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RESEARCH PAPER

Influence of fire on soil and vegetation properties in two contrasting forest sites in Central México

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Abstract

J. Capulin-Grande, A. Suárez-Islas, R. Rodríguez-Laguna, J.J. Mateo-Sánchez, R. Razo-Zárate, and M. Islas-Santillán. 2018. Influence of fire on soil and vegetation properties in two contrasting forest sites in Central México. Cien. Inv. Agr. 45(2): 128-137. Fire produces changes in vegetation, soil, fauna, and water quality, and it can even modify atmospheric chemical composition. Changes in soil fertility, microorganisms and vegetation were evaluated after a fire in two municipalities in the State of Hidalgo, Mexico. Inside and outside the burned area, four 100 m^2 plots were established. In each of the eight plots, soil samples were collected at two depths (0–5 and 5–20 cm) in the following areas: non-burned area (NBA); 15 days after fire (15DAF); and 12 and 24 months after the fire (MAF). Vegetation quantification was carried out at 30, 180 and 540 DAF. The results at 15DAF showed an increase of alkaline and metallic elements as well as pH in the surface layer, and this trend remained the same to 12MAF. There was greater Fe, Mn and Zn content in Zacualtipán and greater K, Ca, Mg and P in Singuilucan. At 24MAF, due to the nutrient requirements of the herbaceous and scrub growth, this effect was reverted. The fire reduced the organic matter (OM) and total nitrogen (TN) contents, without any recovery during the evaluated period. Bacteria showed greater mortality because of the fire: 76% and 50% at the Zacualtipán and Singuilucan sites, respectively. The canopy opening promoted a 50% increase of species in Zacualtipán. In conclusion, the fire temporarily increased soil fertility and the presence of herbaceous vegetation, but it reduced the bacteria and fungi populations.

Keywords*:* Bacteria, fire, fungi, soil fertility, vegetation.

Introduction

As a component of the earth system, fire has influenced the composition of atmospheric gases, climate, biota, geoformations, transportation of materials and sedimentation rates (Fernández and Vega-Hidalgo, 2011; Bodí *et al.,* 2012). Recurrent fires favor a different ecosystem than would be expected based on climate, and species with some fire resistance mechanism persist and develop their own survival strategies (Pausas *et al.,* 2008). Fire is an essential ecological factor in the distribution of ecosystems, acting as if it were a large herbivore (Bond and Keeley, 2005).

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In Mexico, 97% of forest fires are caused by humans, and 54% of these are due to agricultural activities. Over 90% of the fires are surface fires, which reach temperatures of between 200 and 300 °C. Their extension and intensity depend on environmental conditions, topography, quantity and characteristics of the fuel on the site. Fire produces changes in the vegetation, soils, wildlife, hydrological and geomorphological processes (Moody and Martin, 2009), water quality, and even the atmospheric composition (Bravo *et al.,* 2002). Fire effects vary depending on many factors: available biomass, intensity (temperatures reached and their duration), burned area, time elapsed since last fire, soil type, moisture, slope and vegetation.

Some physical and chemical soil properties change during and after the fire (Giovannini and Lucchesi, 1997), such as the ability to retain moisture as a result of vegetation cover loss and darkening due to partially burnt vegetation and ashes (Pereira *et al.,* 2013). Other changes include structure and texture, which can be modified due to the change in the proportion and arrangement of particles (MacDonald and Huffman, 2004). Another change is soil loss by erosion in steeply sloped sites (Moody and Martin, 2009).

The combustion of vegetal waste causes the loss of some elements by volatilization, while others are transformed into oxides which increase the availability of alkaline elements in the soil (Caldwell *et al.,* 2002). The quantity of organic matter of the soil surface may decrease (Mataix-Solera *et al.,* 2002) by greater than 50%. As a result of the generation of large quantities of ash, the pH is modified during combustion, and the formation of organic acids is reduced (Dikici and Yilmaz, 2006).

High temperatures generated during fires cause a decrease in microbiological activity, and the changes in microbial communities can eliminate organisms such as fungi, protozoa and bacteria. In a pine forest, after a controlled burn, it was observed that the mycorrhizal population decreased to one eighth of its size. Although it is known that fungi are more resistant to temperature changes than bacteria (Bárcenas-Moreno *et al.*, 2011), the survival of fungi and bacteria in different environments has not been deeply evaluated. However, stronger activity of these microorganisms has been found after fires (Bodí *et al.*, 2012).

