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Effects of soil type, plant composition and leaching on soil nutrients following a simulated forest fire

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ABSTRACT

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The objective of this study was to determine the effects of a simulated light fire (250°C) on the availability of N and P, and on concentrations of ions in solutions of two typical Mediterranean soils (Chromic Luvisol and Lithic Xerothent) that support an oak shrubland and an Aleppo pine forest respectively. Likewise, the effect of fire on soil taken from beneath pine trees (*Pinus halepensis*) and from the adjacent interspace was investigated.

Soil nutrients in all the types of soil and in all the treatments increased after the fire. However, the extent of the increase of the nutrients and their dynamics depends on the characteristics of the soil and of the microhabitat (the underlying and nearby interspace), on the tree species burnt during the fire, and on the leaching process.

The overall conclusion in this study is that fire increases nutrient concentrations in mineral soil. Yet, changes are distributed in a mosaic pattern, a fact which contributes to the complexity of the ecosystem.

INTRODUCTION

Many studies have shown that fire has an important role in the determination of the amount of available nutrients in burnt mineral soil (e.g. DeBano et al., 1979; Trabuad, 1983; Kutiel and Shaviv, 1989). The extent of the increase or decrease of nutrient availability depends on factors such as fire temperature, plant composition and fuel load. Kutiel and Shaviv (1989) found that an increase in the temperature of the soil from 250°C to 600°C was followed by a reduction of most of the availability nutrients. Likewise, soil combustion with plants reduced the maximum amount of ammonium in the soil, and caused a delay in the nitrification process (which was absent in the soil

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burnt without plants). On the other hand, combusted plants contributed more available P and soluble cations than did unburnt plants. Kutiel and Naveh (1987a) also observed that there is a significant difference in soil nutrient levels measured after a wildfire in various patches that are dominated by different species within the same forest. The content of most of these available nutrients was highest in the pine soil, intermediate in the oak soil, and lowest in the open-grass soil.

Surface soil temperatures remaining for a long time above 250°C during a wildfire is not a rare phenomenon in the Mediterranean region. During the fire that occurred in September 1989 in a mixed pine–oak forest on Mt. Carmel, the authors spent several hours measuring surface soil temperatures, which remained between 250 and 350°C. Moreover, a surface soil temperature remaining at 350°C for 45 min was recorded during a prescribed fire conducted on Mt. Carmel (P. Kutiel, unpublished data, 1991).

Field studies and laboratory studies on fire effects are carried out simultaneously in order to obtain a better understanding of the subject (Kutiel and Naveh, 1987b; Kutiel and Shaviv, 1989). We arrive at most of the burnt areas after a fire. In these cases we have no data on fire intensity and therefore none on soil surface temperatures. Laboratory studies combined with field results enable us to reconstruct the fire conditions. Likewise, questions — such as why similar plant species within short distances of each other react differently after fire — can be answered with the help of experimental studies (Kutiel and Naveh, 1987a).

The objective of the present research was to determine the effects of plant composition and the leaching process on nutrient levels of two typical Mediterranean soils following a light simulated forest fire.

MATERIALS AND METHODS

Samples of clay soils (Chromic Luvisol equivalent to Terra Rossa and Lithic Xerothent equivalent to Light Rendzina) from natural oak (*Quercus calliprinos*) shrubland, and an Aleppo pine (*Pinus halepensis*) forest, respectively, were collected from layers of two depths: layers of 0–2 cm, and 2–10 cm. This was done after the removal of the litter layer, which consisted mainly of undecomposed leaves. The samples were air dried and passed through a 4 mm sieve. Several analytical characteristics of these soils are given in Table 1.

These typical mountainous Mediterranean soils were chosen because they represent two different levels of fertility: Light Rendzina is considered an infertile soil in comparison with Terra Rossa. This aspect, together with other soil characteristics (such as clay composition and the presence of more than 90% $CaCO_3$ (less than 2% in Terra Rossa)) turn the Rendzina into a difficult substrate for plants. A detailed study on Light Rendzina as compared with Terra Rossa and other Mediterranean soils of Israel (with an emphasis on

TABLE 1

Some general properties of the various soils

Soil type	$CaCO_3$ (%)	C (%)	Field capacity in unburnt soil (%)	Field capacity in burnt soil (%)
Terra Rossa	1.2	4.5	35.0	16.1
Light Rendzina adjacent to pine	91.7	2.2	22.2	17.8
Light Rendzina beneath pine	90.1	4.6	29.1	22.3

plant communities associated with these soils) was carried out by Rabinovich-Vin (1979).

