SOIL CHEMICAL CHANGES DUE TO FIRE WHEN PRESCRIBED BURNS ARE APPLIED IN A TEMPERATE FOREST OF MEXICO

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(Recibido octubre 1995, aceptado diciembre 1996)

Keywords: prescribed fires, effects of forest fires, soil, Pinus michoacana Martínez

ABSTRACT

In Mexico the use of fire as a silvicultural tool and its effects on the ecosystem are seldom published. This can be explained because, among other things, little it is known on the effects of fire on the particular Mexican forest ecosystems. Therefore, this project was carried out with the purposes of evaluating the effects of fire on a forest soil under controlled conditions. The experimental part of this work was carried out in a pine forest stand at Tapalpa Saw in Jalisco State, Mexico, dominated by *Pinus michoacana* and *P. oocarpa*, with some broadleaves also occurring. The study investigated both backing and head fire. The burns were carried out on 25 and 26 March, 1991, before the rainy season. Before burning and within the three weeks following burning several soil samples were taken in order to evaluate the effect of fire on soil. The effect of fire evaluated as the most important results and conclusions, that are: 1) in the study area it was feasible to safely carry out both backing and head fire burning under controlled conditions, 2) there was a significant decrease in the concentration of phosphorus in the soil. 3) there were differences in the concentrations of potassium. nitrate and ammonium, although non significant; calcium concentration was not affected either, and 4) there were no changes in the concentration of magnesium and manganese in the soil. In general, it is concluded that it is still necessary to carry out more studies before prescribed fire can be used with confidence in Mexican forest conditions.

RESUMEN

En México el uso del fuego como una herramienta silvícola y sus efectos en el ecosistema rara vez se publicará. Esto puede ser explicado debido a que, entre otras cosas, se conoce poco sobre los efectos del fuego en los particulares ecosistemas de bosques mexicanos. Debido a ello, este provecto se llevó a cabo con el propósito de evaluar los efectos del fuego en un suelo forestal bajo condiciones controladas. La parte experimental de este trabajo se realizó en un rodal de bosque de pino en la Sierra de Tapalpa, Jalisco, México, dominado por Pinus michoacana y P. oocarpa, con algunas hojosas presentes. El estudio investiga tanto la quema en retroceso como la quema en avance. Las quemas sucedieron entre el 25 y el 26 de Marzo de 1991, antes de la temporada de lluvia. Con el propósito de evaluar el efecto del fuego en el suelo, antes de la quema y dentro de las tres semanas siguientes a la misma, fueron tomadas varias muestras de suelo. Los efectos del fuego evaluados como los resultados y las conclusiones más importantes, son los siguientes: 1) en el área de estudio fue posible llevar a cabo con seguridad las quemas en avance y retroceso bajo condiciones controladas, 2) se halló una baja significante en la concentración de fósforo en el suelo, 3) las diferencias en las concentraciones de potasio, nitrato y amonio, aunque marcadas, no fueron significativas, tampoco el incremento en la concentración de calcio y 4) no se notaron cambios en las concentraciones de magnesio y manganeso en el suelo. En general, se concluye que en las condiciones en que se hallan los bosques mexicanos aún se requiere mayor cantidad de estudios antes de que las quemas controladas puedan ser usadas con confianza.

INTRODUCTION

The use of fire as a forest management tool has been practised in many countries with similar conditions to Mexico (Wells *et al.* 1979, Aguirre 1981, Hudson and Salazar 1981). However, the use of prescribed fires in Mexico is very restricted (Toledo 1988). Therefore, there is a limited experience in the use of fire as a silvicultural tool (González-Cabán and Sandberg 1989). This is due to, among other things, a very limited knowledge about the effects of prescribed fires in the particular conditions of the Mexican forests. Therefore, the purpose of this paper is to evaluate the effects of two techniques of prescribed fire, which were carried out in a pine-dominated upland seasonally dry forest in Jalisco State, Mexico.

