CHANGES IN SOIL NITROGEN AVAILABILITY IN RESPONSE TO A PRESCRIBED FIRE IN A MEDITERRANEAN FOREST *(Pinus halepensis)* ECOSYSTEM AROUND MONTPELLIER CITY, SOUTH OF FRANCE.

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ABSTRACT

Ecosystem fire can variably affect soil nitrogen availability, which is a determinant factor for soil fertility and environmental issues. This research was conducted to study changes in soil nitrogen forms in Aleppo pine (*Pinus halepensis*) forest ecosystem, located in the south of France bordering Montpellier city, subjected to a prescribed fire of low intensity on 30 March 2011. Soil ammonium (NH_4^+-N), nitrates (NO_3^--N), and total nitrogen contents were measured, for two depths (0-2 and 2-10 cm), immediately before and after burning for five consecutive months. In parallel, produced nitrogen dynamics (net mineralization, immobilization, and losses by leaching and root absorption) was investigated using field incubation of identical soil samples in situ for three sequences of six weeks. As an immediate response of burning, NO_3^--N content at 0-2 cm depth reduced significantly (P = 0.05) by 62%, but NH_4^+-N content increased significantly (P = 0.01) by 14 times. Thus, transforming organic nitrogen in mineral nitrogen, mineralization, which is here focused on ammonium amount, raised considerably by almost 3 times. These results suggest that a low intensity fires programmed and executed during a cool season, may limit the total ecosystem nitrogen losses reported by several researches. Throughout the study, the burned sites had greater rates of nitrification, meaning that nitrogen was being processed more quickly through the ecosystem than that without a prescribe fire. Differently from nitrates, ammonium is subjected to intense immobilization and seasonal variations. At 2-10 cm depth, no significant effects on nitrogen forms were detected, with the exception of high NO_3^--N concentration. This case raises the question of the effect of burning on the movement of nitrates in the depth of the soil and its potential impacts on groundwater pollution.

Key words: mediterranean forest ecosystem, prescribed fire, soil incubation, nitrogen net mineralization, immobilization.

التغييرات في جاهزية نيتروجين التربة نتيجة لحريق مبرمج في نظام بيئي متوسطي تسوده غابات الصنوبر الحلبي (*Pinus halepensis*) حول مدينة مونبيليه، جنوب فرنسا.

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المستخلص

يمكن أن تؤثر حرائق النُظم البيئية بصور مختلفة في جاهزية النيتروجين في التربة، والذي هو عامل محدد لخصوبة التربة والتلوث البيئي. أُنجز هذا البحث لدراسة تغييرات تراكيز أشكال النيتروجين في تربة نظام بيئي مُشجَّر بغابات الصنوبر الحلبي (*Pinus halepensis*)، يقع بحدود مدينة مونبليه في جنوب فرنسا، وأُخضِع لحريق مبرمج منخفض الشدَّة في 30 مارس 2011. قِيست تراكيز الأمونيوم (NH_4^+–N) والنترات (NO_3^-–N) والنيتروجين الكلي في التربة وبعمقين (0–2 و 2–10 سم)، وذلك مباشرة قبل وبعد الحرق لمدة خمسة أشهر متتالية. في موازاة ذلك، تم أخذ عينات، من المواقع نفسها، متطابقة لسابقاتها لتنفيذ تجربة حضن العينات في الحقل لمدة ثلاثة متواليات من ستة أسابيع لغرض التحقق من ديناميات النيتروجين المُنتَج (عملية المعدنة الصافية، تثبيت داخل اجسام الاحياء المجهرية، والفقد عن طريق الغسل وامتصاص الجذور). في عمق 0–2 سم وكتاثير فوري للحرق، تركيز NO_3^-–N انخفض معنويا (P = 0.05) بنسبة 62%، ولكن محتوى NH_4^+–N تضاعف معنويا (P = 0.01) بمقدار 14 مرة. وهكذا بتحويل النيتروجين العضوي الى نيتروجين معدني في التربة، عملية المعدنة التي ترتكز هنا اساسا على كمية الأمونيوم، إرتفعت بشكل مُعتبر وبما يقارب 3 مرات. تشير هذه النتائج إلى أن الحرائق المنخفضة الشدَّة والمبرمجة خلال مواسم الإعتدال، يمكن ان تحد من ظاهرة فقد النيتروجين من النظام البيئي والتي سجلَّتها العديد من الابحاث. خلال فترة الدراسة، المواقع المحترقة شهدت معدلات نترجة عالية، مما يعني أن جاهزية النيتروجين تجري بسرعة أكبر خلال نظام بيئي مُدار بحريق مبرمج مقارنة بنظام لا يُدار بهذا الاسلوب. بخلاف NO_3^-–N ، NH_4^+–N يتعرض للتثبيت المكثف داخل الاحياء المجهرية وللتقلبات الموسمية. أما في عمق 2–10 سم ، لم يتم الكشف عن تأثيرات ذات أهميَّة على كميات النيتروجين، باستثناء تراكيز NO_3^-–N العالية. وتثير هذه الحالة مسألة تأثير الحرائق على حركة النترات في عمق التربة وآثارها المحتملة على تلوث المياه الجوفية.

كلمات مفتاحية: نظام بيئة غابات البحر الأبيض المتوسط ، حريق مبرمج ، حضن التربة، المعدنة الصافية، تثبيت النيتروجين داخل الاحياء المجهرية.

