Assessment of Soil Parameters Related With Soil Quality in Agricultural Systems

Evelia Cruz Ruiz [1], Araceli Cruz Ruiz [1], Rocio Vaca [2], Pedro del Aguila [2], Jorge Lugo [2]*

[1.] Graduate student in MYDCI, Instituto de Ingeniería, Universidad Autónoma de Baja California, Mexicali, BC 21280, México
[2.] Facultad de Ciencias, Universidad Autónoma del Estado de México, Instituto Literario 100 Toluca, 50000 México
jorgelug@gmail.com

Abstract: The native vegetation in the central highlands of México is being increasingly replaced by agricultural crops; with conventional agricultural practices consisting of intensive tillage, and monocultures, with the subsequent removal of crop residues which have led to soil deterioration and loss of its natural fertility. Studies dealing with soil transformations followed by different land use practices are crucial for the selection of adequate management practices in order to rehabilitate soil efficiency and to maintain sustainability of the system. The aim of this study is the characterization of different soils (cultivated, forest, and reforested) aiming to identify key indicators of soil quality for Andosols in order to elaborate an index of soil quality. The study was conducted in Calimaya area, central Mexico, using five soils under different vegetation: maize (*Zea mays* L.), oat (*Avena sativa* L.), potato (*Solanum tuberosum* L.), a forest soil (*Alnus acuminata*) with minimal human disturbance and reforested site (*Cupressus lusitanica*). A series of physical, chemical and biological properties of the soils were analyzed: water holding capacity (WHC), texture, bulk density (BD), pH, organic matter (OM) content, total nitrogen (TN), electrical conductivity (EC), nitrogen mineralization (N_m), microbial biomass carbon (MBC), basal respiration (CO_2) and enzymatic activities (catalase, urease and acid phosphatase). The results suggested a soil index based on the parameters: TN, OM and acid phosphatase, which showed comparatively large weight in the factorial analysis including all the parameters analyzed.

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1. Introduction

Changes in land use and inappropriate land management practices, that affect the environment often lead to severe soil deterioration [1, 2]. Deforestation of fragile lands, clearing of overcutting of vegetation, shifting cultivation, overgrazing, repetitive tillage, and unbalanced fertilizer use have resulted in progressive loss of soil quality [3]. The loss of organic matter in soils under conventional tillage causes reduced fertility, negatively affects the soil microbial biomass, changes its structure and impedes water infiltration, thereby dragging the ground resulting in accelerated deterioration [4]. Soil quality can be monitored by a series of measurable attributes referred to as indicators. The effects of changing land use and management practices are evaluated using indicators such as the mineralization of nitrogen and carbon [5], the microbial biomass [6], the net emissions of CO_2 and other greenhouse gases [7], soil enzyme activities [8], etc.

Soil biochemical properties can be used as indicators of soil quality as they are more responsive to management practices than soil physical or chemical properties [9, 10]. The importance of using indices to assess soil quality has been recently emphasized [11]. In the last few years, a variety of soil quality indices has been proposed, several based upon biochemical and microbiological features [12]. Some techniques are based on multiple lineal regression (MLR), in which a dependent variable is calculated as a linear combination of others independent variables [13–15]. Multiple lineal regressions constitute an accurate tool to evaluate soil quality, that seems to be able to reflect equilibrium among its physical, chemical and biochemical properties [16].

In Mexico, unsustainable practices, such as deforestation, traditional cultivation involving burning or removal of crop residues, overgrazing and changes in land use, have accelerated decline in organic carbon and soil degradation. As a result, 47% of the soils are now degraded [17]. The objective of the present work is to establish a model using MLR based on different soil physical, chemical and biochemical properties, in soils with different land use, following indexing technique proposed by Andrews *et al*. [18] and Armenise *et al*. [19].

