Research paper

Dynamics of chemical and microbial properties of Algerian forest soils: Influence of natural and anthropogenic factors (Northwest of Tlemcen)

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Abstract. In Djebel Fellaoucene, mattorals and their regressive and progressive dynamics are affected by several factors, namely climate, geography, human activities, overgrazing and fires. This research aims to investigate whether these factors have an impact on the structural dynamics of the area's forest soils and show a correlation between the soils' chemical and microbial properties and these factors. In this regard, we have analysed chemical properties: organic matter, pH, conductivity, calcium carbonate ($CaCO_3$), moisture and carbon as well as microbial properties: basal respiration, microbial biomass and metabolic quotient (qCO_2), all from 80 soil samples collected from degraded mattorals on different altitudes and exposures. Principal Component Analysis (PCA) which has been made revealed that soil dynamics and correlations between chemical and microbial properties depend on the aforementioned factors; an increase in moisture, organic matter, carbon and conductivity as well as a decrease in the mass and bacterial respiration in the North-exposed sites under anthropogenic pressure and overgrazing by sheep and goats. Whereas opposite results were found in the South-exposed sites degraded by fires and undergrazing by cattle. Anthropogenic pressure and overgrazing in sites which have recently been burned lead to a decrease in microbial properties despite an increase in organic matter and moisture content. Qualifying and quantifying the impact of these degradation factors on forest soils allows us to establish effective restoration, conservation strategies and defend rangelands in arid areas.

Key words: Djebel Fellaoucene, dynamics, matorrals, soil, degradation, anthropogenic action.

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Introduction

The Mediterranean Basin witnesses a diversity of degradation factors either natural or mostly anthropogenic (Blondel *et al.*, 2010; Ciccarelli, 2014). For thousand years, man has been exploiting forests and mattorals randomly through his endless effort to seek new pasture lands meant for flocks and fertile agricultural lands causing disturbances and structural degradations which affect vegetation as well as soil dynamics (Borsali *et al.*, 2019; Allam *et al.*, 2019, Allam *et al.*, 2020).

Nowadays, land degradation is a global and complex phenomenon (Turner *et al.*, 2016; Delgado & Marín, 2020) which may jeopardize the future of many nations (Lahmar & Ruellan, 2007) as the soil is considered a non-renewable resource during a human lifespan (Lal, 2009; Schoonover & Crim, 2015). To raise awareness regarding the considerable effects of human activities on soils, decision makers are providing powerful tools for monitoring soil quality and evolution in order to reduce degradation and promote practices for sustainable land use (Vincent *et al.*, 2019).

The region of Tlemcen (Algeria), like other Mediterranean areas, has experienced for decades continual loss of its forest heritage because of the combinations of human actions (deforestation and overgrazing) and climate conditions (summer drought, erratic rainfall, heavy downpour) (Benabadji *et al.*, 2001; Borsali *et al.*, 2019). An increase in fire frequency and climate aridification (GIEC, 2007; Allam *et al.*, 2020) may potentially affect the existing balance and drive ecosystems to become unstable.

In semi-arid regions of Western Algeria, many scientific studies have been conducted on post-degradation dynamics of forest ecosystems and the correlation between degradation factors and vegetation. However, these studies barely analyse the impact of these factors on soil dynamics, especially chemical and microbial properties, and resilience following degradation (Borsali *et al.*, 2017; Zouidi *et al.*, 2018, Zouidi *et al.*, 2019a).

After a rapid approach to different factors of soil degradation in the Mediterranean region in general and Western Algeria in particular, we continue this research paper with a concise analysis (laboratory testing and statistics "PCA") and complementary examinations (field observations), including the current state of degraded forest soils, detection of the impact of leading degradation factors on soil dynamics, assessing resilience and the correlation of chemical and microbiological soil properties in the context of exposure to several degradation factors in the forest area of Djebel Fellaoucene in the Northwest of Tlemcen which is quite representative of mattorals in a semi-arid area affected by an increase in anthropogenic activities (deforestation, overgrazing, fires).

To achieve our aims, eight sites have been selected over the mattorals in this semi-arid area according to disturbance type (natural and anthropogenic) in heterogeneous geographical positions (elevation, slope) on different geological substrates (calcareous or siliceous) with diverse homogeneous forest formations (mattorals: thuja, lentisk, evergreen oak, kermes oak, *olea oleaster* Hoffmanns. & Link, *cistus* L.).