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INTRODUCTION

Although the fire is likely to affect the cycle of all nutrients, its effect is especially important on the amount, form and availability of nitrogen which is often a limiting factor for plants and easily lost by volatilization during the fire (13). In natural ecosystems, studies on mineralization after the fire show that mineral nitrogen forms, ammonium (NH_4^+-N) and nitrates (NO_3^--N), were found in high concentration in the burned areas compared to similar unburned areas (4, 5, 16, 24, and 27). That means the two mineral forms increase as the rate of mineralization is high. In addition, White (28) has reported the same trend; the immediate effect of prescribed fire on a *Pinus ponderosa* stand results in a significant increase in the amount of mineral-N in particular NH_4^+-N at top ten centimeters of soil. However, Knoepp *et al*., (19) found that in mixed oak forests soil, NH_4^+-N concentrations increased only in soil surface (0–5 cm), immediately after burning, but return to pre-burn levels by mid-summer. Moreover, the effects of moderate intensity fire on soil nitrogen in Chaparral, reported by Debano *et al.,* (6), indicate that NH_4^+-N increases as nitrates NO_3^--N and total nitrogen (Tot.-N) decrease at fire passage. In this study, nitrogen mineralization is followed in situ in a burned area and a control area in order to first quantify mineral nitrogen released after burning, comparing NH_4^+-N and NO_3^--N present before and immediately after the fire and during sequences of six successive weeks. Secondly, follow mineral-N dynamics in situ, trying to see if the nitrogen availability is due to immediate effects of heat or rapid mineralization after an increase in the microbial biomass or the combined action of these two parameters. Estimating mineral nitrogen produced in a soil under artificial laboratory conditions (temperature and humidity), cannot be used as an indicator of the rate of mineralization that occurs naturally in the field. Soil disturbance (sieving, drying and rewetting) and incubation conditions remarkably affect the biological activity including the rate of nitrogen mineralization (1, 23). We have therefore chosen to measure the amounts of NH_4^+-N and NO_3^--N produced during six weeks by the soil incubated in situ. Several methods have been used by many researchers to identify different forms of soil mineral nitrogen (min.-N) based on soil type: incubation of disturbed soil or soil cores relatively disturbed buried in plastic bags (18, 21, and 23), and incubation, in field, of isolating soil samples in metal boxes with sides and base perforated (15, 20). Because of the high proportion of pebbles in our soil, which does not allow to isolate undisturbed cores, the latter method was adopted for our work, assuming that a new equilibrium is established quite quickly compared to the incubation period (6 weeks). This technique would keep soil samples properties such as structure, texture, and biological activity as natural as possible, which lead to minimize the differences between the outside and the inside of the boxes. Thus, this method could simulates field condition. In addition, it allows avoidance of the losses of mineral nitrogen, by leaching and rooting absorption, which tend to decrease the mineral nitrogen produced by microorganisms during incubation.

MATERIALS AND METHODS

Study sites description and climate conditions. A piece of forest land, at the experimental station of the Higher Agricultural Institute in the city of Montpellier, southern France, has been divided in two plots (700 m^2 each) identical in vegetation and soil characteristics. One plot was treated by the fire and the other was left as control. Soil is a Mediterranean Fersiallitic on dolomitic limestone bedrock from the Jurassic period (8). The $CaCO_3$ is in the form of pebbles and rocks in place. The texture is a loam with 35.3% sand, 39.78% silt, and 24.92% clay. Soil pH values measured on soil water suspension (1: 2.5 ratio) ranged from 7.8 to 8.3 and those measured from a suspension of KCl (1N) ranged from 7 to 7.3 in the control and the burned areas, respectively. Soil pH practically does not vary during the experiment. The study sites are dominated by Aleppo pine (*Pinus halepensis*) with a density of 3400 trees/ha. The other strata are distributed as follows: undergrowth is dominated by Kermes oak (*Quercus coccifera*) and Rosemary (*Rosmarinus officinalis*) constituting 8.8 tone of dry matter/ha; herbaceous cover is composed of prevailing weed, Bromine erected (*Bromus erectus*) and Brachypodium branching (*Brachipodium ramosum*) representing 0.3 tone of dry matter/ha; fallen leaves and dead twigs (Litter layer) covering 90-100% of the soil surface. The general climate of the region is sub-humid Mediterranean. The rain-heat ratio is 80; the average of the annual temperature is 14.4 °C. The average rainfall of the last 64 years was measured to 770 mm with a characteristic distribution of the Mediterranean climate: rainfall is concentrated in the cold season of the year and vegetation is subject a period of summer drought (Figure 1).

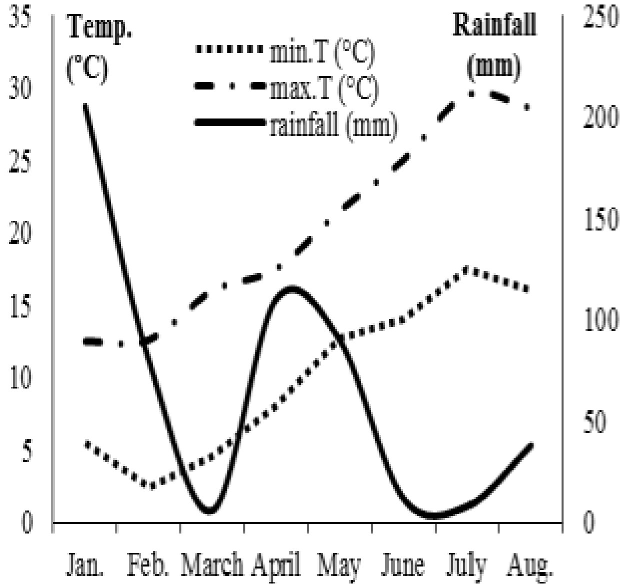

Figure 1. Rain-thermal readings of the weather station of C.N.R.S. Montpellier

Burning experiment and litter and soil temperature. Fire ignition was performed, on 30 March 2011, in the afternoon and lasted two hours, with drip torch by flaming line front against wind direction. Punctual and/or stripping sources were used to increase fire intensity into a satisfactory level, in case of any casual gap. The air temperature was 14.5 °C and the relative humidity was 80% with 0.6 mm precipitation on that day. The average wind speed was 6.5 m/sec and fire speed was from 20 to 25 m/hour. The average height of the fire flames was 1.1 meters.The fire had slightly burned trunks and tops of smaller trees, and often consumed litter and grass as well as the lower thin branches of trees. The temperature in the litter under Kermes oak bushes, ranged from 174 to 260 °C, but it did not exceed 71 °C at the upper thin layer of soil surface (Figure 2).