2. Material and Methods

1.1. Experimental site

This study was conducted in an agricultural area in Calimaya (19° 10' N, 99° 37' W), highlands in State of Mexico, Mexico. The altitude of the study area is

3200 m above sea level. The climate is classified as (Cw_2) subhumid temperate with summer rains under the Köppen system. The mean annual temperature is 14 °C and the mean annual precipitation was 800 mm. The soil is classified as Andosol [20] a locally important agronomic soil of Central Mexico [21].

1.2. Soil sampling

Soil was sampled (0–15 cm) on February 2011, June 2011 and March 2012 from five sites in soils cultivated since about fifty years with maize (CM), oat (CO), potato (CP), of forest sites without human disturbance (F) and reforested thirty years ago (RF). Samples of CM, CO and CP were obtained by systematic sampling at each site; a composite sample from 30 subsamples was collected. Samples F and RF were collected under the canopy of three isolated trees at 1 and 2 m from the stem in four perpendicular directions randomly selected. Soil samples were prepared in the laboratory: air-dried and sieved at 2 mm. Soil samples for microbiological analyses were sieved (particle size < 2 mm), stored at 4 °C and used within a 15 day period.

1.3. Chemical and physical analyses

The soil was analyzed for water holding capacity (WHC) according to Foster [22]; soil particle size distribution using the hydrometer method as described by Gee and Bauder [23]; bulk density by the cylinder method [24]. The pH was measured in soil: H_2O suspension (1:2.5 w/w) using a glass electrode [25]; OM content was determined following the method proposed by Walkley and Black [26]; total nitrogen (TN) was measured by the Kjeldahl method [27]; electrical conductivity (EC) (1:5 w/w) was determined in aqueous extract [28].

1.4. Biological and biochemical analyses

Basal respiration (BR) was estimated by quantifying the carbon dioxide (CO_2) released by microbial respiration in 33 days of incubation at 25 ºC adjusted to 40% WHC [5]. Microbial biomass carbon (MBC) was determined with the fumigation-extraction method [29]. The metabolic quotient was calculated as the radio of basal respiration to microbial biomass C [30]. The concentrations of inorganic N (NH_4^+, NO_3^- and NO_2^-) were measured at zero time and at after 33 days of incubation according to Bremner [31]. Catalase activity was measured by titrating the residual H_2O_2 added to soil and not degraded by catalase with $KMnO_4$ [32], acid phosphatase activity was measured by spectrophotometry (400 nm) [33], urease activity was determined as the amount of NH_4^+ released from 5.0 g soil after a 120 min incubation with a substrate of 0.2 mol L^{-1} urea at 37 °C, 4.5 mL of THAM (Tris buffer) [34].

1.5. Statistical analysis

The relationships between the different soil properties were analyzed by principal component analysis (PCA). The number of components was determined by the eigenvalue-one criterion [35]. A correlation matrix for the highly weighted variables under different PCs was run separately. It was assumed that the variables having the highest correlation sum best represented the group. Multiple regression analysis was performed using component values of minimum data set. The analysis was carried out using the Statgraphics 5.1 software.

3. Results

1.1. Physical, chemical and biochemical properties

As shown by the results shown in Table 1, the WHC was higher in F and RF soils than in cultivated soils. The CM, CO and CP soils showed comparatively high values of bulk density. The pH was lowest in cultivated soils compared with the soils F and RF (Table 1); the electrical conductivity (EC) ranged between 0.11 and 0.57 dS m^{-1}. The OM content was lower on cultivated and reforested soils than in forest soils. The highest content of TN is detected in the soil F. The soils CM showed the lowest values of CBM. In soils cultivated values of qCO_2 (Table 1) were higher compared to forest and reforested soils.