We will investigate whether the chemical and microbial dynamic properties and their resilience depend mostly on the type and intensity of natural and anthropogenic degradation factors. Therefore, we suggest that similar degradation factors may lead to the correlation and similarity of chemical and microbial soil properties.

Material and Methods

Presentation of the study area

The study area is situated in the Northwest of Algeria (Oranie) in the Trara mountain range, "Matorrals of Djebel Fellaoucene" between 35° 05′ 44 .74″ and 34° 94′ 61.06″ North; W: 01° 61′.30.60″ and 01° 72′.53.72″

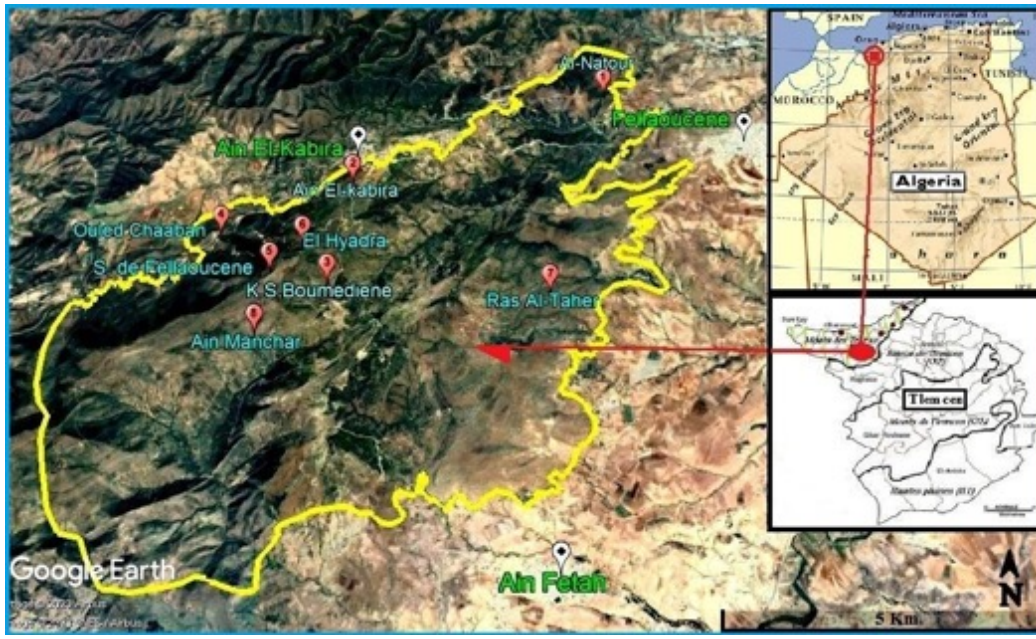


Figure 1. Sampling sites in the matorrals of Djebel Fellaoucene (Tlemcen, Western Algeria) (Google Earth, 2022. Edited).

West at an altitude of 270 m to 1136 m with a surface area of 6259 ha, it is composed of three forestall masses: Fellaoucene, Ain El Kabira, Ain Fetah, (Figure 1).

This zone located on the thermo-Mediterranean floor with mild and hot semi-arid bioclimate is characterized by an annual rainfall average of 400–600 mm, seasonal rainfall regime type: Winter>Spring>Autumn>Summer, the average annual temperature is 18.73°C: "m" of 5°C and "M" of 30 °C.

The peaks of this mountain range are composed of interspersed sandstones of blue limestone of the Upper Jurassic giving steep reliefs above the Oxfordian schists and clays resulting in regular slopes, and above the Liasic limestone giving steep reliefs, as well (Durand, 1954).

Forestall formations of the study area are fragile due to several climatic factors (drought, low and irregular rainfall, thermal amplitude, wind, etc.). These formations are in a permanent struggle with anthropogenic pressures dominated by fires, logging, deforestation and clearings which give a floristic structure and composition towards a balance between natural and human factors of the environment resulting in huge biodiversity erosion. Fellaoucene mountain range is shaped by vegetal formations with a floristic diversity representing thermo-xerophile masses in the northwest of Algeria dominated by *Thuja occidentalis* L., *Olea oleaster*, *Pistacia lentiscus* L. and bushes.

Sites and soil sampling

Site choice and boundaries are defined according to a preliminary survey of the degraded mattorals following different anthropogenic and climatic pressures which enable the detection of leading degradation factors affecting soil dynamics, the assessment resilience and correlation of chemical and microbial soil properties. In these mattorals, eight sampling sites were selected according to diverse anthropogenic and climatic pressures in order to study chemical properties (organic matter, pH, conductivity, calcium carbonate ($CaCO_3$), moisture and carbon) as well as

microbial properties (basal respiration, microbial biomass and the metabolic quotient (qCO_2)) of soils.