The apparent biological vacuum that remains after a fire is fleeting, because high biological activity is frequently observed after the first rains (Mataix-Solera *et al.*, 2002). In addition, there are plant species with adaptations designed to resist fire, and some of them have even developed reproductive mechanisms such as rhizomes to be able to sprout. Low or medium intensity fires have a moderate impact and promote herbaceous vegetation, while increasing the nutrient availability and forming canopy openings, which promote a healthier habitat. However, to determine the forest recovery time, it is necessary to know the variation of the soil nutritional availability over time and the vegetation succession after burning. Therefore, the aim of this study was to evaluate the fire effect on changes in soil chemical fertility, and the survival of fungi and bacteria as well as the variation of vegetation after fire in different environmental conditions.

Materials and methods

Characteristics of the study sites

In April 2012, two burned sites with contrasting climates were identified: a) a humid temperate zone and b) a dry zone. The former is located in the town of Zacualtipán. The vegetation here corresponds to a conifer forest of a mesophilous group, which is formed by forests where *Pinus teocote* is often the only species in the arboreal strata, with heights varying from 15 to 20 meters. The forest is characterized by spaced trees, thin vegetative cover, a luminous understory, disseminated bushes and a discontinuous herbaceous cover (Puig, 1991). The dry zone (b) is located in the town of Singuilucan. This area was found to have a brush vegetation of oaks (Rzedowski, 2006), characterized by the dominance of shrub species that form a thick scrub of deciduous oak, with small, thick and leathery leaves. *Quercus microphylla* predominates with individuals with heights of less than 1 meter. They are leafy, imbricated, and form populations that are difficult to penetrate. Occasionally, there are small *Quercus mexicana* trees with heights less than 5 meters, both located in Hidalgo State, Mexico.

Some of the characteristics of both sites are shown in Table 1. In the Zacualtipan site, the surface fire reached an extension of approximately 15 ha; the tree-shrub strata suffered a high level of fire severity, consuming all the vegetation up to 1.5 meters high. Partial trunk scorch brands were observed in trees of up to 2.5 meters in height (Valor *et al.*, 2013), which managed to survive the disaster. Fire at the Singuilucan site is also classified as a high severity surface fire, with low to regular mortality, due to the intense fire having consumed the entire leaf litter and the aerial portions of the scrub oaks. However, since the individuals showed high re-sprouting capacity (Rodríguez-Trejo, 2014), the mortality was low, and covered an extension of approximately 12 ha. At both sites, the speed and spread of the fire were favored by the gradient (15% to 20%) and a high quantity of available fuel, as well as its having occurred during the hottest month of the year (April) in each site. In this month, the environmental conditions include low relative humidity, high temperature, intense radiation, and dry combustible material with low soil humidity.

Soil sampling

Four sample plots, each 100 m^2 in area, were located within a polygon, and randomly distributed in the burned area. An equal number of plots within the non-burned area was established as a control. In each plot, four subsamples were taken, using a cylindrical auger of 5 cm in diameter, to form one compound sample; sampling was done at two depths: 0 to 5 cm and 5 to 20 cm. Four samples were performed: 1) outside the burned area, simulating conditions before the fire (BTF), to determine the initial conditions for both fertility and the presence of bacteria and fungi; 2) 15 days after the fire (15DAF) to quantify the effect of fire on soil fertility and microorganism survival; 3) 12 months after the fire (12MAF); and 4) 24 months after the fire (24MAF), to observe the variation of soil fertility over time.

Samples collected at the study sites, at different times and two soils depths, were analyzed using the methodology for the study of soils of the Norma Oficial Mexicana (NOM) (2002). pH, contents of total nitrogen (TN), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), sulphates (SO_4), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), organic matter (OM), organic carbon (OC), and texture were determined. To quantify

Table 1. Characteristics of the study sites in Zacualtipán and Singuilucan, Hidalgo, México.