Table 1. Characteristics of soils with different land use sampled in Calimaya, Mexico

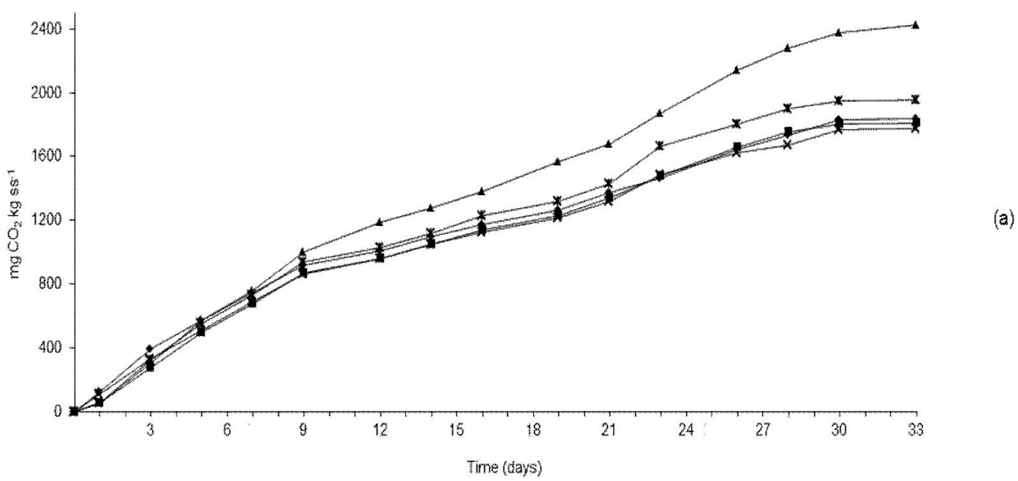
Land use	WHC	BD	pH (H_2O)	OM	TN	EC	C:N	MBC	qCO_2
	%	g cm^{-3}		g kg^{-1}		dSm^{-1}		Mg C kg^{-1} s	
	February 2011								
CM	38 ± 0.90	1.05 ± 0.03	4.2 ± 0.05	5.83 ± 0.51	0.28 ± 0.00	0.57 ± 0.01	12 ± 1.0	288 ± 69	2.28 ± 0.5
CO	43 ± 0.58	0.93 ± 0.03	4.5 ± 0.05	8.18 ± 0.39	0.34 ± 0.00	0.42 ± 0.01	14 ± 0.7	472 ± 34	1.33 ± 0.1
CP	40 ± 0.12	1.00 ± 0.03	4.7 ± 0.05	8.12 ± 0.39	0.34 ± 0.00	0.19 ± 0.00	12 ± 0.5	348 ± 85	1.83 ± 0.4
F	55 ± 0.29	0.68 ± 0.02	5.2 ± 0.06	17.15 ± 0.67	0.84 ± 0.00	0.13 ± 0.02	14 ± 0.7	577 ± 36	1.45 ± 0.1
RF	48 ± 0.52	0.80 ± 0.05	5.3 ± 0.08	7.62 ± 0.51	0.34 ± 0.00	0.14 ± 0.00	13 ± 0.9	633 ± 45	1.07 ± 0.1
June 2011									
CM CM	37 ± 0.22	1.21 ± 0.05	5.3 ± 0.04	4.03 ± 0.34	0.11 ± 0.00	0.26 ± 0.01	21 ± 1.7	111 ± 19	4.07 ± 0.6
CO	42 ± 0.31	1.00 ± 0.02	5.5 ± 0.01	6.50 ± 0.19	0.28 ± 0.00	0.18 ± 0.02	14 ± 0.4	124 ± 19	3.10 ± 0.5

