Changes in the Chemical Properties of a Soil Impacted by Intensive Agriculture, North-eastern Mexico

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Abstract

The present study was carried out in a semi-arid area within the Chihuahuan Desert in the Northern Mexican Plateau. The objective of the study was to evaluate the long term changes in the soil chemical properties after one cycle of potato cultivation with intensive application of agrochemicals.Sampling sites were established in areas that had1, 2, 5 and 10 years of abandonment after potato cultivation and an area of native grassland was also considered as control. Potato cultivation is carried out by a company that rent the land to the peasants, so cultivation is done in the same way all over this area. At each site, the following variables were evaluated at 0-10 and 10-30 cm soil depths: pH, CEC, EC, SOM,$CaCO_3$, $CaSO_4$, Na, K, Mg, P, total N, Ca, Cu, Fe, Mn and Zn. Results showed that even though sites were statistically equal for all the evaluated variables, there were some variables (total N, extractable P, Mg, Cu and Zn) that fell in different ranges according to the Mexican NOM-021-SEMARNAT-2000 of soil classification.

1. Introduction

Agricultural practices and soil management practices are the more significant anthropogenic activities that disturb the physical and chemical characteristics of soil (Buckley and Schmidt, 2001); which by being inadequate, lead to soil degradation (Michelena et al., 2008). Lately, and due to the importance of soil as an essential component of the ecosystem's health, interest has increased in determining the consequences of agricultural practices on soil properties (Schoenholtz et al., 2000). Several researches have been focused on the identification of indicators to estimate the current state and trends in the quality of soils through the evaluation of their physical and chemical properties, looking for sustainable management strategies (Sacchi and De Pauli, 2002; Inzunza-Ibarra and Curtis, 2005; Alejo-Santiago et al., 2012).

The Northeast of Mexico includes a large extension of arid and semi-arid areas that have been particularly affected by soil degradation caused by the transformation of natural ecosystems into irrigated agricultural lands (McCready et al., 2005). A clear example of this problem occurs in the grasslands of the southern region of the Chihuahua Desert, which exhibits a great biological diversity so that its preservation is of imperative importance (Arriaga et al., 2000). According to studies conducted in the area (Pronatura Noreste [PNE] and The Nature Conservancy [TNC], 2007; Estrada-Castillon et al., 2010) such diversity is strongly threatened mainly by the conversion of the gypsophila and halophile grasslands into crop lands, particularly dedicated to grow potatoes. In the area, this crop is cultivated using a high amount of fertilizers and other agro-chemicals and, even so, peasants claim that potato yields notoriously decreased after one cycle of cultivation. The land is abandoned after just one year of use and new grasslands are cleared. Hence, in order to preserve these grassland ecosystems there is a need to establish new management strategies for sustainable agricultural practices and an unavoidable requisite for these strategies to be successful is to know the dynamics of the properties of soils subjected to this type of agricultural use. Thus, this research was conducted to compare the chemical characteristics of the soil in areas with different abandonment times and an adjacent area of natural grassland, looking for an explanation for the abandonment of the areas and setting the basis for management practices that encourage the continued use of already cleared areas. Our hypothesis is that after potato cultivation, the land is depleted of some of the essential nutrients or its chemical characteristics change in a way that prevents the proper development of the crop.

2. Materials and Methods

2.1. Study area

The study area is located in the Southern region of the Chihuahuan Desert, in North-eastern Mexico (Figure 1) (24° 40'55''N, 100°14'20'' W), at an elevation between 1900 and 2000 m. In the area co-exist animal species of great conservation priority, such as the prairie dog (*Cynomys mexicanus*), the burrowing owl (*Athene cunicularia*), the mountain plover (*Charadrius montanus*), the golden eagle (*Aquila chrysaetos*), as well as endemic plant species such as *Frankenia gypsophila* and *Bouteloua chasei* among others. The predominant soil types in the area are slightly alkaline such as Solonchak with a petrogipsic phase and haplic xerosols (INEGI, 1981). The climate of the region is dry, mild, or arid, with an average annual rainfall of 333.8 mm and an average annual temperature of 22°C (Garcia, 1981). For the last 40 years, extensive areas have been cleared in the region to grow potatoes. Potatoes are cultivated by a private company that leases the land all over the area.