Three kilograms of each soil sample collected from the 0–2 cm layer were packed in porcelain trays and exposed to 1 h combustion at 250°C. In some of the treatments, a mixture of pine parts (needles, branches and cones) was used and in others a mixture of oak parts. The parts were placed on top of the soil and burnt with it. The amount of either pine or oak was similar to the amount estimated in the field, i.e. 900 g m^{-1}. The burnt soil was placed in $25 \times 35 \times 6$ cm plastic trays on top of unburnt soil from the 2–10 cm layer (2.5 cm thickness for each layer). This was done in order to simulate field conditions, in which only the soil surface is affected by fire (Ahlgren, 1974).

The soil in the trays was wetted to field capacity, covered with plastic bags, and incubated for 12 weeks at 30°C. Some of the treatments were leached at the end of the burning and before the incubation. This was done by spreading the soil on a Buchner funnel and washing it with 2600 cm^3 distilled water kg^{-1} of burnt soil.

Duplicate samples were taken each week during the entire incubation period. This was done in order to minimize the destruction of the upper soil layers in the trays during the experiment. The decision as to the number of replicas was also supported by a previous study (Kutiel and Shaviv, 1989) in which similar results were obtained for each soil replica because of the homogeneity of the soil in the trays.

Ammonium and nitrate plus nitrite were extracted from each sample using 1 N KCl solutions, and were then determined by an autoanalyzer. Available P was determined using the bicarbonate extraction method (Olsen et al., 1954). Total N and P were determined immediately after the burning by employing the method described by Thomas et al. (1967). Cation concentrations in extracts of distilled water (1:2, soil water ratio) as well as pH and electrical conductivity (EC) were determined right after the fire, and at the end of the incubation period. $CaCO_3$ was determined by the evolution of CO_2

from soil samples (that had reacted with 5% of an HCl solution), immediately after the burning and at the end of the incubation period (four replicas each).

RESULTS AND DISCUSSION

Terra Rossa

Effects of fire on soil nutrients

EC increased slightly after burning owing to the release of soluble cations such as calcium, potassium, and, to some degree, magnesium (Tables 2(a) and 2(b)). The pH was only slightly affected immediately following the fire, but after 12 weeks of incubation, a slight increase was observed in all the treatments. Calcium and potassium were the dominating cations in water extractions. Leaching considerably reduced the concentrations of Ca and Mg, but had a less pronounced effect on K and Na. After 12 weeks of incubation, the Ca concentration increased in the leached soils (dissolution) and decreased in the unleached ones (precipitation). Potassium concentration in all the treatments decreased after the incubation. This can be attributed to its rapid availability for recycling (Rapp and Leonardi, 1988), or to its fixation by clay minerals.

Total N loss during the fire ranged between 15 and 30%. Similar results were observed by Kutiel and Naveh (1987b) and by Kutiel and Shaviv (1989). However, available nitrogen increased. Ammonium content increased significantly immediately after the burning (Fig. 1) as a result of thermal decomposition (Dunn and DeBano, 1977), and continued to increase during the first 2–4 weeks owing to further decomposition of residual organic nitrogen (Kutiel and Shaviv, 1989). The nitrification rate in the unburnt soil and in the unleached soil was faster than in the burnt soil (Fig. 2(b)) which showed a delay of 4–8 weeks in the process of nitrification. Once the oxidation started, nitrate levels in the burnt soil approached those of the control. Moreover, after 12 weeks ammonium levels in this soil were much higher than in the control, implying that higher levels of nitrate could be expected for incubation periods exceeding 12 weeks. Similar results were observed by Kutiel and Shaviv (1989). Available phosphorus increased significantly right after the burning as a result of the combustion of organic P and the transformation of mineral P (Fig. 3). The sharp increase, presumably, induced supersaturation of soil solutions with respect to Ca–P compounds (Kutiel and Shaviv, 1989). As a result a decrease with time of available P was observed during the first 4 weeks. This, however, was then followed by a second increase in available P in the burnt soil (Figs. 3(a) and 3(b)), which started after 4–8 weeks of incubation. The re-dissolution of P was associated with the relatively fast build-up of nitrates that was observed at approximately the same time in the burnt soil (see Figs. 2, 3, 5 and 6). In such cases,

TABLE 2

Total P and N, pH, and Ca, Mg, K and Na concentrations and ratios in the various treatments