In order to statistically validate results, soil sampling was performed repeatedly 10 times in each site. Despite the lack of a public database on different anthropogenic and climatic constraints at the Wilaya of Tlemcen, our survey with the help of forest services, locals and field observations reveals that the investigated sites were exposed to overgrazing by different types of livestock (cattle, sheep and goats), logging, opening of trails for grazing extension, tourism, medicinal plants collection, deforestation and fires. In this context, forest services have declared that the last fire in the study area occurred in 2014 causing the destruction of 6,000 ha.

In each sampling site, 10 samples were randomly taken after plant litter elimination with a depth of 0–15 cm corresponding to organo-mineral surface horizons. Samples were screened to 2 mm and dried before conducting a few chemical analyses or stored for 15 days at a temperature of 4 °C pending microbial analyses.

Table 1 provides all relevant data about vegetation facies, substrate, exposure, GPS coordinates, anthropogenic activities, slopes, and sites.

Chemical analyses of soils

Gravimetric water content (% dry mass) was determined by an aliquot desiccation of the sample at 105 °C for 24 hours, it was obtained by subtracting the mass of the dried soil sample from its mass before drying. Organic matter content was measured by the calcination method of soil samples at 550 °C. The amount of calcium carbonate was measured by using a Bernard calcimeter (Aubert, 1978). Soil pH and conductivity were measured in soil suspension with distilled water (1: 2.5) after two hours of stabilisation at ambient temperature by the use of the conductivity meter. To calculate soil carbon content (CO), soil organic matter is divided by a 1.72 factor according to the equation: % carbon= organic matter/1.72 (Dabin, 1970).

Microbial analyses of soils

Basal Respiration

Basal respiration (µg $C\text{-}CO_2$/g dry soil) was calculated according to the method developed by Anderson & Domsch (1978), to evaluate the physiological state of the soil microbial communities. 10 grams (dry equivalent) of wet soil at 4 °C were placed in glass jars (117 ml), closed by a rubber septum after replacing (4 minutes) the inner atmosphere with a stable atmospheric CO_2 concentration before incubation at 25 °C for 4 hours. The concentration was measured at the end of incubation by injecting one milliliter of the jar headspace gas into a gas chromatograph (Chrompack CHROM 3-CP 9001), the chromatograph was equipped with a TCD detector with a filled column (Porapack) full of helium with a flow of 60 ml h^{-1}. The resulted values have been adjusted at 22 °C following the ideal gas law to Q10=2. Ambient CO_2 concentrations have been subtracted from the measured CO_2 after incubation to get the CO_2 quantity produced by heterotrophic microorganisms present in the sample.

Microbial Biomass

To estimate microbial biomass, the substrate-induced respiration method was used by adding glucose (Anderson & Domsch, 1978). A mixture of talcum and glucose (1 000 µg C g- 1 soil) was incorporated into 10 grams of soil (equivalent dry). To achieve a maximal induced respiration rate, a 100-minute incubation was done. The glass jars were closed by a rubber septum after replacing (4 minutes) the inner atmosphere with a stable atmospheric CO_2 concentration before incubation at 22 °C for 90 minutes. The concentration was measured into a gas chromatograph and the results were adjusted in the same manner as described above (basal respiration). The induced respiration rate was converted into microbial mass by using Beare *et al.* (1990) equation.

Table 1. General characteristics of sampling sites in the study area.