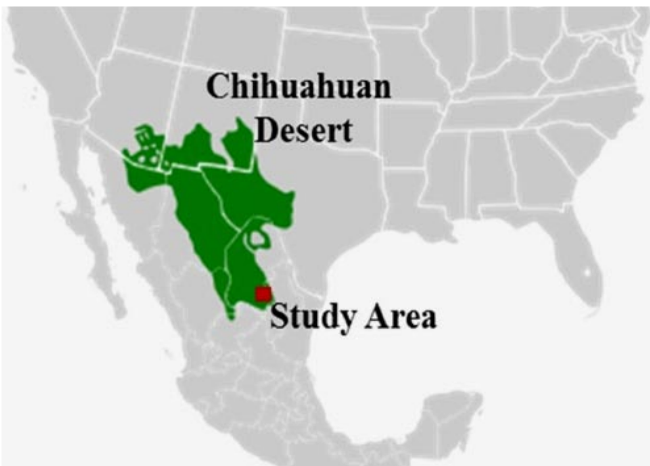

Figure 1: Location of the study area

2.2. Sampling sites

Sampling sites were selected with 1, 2, 5 and 10 resting years after potato cultivation and, as a reference, an area of natural grassland. Three 1-ha sites were selected for each resting period and, in each plot, 5 subsamples of soil were obtained at two depths (0-10 cm and 10-30 cm). The 5 subsamples from each plot were mixed into one homogeneous mixture, given a total of 30 samples to be analyzed for the different agricultural areas as well as the reference site. Sampling was carried out during February 2011. The soil texture for all evaluated sites was fine silt loam.

2.3. Determination of soil chemical properties

Soil samples were air-dried and passed through a 2 mm sieve and determined by the methods described in Table 1.

2.4. Statistical analysis

Since data did not show the assumptions of normal distribution nor equal variances, data were analyzed using the nonparametric Kruskal-Wallis test (Steel and Torrie, 1980). To detect significant differences between resting years at each soil depth

Table 1: Evaluated soil chemical properties and method

Soil chemical property	Method	Unit
pH	Measured in 1:2.5 (soil:water) extracts according to NOM-021-RECNAT-2000.	
Electrical conductivity (EC)	Measured in 1:2.5 (soil:water) extracts according to NOM-021-RECNAT-2000.	dS m^{-1}
Soil organic matter (SOM)	Wet combustion and titration according to Walkley and Black.	%
Cation-exchange capacity (CEC)	Ammonium acetate method.	cmol Kg^{-1}
Sodium (Na)	Acetate -NH_4 pH 7.0.	cmol Kg^{-1}
Calcium carbonate ($CaCO_3$)	Gas-volumetric determination of the total carbonate after its destruction with a strong acid according to Scheibler/Finkener	%
Calcium sulfate ($CaSO_4$)	Acetate -NH_4 pH 7.0.	%
Total nitrogen (TN)	Digestion of total nitrogen and titration according to the semi-micro procedure KJELDAHL.	%
Extractable phosphorus (EP)	Extraction of available phosphorus with sodium bicarbonate as Olsen P	mg L^{-1}
Calcium (Ca)	Acetate -NH_4 pH 7.0.	cmol Kg^{-1}
Potassium (K)	Acetate -NH_4 pH 7.0.	cmol Kg^{-1}
Magnesium (Mg)	Acetate -NH_4 pH 7.0.	cmol Kg^{-1}
Copper (Cu)	DTPA-TEA - $CaCl_2$ pH 7.3 according to LINDSAY/NORVELL.	mg L^{-1}
Zinc (Zn)	DTPA-TEA - $CaCl_2$ pH 7.3 according to LINDSAY/NORVELL.	mg L^{-1}
Iron (Fe)	DTPA-TEA - $CaCl_2$ pH 7.3 according to LINDSAY/NORVELL.	mg L^{-1}
Manganese (Mn)	DTPA-TEA - $CaCl_2$ pH 7.3 according to LINDSAY/NORVELL.	mg L^{-1}

profile for each determined soil variable. The Mann-Whitney U non parametric test with the Bonferroni correction method was employed (Wackerly et al., 2002) at a p=0.05. All statistical analyses were carried out by using the statistical package SPSS version 13 for Windows.

