vegetation, Notaro *et al.* (2018) obtained values in PC1 of 79.01 % for variables such as enzymatic activity, carbon of microbial biomass and soil *OC*, which is directly related to *OM* and humification processes.

In addition, the PC2 was explained by the sand particle (0.47), clay (-0.41), pH (-0.41) and total N (-0.41), being associated with the *Bd* and *OM* values. Alvarez-Arteaga *et al.* (2020) recorded 10.36 % variability associated with the mineral fraction of the soil, true density, silt, sand, and *CEC*. This suggests that the correlations and importance of the soil variables can be modified depending on the specific conditions of each locality. In the soils of the sites under study there is a predominance of the sand fraction, which implies a greater infiltration and, with it, a decrease in the water retention capacity that impacts the absorption by the roots of the plants and, therefore, in the dynamics of organic matter and biological activity of the soil (Díaz *et al.*, 2018).

Garcia-Osorio *et al*. (2020) mention that as the age of a reforestation increases, there will be a gradual integral recovery of the ecosystem, due to the fact that the *OM* incorporation process increases until reaching amounts similar to the original site. This assertion is only partially reflected in this study, since in SBM, at 40 years, there is a notable difference in terms of soil quality with respect to GDO and ZAC. Clearly, in SBM the established tree species plays a relevant role in the lack of recovery of soil properties, unlike ZAC where there are native species with conservation works.

With the results obtained, the relevance of evaluating the impact of establishing soil conservation works through soil properties is confirmed, since they provide more detailed information for planning and management of works and soil conservation or recovery practices.

Conclusions

The bordo ditch is the conservation work that, together with the native vegetation, shows an improvement in the quality of the soil in *Gustavo Díaz Ordaz* and *Zacapexco*, but not in *San Bartolomé Matlalohcan*, where after more than 40 years, the type of vegetation established in the rehabilitation works have not had a positive impact on the biological quality of the soil.

The analysis of principal components allowed us to identify that organic matter, cation exchange capacity, calcium, pH, total N and the proportion of clay and sand are properties that significantly influence soil quality, so monitoring of these variables are useful in evaluating the impact of establishing soil conservation works.

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Conflict of interests

The authors declare they have no conflict of interest.

Contribution by author

Elizabeth García Gallegos, Oscar Gumersindo Vázquez Cuecuecha and Vidal Guerra De la Cruz: determination of the variables, data analysis, structure of the manuscript; Francisco Javier Cocoletzi Pérez: field sampling, determination of variables, capture and analysis of data.

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