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POST-FIRE DYNAMICS OF THE MAIN BIOGENIC NUTRIENTS OF THE *Pinus pinaster* FOREST SOIL OF JIJEL, NORTHEASTERN ALGERIA

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Abstract

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Forest fires are part of the natural dynamics of Mediterranean forest ecosystems. In the Mediterranean regions, the ecosystems are shaped by this disturbance that they have been subjected to for a long time. This work aimed to study the effect of fire on the superficial soil of the *Pinus pinaster* forest of Jijel, Northeastern Algeria. Soil samples were taken at a depth of 0–5 cm at different dates over a period of 24 months, in a diachronic mode. The following parameters have been tested: total carbon (C), total nitrogen (N), pH, cations exchange capacity (C.E.C.) and main exchangeable bases: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}) and potassium (K^{+}). The results of the study showed a significant soil enrichment during the first few months after the fire; this temporary high fertility decreases with time due to ecosystem recovery, which could be interpreted as a return to the pre-fire state.

Key words: biogenic elements, *Pinus pinaster* forest, soil, wildfires.

Introduction

Forest fires can occur in almost every ecosystem. Some of these ecosystems are highly vulnerable to fire. In the Mediterranean basin, fire plays a main role in shaping the structure of plant communities and forests growth; besides, it has been widely used by humans to control these ecosystems (Certini, 2005; García-Orenes et al., 2017). The Mediterranean region is well known for its seasonal climate which is characterized by wet winters that support vegetation growth and hot, dry summers that increase vegetation flammability. Fires are popular especially in summer, when the temperature is very high (Pereira et al., 2014; Moreira et al., 2020).

The soil degradation after wildfire is a result of the deterioration of soil structure, loss of organic matter and mineral elements (Palese et al., 2004). Actually, various soil physical and chemical properties can be changed by burning, including loss of soil structure, porosity decrease, reduction of organic matter and increase in pH. As a result, the impact of fire on soil properties and their severity is highly complex, and no generalized trends can be inferred (DeBano, 2000; González-Pérez et al., 2004; Verma, Jayakumar, 2012).

Over the last century, many efforts and resources were mobilized into studying and managing forest fires. The impact of such disturbances on soil properties has become a topic of great interest. The interest of this research is in the effect of fire on the most mobile elements of the ecosystem, which are permanently recycled in the litter to be made available to the vegetation. These nutrients are immediately affected by fire, resulting in significant changes in their availability in the soil, either through their loss to the atmosphere (by volatilization in gaseous form or as fine particles) or through their input in the ash from burning vegetation and litter (Gillon, Rapp, 1989; Trabaud, Gillon, 1991; Pereira et al., 2014).

Most studies on fire effects on soils of Mediterranean communities have been conducted in Europe; for example: in Spain, Merino et al. (2019) in *Pinus nigra* and *P. pinaster* forests; in Italy, Palese et al. (2004) in a Mediterranean maquis; in France, Guénon et al. (2013) in *Quercus suber* forest; in Portugal, Fonseca et al. (2017) in *Pinus pinaster* forest. Indeed, various authors agree that fire changes the nutrient content of the soil, but their observations are different and their results are variable (Wan et al., 2001; Duguy et al., 2007; Santín, Doerr, 2016).

In Algeria, few studies have been done and little is reported about this subject. Rashid (1987), Lounis (1998), Slimani (2002) and Bekdouche (1997, 2010) all worked on *Quercus su-*