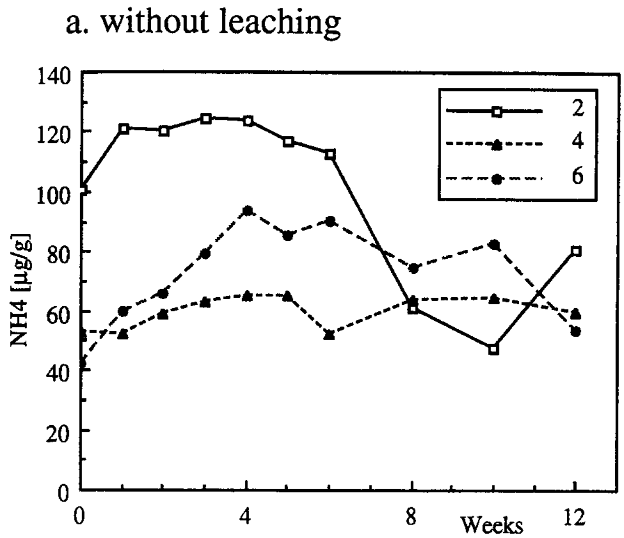
(a) Immediately after the burning and before the incubation

Treatment	Total P (%)	Total N (%)	pH	EC (dS cm^{-1})	Ca	Mg	K	Na	Ca/Na	Ca/K
					Water extracting $\mu g\ g^{-1}$					
1	0.09	0.22			57.6	5.9	52.6	27.1	2.1	1.1
2	0.08	0.20	7.73	1.10	237.6	12.1	48.2	40.1	5.9	4.9
3	0.08	0.19			63.7	4.4	41.8	20.9	3.0	1.5
4	0.09	0.22	7.44	1.15	285.6	16.8	70.2	26.9	10.6	4.1
5	0.08	0.22			80.9	5.4	49.1	28.3	2.9	1.7
6	0.09	0.24	7.33	1.01	232.8	14.1	35.9	24.3	9.6	6.5
13	0.06	0.28	7.36	1.10	106.8	11.6	30.5	27.7	3.9	3.5
7	0.06	0.09	8.27	0.70	178.5	8.9	46.2	24.2	7.4	3.7
8	0.06	0.07			61.7	3.8	50.1	23.8	2.6	1.2
9	0.06	0.13	8.38	0.72	192.5	13.5	124.0	28.3	6.8	1.6
10	0.06	0.10			80.5	5.6	85.8	29.5	2.7	0.9
11	0.06	0.11	8.24	0.84	179.4	10.2	70.8	27.4	6.6	2.5
12	0.06	0.12			63.7	4.6	46.1	22.2	2.9	1.4
14	0.06	0.21	7.73	0.22	71.8	8.9	55.7	31.5	2.3	1.3
15	0.07	0.20	8.80	1.15	275.2	18.0	58.2	31.5	8.7	4.7

(b) After 12 weeks of incubation

Treatment	pH	EC (dS cm^{-1})	Ca	Mg	K	Na	Ca/Na	Ca/K
			Water extraction $\mu g\ g^{-1}$					
1	8.05	0.57	87.6	5.4	23.9	29.2	3.0	3.7
2	8.15	1.05	186.0	7.6	24.4	33.9	5.5	7.6
3	8.20	0.52	128.4	6.7	27.2	31.4	4.1	4.7
4	8.20	0.96	205.2	10.2	31.5	34.3	6.0	6.5
5	8.20	0.27	101.6	5.6	22.7	26.5	3.8	4.5
6	8.10	0.09	214.8	11.4	30.0	32.0	6.7	7.2
13	8.20	0.32	83.6	8.0	15.4	34.7	2.4	5.4
7	8.35	0.40	120.0	7.5	17.8	29.8	4.0	4.0
8	8.40	0.47	93.2	8.2	21.2	30.7	3.0	3.0
9	8.50	0.36	127.2	11.8	28.5	42.6	3.0	4.5
10	8.50	0.28	87.6	7.8	23.2	30.0	2.9	3.8
11	8.40	0.27	125.6	11.0	25.8	35.7	3.5	4.9
12	8.50	0.28	80.8	7.1	17.9	23.3	3.5	4.5
14	8.50	0.26	76.0	7.3	12.6	34.8	2.2	6.0
15	8.70	0.24	210.0	25.7	31.7	61.3	3.4	6.6

Terra Rossa soil —1 and 2: burnt without plants; 3 and4: burnt with oak; 5 and 6: burnt with pine; 13: unburnt soil. Light Rendzina soil—7 and 8: burnt without plants; 9 and 10: burnt with oak; 11 and 12: burnt with pine; 14 unburnt soil; 15: unburnt soil beneath pine trees. Samples 1, 3, 5, 13, 8, 10, 12 and 14 were leached before incubation.