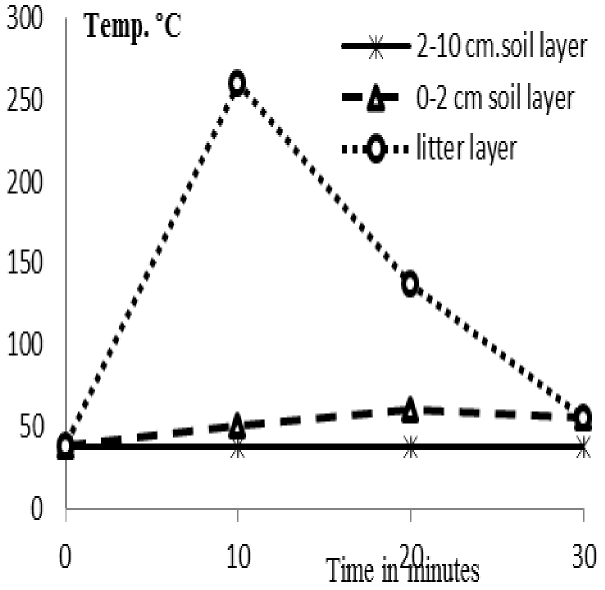

Figure 2. Soil and litter layer temperatures during ecosystem burning

It was less than 40 °C on the soil surface below the litter in the herbaceous areas. In general, the soil temperature at 0-2 cm depth varied between 40 and 60 °C, but it did not increase at a depth of 2-10 cm

Moisture determination.

Soil water holding capacity (WHC) was determined using the method described by Duchaufour (8). Soil moisture content was measured by gravimetric method. Fresh sample of soil was oven dried at 105 °C until reaching constant weight. Then, water content was calculated on the basis of fresh and dry weight difference and expressed as percentage of dry weight.

Soil sampling and preparation.

Sampling was done at the same time that the sampling for microbial biomass on the same 8 sampling sites, described in previous research (10). Soil samples of the two depths (0-2 and 2-10 cm) were rid of litter, roots and stones by sieving at 2 mm. The homogenized soil was divided into 2 lots; one used for incubation in the field and the other was brought to the laboratory to determine the initial nitrogen: NH_4^+-N, NO_3^--N and Tot.-N

Incubation in situ.

The prepared soil material was distributed in metal boxes, 8 cm in diameter and 10 cm in height, drilled laterally and at the base. For the control plot, two sets of boxes were placed in the 0-2 cm and two sets in the 2-10 cm depth for each sampling site. The same procedure was followed for the burned plot with two replications in plus at 0-2 cm depth. The soil was incubated for six weeks under conditions of temperature and humidity close, if not identical, to those of the soil nearby

Extraction, distillation and determination

Soil min.-N was extracted with a K_2SO_4 solution (1N), extracting agent/soil ratio was 4/1. The mixture is stirred for 45 minutes, centrifuged at 4000 rpm for 15 minutes and then filtered through Whatman No. 42 filter paper. The extract was added, a small amount (about 2 grams) of magnesium oxide and 150 ml of demineralized water. Then by distillation, 120 ml of the extract was collected into a beaker containing 20 ml of sulfuric acid H_2SO_4 (2.7N). Thus the whole NH_4^+-N of the extract was obtained in the form of $(NH_4)_2SO_4$. The distillate was transferred to a 150 ml volumetric flask and readjusted. To obtain NO_3^--N, the method of Devarda was applied on the rest of the extract to reduce NO_3^--N to NH_4^+-N then by distillation using the same procedures as for ammonium (2). Tot.-N was obtained according to Kjeldahl method. Ammonium and nitrates from distillation and total nitrogen transformed to NH_4^+-N were determined by colorimetric method according to Berthelot technique based on the Beer-Lambert law (17).=

RESULTS AND DISCUSSION

Fire and rain interference effect on fire type and lethal temperature of microorganisms. One of the first observations is that the temperature gradient between the litter layer and soil layers is very steep (Figure 2). This wide difference between temperatures is explained by the attenuating effect of 0.6 mm precipitation, the day of the experiment, through two possible mechanisms; first, the organic matter conducts heat poorly and second, as long as its moisture increases, its insulating capacity reinforces by latent heat effect (29). Although heat in moist soil is transported faster and penetrates deeper, latent heat of vaporization prevents soil temperature from rising rapidly until water completely vaporizes (3). For this reason and despite precipitation, soil water content decreases about 5% (from 15.18 to 10.63%) at 0-2 cm depth one day after burning. At the depth 2-10 cm, the temperature remains lower than 40 °C and soil water content decreases only by 1% (from 13.84 to 12.46%) as reported in Figure 3. Soil temperature and humidity results combined with the measured values of weather data (Figure. 1), registered observations of burned strata, and fire behavior description in terms of flame length, spread rate, suggest, according to Fernandes' and Loureiro's index (11) concerning the optimal range of prescribed fire variables, that the type of our prescribed fire was of low intensity. Consequently, soil sterilization and lethal effect on microorganisms, except for *Nitrobacter* and some nitrifying as *Nitrosomonas*, are likely not reached. In fact, these species may be killed at 50 °C and 75 °C, respectively, in a moist soil (9). In general, bacteria and actinomycetes are more resistant to heat than fungi. The lethal temperature for bacteria is around 110 °C in moist soil in Chaparral (4). Fungi could persist up to 100 °C temperature, point at which they are finally destroyed.