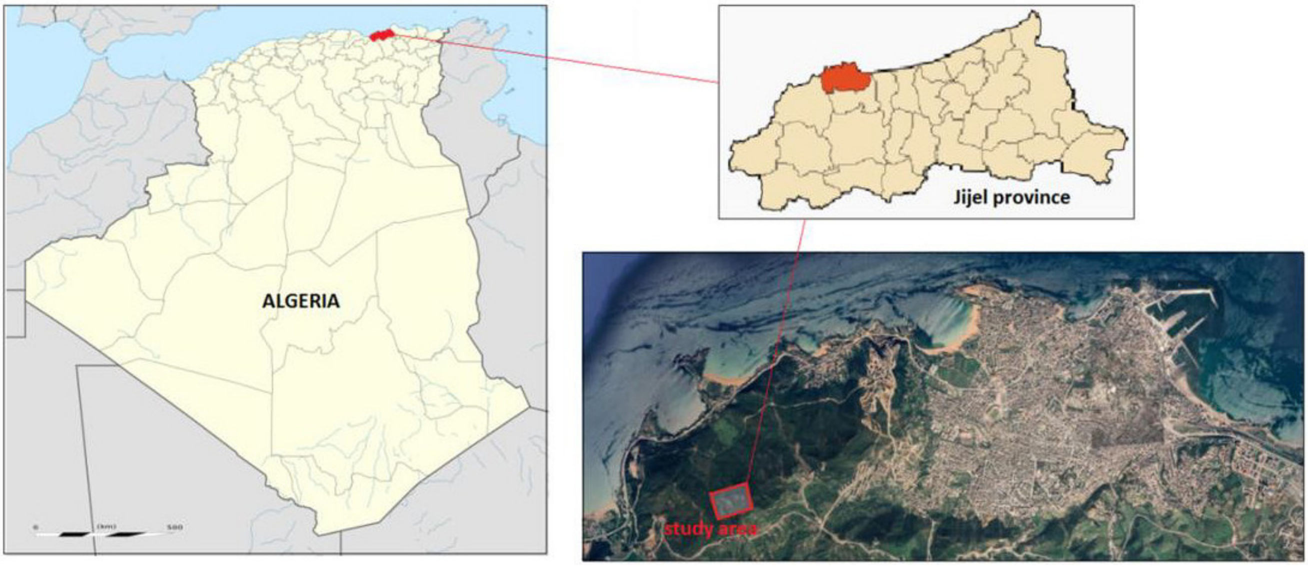

Fig. 1. Location of the study area (Jijel, Algeria). Source: https://fr.wikipedia.org/wiki/Jijeland Google Earth 2021).

ber communities. This work aimed to study the evolution of biogenic elements of surface soil over the medium term (2 years) after the fire of *Pinus pinaster* forest in Jijel, Northeastern of Algeria; to the best of our knowledge, this study is the first report on *P. pinaster* forest in Algeria, and the ultimate goal of this work is to enrich the scientific literature on the Algerian forest ecosystem.

Material and methods

Study area

The study was carried out in a *P. pinaster* forest located near the locality of Kissir (El Aouana), 7 km from the coastal city of Jijel (Fig. 1). The understory dominant species are *Retama monosperma*, *Pistacea lentiscus*, *Erica arborea* and *Myrtus communis*. Average altitude is about 215 m. According to the nearest weather station (Jijel), for the period 2000–2020, the average of maximum and minimum temperatures of the hottest month (August) and the coldest month (January) is 31.55 and 6.92 °C, respectively; the annual average rainfall is 1,008.8 mm. Following Emberger (1971), the area is classified under the temperate variant of the sub-humid bioclimatic stage.

The region's soil was classified as raw mineral soils. The bedrock consists of flysch and granite formations with a sandy-loamy texture (Ramdane, 2001; Nehaï, Guettouche, 2020). The fire started in the Pine Forest on August 01, 2017, and burned a large portion of the area in three days.

Experimental design

Soil sampling

Inside the burned area, six permanent plots (1×1 m^2) were established randomly on a homogeneous surface with the same characteristics with a very low slope in order to reduce the effect of water erosion. The fire severity was low in most of the zone and medium in a few zones because the trees retained some pine needles and a large number of branches (Úbeda et al., 2006). The soil samples were collected from 0 to 5 cm deep using a steel cylinder (Trabaud, 1980; Gillon, 1990), at different dates during a period of 24 months after the fire, in diachronic mode. Sampling began immediately after the fire according to the following time intervals: 15 days, 1, 3, 6, 9, 12, 18 and 24 months. At every sampling date, six samples of 1 kg for each permanent plot were collected.

Laboratory processing

In the laboratory, the samples were air dried at room temperature for ten days. The samples were crushed using a mortar and sieved at < 2 mm. After that, they were carefully homogenized and stored in labeled paper bags.