This study deals with both backing fire and head fire. According to Van Lear and Waldrop (1991), a backing fire moves into the wind or down slope. Its temperatures are generally cool, and it travels very slowly. This technique produces the least intense fire of any firing method, moving approximately 20 to 60 m/hour and causing little crown scorch. It is recommended for areas where fuel loading is high, summer burning, or young stands where crown damage is likely. In contrast, head fires move upslope or with the wind, are specifically hot, and travel very quickly. This technique is less expensive and since it produces a more intensive fire, it can be used under marginal burning conditions, such as high relative humidity and fuel moisture, or low temperature and wind speed (Van Lear and Waldrop 1991).

MATERIALS AND METHODS

Study area

The Colomos Experimental Station, which belongs to the National Institute for Research in Forestry, Agricultural and Animal Husbandry of México (INIFAP), carried out an experiment to determine the value of two prescribed fire techniques on soil conditions of a temperate forest in Jalisco State. The study area is located in the Tapalpa Saw, 5 km to the West of Tapalpa town.

The Tapalpa Saw has the following general characteristics (Martínez *et al.* 1994): Altitude: 1900-2400 m.a.s.l. Mean annual rainfall: 883.1 mm. Mean temperature: 16.6°C. The region of the study area is in the tropics but, due to its altitude and rainfall, it corresponds to a temperate sub-humid climate (Benavides 1987). This forest is formed principally by *Pinus michoacana* var. cornuta Martínez, *Pinus oocarpa* Schiede, *Quercus spp, Alnus spp,* and other broadleaves. The study area is located within the 19° 56' and 19° 58' North latitudes and 103° 47' and 103° 51 West longitudes (**Fig. 1**) (Benavides 1987). Specifically, the study site is on north-facing slopes, at an altitude of 2110 m.a.s.l. Its slope varies between 15 and 25%.



Figure 1. Approximate location of the Tapalpa Saw

Experiment

This study deals with both backing fire and head fire. Both, backing fire and head fire, were applied in 6 sample plots each of 30 X 20 m, corresponding to 3 sample plots per type of burning. These sample plots were into a stand of Pinus michoacana (60%), P. oocarpa (30%) and broadleaves (10%), the average age for pines was 30 years and the stand density was 367 tree/Ha. The set of data used in this study is the result of various measures taken before and after applying these two methods. The burns were held on 25 and 26 March. 1991; 3 months before the rainy season (summer). Due to some limitations of equipment and labour, it was necessary to define in situ a simple design to make the implementation of the two types of burning as easy and safety as possible. Hence, the option chosen was to locate the three sample plots of each type of burning side by side. All plots were located in the declivity of a hill. Thus, the backing fire plots were located slightly uphill (at 1.5 m) to the head fire plots. The treatments were analysed as a randomly design.

Due to the fact that just two treatments were compared, the statistical analysis was carried out through several t-Test.

Sampling

Two weeks before and three weeks after burning, soil samples were obtained from the treatment plots. The samples were taken randomly. Before burning 6 soil samples per plot were analysed, however, due to the high cost of such analyses, just 2 samples per plot were analysed after burning. To get a soil sample, a cylindrical large drill was used. The drill was 10 cm in diameter, and 20 cm in height.

With the exception of Ca and K, soil mineral nutrients were measured using Morgan's method, which uses ppm as a unit of measurement. According to Ferreira *et al.* (1985) and Islam and Bhuiyan (1988), the measures obtained through Morgan's method correspond to extractable soil



Figure 2. Comparison of the proportional changes in nutrient contents between BFPs (A) and HFPs (B); before treatment values are fixed at 100%

mineral nutrients. The measure unit for Ca and K were g/Ha and kg/Ha, respectively. Organic matter and pH were evaluated as well. The mineral nutrients evaluated were: calcium, potassium, magnesium, manganese, phosphorus, nitric and amoniacal nitrogen.

RESULTS

Nutrient changes

Changes in nutrient contents after burning, were larger in the head fire plots than in the backing fire plots (**Fig. 2**). For example, nitric nitrogen dropped to 46.9% of its original value in the Head Fire Plots (HFPs), while in the Backing Fire Plots (BHPs) it remained steady. In the HFPs calcium concentration increased up to 125.1% and in the BFPs it remained constant. Potassium content in BFPs increased up to 109.26%, while in the HFPs it declined to 60.8% of the original value. In the BFPs the rest of the nutrients showed no changes, while in the HFPs, with the exception of manganese, they decreased.