	Experimental site	
	Zacualtipán	Singuilucan
Location	20º 37´ 20” NL and 98º 40´ 00” WL	20º 00´ 46” NL and 98º 33´ 22” WL
Altitude (m)	2950	2725
Gradient (%)	15	20
Exposition	Southeast	Northeast
Average Annual Temperature (°C)	14.0	13.2
Precipitation (mm year^{-1})	2047	575
Geological substrate	Limestone, shale and sandstone	Basic volcanic breccia
Soil classification	Leptic Siderudalf	Typic Fragxerent

the presence of Colony Forming Units (CFU) of fungi and bacteria, samples were analyzed by the technique described by Díaz-Martínez *et al.* (2013) at the Soil Microbiology Laboratory of the Colegio de Postgraduados. This technique consists of sifting soil and placing it in Petri dishes with nutrient agar, which were immediately incubated at 28 °C for 48 hours, after which time the CFU were quantified.

Collection of plant material

The fine fuel loading was quantified at each site before the fires. In Zacualtipan, it consisted of pine needles, oak leaves, and other broadleaved hardwoods and herbaceous vegetation, for a total of 10.0 Mg ha^{-1}. In Singuilucan, the fuel was mostly oak leaves and some grasses, corresponding to 9.62 Mg ha^{-1}. The vegetation collection was performed at 30, 180 and 540 DAF using the scanning method, through the collection of the species in the burned and control plots. The botanical identification was carried out with the help of plant identification guides (Villavicencio *et al.,* 2002).

Experimental design

The study was established as a completely randomized design. The sets of conditions included the combination of the presence or absence of fire in the forest soil (with fire/no fire), and soil sampling depths (0–5 cm/5–20 cm) resulting in a total of four. These each had four repetitions.

Statistical analysis

Data obtained were analyzed using the SAS® statistical program, using the analysis of variance and Tukey's comparison test tools to compare the sets of conditions, at the 95% probability level (SAS, 1997).

Results and discussion

Changes in properties and soil fertility

Soil warming produces variations in some of the physical and chemical properties. Table 2 shows the variation of the soil nutrient content of the study site. It has been reported that the severity fires markedly affects the surface layer of the soil (Wieting *et al.*, 2017) due to the combustion of the material present on the surface that produces heating and modifies the properties of texture and nutritional availability (Badia and Marti, 2003; Thomaz, 2017). The effect of fire decreases gradually with depth. This phenomenon is demonstrated by collecting and mixing the soil layers with depths from 5 to 20 cm, such that the effect of fire decreases and sometimes disappears. In this study, only the soil surface layer (0–5 cm) was considered, to show the variation in the nutritional content.

The surface layer (0–5 cm) shows the highest content of nutrients, because it is where organic waste is deposited and most decomposition and mineralization occurs. On the other hand, after a fire, ashes, which contain significant quantities of nutrients beneficial for vegetation, accumulate. At the greater depth (5–20 cm), the content of most nutrients is reduced, because the temperature reached in a fire has a major impact on the soil surface layer (Fernández and Vega-Hidalgo, 2011; Bodí *et al.,* 2012).

Comparing both sites, Zacualtipán has more acidic pH levels, which causes differences in nutritional availability to plants. It also showed a high content of organic matter and organic carbon, but the nitrogen content of the soil was low, confirming that the organic matter does not completely decompose (Arias *et al.,* 2005). This is because of its high content of resin, lipids and lignin with a C/N ratio over 50, leading to the slow transformation of humus. Therefore, the mineralization process is very slow, and consequently, the availability of nitrogen and other

Table 2. Variation in soil fertility before and after the fire at two places for different depths (cm) (average of four repetitions, n=4)

Parameter	Zacualtipán				Singuilucan			
	BTF		15DAF		BTF		15DAF	
	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20
pH	4.10	4.00	5.00	4.70	6.10	6.00	6.80	6.40
OM (%)	47.9	11.6	29.3	9.90	22.8	17.4	20.9	16.2
OC (%)	27.8	6.70	16.9	5.80	13.2	10.1	12.1	9.40
Total N (%)	0.56	0.18	0.56	0.17	0.60	0.38	0.56	0.42
P (mg kg^{-1})	22.0	13.0	41.0	16.0	16.0	10.0	41.0	12.0
K (Cmol kg^{-1})	0.60	0.40	0.95	0.35	2.50	2.20	2.85	1.15
Ca (Cmol kg^{-1})	6.70	1.80	9.80	3.10	21.5	17.2	38.5	23.7
Mg (Cmol kg^{-1})	2.20	0.70	2.90	1.40	12.1	10.1	11.6	9.80
SO_4 (mg kg^{-1})	6.00	6.00	16.0	9.0	8.00	7.00	27.0	24.0
Fe (mg kg^{-1})	65.0	116	53.0	99.0	9.00	10.0	63.0	42.0
Mn (mg kg^{-1})	69.0	40.0	265	96.0	84.0	74.0	147	91.0
Cu (mg kg^{-1})	0.30	0.50	0.20	1.10	1.40	0.40	1.00	1.20
Zn (mg kg^{-1})	2.80	1.50	3.30	1.80	4.60	2.80	4.90	3.60