Analytical methods

The soil analyses were carried out mainly in V. V. Dokuchaev Soil Science Institute in Moscow. Total carbon and total nitrogen were determined by Dumas combustion using elemental analyzer Vario Macro cube. The organic matter rate was obtained by multiplying the total carbon value by 2.0 (Baize, 1990). The cation exchange capacity (CEC) was obtained by the reaction that consists in saturation of the clay-humus with a solution of normal ammonium acetate at pH 7, washing with alcohol of the excess acetate; the ammonium was then determined by colorimetry according to the Berthelot method. Exchangeable cations were determined by flame photometry for Na and K, and atomic absorption for Ca and Mg (Sarkar, Haldar, 2005).

Statistical analysis

The data are processed by one-way analysis of variance (ANOVA), followed by the least significant difference (LSD) test for multiple

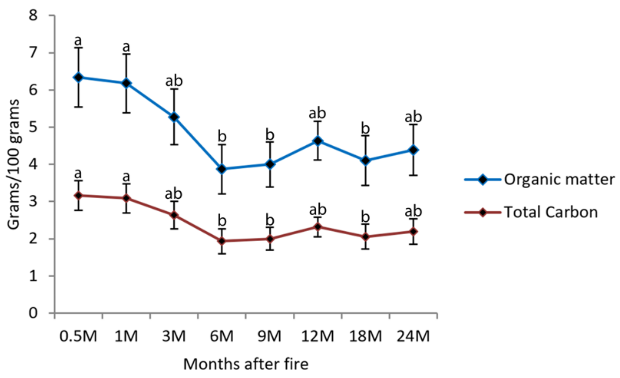

Fig. 2. Post-fire evolution of the organic matter and total carbon in the *Pinuspinaster* forest soil of Jijel (Algeria) during the first two years. The results are means and the bars indicate standard errors. Different letters indicate significant differences between months (LSD test, $p < 0.05$, $n = 6$).

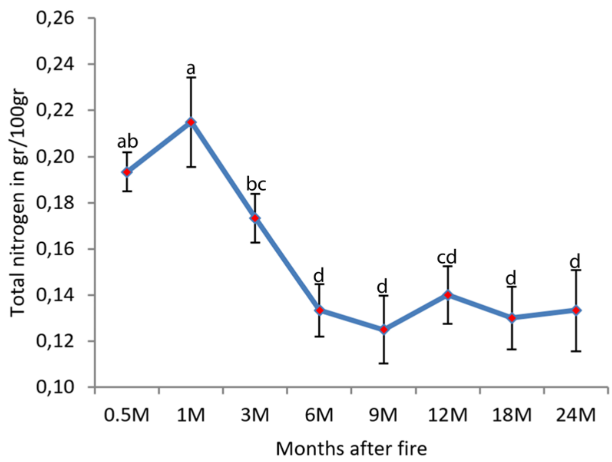

Fig. 3. Post-fire evolution of the total nitrogen in the *Pinus pinaster* forest soil of Jijel (Algeria) during the first two years. The results are means and the bars indicate standard errors. Different letters indicate significant differences between months (LSD test, $p < 0.05$, $n = 6$).

comparisons. The data were subjected to the Shapiro and Wilk›s normality test and Levene›s test for homoscedasticity before the ANOVA. All analyses were done on Xlstat.2016.02.28451 and the results were expressed as means ± SE (standard error). The significance level was fixed at P<0.05.

Results and discussion

Organic matter and total organic carbon

Immediately after the fire, an important rate of organic matter was recorded (6.33 ± 0.8% at 15 days). After a significant increase (P<0.05) during the first month, it falls slightly to stabilize from the 6th month (Fig. 2). Similarly, the rate of total organic carbon during the first month was significantly important (3.17 ± 0.4% at 15 days). After that, it decreased in 3 months (2.64 ± 0.37%) and tended to stabilize over time (P<0.05) (Fig. 2).