Burning effect on soil moisture content. Soil moisture results (Figure 3) show that whatever depths and sampling periods, soil water content is higher in burned sites than in control sites; over the ten sampling periods after burning, the mean increase was as much as 6%. As a management practice, prescribed fire could prove soil water retention and subsequent resistance against drought of summer months in Mediterranean basin region

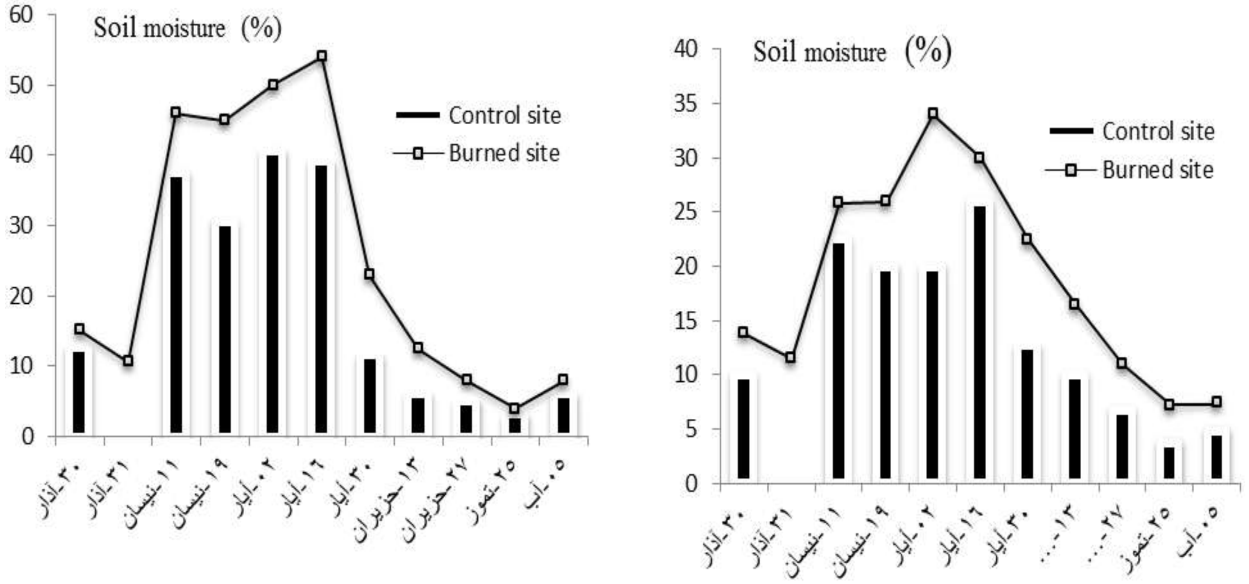

Figure 3. Burning Effect on Soil Moisture Content (%), at 0-2 cm (left) and 2-10 cm depth (right

Representative of Sites.

A day before the fire, and over the eight soil samples collected at 0-2 cm and 2-10 cm from both the forward control and the plot to burn, analyses of NH_4^+-N and NO_3^--N values (Table 1) showed an excellent repeatability. Those of Tot.-N values were not significantly different. NH_4^+-N values respectively varied between 3.3 and 3.5 mg N Kg^{-1} dry soil at 0-2 cm, and 0.8 and 1.2 mg N Kg^{-1} at 2-10 cm depth. NO_3^--N values ranged between 0.5 and 0.4 and 0.5 and 0.2. Note here that the microbial biomass, determined by the author in a previous paper (10), confirms the relative homogeneity of the two plots studied with respectively 222 and 243 mg C / 100 g dry soil at 0-2 cm and 93 and 111 mg C / 100 g dry soil at 2-10 cm depth

Influence of prescribed fire on current nitrogen. Immediate effect.

Immediate dynamics of min.-N was in strong connection with the process of fire. A day after the passage of fire, the increase of NH_4^+-N, was more than 4 times compared to its content from before the fire (from 3.5 to 15.1 mg N Kg^{-1} dry soil) at 0-2 cm (Table 1), such increases are noted and discussed by several researchers, among them Fultz *et al.* (12); DeLuca and Zouhar (7); Raison *et al.* (23). Its origin is still debated. In fact this increase coincides with a highly significant increase (P = 0.01) of microbial biomass one day after the passage of fire (10). The temperature rise limited to the soil surface (T < 71 °C) (Figure 2), does not cause a physico-chemical release of NH_4^+-N from clay-organic complexes in the soil. But the temperature of the litter in contact with the soil surface (143 < T < 170 °C) causes a thermal decomposition 'pyrolysis' of amino acids. These amino acids decomposed from the litter and microbial activity can be the source of NH_4^+-N produced. On the contrary the NO_3^--N content decreased 2.5 times (from 0.4 to 0.15 mg N Kg^{-1} dry soil) at 0-2 cm a day after burning. This significant reduction (62%) (P = 0.05) can be explained by NO_3^--N movement to 2-10 cm depth, elimination Nitrobacters, and partial sterilization of other nitrifying bacteria

as Nitrosomonas, which means a decrease in

Table 1. Changes in current levels of NH_4^+-N, NO_3^--N, min.-N, and Tot-N (min. + org.), before and after burning