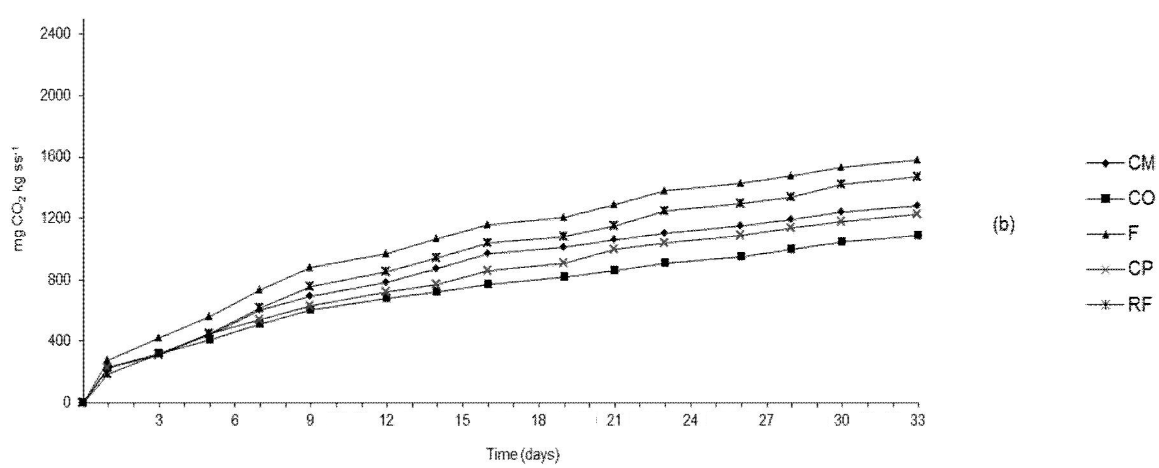
CP	38 ± 0.07	0.87 ± 0.01	5.5 ± 0.01	7.40 ± 0.00	0.34 ± 0.00	0.15 ± 0.01	9 ± 0.4	101 ± 0	4.19 ± 0.0
F	54 ± 0.21	0.67 ± 0.02	5.6 ± 0.08	12.55 ± 0.51	0.84 ± 0.00	0.30 ± 0.00	13 ± 3.0	354 ± 20	1.54 ± 0.1
RF	47 ± 0.38	0.77 ± 0.01	5.6 ± 0.08	6.72 ± 0.89	0.30 ± 0.03	0.11 ± 0.01	13 ± 3.0	182 ± 20	2.80 ± 0.3
March 2012									
CM	39 ± 0.21	0.88 ± 0.02	5.4 ± 0.02	5.49 ± 0.48	0.36 ± 0.06	0.24 ± 0.01	9 ± 2.0	223 ± 23	2.29 ± 0.3
CO	38 ± 0.65	0.96 ± 0.01	5.5 ± 0.01	7.28 ± 0.51	0.29 ± 0.03	0.28 ± 0.01	15 ± 1.6	308 ± 45	1.75 ± 0.2
CP	40 ± 0.44	0.87 ± 0.02	5.2 ± 0.04	7.17 ± 0.19	0.33 ± 0.00	0.20 ± 0.00	12 ± 0.5	278 ± 23	2.19 ± 0.3
F	51 ± 0.66	0.56 ± 0.01	5.9 ± 0.04	21.18 ± 0.67	1.06 ± 0.03	0.15 ± 0.00	12 ± 0.4	559 ± 70	1.46 ± 0.1
RF	45 ± 0.52	0.77 ± 0.03	5.6 ± 0.01	8.52.± 0.48	0.34 ± 0.02	0.12 ± 0.01	14 ± 0.7	456 ± 69	1.57 ± 0.2
Land use	WHC	BD	pH (H2O)	OM	TN	EC	C:N	MBC	qCO2
	%	$g\ cm^{-3}$		$g\ kg^{-1}$		dSm^{-1}		$Mg\ C\ kg^{-1}\ s$	

OM: organic matter; TN: total nitrogen; EC: electrical conductivity; BD: bulk density; MBC: microbial biomass carbon; qCO_2: metabolic coefficient; CM: cultivated with maize; CO: cultivated with oat; CP: cultivated with potato; F: forest; RF: reforested. Values (means ± standard desviation, *n* = 4)

1.6. Production of CO_2

The greatest amount of CO_2 released was observed (Fig. 1) in the less disturbed, forest soil, where there was a comparatively higher concentration of OM. The lower emission of CO_2 was found in cultivated soils. In the first and second sampling the lowest CO_2 was detected in cultivated potato soils while the third sampling the lowest CO_2 was detected in soils cultivated with maize (Fig. 1).