Site	Exposure	GPS coordinates	Slope (%)	Substrate	Anthropogenic activities	Dominant species
1. Al-Natour	South	35° 2'32.60»N 1°37'39.54»0 Al: 450 m	< 25	calcareous	Overgrazing (sheep and goats), Logging, Opening of trails, Tourism, Medicinal plant collection, Deforestation.	Sclérophylles and thermophiles: *Pistacia lentiscus* L., *Quercus Ilex* L., *Quercus coccifera* L., *Tetraclinis articulata* (Vahl) Mast., *Cistus monspeliensis* L., *Calicotome intermedia* (Salzm. ex C. Presl) Boiss. ex Rchb.f., *Chamaerops humilis* L., *Ulex parviflorus* Pourr., *Ampelodesmos mauritanicus* (Poir.) T. Durand & Schinz
2. Ain El Kabira	Southeast	35° 1'33.09»N 1°40'28.73»0 Al: 740 m	20 to 25	siliceous	Overgrazing (cattle), Fires.	
3. Karkoum Sidi Boumediene	South	35° 0'32.02»N 1°40'43.39»0 Al: 750 m	03 to 10	siliceous	Overgrazing (cattle), Fires.	
4. Ouled Chaaban	North	35° 0'58.99»N 1°42'0.75»0 Al: 685 m	10 to 15	calcareous	Overgrazing (sheep and goats), Logging, Opening of trails, Tourism, Medicinal plant collection, Deforestation.	
5. Peak of Fellaoucene	North	35° 0'32.04»N 1°41'21.02»0 Al: 1130 m	03 to 15	siliceous	Overgrazing (cattle), Logging, Opening of trails, Tourism, Medicinal plant collection, Fires, Deforestation	
6. El Hyadra	North	35° 0'49.54»N 1°41'2.81»0 Al: 930 m	05 to 15	siliceous	Overgrazing (cattle), Logging, Opening of trails, Tourism, Medicinal plant collection, Fires, Deforestation	
7. Ras Al-Taher	Northwest, Southeast	35° 0'27.04»N 1°38'18.96»0 Al: 500 m	10 to 20	calcareous	Overgrazing (sheep and goats), Logging, Opening of trails, Medicinal plant collection, Deforestation	
8. Ain Manchar	South	35° 0'0.81»N 1°41'30.89»0 Al: 780 m	< 25	siliceous	Overgrazing (cattle), Fires	

Statistical analysis

Principal Component Analysis (PCA) was used to test leading degradation (natural or anthropogenic) factors affecting soil dynamics and to find the correlation between chemical and microbial soil properties and those factors. PCA will allow the obtaining of clear data, detecting dubious values and help to study the junction linear structure of chemical and microbial variables of every site in the study area. We will try to identify groups of all variables by considering similar variables. Statistical analyses were done using Minitab 19.

Results

Chemical analyses of soils

Chemical parameters are listed in Table 2. The obtained results reveal that moisture is higher in the samples of the North Ouled Chaaban, peak of Djebel Fellaoucene and El Hyadra.

Ouled Chaaban, Ras Al-Taher and Al-Natour sites have a calcareous substrate with a high $CaCO_3$ rate representing more than 25% in samples of Ouled Chaaban and Ras Al-Taher; a low level was found in Al-Natour. In other sites of the study area, we found siliceous substrate mainly in Djebel Fellaoucene and Karkoum Sidi Boumediene with a $CaCO_3$ rate lower than 1%.

Organic carbon concentrations (C) and organic matter (OM) rates are higher since the organic matter level varies between 5.30% and 17.47% to reach the highest ratio in the Djebel Fellaoucene peak and the lowest level in Karkoum Sidi Boumediene. The pH is alkaline in all sites of the study area with a level ranging from 7.49 to 7.79. According to the saltiness scale, samples belong to the non-saline category and conductivity is slightly higher in the El Hyadra site.

Table 2. Analysis results of soil chemical properties.

SITE	Average of soil chemical properties					
	H (%)	OM (%)	pH	CON (ms)	C (%)	$CaCO_3$ (%)
Al-Natour	11.25	8.95	7.76	0.19	5.19	7.56
Ain El Kabira	14.78	9.07	7.67	0.16	5.26	1.26
Karkoum S.B	9.63	5.30	7.57	0.14	3.08	0.61
Ouled Chaaban	18.70	12.23	7.79	0.20	7.09	78.43
S. Fellaoucene	22.83	17.47	7.49	0.23	10.13	0.63
El Hyadra	23.24	7.40	7.59	0.27	4.30	2.93
Ras Al-Taher	14.99	10.45	7.77	0.19	6.07	37.49
Ain Manchar	11.69	7.02	7.61	0.15	4.08	1.00

Microbiological analyses of soils

Microbiological analyses, as recorded in Table 3, reveal that basal respiration and microbial biomass are higher in Karkoum S.B, Ain Manchar and Ain El Kabira in comparison with the other sites. The metabolic quotient ranges from 4.5 to 4.91 µg $C\text{-}CO_2/h/g$ in the study area.

Table 3. Results of soil microbial properties in the study area.