	NH_4-N		NO_3-N		mineral-N		total-N	
Date	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**
				At 0-2 cm soil				
30/3	3.3	3.5	0.5	0.4	3.8	3.9	5271	4150
	(0.5)	(2)	(0)	(0.1)	(0.5)	(1)	(550)	(760)
Prescribed Fire from 2:45 p.m. to 4:35 p.m.								
31/3	ND	15.1**	ND	0.15*	ND	15.3**	ND	4882
		(4)		(0.04)		(4)		(856)
16/5	4.3	12.1**	1.4	7.3**	5.7	19.4	2720	5260
	(2.5)	(1.5)	(0.9)	(1.1)	(3)	(2.6)	(880)	(650)
27/6	2.6	6.5**	0.27	5.1**	2.93	11.65**	2260	3460**
	(0.7)	(0.1)	(0.1)	(2)	(0.7)	(3.4)	(480)	(140)
05/8	8.27	10.22	1.5	5.71**	9.76	15.94**	3700	5620
	(2.4)	(2.7)	(0.6)	(0.6)	(2.5)	(2.2)	(1560)	(1520)
				At 2-10 cm soil				
30/3	0.8	1.2	0.5	0.2	1.3	1.4	1900	2560
	(0.5)	(0.7)	(0.4)	(0)	(0.5)	(0.7)	(520)	(480)
Prescribed Fire from 2:45 p.m. to 4:35 p.m.								
31/3	ND	1.6	ND	0.0	ND	1.6	ND	2325
		(0)		(0)		(0.6)		(210)
16/5	2.7	4.64	0.59	2.1**	3.3	6.71	2060	2540
	(1.5)	(2.8)	(0.4)	(0.06)	(1.9)	(2.8)	(110)	(460)
27/6	2.48	3.94	0.14	0.77**	2.62	4.72	1730	2040
	(0.5)	(1)	(0.06)	(0.1)	(0.4)	(1)	(190)	(340)
05/8	8.38	8.53	0.64	1.84*	9	10.4	2000	2510
	(0.7)	(0.6)	(0.2)	(0.6)	(0.8)	(0.8)	(100)	(730)

Each value expressed in mg N Kg^{-1} dry soil, represents the average of four to six replicates
C: Control Sites. B: Burned Sites. ND: None Determined. ( ): Standard Deviation. *: Significant Difference at 95% of Probability. **: Significant Difference at 99% of Probability

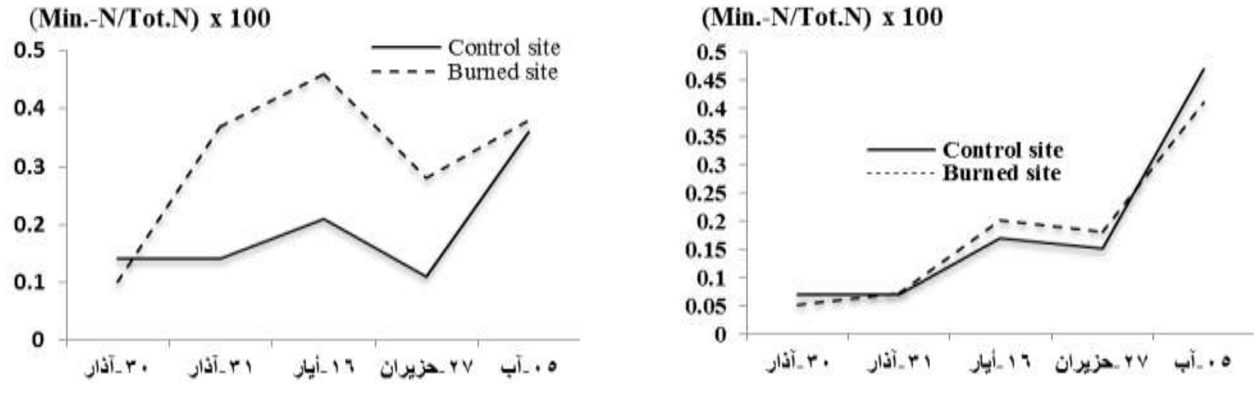

Figure 4. Nitrogen Mineralization Rates in Situ, at 0-2 cm (left) and 2-10 cm depth (right).=

nitrification process under the effect of heat. These results confirm the findings found by several researchers among them Debano *et al.*, (6) and Knoepp *et al*., (19), and Wang *et al.*, (27). Whereas Wallace Covington and Sackett (26) found no change in NO_3^--N content immediately after burning. Tot.-N (mineral + organic) at 0-2 cm, did not vary. In general within 24 hours after fire, mineralization rate increased from 0.1% to about 0.4% as shown in Figure 4 (left). The low intensity of the fire, combined the day of the burning with precipitation, is probably the key factor for this increase, since the degree of calcination of organic matter modules Tot.-N variation (25). In addition to volatilization of nitrogen from the soil, which is under weak temperatures, is at its minimum, fuels (trunks, branches, leaves, etc.) have been partially burned. However, most remaining organic residues represent more or less an extra supply of organic nitrogen to the soil surface. Wallace Covington and Sackett (26), reported an immediate reduction of Tot-N after the passage of fire in an ecosystem of *Pinus ponderosa*. At 2-10 cm depth, Tot.-N, NH_4^+-N, NO_3^--N and min.-N contents (Table 1) as well as la mineralization rate (Figure 4 right) were practically not affected one day after fire passage. Switzer *et al.*, (25) found no significant decrease in Tot.-N of the soil, which is identical to our results between 2 and 10 cm depth

Influence of prescribed fire on current nitrogen. Over time effect.