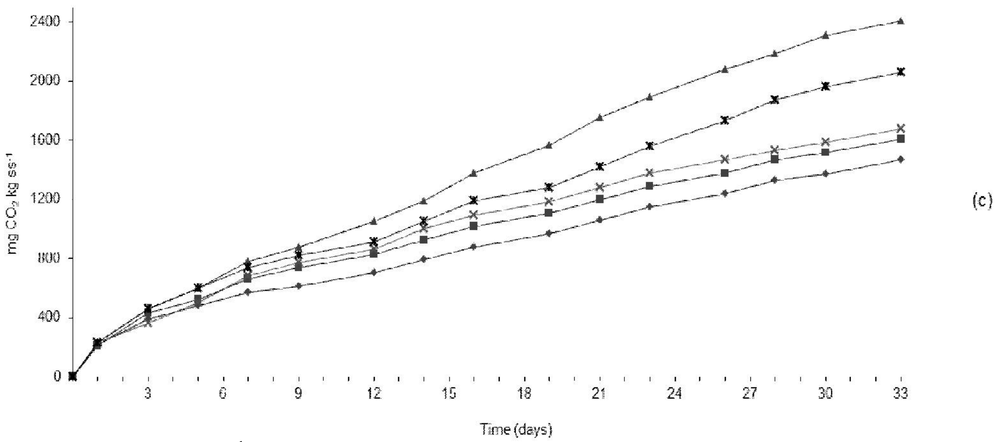


Fig. 1. Production of CO_2 (mg C kg^{-1} soil), in soils with different land use. CM: cultivated with maize; CO: cultivated with oat; CP: cultivated with potato; F: forest; RF: reforested; (a) February, (b) June and (c) March.

1.7. Mineralized nitrogen

The concentrations of mineralized nitrogen (Fig. 2) measured as the sum of NH_4^+ and NO_3^- were largest in soils cultivated with maize and oat. The concentration of inorganic N is lower in forest and reforested soils indicating that nitrifying populations in forest soils are depleted, either in their diversity or size. This concentration could also be attributed to poor quality of available OM.

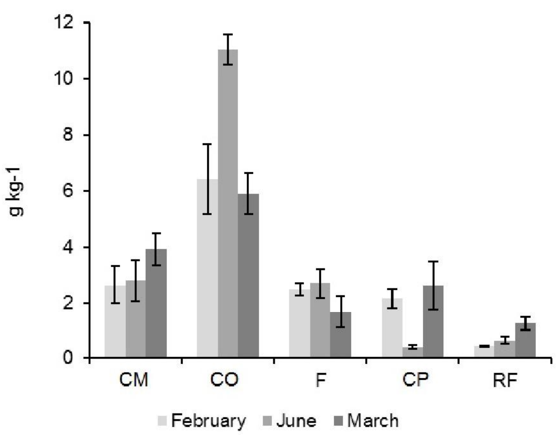


Fig. 2. Mineralized nitrogen (NH_4^++NO_3^-) in soils with different land use. CM: cultivated with maize; CO: cultivated with oat; CP: cultivated with potato; F: forest; RF: reforested.

1.8. Enzyme activity

Catalase activity (Fig. 3) was lower in cultivated soils than in forest soils, due to the removal of crop residues reduces the organic content. The highest phosphatase activity (Fig. 4) was found on the forest soil, the lower phosphatase activity was detected in the soil cultivated with potatoes where the application of phosphate fertilizer is made, and the supply of inorganic P suppresses the activity of the phosphatase. Urease activity varied between samples being higher for the second sampling when the temperature was higher as the moisture content (Fig. 5). In all three samples were differences in the activity of urease in soils, the increased activity of soil urease found on the forest soil that had the highest content of organic matter.