BTF=before the fire; 15DAF=15 days after the fire; OM=organic matter; OC=organic carbon

nutrients for vegetation is low (Almendros and González-Vila, 2012). In Singuilucan, the pH levels are close to neutral. The vegetation residues are mainly *Quercus*, which decompose faster than pine residues and contribute greater quantities of Ca, Mg, K, SO_4, Cu and Zn to eventually benefit the standing *Quercus* shrubs (Bodí *et al.,* 2012).

At both sites, soil fertility increased after the fire occurred. This is because of the ash deposited on the surface layer with a high content of carbonates and oxides (Granged *et al.,* 2011), as well as alkaline and metallic elements as P, K, Ca, Mg, SO_4, Mn, Cu and Zn (Capulin-Grande *et al.,* 2010). Additionally, the destruction of organic acids reduces soil acidity (Bodí *et al.,* 2012), which increased the pH by one unit. The reduced acidity and the ash are used by herbaceous vegetation for their rapid establishment. However, the TN, OM and OC decreased in content, since ammonium is transformed into ammonia gas, and it is lost by volatilization. The OM and OC were partially consumed by fire (Capulin-Grande *et al.,* 2010).

The texture and the stability of the soil aggregates were modified by fire. The particle distribution at both sites at 0–5 cm depth showed an increase in the sand fraction and a decrease in the clay fraction (Table 3). This change is due to the fusion of clays, as a result of the thermal modification of the iron and the aluminosilicates that form them, which increase their size and mass (Giovannini and Lucchesi, 1997; Capulin-Grande *et al.,* 2010; Bodí *et al.,* 2012). Due to the loss of organic matter, the heat hardens the aggregates and reduces their stability (Badia and Marti, 2003). This modification was more evident at the Singuilucan site where there was a change in the soil texture.

The variation of soil surface fertility across time is shown in Table 4. From 15DAF until 12MAF, the fire increased the content of nutrients, and therefore soil fertility, in a statistically significant manner. It should be noted that the contents of K, Ca, Mg, P and Cu increased at Singuilucan, while higher levels of Fe, Mn and Zn were observed at Zacualtipán. This difference was facilitated by the soil pH and by the accumulation at each site of these elements in the calcined vegetation ashes (Fernández and Vega-Hidalgo, 2011).

After this period, the availability of most nutrients decreased, but showed a tendency to return to the initial stage (24MAF). This is possibly because of the growth of herbaceous vegetation, which propagates after the fire, and the nutrient requirements for the development of the shoots from the burned bushes (Afif and Oliveira, 2006; Raison *et*

Table 3. Proportion of particles and soil textural classes at the two sites for different depths for before and 15 days after the fire.

Parameter	Zacualtipán		Singuilucan	
	0-5 cm	5-20 cm	0-5 cm	5-20 cm
Before the fire				
Sand (%)	38	28	33	35
Silt (%)	36	43	38	26
Clay (%)	26	29	29	39
Texture	Loam	Clay-loam	Clay-loam	Clay
15 days after the fire				
Sand (%)	47	29	55	37
Silt (%)	31	38	23	29
Clay (%)	22	33	22	34
Texture	Loam	Clay-loam	Sandy-Clay-loam	Clay-loam

al., 2009). Several authors have suggested that the availability of these nutrients can be ephemeral, lasting from 4–5 months (Gimeno-García *et al.,* 2000) until 14 months (Kutiel and Naveh, 1987), depending on soil conditions, the intensity of burning, the slope of the terrain and precipitation. For this study, Zacualtipán showed a more drastic reduction of nutrients, which was perhaps caused by increased precipitation and poor forest cover. The Cu, Zn, and SO_4 did not show a statistically significant difference in their contents in the soil for the different sampling dates. They exhibited a deviation from the tendency described above.