Considering the BFPs and the HFPs separately before and after prescribed fire the former did not show any significant changes (t-Test) in nutrient concentrations. The latter showed significant decreases in phosphorus $[p(T \le t)= 0.0268]$. The difference in NO₃⁻ concentration was very close to be significant $[p(T \le t)= 0.0787]$, while the difference in NH₄⁺ had a $p(T \le t)$ of 0.1353 (no significant).

Considering the BFPs and the HFPs together, soil conditions noticeably changed after prescribed fire. This is easier to appreciate in **figure 3**, where the initial soil concentrations is 100%. Almost all nutrients show a drop in their concentration. Nitric nitrogen shows the greatest de-



Figure 3. Proportional changes in nutrients contents after prescribed fires

cline (to 36.2% of its original value). Phosphate was reduced to 75%. Calcium was the only nutrient that showed an increase (to 112.9%). Nevertheless, despite the differences in the concentration of nutrients before and after burning, the corresponding t-Test showed no significant differences, except for phosphate (**Table I**). However, once again, the change in NO₃ was very close to be significant, $p(T \le t) = 0.079$.

 TABLE I. t-TEST OF THE DIFFERENCE OF NUTRIENT CONCENTRATIONS, OM AND pH, BEFORE AND AFTER BURNING

NUTRIENT	p (T≤ t) =	SIGNIFICANCE	
		p< 0.05	NS
Ca	0.2752		x
К	0.2816		X
Mg	0.1810		X
Mn	1.0000		X
PO4	0.0121	Х	
NO ₃	0.0790		X
NH4	0.1180		X
OM	0.1294		X
pH	0.1944		X

NS = no significant

Changes in organic matter and pH

Comparing **tables II** and **III**, there is clear evidence that the changes before and after burning in both organic matter (OM) and pH were greater in the HFP than in the BFP plots. This can be easily appreciated in **figure 4**. pH had its highest level in the HFPs before burning (6.8), but it was lower in the BFPs before burning (6.2). The pH levels after prescribed fires were 6.3 in the BFPs, and 6.5 in the HFPs. The corresponding t-Test of variance (**Table IV**) indicated that these changes in both OM and pH were not significant for BFPs. In contrast, these changes were significants for HFPs.

Considering the BFPs and the HFPs together, after prescribed fire, levels of OM tended to increase, changing from 6.8 (**Table II**) to 7.5% (**Table III**), while pH levels had a slight drop (from 6.5 to 6.4). According to the corresponding t-Test, these small changes were not significant (**Table I**). Nevertheless, the effect of fire seems to have made pH and OM % more similar. This was true in most of the plots in each treatment, where the standard error was smaller after fire than it was before (with exception of plots III and VI for OM, and also VI for pH).

DISCUSSION

Before burning, with the exception of potassium, nitrate and ammonium, the initial nutrient concentration of the soils was similar in the plots of both treatments. However, the

FABLE II.	VALUES AND MEANS OF CONTENTS OF BOTH ORGANIC
	MATTER (OM) AND pH, PER TREATMENT PLOTS GROUP.
	BEFORE BURNING

TREATMENT	PLOT	OM (%)	pН
BACKING FIRE	I	7.79	6.37
	II	7.11	6.25
	III	7.67	6.10
MEAN	·**	7.52	6.24
<i>S.E</i> .		0.21	0.08
HEAD FIRE	IV	6.07	6.90
	V	6.02	6.76
	VI	5.99	6.68
MEAN		6.03	6.78
<i>S.E</i> .		0.02	0.06
GENERAL MEAN		6.77	6.51
GENERAL S.E.		0.35	0.13

levels of OM and pH were very different. According to Schoch and Binkley (1986), this means that the decomposition rate was accelerated in the HFPs, perhaps due to a higher moisture content, a result of the location of these plots (down-slope). This indicates that the plots were not equal before the treatments, and it is an important fact for the interpretation of the results considering that the treatments were not applied randomly. This lowers the data confidence, and it can not be concluded differences between BFPs and HFPs after treatment were caused by differences in the firing methods. Therefore the homogeneity of the plots must be checked more carefully in future studies, if the treatments can not be applied randomly. A better alternative could be to use a split plot design, or to have an assignation of treatment based on pre-burn lab results.