Our results are comparable to those noted in Spain by Sanroque et al. (1985) and Vega et al. (1987) in *Pinus halepensis* forests: after an initial increase following the fire, they stated a progressive decrease in organic matter and total carbon. The same result is disclosed by Trabaud (1983, 1990) for the *Quercus coccifera* garrigue in France. The high carbon and organic matter content during the first few months after the fire can be due either to the input of ash and charcoal incorporated into the surface soil layer, or to compensations resulting from the decomposition of underground plant organs near the surface, which were destroyed during the fire (Raison, 1979; Trabaud, 1990; González-Pérez et al., 2004). The effect of fire on carbon and organic matter is highly variable and depends on several factors including fire type, duration and intensity, topography, soil moisture, soil type and vegetation cover (Caon et al., 2014). This impact can range from their total destruction to an increase of 30% over pre-fire levels (González-Pérez et al., 2004). Studies confirmed that organic matter and carbon return to normal after one year following the fire (Bridges et al., 2019). Other researchers (Ahlgren, Ahlgren, 1960; Ueckert et al., 1978) suggested that the increased heat balance of the burned soil surface stimulated decomposing microorganisms, leading to increased carbon levels. Duguy et al. (2007) reported a decrease in carbon with fire frequency; this can be explained by the decrease in vegetation cover and consequently organic matter. In Italy, in a mixed pine and hardwood forest on acidic soil, Vidrich et al. (1977) observed an increase in organic carbon immediately after the fire, then returning to the initial state after one year (Badía et al., 2014). In a review paper, Caon et al. (2014) noted that two as well as three years after the fire, different authors reported similar soil organic carbon contents in both burnt and control sites.

In Algeria, Rashid (1987) marked an increase in total carbon and organic matter in the burned plots in a *Quercus suber* forest, then a progressive decrease to reach the unburned plot values 2 years after the fire. This result is in agreement with Bekdouche (1997, 2010), Slimani (2002) and Lounis (1998) for different oak forests of the Kabylia region.

Total nitrogen

The results illustrated in Figure 3 showed that during the first three months after the fire, nitrogen presented at its highest values at the first month (P<0.05). Thereafter, a decline and stabilization for the rest of the sampling period were noticed. Total nitrogen is the sum of nitrate ($NO3^-$), nitrite ($NO2^-$), ammonia ($NH4^+$) and organic nitrogen. It should be noted that the results for nitrogen can be explained by the composition of the vegetation, and more particularly of the leguminous plants, following the fire. Indeed, several studies have shown that the floristic richness is maximal during the first year (Bekdouche, 2010). Subsequently, the floristic richness decreases mainly due to the extinction of annual plants following the abundance of the vegetation cover by ligneous plants. The annual plants that appear in the burned territories are in a great proportion represented by leguminous plants that enrich the soil in nitrogen due to the symbiotic association with the *Rhizobia* (DeBano et al., 2000; Duguy et al., 2007; Bekdouche, 2010). After the first year, leguminous plants become less important, and nitrogen synthesis decreases as a result (Bekdouche et al., 2011).

The result of nitrogen is the consequence of a loss by volatilization and an enrichment provided by the ashes, the hydrolysis of proteins and the symbiotic fixation (Duguy et al., 2007; Giovannini, 2012). In fact, Gillon, Rapp (1989), Gillon (1990) and Fisher, Binkley (2000) revealed that during fire, nearly all of the nitrogen in the plant fuel was lost through volatilization. As a general rule, the amount of total N that is volatilized during combustion is directly proportional to the amount of organic matter destroyed (DeBano, Neary, 2005). Caon et al. (2014) who reviewed the effects of wildfire on soil nutrients noted that generally fire tends to decrease the soil total nitrogen content in the A horizon. However, an increase in mineral nitrogen in ammonia form was noted (Caon et al., 2014). Therefore, Rapp (personal communication) cited by Gillon (1990) measured a few hours after a prescribed fire under *Pinus halepensis*; in the first two centimeters of the soil, the amount of inorganic nitrogen in the ammonia form was four times greater than it was before the fire, while inorganic nitrogen in the nitrate form had decreased. However, ashes are poor in mineral nitrogen. Therefore, this immediate and important production of ammoniacal nitrogen at the soil surface does not seem to be linked to the ash input but is due to the heating of the soil surface layers and the hydrolysis of proteins (Raison, 1979; Badía et al., 2014). Covington and Sackett (1986) recorded generally higher NH_4^+ and NO_3^- concentrations in plots subjected to repeated fires than unburned plots. Nevertheless, after four to five years without fire, the burned and unburned plots become similar. In the same way, Wan et al. (2001) concluded that fire induces an increase in assimilable nitrogen (NH_4^+ and NO_3^-); however, frequent fires with short periodicity can induce a decrease in nitrogen. In a *Pinus pinaster* forest, Prieto-Fernandez et al. (1993) noted an increase in nitrogen concentration in the surface layer of the soil one month after the fire. This increased N availability enhances post-fire plant growth and gives an impression that more total N is present after fire. However, this nitrogen is quickly utilized by plants within the first few years after burning (Knoepp et al., 2005). The most basic soil chemical property affected by soil heating during fires is organic matter. When it is combusted, the stored nutrients, in particular nitrogen, are either volatilized or are changed into highly available forms that can be taken up readily by microbial organisms and vegetation (Busse, DeBano, 2005). In the *Quercus suber* forest under the same climatic conditions as our *Pinus pinaster* forest, Rashid (1987) and Bekdouche (2010) revealed high nitrogen levels immediately after the fire, which gradually declined and stabilized after two years.