The content of OM and TN was reduced by the fire and continued so over the evaluation period. This is contrary to what was reported by Bodí *et al.* (2012), who indicated that the nitrogen level can recover due to the effect of the microorganisms promoted by the fire, as well as the action of nitrogen fixative leguminous species in successive months (Raison *et al.,* 2009).

Fungi and bacteria variation in the soil

The fire effect on fungi and bacteria is shown in Table 5. The presence of the microorganisms is different in each environment, with fungi showing a statistically significant dominance in Zacualtipán, because of the acidic pH of soil. This is consistent with reports in the literature,

Table 4. Change in the fertility of burnt soil at 0–5 cm depth in two environments and for different time periods.

Parameter	Zacualtipán				Singuilucan				LSD
	BTF	15DAF	12MAF	24MAF	BTF	15DAF	12MAF	24MAF	
pH	4.0 ± 0.14d	5.0 ± 0.56bcd	5.7 ± 0.78abc	4.6 ± 0.14cd	6.0 ± 0.14abc	6.8 ± 0.28a	6.8 ± 0.28a	6.3 0.06ab	1.44
OM (%)	37.7 ± 14.35a	29.2 ± 3.18ab	11.4 ± 2.33b	7.8 ± 0.78b	20.9 ± 2.19ab	19.9 ± 4.03ab	10.8 ± 1.41b	12.2 ± 6.57b	23.7
TN (%)	0.56 ± 0.16ab	0.56 ± 0.16ab	0.35 ± 0.15ab	0.17 ± 0.007b	0.6 ± 0.008a	0.55 ± 0.021ab	0.47 ± 0.056ab	0.27 ± 0.17ab	0.40
P (mg kg^{-1})	15 ± 9.89b	41 ± 15.55ab	56 ± 2.83a	38 ± 33.94ab	13 ± 4.24b	41 ± 9.19ab	6 ± 2.82b	6 ± 2.82b	39.1
K (Cmol kg^{-1})	0.5 ± 0.14c	0.95 ± 0.35bc	0.6 ± 0.28c	0.45 ± 0.21c	2.7 ± 0.29a	1.85 ± 0.22ab	2.85 ± 0.49a	1.05 ± 0.35bc	1.22
Ca (Cmol kg^{-1})	6.3 ± 0.56b	9.8 ± 0.55b	13.3 ± 11.17b	5.15 ± 2.19b	23.1 ± 2.18ab	41.4 ± 13.57a	20.1 ± 2.61ab	13.3 ± 2.26b	25.4
Mg (Cmol kg^{-1})	2.1 ± 0.14c	2.9 ± 0.56bc	1.7 ± 0.91c	1.2 ± 0.42c	11.2 ± 1.20ab	11.6 ± 5.58a	11.9 ± 3.53a	10.8 ± 1.91ab	8.68
SO_4 (mg kg^{-1})	6 ± 2.81a	16 ± 14.14a	36 ± 0.71a	12 ± 1.41a	6 ± 2.82a	27 ± 9.89a	11 ± 0.71a	15 ± 13.43a	33.8
Fe (mg kg^{-1})	53 ± 26.87ab	62 ± 4.95ab	155 ± 41.01a	169 ± 52.32a	18 ± 12.72b	63 ± 36.77ab	84 ± 16.97ab	83 ± 16.97ab	192.8
Mn (mg kg^{-1})	93 ± 34.64b	326 ± 74.25a	104 ± 57.27b	125 ± 87.68b	101 ± 24.04b	146 ± 118.1ab	97 ± 4.95b	84 ± 18.38b	182.2
Cu (mg kg^{-1})	0.25 ± 0.07a	0.2 ± 0.07a	0.45 ± 0.08a	1.35 ± 1.34a	1.6 ± 0.28a	0.95 ± 0.49a	0.75 ± 0.06a	0.9 ± 0.51a	2.63
Zn (mg kg^{-1})	2.9 ± 0.22a	3.3 ± 1.98a	5.3 ± 0.99a	3.5 ± 1.27a	4.0 ± 0.84a	3.9 ± 0.21a	3.2 ± 0.85a	2.8 ± 1.06a	4.62

For each parameter in each row, values with the same literal are statistically equal, according to Tukey test $P \leq 0.05$; BTF=before the fire; DAF=days after the fire; MAF=months after the fire; OM=organic matter; TN=total nitrogen; LSD=least significant difference.

which mention that fungi are the microorganisms which dominate the soils of pine forests. Bacteria dominated in Singuilucan due to the neutral pH soil, which favors the development of such microorganism populations.