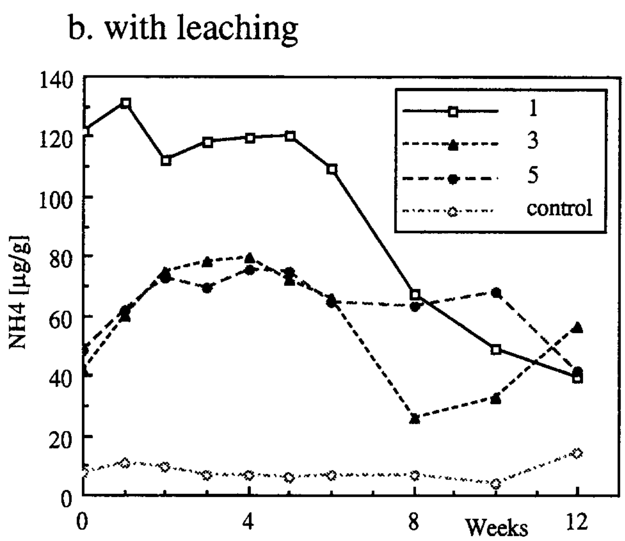


Fig. 1. Ammonium concentrations in the burnt Terra Rossa soil versus incubation time obtained for the various treatments (1 and 2: burnt without plants; 3 and 4: burnt with oak; 5 and 6: burnt with pine; control: unburnt soil). The lines connect averaged experimental values.

it may be explained that the protons that were released by oxidizing the ammonium temporarily reduced the soil pH (Nedan, 1990) and increased P availability (Hanson and Westfall, 1986). After 12 weeks of incubation, the burnt soil still contained at least five times more available P than the unburnt soil.

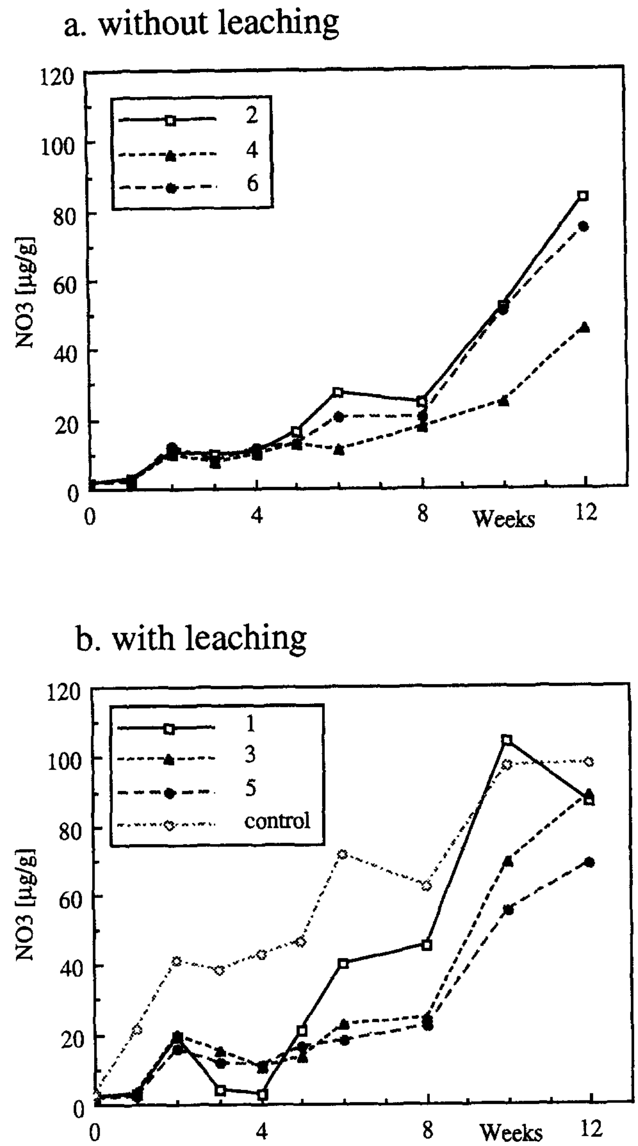


Fig. 2. Nitrite plus nitrate concentrations in the burnt Terra Rossa soil versus incubation time obtained for the various treatments (1 and 2: burnt without plants; 3 and 4: burnt with oak; 5 and 6: burnt with pine; control: unburnt soil). The lines connect averaged experimental values.