C/N ratio

The C/N ratio illustrated by Figure 4 is a particularly useful index for determining a soil›s biological potential (Viro, 1974). The organic matter content of the soil provides information on its carbon content, whereas the C/N ratio indicates the soil›s nitrogen level. Soil nitrogen richness is inversely correlated to the C/N ratio; a low C/N ratio indicates a high nitrogen content and an important mineralization process.

Depending on carbon and nitrogen, this ratio varies with the evolution of these two elements. The ratio values are the lowest between one month and six months after the fire (14.18 ± 1.62 at 6 months) but not significant (P<0.05). It is, therefore, during the first few months after the fire that the soils are biologically more active, which allows a very rapid recovery of the vegetation immediately after the disturbance: vegetative regrowth has been noted in almost all the woody and semi-woody taxa of the community and germination of numerous herbaceous species at two months after the fire on all the sampled plots. Our results are consistent with those of Trabaud (1990) and Gillon et al. (1999), who reported a significant decrease in the C/N ratio immediately after the fire corresponding to the highest N contents. Generally, the C/N ratio is lower after the fire than in the pre-disturbance state (Jiménez-González et al., 2016).

Our results agree with those noted by Bekdouche (2010) for the *Quercus suber* forest of Mizrana (Tizi-Ouzou) and higher

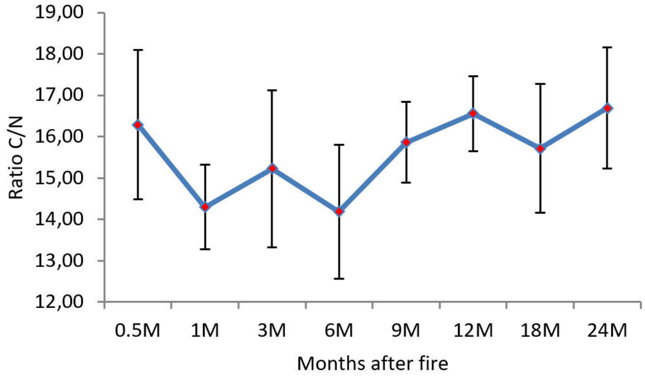

Fig. 4. Post-fire evolution of the C/N ratio in the *Pinus pinaster* forest soil of Jijel (Algeria) during the first two years. The results are means and the bars indicate standard errors. There are no significant differences between months (LSD test, $p < 0.05$, $n = 6$).

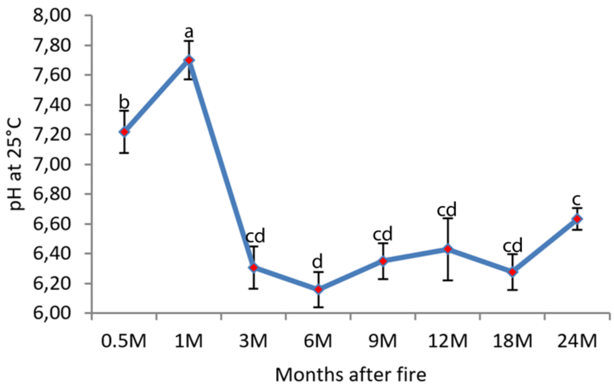

Fig. 5. Post-fire evolution of the pH in the *Pinus pinaster* forest soil of Jijel (Algeria) during the first two years. The results are means and the bars indicate standard errors. Different letters indicate significant differences between months (LSD test, $p < 0.05$, $n = 6$).