SITE	Soil microbial analyses		
	Basal respiration ($\mu gC\text{-}CO_2/h/g$)	Bacterial biomass ($\mu gC_{mic}/g$)	qCO_2 ($\mu gC\text{-}CO_2/h/g$)
Al-Natour	0.14	0.03	4.64
Ain El Kabira	0.38	0.08	4.91
Karkoum S.B	0.43	0.09	4.85
Ouled Chaaban	0.13	0.03	4.64
S. Fellaoucene	0.14	0.03	4.50
El Hyadra	0.14	0.03	4.56
Ras Al-Taher	0.13	0.02	4.64
Ain Manchar	0.42	0.09	4.86

Discriminant analysis by PCA of chemical and microbial properties in the study area

Principal Component Analysis (PCA) is a powerful statistical technique for reducing the dimensionality of a dataset. Our PCA of soil chemical and microbial properties in the study area axis 1 shows a proper value of 9.01 with an inertia ratio of 90.2%. Variables having a strong relative contribution with proper values of this axis are as follows (Table 4).

Table 4. Values of the PCA axis 1 of soil chemical and microbial properties.

Positive side of axis 1		Negative side of axis 1	
Variable	Value (+)	Variable	Value (–)
Moisture	4.48	Basal respiration	3.53
Organic matter	2.82	Microbial biomass	3.49
		Conductivity	3.61

In this axis, we have defined a gradient of moisture and organic matter on the positive side and a gradient for basal respiration, bacterial biomass and conductivity for the driest soils in the South from the positive to the negative sides of the axis. Overall, soils in this zone are impacted by moisture and/or drought, organic matter and alkalinity, respectively.

Axis 2 shows a proper value 0.94 with an inertia ratio of 9.5%. Variables, having a strong relative contribution with proper values of this axis are as follows (Table 5).

Table 5. Values of the PCA axis 2 of soil chemical and microbial properties.

Positive side of axis 2		Negative side of axis 2	
Variable	Value (+)	Variable	Value (–)
		Moisture	0.69
$CaCO_3$ (%)	2.53	Organic matter	0.61

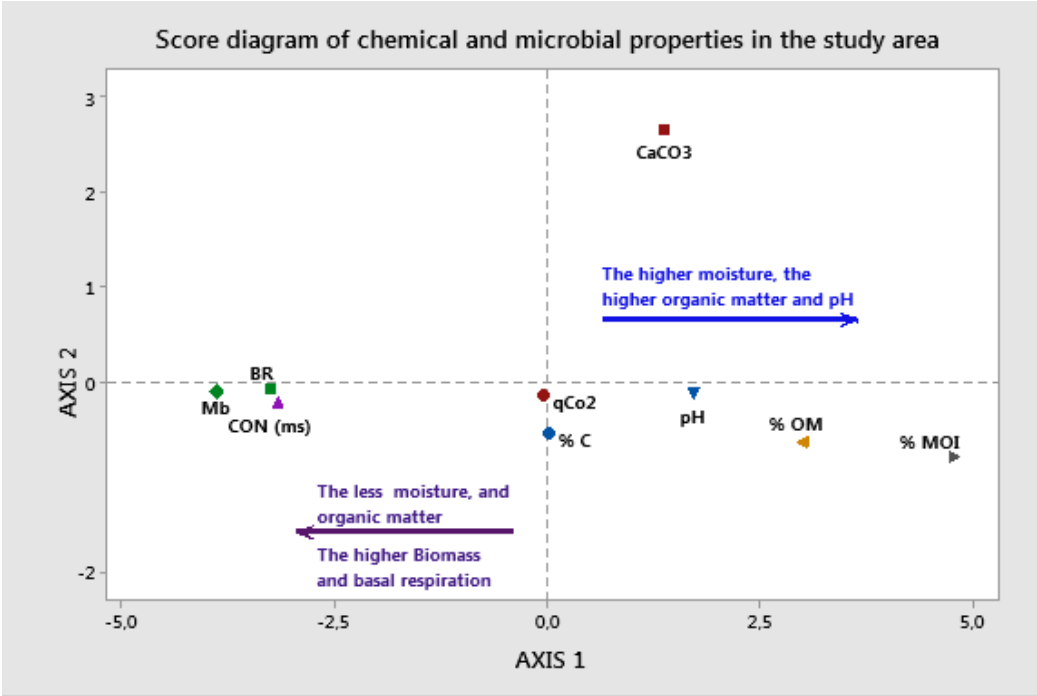


Figure 2. PCA of soil chemical and microbial properties in the study area "MOI: moisture, OM: organic matter, pH: potential of hydrogen, CON: conductivity, C: organic carbon, $CaCO_3$: total calcium, Mb: Microbial biomass, BR: Basal respiration, qCO_2: Metabolic quotient".