Four months after burning, NH_4^+-N, NO_3^--N and N-min. contents at 0-2 cm of the burned plot, were respectively 3, 14 and 4 times greater than those from before the fire of the same plot (Table 1). On the other hand they were significantly higher ($P = 0.01$) than in the control plot on the same date, except for the NH_4^+-N content which approached that of the burned plot. Tot.-N did not increase significantly in the two plots (control and burned) and subsequently mineralization rates were almost the same at their high levels (Figure 4 left). At 2-10 cm soil depth and in two plots, Tot.-N was not varying from baseline values of before the fire (Table 1). NH_4^+-N reached equal values (8.38 and 8.53 mg N Kg^{-1} dry soil) in two plots, control and burned, under seasonal conditions. But NO_3^--N in the burned plot retained higher content than those of the control. NH_4^+-N increases at 0-2 cm indicate the combine effects of the moderate fire and the seasonal evolution of the microbial activity (10). At 2-10 cm, slight microbial stimulation and a punctuated NO_3^--N movement from the soil surface during the study, were not enough to make a significant increase in NH_4^+-N content. In plus, in early August, the contents of NH_4^+-N in both plots were identical as a result of the absence of the main factors intervening on mineralization and NO_3^--N movement to 2-10 cm depth. NO_3^--N increases can be explained by the intense nitrification in the burned area after reactivation of nitrifying bacteria due to the presence of NH_4^+-N in sufficient quantity as a source of energy and favorable soil conditions as temperature and moisture (Figure 3). However in the control area there is probably great root absorption. This accumulation in NO_3^--N is in agreement with the findings of most research on this subject (12). At 2-10 cm, the NO_3^--N content evolves in the same way as at 0-2 cm of the soil, but always in smaller proportion, and with significant differences. Total-N increased at the beginning of August at 0-2 cm depth in the two plots in particular the control plot (Table 1), was due to contamination of the samples in dry dead organic matter on site, at the time of sampling. The comparison of current levels of nitrogen at 0-2 cm, between mid-May and June, showed that NH_4^+-N decreased in the control plot and burned plot by 40 and 47%, respectively, NO_3^--N by 81 and 30% and min.-N by 49 and 40%. But these levels remained significantly higher in the burned plot than in the control. This unusual reduction for the season was the result of a phase of soil saturation in water (Figure 3 left). At 2-10 cm and in the two plots, this decrease was less brutal for NH_4^+-N and min.-N, but it remains sensitive to NO_3^-–N

Mineralization of nitrogen in soil incubated in situ. Incubation allows to appreciate the importance of exports and immobilization of mineral nitrogen; they can be estimated by the difference between the contents in the boxes and areas nearby them at the end of the incubation. The exports (losses by NO_3^--N movement to deeper depth and root uptake) were suppressed in the boxes. This theoretically results in an enrichment of N-mineral in them. But our results indicate that the immobilization in the boxes is higher than the exports of mineral-N at the end of the first and third periods of incubation (Table 2). The production of mineral nitrogen (the amount really produced by microorganisms) is much higher in the burned area than in the control area during the first period followin

Table 2. Content of NH_4-N, NO_3-N and mineral-N in the soil incubated in situ. Each value expressed in ppm/dry soil, represents the average of four to six replicates

Date	Time function	NH_4-N		NO_3-N		mineral-N	
		C	B	C	B	C	B
			At 0 -2 cm depth				
30 March	N (t_0)	3.3	3.5^{NS}	0.5	0.4^{NS}	3.8	3.9^{NS}
		(0.5)	(2)	(0)	(0.1)	(0.5)	(1)
16 May	N (t_6)	2.5	8.7	0.7	3.9	3.3	12.6
		(0.6)	(4)	(0.6)	(1)	(1)	(5)
N (t_6 - t_0)		- 0.8	$+ 5.2^{*}$	+ 0.2	$+ 3.5^{*}$	- 0.5	$+ 8.7^{*}$
16 May	N (t_0)	4.28	12.1^{**}	1.4	7.3^{*}	5.7	19.4^{**}
		(2.5)	(1.5)	(0.1)	(1)	(3)	(2.6)
27 June	N (t_6)	3.18	3.14	0.7	12.15	3.87	15.29
		(1)	(1.7)	(0.2)	(2)	(1.2)	(2.5)
N (t_6 - t_0)		- 1.1	$- 8.9^{**}$	- 0.7	$+ 4.83^{*}$	- 1.8	$- 4.1^{NS}$
27 June	N (t_0)	2.6	6.5^{**}	0.27	5.1^{**}	2.93	11.65^{**}
		(0.7)	(0.1)	(0.1)	(2)	(0.7)	(3.4)
05 August	N (t_6)	4.1	6.33	0.76	6.53^{**}	4.85	12.86^{*}
		(1)	(2.3)	(0.2)	(1.5)	(1.2)	(3.8)
N (t_6 - t_0)		+ 1,5	$- 0.17^{*}$	+ 0.49	$+ 1.43^{*}$	+ 2	+ 1.26
05 August	N (t_0)	8.27	10.22^{NS}	1.5	5.71^{**}	9.76	15.94^{*}
		(2.4)	(2.7)	(0.6)	(0.6)	(2.5)	(2.2)
			At 2 - 10 cm depth				
30 March	N (t_0)	0,8	$1,2^{NS}$	0.5	0.16^{NS}	1.3	1.4
		(0.5)	(0.7)	(0.4)	(0)	(0.5)	(0.7)
16 May	N (t_6)	2.3	3.1	0.4	1.1	2.7	4.2
		(0)	(0.5)	(0.4)	(0.5)	(0.4)	(0.9)
N (t_6 - t_0)		+ 1.5	$+ 1.9^{NS}$	- 0.1	$+ 0.94^{NS}$	+ 1.4	$+ 2.8^{NS}$
16 May	N (t_0)	2.71	4.64^{NS}	0.59	2.1^{**}	3.3	6.71^{NS}
		(1.5)	(2.8)	(0.37)	(0.06)	(1.9)	(2.85)
27 June	N (t_6)	2.03	2.67	0.65	4.58	2.69	7.25
		(1.3)	(0.6)	(0.4)	(0.9)	(1.6)	(1.24)
N (t_6 - t_0)		- 0.67	$- 1.96^{NS}$	+ 0.06	$+ 2.5^{NS}$	- 0.6	+ 0.54
27 June	N (t_0)	2.48	3.94^{NS}	0.145	0.77^{**}	2.62	4.72^{*}
		(0.5)	(1)	(0.06)	(0.13)	(0.4)	(1)
05 August	N (t_6)	2.10	2.6^{NS}	0.69	2.93^{NS}	3	5.53^{*}
		(0.9)	(1)	(0.3)	(1.3)	(1.2)	(1)
N (t_6 - t_0)		- 0.38	$- 1.35^{*}$	+ 0.54	+ 2.16	+ 0,16	$+ 0.81^{*}$
05 August	N (t_0)	8.38	8.53	0.64	1.84^{*}	9.03	10.37
		(0.7)	(0.6)	(0.2)	(0.6)	(0.8)	(1.8)