Table 1. Post-fire evolution of the exchangeable cations (Ca^{2+}, Mg^{2+}, Na^+ and K^+) in the *Pinus pinaster* forest soil of Jijel (Algeria) during the first two years. The results are means ± standard errors. Different letters for the same column indicate significant differences between months (LSD test, $p < 0.05$, n = 6).

Month	Exchangeable cations $cmol_{(+)}$/kg				
	Ca^{2+}	Mg^{2+}	Na^+	K^+	Base saturation
0.5M	32.02 ± 1.95^{a}	19.24 ± 1.23^{a}	2.98 ± 0.24^{ab}	0.339 ± 0.048^{a}	79.26%
1M	29.05 ± 1.34^{a}	18.73 ± 2.06^{a}	3.90 ± 0.65^{a}	0.352 ± 0.052^{a}	76.85%
3M	18.23 ± 1.78^{bc}	13.17 ± 1.10^{bc}	2.71 ± 0.32^{bc}	0.282 ± 0.050^{ab}	71.66%
6M	15.87 ± 1.30^{c}	11.91 ± 0.85^{bc}	1.85 ± 0.39^{c}	0.140 ± 0.024^{c}	69.36%
9M	15.89 ± 0.96^{c}	11.14 ± 0.77^{c}	1.84 ± 0.24^{c}	0.178 ± 0.026^{bc}	74.88%
12M	17.79 ± 1.25^{c}	11.96 ± 0.82^{bc}	2.22 ± 0.31^{bc}	0.212 ± 0.028^{bc}	78.83%
18M	19.96 ± 2.51^{bc}	12.43 ± 1.07^{c}	2.30 ± 0.32^{bc}	0.210 ± 0.045^{bc}	82.66%
24M	22.78 ± 2.25^{b}	13.66 ± 0.82^{b}	1.98 ± 0.34^{bc}	0.191 ± 0.042^{bc}	83.70%

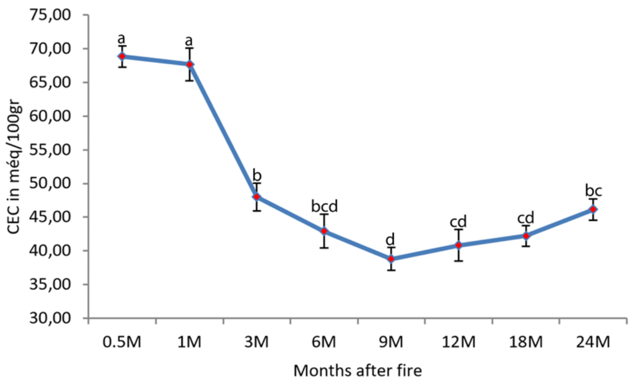

Fig. 6. Post-fire evolution of the cation exchange capacity (CEC) in the *Pinus pinaster* forest soil of Jijel (Algeria) during the first two years. The results are means and the bars indicate standard errors. Different letters indicate significant differences between months (LSD test, $p < 0.05$, n = 6).

than those recorded by the same author for the *Q. suber* forest of Bouhatem (Bejaia).

pH

Soil pH is an important parameter for assessing the potential availability of nutrients to plants. It gives information on the acidity of the soil and the state of the absorbent complex. The pH of our pine forest recorded its highest values during the first month after the fire (7.70 ± 0.13 at 1st month and 7.22 ± 0.14 at 15 days) and then decreased significantly (P<0.05) from the 3rd month to show nearly equivalent values until the end of the sampling period (Fig. 5). It is generally accepted that fire stimulates soil microorganisms by increasing soil pH with the incorporation of ash, mainly by modifying soil microclimatic conditions (Gillon, 1990). Vidrich et al. (1977) recorded 2 units increase in pH after the fire in mixed pine and deciduous forest in Italy. In general, the pH of soils tends to rise following fires, though briefly, due to the release of alkaline cations (Ca^{2+}, Mg^{2+}, K^+, Na^+) linked to the organic matter (Certini, 2005; Bridges et al., 2019). The heat of fire denatures organic acids resulting in a sharp increase in soil pH (Guénon, 2010). Pritchett, Fisher (1987) reported that pH depends on the ash amount, soil texture and organic matter content.