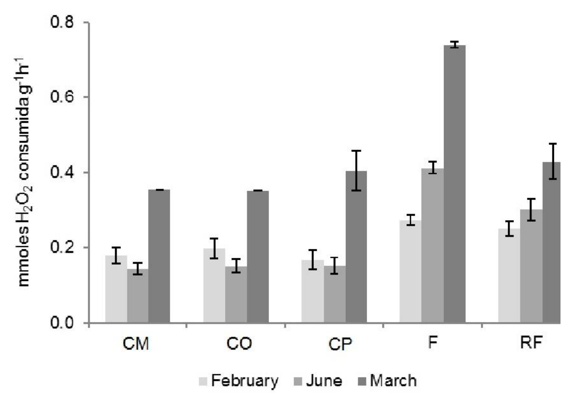


Fig. 3. Catalase activity in soils with different use (Calimaya, Mexico). CM: cultivated with maize; CO: cultivated with oat; CP: cultivated with potato; F: forest; RF: reforested.

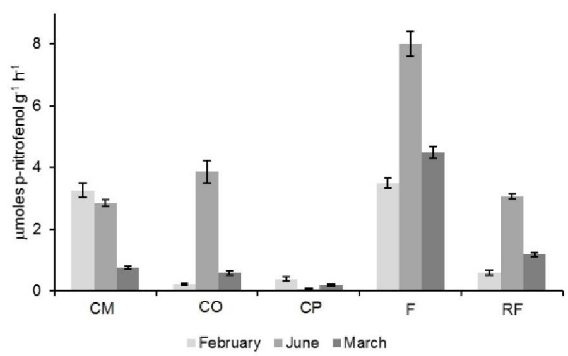


Fig. 4. Phosphatase activity in soils with different use (Calimaya, Mexico). CM: cultivated with maize; CO:

cultivated with oat; CP: cultivated with potato; F: forest; RF: reforested.

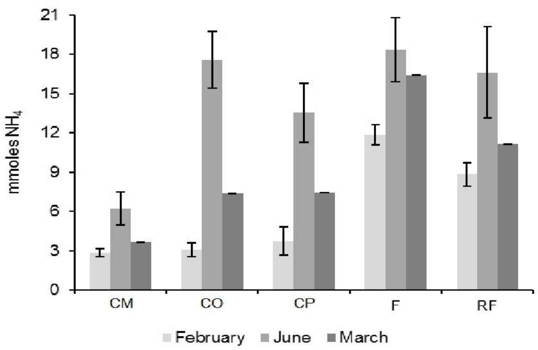


Fig. 5. Urease activity in soils with different use (Calimaya, Mexico). CM: cultivated with maize; CO: cultivated with oat; CP: cultivated with potato; F: forest; RF: reforested.

1.9. Principal components analysis

Principal Component Analysis was employed as a data reduction tool to select the most appropriate indicators. If was found that OM, TN, WHC and BD on the first PC (PC1) explained up to 47.1% of the total variation. PC1 had positive loadings for OM, TN and WHC and negative for BD. A second PC (PC2) explained another 24.5% of variation. PC2 had positive loadings for phosphorous. A third PC (PC3) explained 10.2% of variation and had positive loading from phosphatase. Therefore, the PCs that explained some percentage of the variation in the data were retained and examined for Minimum Data Set (MDS). Highly weighted factor loadings are defined as having absolute values within 10% of the highest factor loading.

Table 2. Results of principal component analysis (PCA) of soil quality indicators

PC's	PC1	PC2	PC3
Eigenvalue	6.1	3.1	1.3
% of variance	47.1	24.5	10.2
cumulative	47.1	71.6	81.8
Factor loading/eigenvector			
Variable			
OM	**0.369**	0.122	0.113
pH	0.221	-0.349	-0.293
EC	-0.174	0.289	0.478
BD	**-0.380**	-0.001	0.085
MBC	0.255	0.361	-0.113
CO_2	0.263	0.408	-0.090
TN	**0.370**	0.079	0.212
urease	0.272	-0.399	0.072
catalase	0.298	0.092	-0.057
phosphorus	-0.089	**0.513**	0.008
WHC	**0.366**	0.005	0.116
Nmin	-0.122	-0.132	0.493
phosphatase	0.223	-0.170	**0.578**