C: Control Sites. B: Burned Sites. ( ): Standard Deviation. ^{NS}: No Significant. *: Significant Difference at 95% of Probability. **: Significant Difference at 99% of Probability. *N (t_0)*: Nitrogen content at the start of incubation. *N (t_6)*: Nitrogen content at the end of the incubation. *N (t_6 - t_0)*: Production of nitrogen for 6 weeks incubation

the passage of fire and these as well in terms of ammonification, nitrification, 0-2 and 2-10 cm depths (Table 2). The values **N (t_6 - t_0)** found in this first sequence represent a maximum productivity (8.7 mg N Kg^{-1} dry soil) observed throughout the study. Net mineralization was much more intense at 0-2 cm than at 2-10 cm depths (Figure 5), and focuses on the net ammonification rather than net nitrification (comparison between Figure 5 left and 6 left). This is due to the strong stimulation of ammonificateurs. Meanwhile this NH_4^+-N availability and favorable weather conditions, will quickly stimulate the nitrification process that will also contribute to the pool of mineral nitrogen. On the other hand we see that at 2-10 cm, the comparison between mineralization and nitrification rates (Figures 5 right and 6 right) shows that ammonification is almost the same in the control area and the burned area, while NO_3^--N reorganization is more important in the control. At the end of the second period of incubation (27 June), NO_3^--N content was too high in burned sites. However, the values of NH_4^+-N content are negative everywhere (Table 2). In general, negative or zero values indicate an immobilization of mineral nitrogen by microorganisms and/or losses by NO_3^--N movement to deeper depth and root absorption. Graphically, this means that net mineralization is zero in all cases, with the exception of the 2-10 cm depth of the burned plot (Figure 5 right). There were N-mineral loss, either by anaerobic respiratory denitrification, where NO_3^- and NO_2^- could be reduced to gaseous nitrogen (N_2 and N_2O), or by reorganization in the control sites (Figure 6). Actually this period presents some anomalies due to the fact that the soil at 0-2 cm was saturated at the beginning of incubation (e.g. the moisture was 54% in burned sites (Figure 3 left). In fact, the content of the soil in hydrophobic organic substances was high in the first two centimeters of the burned plot. Therefor repeated rains may clog fine pores with soil and hydrophobic carbon particles, decreasing infiltration rates and aeration of the soil (14, 22). These conditions may have enabled the nitrifying microflora using NH_4^+-N as an energy source. The exception observed in 2-10 cm (positive mineralization) supports this hypothesis. Besides the fact that soil moisture at the time of incubation (30.5%) is a favorable factor to microbiological processes, it is possible that the soil structure characterized by good aeration and lower hydrophobic organic substances, was favorable to mineralization. Exports of mineral-N observed nearby boxes were more important than mineral-N immobilized inside boxes (Table 2). This is evident when in addition to NO_3^--N movement towards 2-10 cm depth, nutrient needs of the plants are important in May. In July and August NH_4^+-N is nitrified as it is produced, where its negative value (Table 2). Consequently, the net nitrification remains dominant in all studied sites as drawn in figure 6, but ammonification remains always negative except for the 0-2 level of the control sites, where ammonia production is more important. The general rise in the levels of mineral-N during this period shows a positive assessment of net mineralization accompanied by an immobilization of NH_4^+-N greater than the exportations outside the boxes. This can be explained firstly because it occurs outside the vegetation season and that min-N movement almost zero, due to the lack of precipitation, partly because it is a period coinciding with a recovery of microbial development (10). In general, four months post prescribe fire created more favorable conditions for nitrification, with a nitrification peak from mid-May to end of June , resulting in increased NO_3^--N concentration, which confirm the finding of Fultz et al., (12) and Rau *et al*., (24). The ammonification is subject to great variations in all study sites with a large deficit from mid-May to end of June