Cation exchange capacity (C.E.C.) and main exchangeable bases

The cation exchange capacity (CEC) represented in Figure 6 showed higher values just instantly after the fire (68.86 ± 1.55 cmol (+)/kg at 15 days and 67.71 ± 2.42 cmol (+)/kg at 1st month) and decreased from the 3rd month (47.99 ± 2.09 cmol (+)/kg) and stabilized at the end of the observation period (P<0.05).

Trabaud (1990) noted generally higher values of CEC in burned soils than in soils that have not been subjected to fire. Certini (2005) demonstrated a proportional decrease between CEC and organic matter, which agrees with our results and those of Bekdouche (2010). In normal conditions, mineral elements are released continuously and slowly and are available to vegetation. Fire disturbs this balance and causes a massive release of nutrients. One part is made directly accessible to the growing vegetation; the other part is rapidly carried into and out of the profile by runoff, internal leaching and erosive action of the wind (Raison, 1979, 1980).

Calcium

Most of the cation exchange capacity is provided by calcium. The quantitative evolution of this cation, represented by Table 1, showed its highest values during the beginning of the observations (32.02 ± 1.95 cmol (+)/kg at 15 days after the fire) and decreased in the same time as the decrease of the cationic exchange capacity to show its lowest values between 6 and 9 months, to recover slightly after that (P<0.05).

Viro (1974) and Gillon (1990) noted that calcium is the least affected of all exchangeable cations, because its losses during combustion are due solely to particle transport. On the other hand, Viro (1974) recorded a three-fold increase in burned soils of a coniferous forest.

Magnesium

During the first few months after the fire, magnesium values were significantly elevated; then, they decreased with time (Table 1, $P<0.05$). The results given by various authors concerning this cation are divergent. For example, Ahlgren and Ahlgren (1960), Viro (1974), Woodmansee and Wallach (1981) and Kutiel and Naveh (1987a) stated an increase in magnesium content following fire, while Rundel and Parsons (1980) and Kutiel and Naveh (1987b) reported a decrease. However, despite the increase, the amount of magnesium released immediately after fire decreases rapidly due to losses through runoff, leaching and wind erosion (Raison, 1979, 1980; Certini, 2005).

Potassium

Among all the exchangeable bases studied, potassium showed the lowest values. Overall, the highest values of potassium are noted immediately after the fire: 0.352 ± 0.052 cmol (+)/kg in the 1-st month and only 0.140 ± 0.024 cmol (+)/kg in the 6-th month ($P<0.05$). As for calcium, results from different researchers are variable among different ecosystems and fire events (Raison, 1979; Woodmansee, Wallach, 1981; Trabaud, 1990). Generally, after high levels brought by the ashes, there is a return to the pre-fire state due to losses by runoff and leaching.

Sodium

There are no significant changes for this exchangeable base during the observation period (Table 1): it is the most stable element except for the values recorded at 1st month after the fire, which are statistically the highest ($P<0.05$). Trabaud (1980, 1983, 1990) noted a decrease in sodium immediately after the fire compared to the state before the fire, but Bekdouche (2010) observed a slight increase in sodium at the beginning of the observations.

Conclusion

The monitoring for two years of the main biogenic elements of the *Pinus pinaster* forest soil of Jijel (Northeastern Algeria) allows us to conclude that the soils are enriched during the first few months following the fire; this temporary high fertility decreases with time. Immediately after the fire, the highest rates for all the studied nutrients were recorded.

With the recovery of vegetation, the levels of these elements decrease. This decrease can be interpreted as a return to the pre-fire state, which confirms with various researchers that the surface layer of the pine forest soil studied is enriched in the first few months following the fire. The inter-plot heterogeneity of the soil is reported by various authors as a major constraint to study the dynamics of biogenic elements after the fire. In order to be able to conclude on the impact of fire, it is essential to establish a sampling system that includes controls which permit to control the different sources of spatial and temporal variation of the soil and that is monitored diachronically over a period of time sufficient for the complete healing of the site. It seems that only experimentation can bring together all the conditions for such an approach.

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