2.5. Classification of variables

Many times, statistical differences in soil variables do not mean differences in the quality of the soil or the way the soil needs to be managed. When comparing two soils or changes of one soil overtime it is important to consider the classification of soils as a tool of analysis to detect if the values of the variables of interest fall in a different category. To do this, we used the official classification of soils of the Official Mexican standard NOM-021-SEMARNAT-2000.

3. Results and Discussion

Values for all the analyzed variables were equal between different resting time sites and equal to the native grassland areas, both at 0-10 and at 10-30 depth (Tables 2 and 3). However, according to the Official Mexican Classification of Soils, some of the evaluated soil chemical properties fell in different categories in sites with different resting times and in the grassland site. Thus, at the 10-30 depth, total nitrogen content was classified as high in the grassland site, moderate in the site with one year of rest after cultivation, low in the site with two years of rest, and then increases to moderate for the sites with five and ten years of resting (Table 5). This pattern coincides with the results documented by Wang et al. (2009) who analyzed total nitrogen in the soil of several land uses in China and reported lower content of total nitrogen in agricultural soils than in grasslands, and concluded that it is related to the decrease in organic matter.

Other variable that showed differences in the classification was phosphorous. The effect of fertilization was notorious in the pattern of this element since, at the top soil layer, the native grassland had a low content of phosphorous while sites with 1 and 2 years of rest after cropping showed a high content. The content of phosphorous started decreasing after the second year of resting, however, even after 5 and 10 resting years, the content was still classified as moderate (Table 4). At the lower soil layer (10-30 cm), the native grassland and sites with 5 and 10 resting years fell into the same category, classified as low content of phosphorous, different to sites with 1 and 2 resting years which were classified as having a high content of this element (Table 5). These results are similar to those reported by Agashi et al. (2010) who compared grasslands with agriculture

Table 2: P values of the Mann Whitney U test with the Bonferroni correction method for soil depth profile 0-10 cm

Mean Comparison										
	1 year				2 years			5 years		10 years
	vs				vs			vs		vs
Soil chem. property	2 years	5 years	10 years	Grassland	5 years	10 years	Grassland	10 years	Grassland	Grassland
pH	0.050	0.050	0.827	0.658	0.077	0.050	0.050	0.077	0.077	0.500
EC	0.827	0.127	0.050	0.050	0.275	0.050	0.050	0.127	0.050	0.184
SOM	0.275	0.050	0.050	0.050	0.050	0.050	0.050	0.275	0.827	0.275
$CaCO_3$	0.050	0.050	0.376	0.050	0.050	0.050	0.050	0.050	0.376	0.050
$CaCO_4$	0.827	0.050	0.827	0.050	0.050	0.827	0.050	0.050	0.275	0.050
Ca	0.050	0.827	0.050	0.050	0.050	0.513	0.513	0.050	0.050	0.827
K	0.275	0.275	0.275	0.050	0.050	0.050	0.050	0.513	0.050	0.050
Mg	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
Na	0.513	0.050	0.050	0.050	0.050	0.050	0.050	0.827	0.827	0.513
Cu	0.050	0.050	0.050	0.050	0.513	0.658	0.127	0.827	0.184	0.050
Mn	0.513	0.827	0.127	0.050	0.275	0.513	0.050	0.827	0.050	0.050
Fe	0.127	0.513	0.827	0.827	0.827	0.127	0.127	0.275	0.275	0.827
Zn	0.275	0.050	0.050	0.046	0.050	0.050	0.046	0.127	0.072	0.046
CEC	0.275	0.050	0.050	0.127	0.127	0.275	0.127	0.513	0.513	0.827
TN	0.043	0.046	0.043	0.043	0.046	0.043	0.043	0.653	0.346	0.068
EP	0.275	0.050	0.050	0.050	0.050	0.050	0.050	0.513	0.127	0.050

p=0.05/10=0.005. If p values are ≤0.005, the mean treatment comparison is declared different.