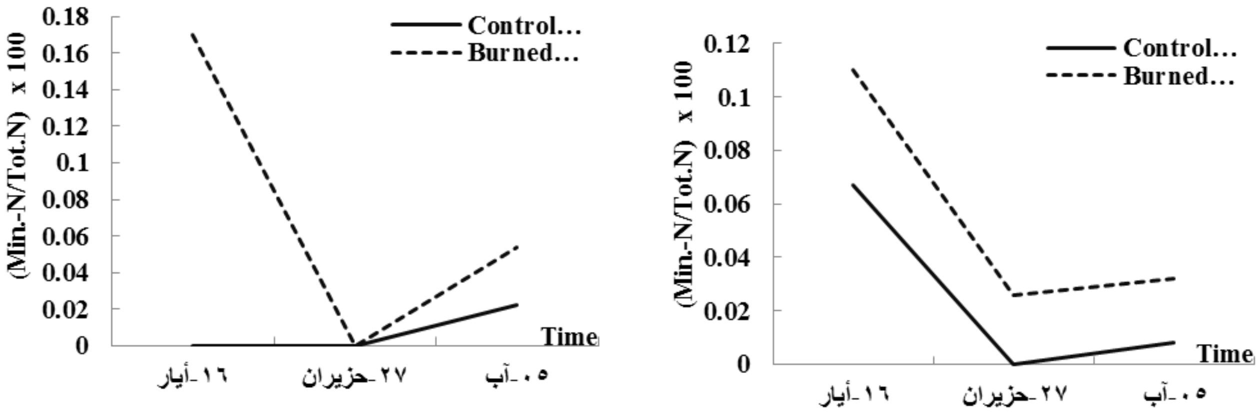

Figure 5. Nitrogen net mineralization rates after six weeks of soil incubation in situ at 0-2 cm *(left)* and 2-10 cm depth *(right*

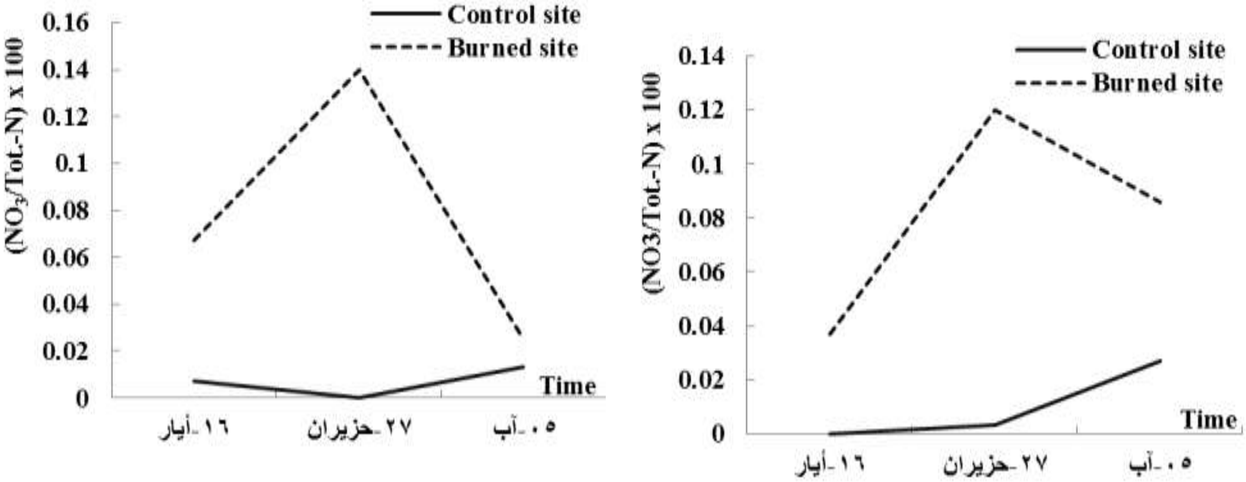

Figure 6. Net nitrification rates after six weeks of soil incubation in situ at 0-2 cm *(left)* and 2-10 cm depth *(right)*.

The results of this work concern the biological activity in term of nitrogen mineralization in a soil of a forest ecosystem in Aleppo pine (*Pinus halepensis*), before and after passage of a prescribed fire of low intensity. They indicate a significant amount of organic nitrogen is mineralized and transformed in ammoniac form in the soil surface a day after burning, as a result of a significant increase of microbial biomass found in earlier research on the same topic. While nitrates decrease due to the elimination and sterilization of nitrifying and NO_3^--N movement to deeper depth in soil. The amount of organic residues partially burned, at the soil surface, increases the total nitrogen of 15%. Thus, our results suggest that a low intensity fire programmed and executed during a cool season, may limit the total ecosystem nitrogen losses reported by several studies. The immobilization is more important for NH_4^+-N than for nitrates throughout the study, where accumulation of nitrates. Meanwhile, the very high level of net mineralization during the first six weeks of incubation in situ after the passage of fire are attributed to a considerable microbiological activity. After which it appears, and unexpectedly, a period of decline in mineral product nitrogen, following a decrease in microbial biomass, we assign, because the characters of the studied soil subjected to intense rainfall, a temporary disappearance of aerobic microflora and a likely substitution of an anaerobic microflora. The hydrophobic character of certain organic substances produced by fire, can activate the microflora of ammonificateurs at the expense of nitrifying bacteria. At the end of June and in early July, a new production of mineral nitrogen occurs as an expression of a new recovery of microbial development, beginning from the end of May following a strong immobilization of ammoniac nitrogen, and due to an improvement of moisture conditions and soil temperatures. But this production is still negative on the surface of the soil compared to mineral nitrogen losses from non-incubated soil. It is positive and high in depth, between 2 and 10 cm, in a horizon that is relatively immune to climate contingencies

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