The fire caused a decrease in the number of CFUs of bacteria and fungi, and the effect was greater in the topsoil (0–5 cm) because it experiences the temperature increase. This reduction was 40% and 76% in Zacualtipán, and 17% and 50% in Singuilucan, for fungi and bacteria, respectively. On this topic, Torres *et al.* (2004) reported a sharp decline in the population of bacteria by 72% and fungi by 28% on burnt ground, confirming that bacteria are the organisms most affected by fire (Barcenas-Moreno *et al.,* 2011). Among them, the nitrifying bacteria have narrow thresholds, which are easily wiped out at temperatures ranging from 53 to 56 °C. However, their population increases in size by 3 to 10 times in the first months of recovery of the burned area. Contrary to the information presented in the literature, the most dramatic effect was observed in the wettest site, as a result of the dry conditions that had prevailed in the period during which the fires occurred.

Quantification of vegetation

Table 6 shows the total of species and the dominant species of the strata in each study site. Although there is more rainfall in Zacualtipán, the dominance of an arboreal stratum reduces the presence of numerous species in the lower strata. The number of species in the lower strata is 48% lower than Singuilucan. In Zacualtipán, the dominant species are *Pinus teocote, Pinus patula, Quercus*

Table 5. Presence of fungi and bacteria in soil from the two sites at two depths (cm) before and 15 days after the fire.

Organism	Zacualtipán				Singuilucan				LSD
	BTF		15DAF		BTF		15DAF		
	0-5	5-20	0-5	5-20	0-5	5-20	0-5	5-20	
Fungi (CFU x 10^4)	51 ± 2.61a[¶]	48 ± 9.54a	31 ± 10.92b	45 ± 1.87ab	12 ± 4.31cd	11 ± 4.32cd	10 ± 6.78c	6 ± 2.83d	16.6
Bacteria (CFU x 10^7)	9.1 ± 6.31b	4.5 ± 3.75b	2.2 ± 0.72b	5.3 ± 3.10b	24 ± 8.19a	8.3 ± 1.87b	12 ± 8.18ab	6.7 ± 3.25b	14.5

For each organism in each row, values with the same literal are statistically equal, according to the Tukey test p≤0.05; BTF=before the fire; 15DAF=15 days after the fire; (CFU)=Colony Forming Units per g of dry soil); LSD=Least Significant Difference.

Table 6. Number of vegetal species in the study areas after the fire

Stratum	Number of species							
	Zacualtipán[†]				Singuilucan[‡]			
	Control	Days after the fire 30	180	540	Control	Days after the fire 30	180	540
Arboreal	9	9	9	9	1	1	1	1
Shrubby	5	2	4	5	4	1	3	4
Herbaceous	14	1	13	21	48	5	45	52
Total	28	12	25	35	53	7	49	57

[†]Zacualtipán site. Arboreal species: *Pinus teocote, Pinus patula, Quercus crassifolia, Quercus rugosa, Prunus serotina, Crataegus pubescens, Alnus arguta, Crataegus mexicana, Quercus obtusata.* Shrubby species: *Vaccinium leucanthum, Rubus parviflorus, Senecio albonervius, Garrya ovata, Baccharis conferta.* Herbaceous species: *Aster moranensis, Cirsium ehrenbergii, Cuphea aequipetala, Eryngium beecheyanum, Oxalis alpina, Pinnaropappus roseus, Geranium schiedeanum, Prunella vulgare, Salvia prunelloides, Stevia iltisiana, Bidens triplinervia, Cosmos diversifolius, Briza subaristata, Gentiana spathacea.*