Table 3: P values of the Mann Whitney U test with the Bonferroni correction method for soil depth profile10-30 cm

	Mean Comparison									
	1 year				2 years			5 years		10 years
	vs				vs			vs		vs
Soil Chemical Property	2 years	5 years	10 years	Grass-land	5 years	10 years	Grass-land	10 years	Grassland	Grass-land
pH	0.121	0.814	0.796	0.268	0.046	0.046	0.050	0.239	0.121	0.268
CE	0.376	0.275	0.050	0.050	0.127	0.050	0.050	0.184	0.050	0.050
SOM	0.127	0.827	0.127	0.513	0.127	0.050	0.827	0.513	0.513	0.275
$CaCO_3$	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.275	0.050
$CaCO_4$	0.827	0.127	0.513	0.050	0.184	0.275	0.050	0.050	0.275	0.050
Ca	0.513	0.827	0.513	0.513	0.513	0.827	0.513	0.513	0.513	0.513
K	0.050	0.050	0.275	0.050	0.050	0.275	0.050	0.050	0.513	0.050
Mg	0.050	0.127	0.050	0.050	0.050	0.050	0.050	0.827	0.050	0.050
Na	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.827	0.050
Cu	0.275	0.275	0.376	0.050	0.827	0.827	0.050	0.827	0.077	0.050
Mn	0.275	0.827	1.000	0.050	0.513	0.127	0.050	0.827	0.050	0.050
Fe	0.513	0.827	0.658	0.827	0.513	0.513	0.827	0.827	0.827	0.513
Zn	0.658	0.050	0.127	0.050	0.050	0.127	0.050	0.827	0.513	0.050
CEC	0.513	0.513	0.275	0.513	0.275	0.513	0.513	0.827	0.513	0.275
TN	0.077	0.653	0.105	0.077	0.046	0.046	0.050	0.043	0.046	0.346
EP	0.513	0.046	0.127	0.050	0.046	0.050	0.050	0.507	0.046	0.050

p=0.05/10=0.005. If p values are less than 0.005, the mean treatment comparison is declared different

Table 4: Soil classification (letters) of the variables analyzed and average values (n=6), ±standard deviation for the soil depth 0-10 cm