Effects of different combusted plants and leaching on soil nutrients

Initial ammonium concentration in the soil burnt without plants was higher than in the soil burnt with plants. Similar results were obtained in a previous study with different soil (Kutiel and Shaviv, 1989). Small differences in ammonium content in soil burnt with either pine or oak were observed during

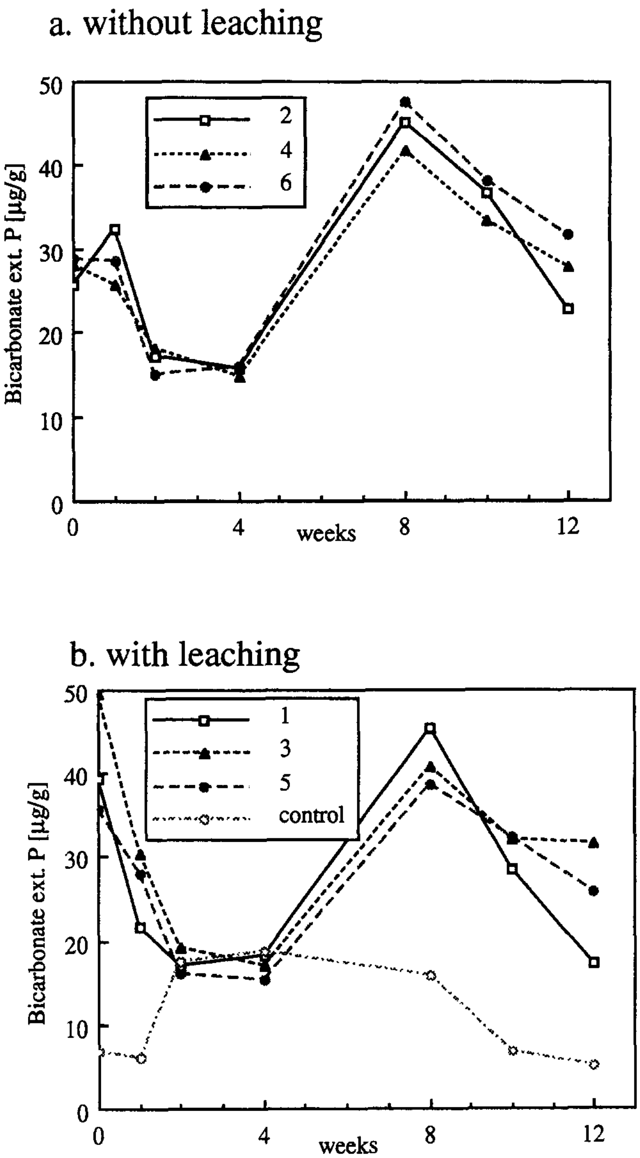


Fig. 3. Available phosphorus concentrations in the burnt Terra Rossa soil versus incubation time obtained for the various treatments (1 and 2: burnt without plants; 3 and 4: burnt with oak; 5 and 6: burnt with pine; control unburnt soil). The lines connect averaged experimental values.

the first 4 weeks of the incubation of the unleached soil. Yet, ammonium in the burnt 'pine soil' continued to increase with time, whereas only minor changes occurred in the 'oak soil' (Fig. 1(a)). However, ammonium levels and the rate of increase were similar in both leached treatments (3 and 5 in Fig. 1(b)).

Nitrate started to build up in the soil burnt without plants and with no leaching after about 8 weeks of incubation (Fig. 2(a)), while in the respective leached soil it started to build up after 4 weeks (Fig. 2(b)). The effect of leaching was less pronounced with soil burnt with either pine or oak. Nitrification rate in the soil burnt with pine was higher than in the soil burnt with oak where no leaching was performed. Leaching eliminated the differences between the two soils. Thus, if there is any inhibitory effect on nitrification caused by burnt oak, it seems that it could be removed by leaching. In contrast, Almendros et al. (1984, 1990) found that the microbial activity in 'pine soil' after a simulated forest fire was reduced in comparison with 'oak soil'. This reduction was ascribed to the higher combustibility of the resinous plants which were almost totally destroyed during the forest fire (the soils were burnt at 350°C), resulting in the accumulation of hardly biodegradable organic matter in the soil. No significant differences in available P were observed in the various treatments (Figs. 3(a) and 3(b)).