Axis 2 is characterized mostly by the gradient of $CaCO_3$ on the positive side while the gradient of organic matter, pH, microbial biomass and conductivity of all samples from the negative to the positive side (Figure 2).

Discriminant analysis by PCA of chemical and microbial properties in each site

Axis 1 shows a proper value of 4.18 with an inertia ratio of 46.5%. Variables, having a strong relative contribution with proper values of this axis are as follows (Table 6).

Table 6. Value of axis 1 of the ACP of the chemical and microbial properties of the soils of each station.

Positive side of axis 1		Negative side of axis 1	
Sample	Value (+)	Sample	Value (–)
Spl.4f	3.93	Spl.2a	3.37
Spl.5a	3.51	Spl.3b	4.10
Spl.5f	3.57	Spl.3g	3.47
Spl.5j	3.60	Spl.8a	3.46

NB: Spl.4f: site 4, samplef; Spl.5j: site 5, samplej, etc.

Axis 1 is characterized by samples from sites of Djebel Fellaoucene peak, El Hyadra and Ouled Chaaban. These soils are more moist and rich in carbon and organic matter, Ouled Chaaban is influenced by alkalinity. The negative side is characterized by samples from the sites: Ain El Kabira, Karkoum S.B and Ain Manchar where soils are drier adding to the fact that microbial mass and basal respiration were higher in comparison with other samples (Figure 3).

Axis 2 shows a proper value of 1.58 with an inertia ratio of 17.6%. Variables having a strong relative contribution with proper values of this axis are as follows (Table 7).

The positive side of axis 2 refers to Al-Natour, Ouled Chaaban and Ras Al-Taher; calcareous substrate and pH in these soils are more alkaline. However, on the negative side of the axis, soils are siliceous or have low limestone.

Table 7. Value of Axis 2 of the ACP of the chemical and microbial properties of the soils of each station.

Positive side of axis 2		Negative side of axis 2	
Samples	Value (+)	Samples	Value (–)
Spl.1c	2.30	Spl.5f	2.28
Spl.4f	3.08	Spl.5i	3.07
Spl.6d	2.25	Spl.5j	2.77

Analysis of main factors of correlation between soil chemical and microbial properties

The statistical analysis results revealed several correlations between different soil samples, each correlation is distinctive as it is influenced by numerous climatic and anthropogenic factors.

Samples from Ouled Chaaban, S. Fellaoucene, El Hyadra and some samples from Al-Natour and Ras Al-Taher are distributed on the positive side in relation to axis 1, one of the leading factors in controlling this correlation is exposure at the North since climate is wetter with anthropogenic pressures including grazing, forest exploitation, the opening of trails and fires. On the negative side of this axis are Ain El Kabira, Karkoum S.B, Ain Manchar, and a few samples from sites of Al-Natour and Ras Al-Taher.

One of the main factors characterizing this correlation is South exposure since the climate is drier as soils are siliceous or have low limestone and these sites are almost at the same altitude. Fire intensity as well as grazing have played a major role in developing the correlation between these soils (Figure 4).

Regarding axis 2, soils of Ouled Chaaban, Al-Natour, Ras Al-Taher and a few samples from El Hyadra are distributed on the positive side of this axis since the substrate is calcareous, the altitude is low with anthropogenic pressures, mainly grazing and abandoned agricultural lands are among the leading factors in controlling the correlation between these soils. However, soils in Ain El Kabira, Karkoum S.B, Ain Manchar, S. Fellaoucene and a