Soil Chemical Property	Unit	Grassland	1 year	2 years	5 years	10 years
pH		7.8±0.03[d]	7.9±0.03[d]	7.8±0.02[d]	7.8±0.02[d]	7.8±0.04[d]
EC	dSm^{-1}	2.1±0.04[c]	2.4±0.10[c]	2.7±0.73[c]	2.3±0.06[c]	2.2±0.05[c]
SOM	%	3.1±0.20[c]	2.2±0.16[c]	2.3±0.10[c]	3.1±0.17[c]	3.3±0.30[c]
CEC	cmol Kg^{-1}	18.4±3.37[c]	14.7±3.76[c]	15.9±2.19[c]	18.6±3.49[c]	19.8±3.28[c]
Na	cmol Kg^{-1}	2.0±0.76[c]	6.5±0.92[c]	8.7±7.44[c]	3.8±3.40[c]	1.9±1.45[c]
C_aCO_3	%	4.5±0.05[c]	8.9±0.05[c]	3.0±0.03[c]	14.3±0.12[c]	13.5±0.23[c]
C_aSO_4	%	14.5±0.18[c]	13.4±0.28[c]	13.4±0.15[c]	47.1±0.20[c]	44.3±0.41[c]
TN	%	0.18±0.004[d]	0.16±0.009[d]	0.13±0.01[c]	0.20±0.03[d]	0.20±0.01[d]
EP	mg L^{-1}	4.5±0.53[a]	28.1±8.47[c]	22.7±6.89[c]	7.2±3.29[b]	8.4±0.86[b]
Ca	cmol Kg^{-1}	2489.3±57.4[b]	2596.7±63.6[b]	2523.9±23.3[b]	2588.5±109[b]	2519.0±73.7[b]
K	cmol Kg^{-1}	3.5±0.22[b]	9.6±3.3[b]	11.6±3.2[b]	9.2±3.8[b]	6.2±1.9[b]
Mg	cmol Kg^{-1}	0.90±0.23[b]	15.9±.68[b]	27.2±20.02[b]	7.4±1.99[b]	4.1±3.18[b]
Cu	mg L^{-1}	0.24±0.19[a]	0.70±0.12[b]	0.41±0.12[b]	0.37±0.11[b]	0.36±0.02[b]
Zn	mg L^{-1}	0.24±0.03[a]	2.38±0.21[c]	2.17±0.35[c]	0.72±0.38[b]	1.27±0.34[c]
Fe	mg L^{-1}	1.6±0.35[a]	1.5±0.14[a]	1.2±0.27[a]	1.4±0.41[a]	1.7±0.44[a]
Mn	mg L^{-1}	1.8±0.24[b]	3.9±0.50[b]	3.5±1.31[b]	4.2±1.03[b]	4.7±0.55[b]

Same letter are for sites that are within the same category for each variable assessed; Values range from the lowest to the highest are a>b>c>d

Table 5: Soil classification (letters) of the variables analyzed and average values (n=6), ±standard deviation for the soil depth 10-30 cm

Soil Chemical Property	Unit	Grassland	1 year	2 years	5 years	10 years
pH		7.9±0.04[d]	8.0±0.06[d]	8.0±0.05[d]	7.9±0.03[d]	7.8±0.01[d]
EC	dSm^{-1}	2.1±0.04[c]	2.3±0.20[c]	2.4±0.07[c]	2.2±0.04[c]	2.2±0.02[c]
SOM	%	1.8±0.57[c]	1.8±0.17[c]	1.6±0.11[c]	2.1±0.56[c]	2.4±0.53[c]
CEC	$cmolKg^{-1}$	14.5±4.92[c]	13.2±5.58[c]	14.4±2.81[c]	15.6±1.45[c]	17.7±5.75[c]
Na	$cmolKg^{-1}$	2.0±0.46[c]	4.8±1.26[c]	7.2±1.87[c]	3.0±1.08[c]	1.1±0.38[c]
$CaCO_3$	%	4.4±0.21[c]	7.9±1.40[c]	2.9±0.15[c]	4.6±0.05[c]	9.4±0.17[c]
$CaSO_4$	%	14.7±0.07[c]	14.0±0.12[c]	14.1±0.19[c]	14.4±0.14[c]	13.8±0.24[c]
TN	%	0.15±0.007[c]	0.13±0.01[c]	0.09±0.01[b]	0.12±0.006[c]	0.14±0.004[c]
EP	$mg\ L^{-1}$	2.4±0.47[a]	13.5±7.85[c]	14.1±0.35[c]	5.1±0.50[a]	5.5±1.30[a]
Ca	$cmol\ Kg^{-1}$	2507.2±55.0[d]	2563.6±203[d]	2559.9±93.0[d]	2543.6±152[d]	2513.3±67.4[d]
K	$cmol\ Kg^{-1}$	1.8±0.88[d]	6.2±3.10[d]	6.9±1.64[d]	6.1±6.0[d]	4.8±1.8[d]
Mg	$cmol\ Kg^{-1}$	0.65±0.46[b]	11.8±1.52[d]	22.5±4.91[d]	8.7±4.88[d]	3.2±1.36[c]
Cu	$mg\ L^{-1}$	0.13±0.02[a]	0.37±0.09[b]	0.30±0.08[b]	0.25±0.09[b]	0.27±0.11[b]
Zn	$mg\ L^{-1}$	0.06±0.02[a]	1.4±0.33[c]	1.4±0.13[c]	0.37±0.27[a]	0.71±0.58[b]
Fe	$mg\ L^{-1}$	0.93±0.16[a]	0.98±0.20[a]	0.91±0.05[a]	0.89±0.38[a]	1.0±0.44[a]
Mn	$mg\ L^{-1}$	1.1±0.14[b]	2.0±0.46[b]	1.8±0.28[b]	2.2±0.55[b]	2.2±0.19[b]