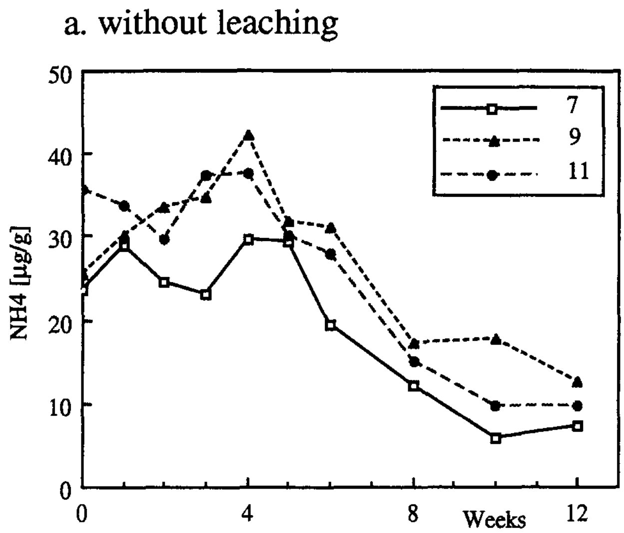
Light Rendzina

Effects of fire on soil nutrients

Significant changes in EC, pH, and total N were obtained in Rendzina soil after burning, while the changes in Terra Rossa were less meaningful (Table 2). A three to four-fold increase in EC was observed in the Rendzina soils right after the fire. Twelve weeks later, at the end of the incubation, the EC of the burnt soil decreased, but still remained higher than the EC of the unburnt soil. The decrease was associated mainly with a reduction of the Ca concentration in the soil solution (Table 2(b)) that resulted from precipitation reactions. Total nitrogen loss during the burning was about 40–50% in soil burnt with plants, and about 60% in soil burnt without plants.

Ammonium concentration in soil increased from 10 $\mu g\ g^{-1}$ in the unburnt soil to 25–35 $\mu g\ g^{-1}$ in the burnt soil. These levels were significantly smaller than those obtained in Terra Rossa, although the unburnt soil in both cases had similar amounts of ammonium (Figs. 1 and 4). This is attributed to either the lower levels of organic nitrogen in the light Rendzina which generated less ammonium or to higher volatilization of the ammonium from the calcareous soil that was caused by a higher pH.

Nitrification rate in the soil burnt with plants was similar to the rate of that in the unburnt soil. Maximum values obtained after 12 weeks were also similar to those obtained in the unburnt soil, despite the larger amounts initially found in the burnt soil (Fig. 5). Unlike the Terra Rossa, the burnt Rendzina did not supply any more mineral N to the burnt soil than it did to the unburnt soil. Available P increased after the fire, and in time showed similar changes to the changes that occurred in burnt Terra Rossa soil (Fig. 6).



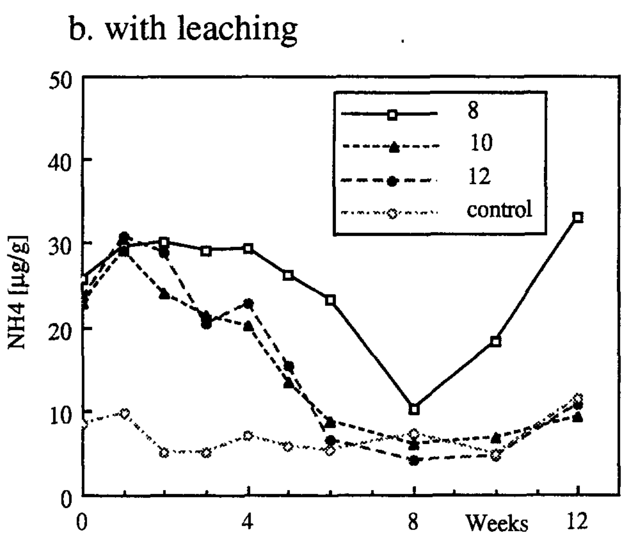
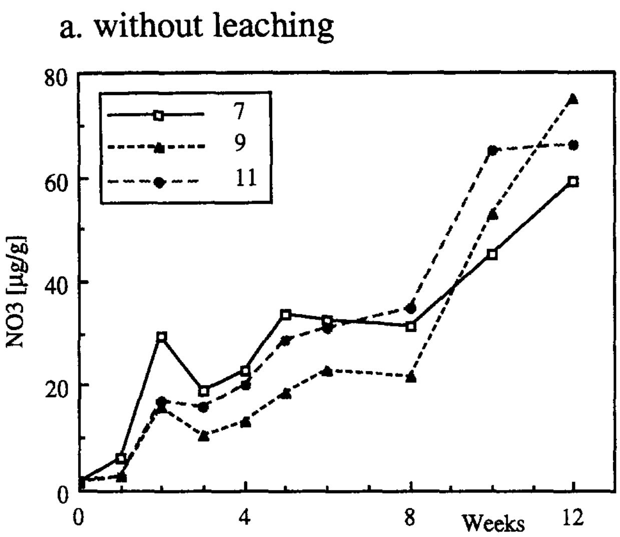


Fig. 4. Ammonium concentrations in the burnt Light Rendzina soil versus incubation time obtained for the various treatments (7 and 8: burnt without plants; 9 and 10: burnt with oak; 11 and 12: burnt with pine; control: unburnt soil). The lines connect averaged experimental values.