It was expected that there would be an initial increase in extractable nutrients concentrations after fire due to release of nutrients from burnt litter and OM. Nevertheless, the contents of nutrients tended to go down. This is clearer in the HFPs where only calcium and manganese did not decrease, while in the BFPs only phosphate decreased. According to De Bano (1976), Raison et al. (1986) and Van Lear and Waldrop (1991), there is a considerable loss of the total amount of some nutrients such as nitrogen and phosphorus after a fire. A reduction in the ability of soil to absorb phosphorus could be due to a greater phosphorus mobility, characteristic of the «ash-bed-effect», which is produced after a fire (Humpreys and Lambert 1965). In the case of nitrogen, according to Kellman and Sanmugadas (1985), the low proportion that was lost could be attributed to the capacity of the soil to immobilise rapidly any large quantity of nutrients in solution. This could have happened because slight rains were registrated some days after. Gilmour and Cheney (1968), suggest that nutrient loss can occur because of rainfalls after fire. The after burning soil samples were taken three months after fire. Although the results showed that these decreases were not significant, except

TREATMENT	PLOT	SAMPLE	OM (%)	рН
BACKING FIRE	I	А	8.83	6.1
		В	8.14	6.2
	II	А	4.48	6.4
		В	5.78	6.2
	III	Α	7.24	6.5
		В	10.48	6.4
MEAN			7.5	6.3
<i>S.E</i> .			0.88	0.06
HEAD FIRE	IV	А	6.21	6.1
		В	6.83	6.2
	V	Α	6.65	6.6
		в	7.59	6.4
	VI	А	7.45	6.4
		В	10.21	7.0
MEAN			7.5	6.5
<i>S.E</i> .			0.58	0.13
GENERAL MEAN			7.5	6.4
GENERAL S.E.			0.50	0.07

TABLE III. ORGANIC MATTER (OM) AND pH VALUES,	PER PLOT (2 SAMPLES) AND TREATMENT GROUP. AFTER
BURNING	

for phosphate, this does not mean that they were not real, because the significance in these changes was entirely a matter of the experimental design, the number of replicate samples and plots.

On the other hand, only calcium showed an overall increase. De Bano (1976), Schoch and Binkley (1986), Knoepp and Swank (1993) and Van Lear and Waldrop (1991) suggest that the availability of nitrogen, calcium and phosphorus increases after a fire. This is related to a short-term increase of soil fertility (Kimaryo 1988). Kutiel and Naveh (1987) found, in a study of the effect of fire in an Aleppo pine forest soil, that immediately after fire total nitrogen decreased but available forms of nitrogen were much higher. However, it is important to consider that, as general accepted model, an initial pulse of increased available nutrients is followed by a decline in the middle- or short-term availability. According to Davis (1959), chemical effects of fire tend to be favourable for soil fertility in the short-term, but may not be in the long-term, because there is loss of mineral nutrients in ash, smoke particles and gases, and direct volatilisation. Added to this, Knight (1966) argues that the amount of nutrients that can be fixed by organisms in forest soil is limited.

The most striking effect of the fires was that they made the pH and concentrations of OM, K, PO_4^{3-} , NO_3^{-} and NH_4^{+} much more similar between the plots. This could be explained because rainfall could have helped to wash a great amount of soil, and thus, nutrients. There were around 30 mm of rainfall between prescribed fire and soil sampling. According to Fagberno (1980), nutrients loss occurs from rainfalls after fire, which is more notable in the first rainfall events.