Bold face factor loadings are considered highly weighted within 10% of variation of the absolute values of the highest factor loading in each PC. OM: organic matter; pH; EC: electrical conductivity; BD: Bulk density; MBC: microbial biomass carbon; CO_2: respiratory activity; qCO_2: metabolic quotient; TN: total nitrogen; urease: urease activity; catalase: catalase activity; phosphorus: available phosphorus; WHC: water holding capacity; Nmin: mineralized nitrogen; phosphatase: phosphatase activity.

The soils are grouped into two visually distinct groups, the first group is located on the right side of the quadrant, and represented by the forest and reforested soils. Group 2 is represented by the cultivated soils. The first group consist of soils rich in OM, TN and MBC, which display high enzyme activity (Fig. 6). According to the PCA results of the variables OM, WHC and TN were the most important as regards the activity of catalase, MBC and respiratory activity of the microorganisms. Phosphatase and urease were located on the same side and near pH indicating that mainly the activity of these enzymes vary in terms of this soil property.

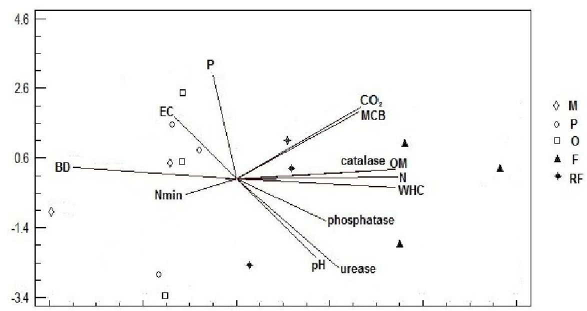


Fig. 6. Principal component analysis (PCA) performed on soil properties

A correlation matrix for the highly weighted variables under different PCs was run separately (Table 3). It was assumed that the variables having the highest correlation sum best represented the group. Among the four variables in PC1, total nitrogen was chosen for the MDS because of its highest correlation sum. The variable with second highest correlation sum was OM and was also retained for MDS. Volcanic soils have been traditionally recognized to have a high environmental quality [12]. Andosols are usually rich in OM (80–300 g kg^{-1}), which occurs as stable organomineral compounds or organ-metallic complexes, physically protected from mineralization inside the peculiar granular or crumb-type aggregates appearing commonly in their surface horizons [36]. Although phosphorous was found as a highly weighted variable under PC2, it could not be retained because in Andosols, available P for crops is limited primarily by sorption and precipitation processes [37]. Phosphatase was another variable, which was qualified under PC3 and was considered under MDS because values are significantly related to the soil available P content. The final MDS consisted of OM, TN and acid phosphatase.

Table 3. Correlation matrix for highly weighted variables under PC's with high factor loading

Variables	OM	BD	TN	WHC
PC1 variables				
Pearson's correlation				
OM	1.000	-0.818**	0.960**	0.779**
BD	-0.818**	1.000	-0.810**	-0.857**
TN	0.960**	-0.810**	1.000	0.813**
WHC	0.779**	-0.857**	0.813**	1.000
Correlation sums	3.557	3.485	3.583	3.449
	phosphorous			
PC2 variables				
phosphorous	1.000			
	phosphatase			
PC3 variables				
phosphatase	1.000			

OM: organic matter; BD: bulk density; TN: total nitrogen; phosphorus: available phosphorus; WHC: water holding capacity; phosphatase: phosphatase activity.
*Correlation is significant at the $P < 0.05$ level; **Correlation is significant at the $P < 0.01$ level