Effects of different combusted plants and leaching on soil nutrients

Effects of burning plants on changes in mineral N in Rendzina soil — and to a certain extent the effect of leaching — were different from the effects obtained with the Terra Rossa soil. Ammonium content (during the incuba-



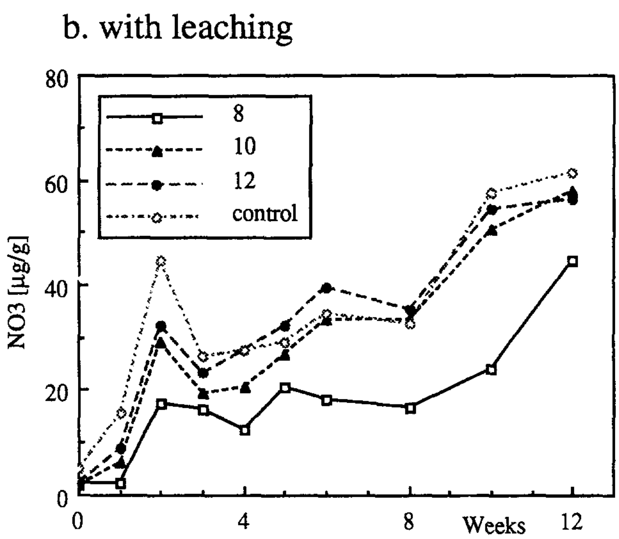


Fig. 5. Nitrite plus nitrate concentrations in the burnt Light Rendzina soil versus incubation time obtained for the various treatments (7 and 8: burnt without plants; 9 and 10 burnt with oak; 11 and 12 burnt with pine; control: unburnt soil). The lines connect averaged experimental values.

period) in the soil burnt without plants and with no leaching was consistently lower than that in the soil burnt with plants (Fig. 4(a)). In contrast to this occurrence, ammonium content under leaching was higher in the soil burnt with plants (Fig. 4(b)). The trend observed with ammonium was reflected in nitrate formation (Figs. 5(a) and 5(b)). The higher nitrate levels are as-

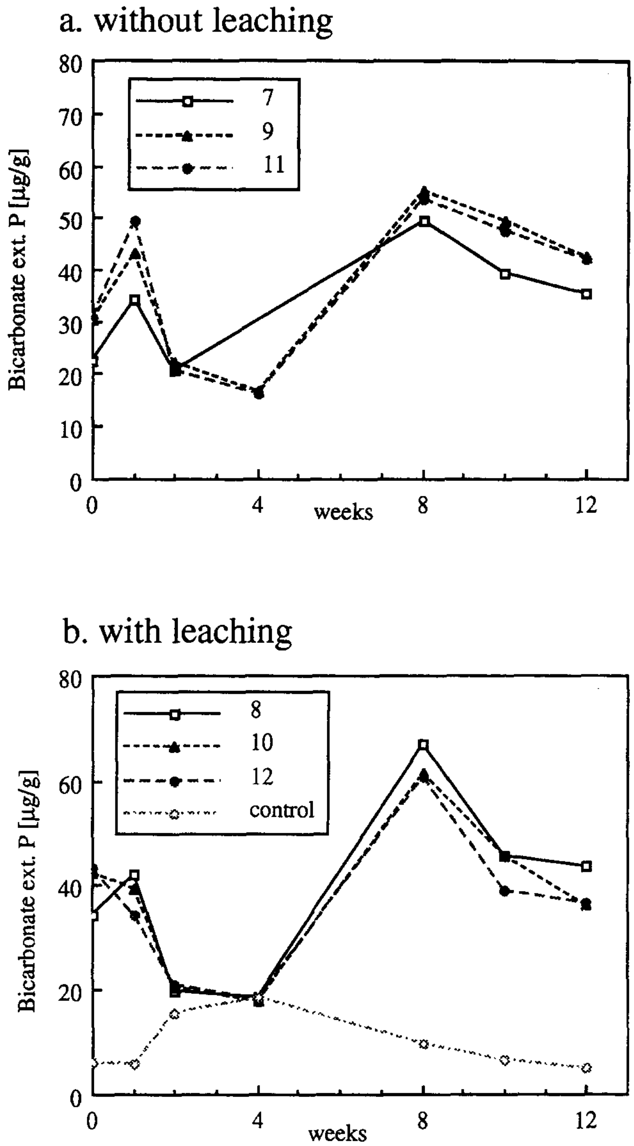


Fig. 6. Available phosphorus concentrations in the burnt Light Rendzina soil versus incubation time obtained for the various treatments (7 and 8: burnt without plants; 9 and 10 burnt with oak; 11 and 12: burnt with pine; control unburnt soil). The lines connect averaged experimental values.

sociated with the lower ammonium concentrations, implying that nitrification rate dominated the dynamics of both mineral N forms. In this case, leached soil burnt without plants produced the lowest nitrification rate — the opposite of the result obtained with the Terra Rossa soil. No notable differ-