Same letter are for sites that are within the same category for each variable assessed; Values range from the lowest to the highest are a>b>c>d

and abandoned lands in an arid area in Iran and detected higher content of extractable phosphorous in agricultural lands due to the continuous fertilization, even though the differences were not statistically significant.

Pattern of magnesium at the second layer was similar to that of phosphorous with low content in the grassland, high in the 1, 2 and 5 year sites, and moderate at the 10 resting year site (Table 5). At the top layer, content of magnesium was classified as high for all the resting sites and low in the grassland (Table 4).

Content of Cu and Zn micronutrients were high for the sites with 1 and 2 years of rest, deficient for the grassland site and adequate for the rest of the treatments in the 0-10 cm depth. Zinc had a slightly different response being deficient in the grassland and adequate for the sites with 1 and 2 years at both depths. The 5 year treatment showed a marginal content of zinc at the top soil layer and deficient at the second layer while sites with 10 years of rest had an adequate content at the 0-10 layer and marginal in the second layer (Tables 4 and 5). These tables illustrate how content of zinc is in a higher category after 10 years of application of fertilizers than in the control.

The other variables did not show differences either statistically or in the classification between the different resting times nor with the native grasslands. These variables were classified as follows: pH moderately alkaline, moderate salinity, medium CEC, medium content of organic matter and calcium carbonate, high content of Ca, Na and K, adequate Mg and deficient in Fe (Tables 4 and 5).

Results found in this study are somehow similar to those reported by Alejo-Santiago et al. (2012) who also found no differences in chemical properties between cultivated and natural vegetation. Conversely, Inzunza-Ibarra and Curtis (2005) as well as Presley et al. (2004) reported an increase in pH values in agricultural lands and concluded that this might be due to an increase in the amount of salts from fertilizers. In present study, values of electrical conductivity slightly increased during the first two years after cultivation of soil from 2.1 dSm^{-1} in the grassland to 2.4 y 2.7 dSm^{-1} in the first and second year of resting, respectively (Table 4), however these values were statistically equal and fell into the same category in the classification.

On the other hand, contrary to the expected results, content of organic matter did not change after cultivation as has been reported by several authors. For example, Agashiet al. (2010) and Alejo-Santiago et al. (2012) reported a significant decrease in organic matter content in agricultural lands as a consequence of continuous tillage. In addition, Bowman et al. (1990) stated that loss of organic matter during the first years of conventional agriculture is higher than in the subsequent years and about 80% of labile C is lost during the first three years of cultivation.

When comparing soil properties of agricultural lands and native vegetation, some authors reported a decrease in the CEC in agricultural areas (Sacci and De Pauli, 2002 and Agashi et al., 2010), differing to our results where no differences were detected in the CEC of evaluated areas.

4. Conclusions

Results of this investigation show that, after one year of intensive cultivation of potato, chemical properties of the soil did not statistically differ over time up to 10 years of rest nor compared to those of the native grasslands. However, we emphasize the importance of considering not only statistical analysis but also soil classifications in order to detect changes that can be more relevant for management purposes.

According to the official Mexican soil classification, we detected that total N, extractable P, Mg, Cu and Zn fell in a higher category for the treatments of 1 and 2 years of rest than the native grasslands, and these values started decreasing at the fifth year approaching the values of the control areas.

These results lead us to reject our hypothesis as soil nutrients do not seem to be lost after this type of cultivation and the answer for the abandonment of the lands must be other.

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