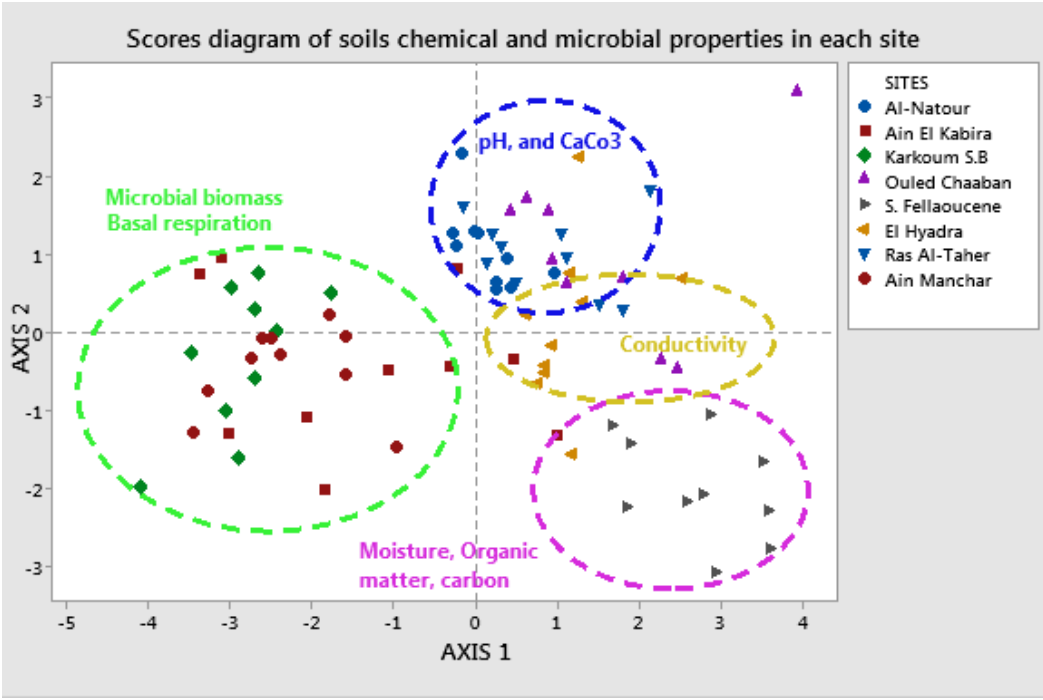


Figure 3. Analysis by PCA of soil chemical and microbial properties in each site.

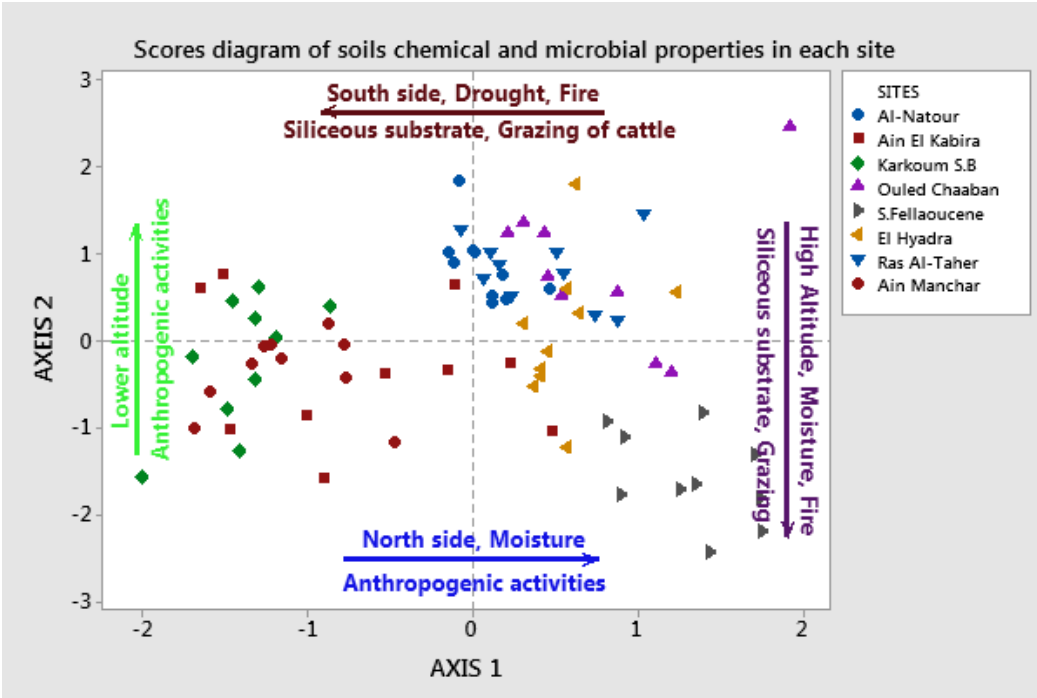


Figure 4. Main factors of correlation between soil chemical and microbial properties.

few samples from El Hyadra are distributed on the negative side in this axis as the substrate is siliceous, fires and grazing have played a major role in developing the correlation between these soils. The further the negative side, the higher the altitude and thus, the humidity of the climate is high resulting in an increase in moisture, organic matter and organic carbon in soils (Figure 4).