After obtaining various equations from the analytical descriptors of the soil samples from the five sites studied, an analysis of residuals was developed, and R^2 values were studied. We selected the equation where this ratio was closer to 1. The equation selected showed how nitrogen can be estimated (TN) by means of OM and the biochemical activity involved in cycle of P (acid phosphatase) can account for 95% of the observed for Equation selected:

N= 0.050*OM + 0.023*phosphatase – 0.067

4. Discussion

4.1. Soil physicochemical and microbial parameters

Water holding capacity was higher in F soils, than in agricultural soils, which could be attributed to their decreased OM content [38], and a process associated with fallow. The increase in BD observed on the cultivated soils could be due to agricultural practices [39]. The OM content in cultivated soils was lower than in the forest and reforested sites. Converting soil under natural vegetation to arable soil was not only detrimental for soil quality, but might be unsustainable as organic matter input is limited [40].

Nitrogen loss can be attributed to both the extraction by crops, active N mineralization and / or N storage, expected from the enhancement in soil aeration under fallow and leaching processes [41]. In soils F and RF, the microbial biomass carbon was high, which could provide appropriate conditions (OM and WHC) for retention of moisture and accumulation of carbon substrates. Due to corn, which is known, that degraded the soil has less CBM. Vásquez-Murrieta *et al.* [42] reported that continuous cultivation rapidly declines OM and also reduces the availability of nutrients, which adversely affects soil biomass content. The lower release of C-CO_2 observed in agricultural soils appears to confirm the low concentration of OM (Fig.1). Smith and Conen [43] argued that microbial populations and activity are higher in no tilled soils than in soils under conventional farming. In June soils cultivated with maize shown increase values of qCO_2 along with the increased levels of agrochemicals favoring the respiratory activity as a result of environmental stress and a reduction of the ratio of microbial biomass C. Deenik [44] agree assert that the degradation, associated with the change of use, drastically changes the dynamics of nitrogen in soils. Catalase activity was higher in F and RF soils where there is a continuous supply of residues Benítez *et al.* [45] reported that organic residues increases the enzymatic activity due to the direct addition of microorganisms and enzymes to soil or, indirectly, through the addition of microbially-available substrates. Intense phosphatase activity was detected in forest soil, which can be attributed to the continuous litter input from the forest canopy. Purakayastha *et al.* [46] indicated that the application of OM increases the activity of phosphatases, stimulating microbial biomass and root secretion. Olander and Vitousek [47] indicate that this enzymatic activity decreases if the increased availability of soil P. The urease activity decreased in cultivated corn; apparently nitrogen fertilization caused an inhibition of urease activity. In fact, Pajares *et al.* [48] reported the decreased urease activity in soils after repeated applications of ammonia fertilizer.

4.2. Principal components analysis

Results of Sadegh *et al.*, [49] showed that an appropriate reduction in the number of indicators to form and MDS still provides enough information for evaluating management intensity impact on soil quality. In a study conducted by D'Hose *et al.* [50] TN was retained in the MDS being an important indicator of soil fertility, these key indicator were integrated into a single index. Trasar-Cepeda *et al*. [13] proposed a regression model to estimate soil total N in non-degraded, nearly mature ecosystems using a linear combination of microbial biomass carbon, potentially mineralizable N and several enzymatic activities affecting C, N and P biogeochemical cycles: i.e., phosphomonoesterase, glucosidase and urease. Using MLR Zornoza *et al*. [16] obtained models relating physical, chemical and biochemical properties of soils.

5. Conclusions

The impact of different types of land use on the physical, chemical and biochemical properties of soil was found closely related to defined cultural and management practices. Principal component analysis succeeded in betraying valuable soil quality indicators in soil after changes in use of agricultural forest systems. This study demonstrates that OM, NT and soil acid phosphatase can be used as soil quality indicators in temperate highlands subjected to different land use.

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Corresponding Author:
Dr. Jorge Lugo
Universidad Autónoma del Estado de México, Instituto Literario 100 Toluca, 50 000 México.
E-mail: jorgelug@gmail.com

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