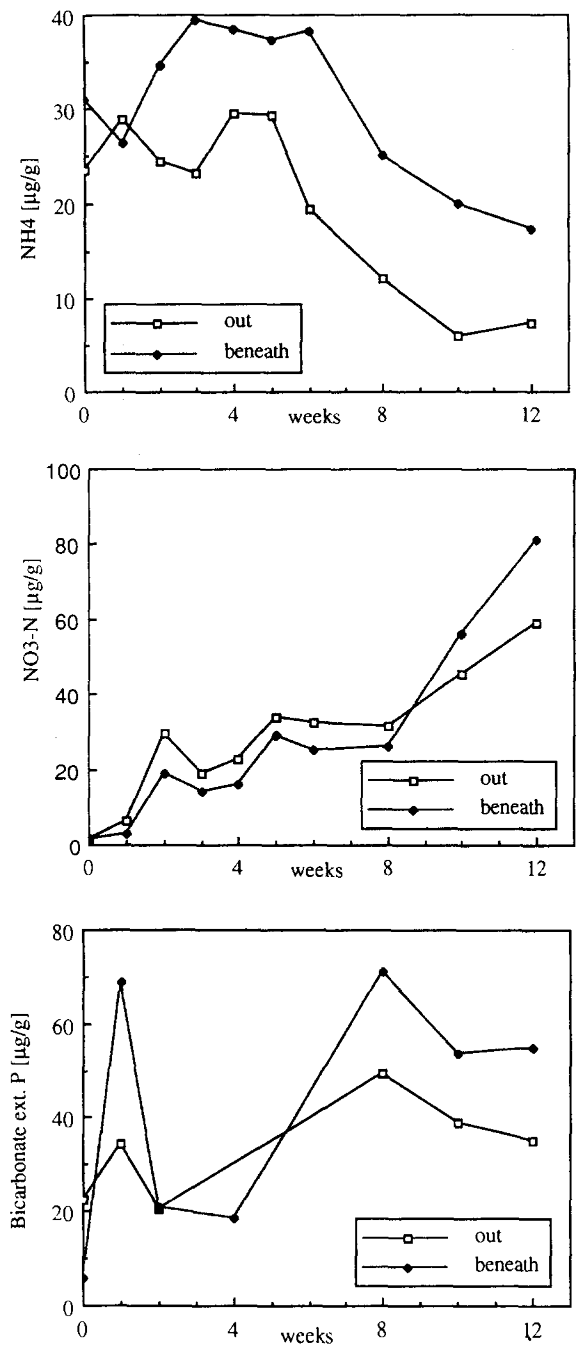


Fig. 7. Changes in ammonium, nitrite plus nitrate, and available phosphorus in burnt Light Rendzina soil from pine trees and the soil beneath them.

ences in available P were observed in the various treatments (Figs. 6(a) and 6(b)); the same P that was found in Terra Rossa soil was also found in Rendzina soil.

Effects of fire on different microhabitats

Differences in soil nutrients of burnt soil taken from beneath pine trees and soil nutrients taken from the adjacent interspace demonstrate the complexity of fire effects, and thus, shows the heterogeneity that exists within one habitat.

As shown above, burning Light Rendzina soil either with various plant species or without plants did not result in significant differences in the treatments. However, there were significant differences between burnt Rendzina soil from the interspace (occupied by sparse herbaceous and shrubby vegetation) and burnt Rendzina soil taken from beneath mature Allepo pine trees. Available N and P in the burnt soil beneath the pine trees were higher in comparison with the available N and P in the burnt soil from the interspace (Figs. 7(a) and 7(c)).

CONCLUSIONS

Burning the Terra Rossa soil without plants caused a significant increase in ammonium and nitrate, as compared with the Terra Rossa soil burnt with plants. However, soil burnt with pine contained more ammonium and nitrate than soil burnt with oak. These results were assumed to be caused by inhibitors, which produced different effects in each treatment. In general, the higher the cation concentrations, the less ammonium and nitrate were obtained. This assumption was also supported by the leaching experiments, in which cations, and possibly other materials, were washed out. Consequently, the inhibition period of nitrification was reduced, and the amount of mineral N increased.

No notable changes were observed between Light Rendzina soil burnt without plants and that burnt with different tree species. The assumption was that soil characteristics such as low concentrations of organic N, pH above 8 and a high amount of $CaCO_3$ rather than the presence of plants are the main factors dominating the ammonification and nitrification processes.

The effects of fire on soil taken from two different microhabitats were significantly different. The findings in this study lead to the conclusion that soil nutrient distribution following fire attains a mosaic pattern, which reflects the differences between soil type, plant composition, and cover.

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