[‡]Singuilucan site. Arboreal species: *Quercus mexicana.* Shrubby species: *Quercus microphylla, Quercus greggii, Quercus frutex, Rhus standleyi.* Herbaceous species: *Commelina coelestis, Weldenia candida, Baccharis conferta, Spilanthes beccabunga, Dugesia mexicana, Conyza microcephala, Erigeron maximus, Tagetes lucida, Verbesina pedunculosa, Heliopsis procumbens, Sonchus oleraceaus, Heterosperma pinnatum, Eupatorium petiolare, Baccharis ramulosa, Ipomoea pubescens, Cyperus spectabilis, Astragalus seatonii, Desmodium venustum, Salvia longispicata, Marrubium vulgare, Mimosa acanthocarpa.*

crassifolia and *Quercus rugosa*, which suffered minor damage, with burns observed at the base of the trunks. The shrubs and herbaceous layers were the most exposed strata to the fire and the most damaged, decreasing by 60% and 92%, respectively.

The Singuilucan site does not have an arboreal stratum, with the most affected individuals being *Quercus microphylla* Née shrubs and herbaceous plants. Sampling at 30 DAF showed a reduction of 75% of shrubs and 90% in the herbaceous vegetation (Table 6). At 540 DAF, the vegetation at both sites fully recovered, with even more herbaceous species growing than initially. They increased by 50% and 8% for Zacualtipán and Singuilucan, respectively. This confirms that, in an area with reduced forest cover, some species appear after their seeds are dormant. This favors their growth since they are able to take advantage of the nutrients in the ashes (Bodí *et al*., 2012). After a fire, herbaceous vegetation and shrubs cover the ground and produce more biomass (Sabadin *et al*., 2015), reaching their maximum abundance and diversity in 1 to 5 years. Later, the population of herbaceous plants decreases (Pausas *et al*., 2008).

The main conclusions are as follows. Fire temporarily increases soil fertility up to twelve months because of ashes, which favors the immediate availability of nutrients for herbaceous plants, but this phenomenon decreases over time. The populations of soil microorganisms such as fungi and bacteria are reduced by ground level fire, with this effect being more evident in the surface layer bacteria. At 540 days after the fire, the number of species of vegetation increased, favoring greater coverage, and a similar vegetal community was re-established as existed before the fire.

Resumen

J. Capulin-Grande, A. Suárez-Islas, R. Rodríguez-Laguna, J.J. Mateo-Sánchez, R. Razo-Zárate, y M. Islas-Santillán. 2018. Influencia del fuego en el suelo y las propiedades de la vegetación en dos sitios forestales contrastantes en el centro de México. Cien. Inv. Agr. 45(2): 128-137. El fuego produce cambios en la vegetación, suelo, fauna, calidad de las aguas e incluso modificaciones en la composición de la atmósfera. Se evaluaron los cambios en la fertilidad del suelo, de microorganismos y de la vegetación después del incendio en dos municipios del estado de Hidalgo, México. Dentro y fuera del área incendiada se ubicaron cuatro parcelas de 100 m^2, en cada parcela se colectaron muestras de suelo a dos profundidades 0–5 y 5–20 cm: área no incendiada (ANI), 15 días después del incendio (15DDI), 12 y 24 meses después del incendio (MDI). La cuantificación de la vegetación se realizó a los 30, 180 y 540 DDI. Los resultados a 15DDI mostraron un incremento de elementos alcalinos y metálicos, y de pH en la capa superficial, manteniendo esta tendencia hasta 12MDI, con mayor contenido de Fe, Mn y Zn en el sitio Zacualtipán y de K, Ca, Mg y P en Singuilucan; este efecto se revierte a los 24MDI debido al crecimiento de las herbáceas y matorrales que demandan nutrimentos. El incendio redujo el contenido de materia orgánica (MO) y nitrógeno total (Nt) sin recuperación durante el periodo de evaluación. Las bacterias mostraron mayor mortandad por efecto del fuego, del 76% y 50% para los sitios Zacualtipán y Singuilucan, respectivamente. La apertura de espacios en la cobertura, propició incremento de 50% de especies en sitio Zacualtipán. Se concluye que el fuego incrementó la fertilidad del suelo y la presencia de herbáceas de forma temporal, pero redujo las poblaciones de bacterias y hongos.

Palabras clave: Bacterias, fertilidad del suelo, hongos, incendio, vegetación.

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