Figure 4. Comparison of levels of OM (A) and pH (B) between backing fire (B.F.) and head fire (H.F.) plots, before and after prescribed fires

FACTOR	TREATMENT	F	<i>p</i> -value	F critical
ОМ	BACKING	0.00	0.98	7.71
	HEAD	0.63	0.47	7.71
рН	BACKING	4.37	0.10	7.71
	HEAD	5.22	0.08	7.71

TABLE IV. DIFFERENCE OF OM AND pH LEVELS PER TREATMENT, BEFORE AND AFTER FIRE

Therefore, although either the BFPs or the HFPs could had contained higher concentrations of these nutrients immediately after fire, following several rainfall events the amounts of nutrients in both treated plots tended to be similar. Thus, to accurately evaluate the effect of fire on soil, future studies must consider more soil sampling, not only immediately after fire (1 or 2 days after), but also in the long term. On the other hand, the great difference in nutrient concentration among the BFPs and the HFPs before and after fire must be pointed out. While in the former the concentration of most of the nutrients remained steady, in the latter just manganese remained constant. As was mentioned before, differences on the initial levels of OM and pH could have had certain influence on this results. This condition could also have influenced the increase in the levels of OM and pH that were greater in the HFPs than in the BFPs. These results indicate that future experiments need to study the influence of the initial levels of OM and pH and the effect of fire on them and on other nutrients.

On the other hand, the levels of OM after fire were greater. However, in the BFPs the level of OM remained constant, while the levels of pH tended to diminish. This result was influenced by the HFPs response, because there was a slight increase of pH in the BFPs. According to Humpreys and Lambert (1965), levels of pH in soil tend to increase after a fire. Although these differences between the BFPs and the HFPs could be the result of differences between the treatments, the influence of the initial plot conditions must be considered.

In general, these results show that, in one way or another, fire affected the original soil fertility. Nevertheless, the effects of prescribed fires on soil fertility are difficult to predict because they can be affected by leaching, erosion and volatilisation resulting from fires (Gilmour and Cheney 1968, Hardwood and Jackson 1975, Schoch and Binkley 1986). The action of these factors depends principally on the intensity, duration and frequency of the fires (Davis 1959). According to Gilmour and Cheney (1968) and Schoch and Binkley (1986), nutrient leaching is not significantly altered by fire. Schoch and Binkley (1986) argue that nutrient losses after fire will occur if erosion is increased. According to Knight (1966) and Raison *et al.* (1985), smoke can contain large amounts of ash material rich in all nutrients, therefore very intense fires may remove substantial quantities of all nutrients.

To evaluate the effect of prescribed fire on soil fertility was possible by comparing the nutrients concentrations that were found in this study with published studies held in similar forests. For example, in this study, the amounts of K were 295.5 before and 223.3 kg/Ha after fire on average, while Covington and Sackett (1984) report, for a ponderosa pine stand (in Arizona, USA), 149 and 168 kg/Ha before and after fire respectively. For NH⁺, Koviac et al. (1986) report 10 ppm before and 24 ppm after fire (ponderosa pine, New Mexico, USA), while in this study the means were 14.6 and 12 ppm respectively. However, no study carried out in conditions similar to ours was found (considering principally species, climate and the use of the same units to evaluate all the nutrients). Moreover, Koviac et al. (1986) argue that although the effect of fire on soil nutrients has been studied by numerous investigators, the studies vary so greatly in design and chemical analysis that it is often impossible to directly compare the results. Thus, according to Schoch and Binkley (1986) it is not possible to assess the nutritional status of a new, unexamined type of forest until experiments have identified a standard workable method.

Finally, these results can not be only attributed to the effect of the two treatments, but also, and perhaps more likely, to the differences in the initial OM and pH conditions between the BFPs and the HFPs. The rain after burning could also have influenced the results. According to Connaughton (1935) and Scott and Schulze (1992), when the layer that covers the soil is eliminated by fire the resulting condition favours erosion, which, according to Pase and Lindenmuth (1971) greatly influences the post-fire sediment movement. On the other hand, little is known about soil fertility, thus many studies are needed, for example about nutrient capital, input and output of nutrients, tree species nutritional requirements, etc.

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