Discussion

Discriminant analysis by PCA of chemical and microbial properties in the study area

The results of this study on correlations between chemical and microbial properties indicate clearly that soil organic matter correlates positively to most of the chemical parameters investigated, notably pH, moisture and $CaCO_3$ rate as pH varies according to the organic matter content (McCauley *et al.*, 2009), pH depends on ion H^+ concentrations resulting from carbon oxidation in the organic matter. Furthermore, the organic matter content increases due to the soil moisture level and the global vegetation cover, as well (Zouidi *et al.*, 2019b; Zouidi *et al.*, 2020; Taneja *et al.*, 2021). On the other hand, Ozores-Hampton *et al.* (2011) found that organic changes increase significantly (35%) the soil moisture in the field capacity, they also found that calcium carbonate $CaCO_3$ solubility is directly affected by organic matter as $CaCO_3$ reacts with hydrogen ions resulting in organic matter mineralization to form water (H_2O), Ca^{+2} and carbon dioxide ($CO_2 \uparrow$), calcium carbonate reacts with two hydrogen ions to form water and carbon dioxide (CO_2). $CaCO_3 + 2H^+ \rightarrow H_2O + Ca^{+2} + CO_2\uparrow$ (Munroe *et al.*, 2018).

This study shows also a strong correlation between bacterial biomass, basal respiration and conductivity; the results indicate clearly that these parameters negatively correlate with organic matter. According to a previous study of Dommergues & Mangenot (1970), we have noticed that soil organic matter retains water which weakens gas exchange in the soil; aeration is low while moisture is higher which reduces aerobic bacterial activity and leads to a decrease in microbial biomass and basal respiration. These findings are consistent with the obtained results as microbial characteristics (microbial mass and basal respiration) are weaker in wetter soils which leads to slower mineralization of organic matter (organic carbon mineralization). The experiment conducted by Valé *et al*. (2007) revealed that in dry soil (wilting point), azote mineralization is higher with a 53% potential (noted when soil is at the capacity field), and summer mineralization might be found high in relatively dry soils since high temperature compensates for the drying effect of superficial layers.

The increase in microbial biomass and basal respiration led to a relatively decreased electrical conductivity resulting in a low organic matter rate in the soil due to the acceleration of its decomposition. Koull & Halilat (2016) highlighted the organic matter impact on the chemical and physical properties of sandy soils, where electrical conductivity increases with the organic matter input. Furthermore, Wendling *et al.* (2020) indicate the higher the rate of clay and organic matter in the soil, the higher the CEC. Soils with a high cation-capacity exchange (CEC) have a higher conductivity. (Kweon *et al.*, 2013; Ramos *et al.*, 2018).

CO_2 fluxes in microbial biomass are known as the metabolic quotient (qCO_2) which is used not only to assess the organic carbon use by the soil microbial biomass, but it is also a means to describe precisely the soil organic compounds by microorganisms (Vincent *et al.*, 2019). These CO_2 fluxes resulting from organic matter mineralization seem to be correlated with organic matter since we have noticed a relative increase of the substrate quantity rejected in the form of CO_2 in soils with a low or-

ganic carbon rate. Thus, we can conclude that CO_2 quantity is higher with elevated organic carbon consumption. The work group (BSA, 2009) highlighted that the higher the qCO_2, the higher is the substrate quantity rejected in the form of CO_2 with a low substrate proportion incorporated in the microbial biomass. Chabroullet (2007) indicated that for the same amount of degraded organic matter, soil microorganisms assimilate globally more organic matter at the expense of carbon mineralization.

Discriminant analysis by PCA of chemical and microbial properties in each site

The analysis results of the main compounds in chemical and microbial properties reveal that soils in the study area are usually heterogeneous. Meanwhile, there is a relative homogeneity between samples of some sites with a correlation between soils in Ouled Chaaban, Al-Natour and Ras Al-Taher depending on calcium carbonate $CaCO_3$ and pH. The studies by Guerin (2016) and Zouidi *et al.* (2018) notably in arid and semi-arid areas indicate that soil calcium is highly related to pH. Furthermore, we have found a correlation depending on microbial biomass, basal respiration and the metabolic quotient (qCO_2) in Ain El Kabira, Karkoum S.B and Ain Manchar soils. Vincent *et al.* (2019) highlighted that microbial biomass reflects microorganisms' quantity and activity in the soil. Therefore, low microbial biomass is generally related to low decomposition activity. However, the samples in S. Fellaoucene were characterized by a correlation between both elements in terms of moisture, organic matter and organic carbon. These results confirm what is mentioned above, the capacity of organic matter to retain water. The total organic matter content gives an indication of the soil's organic matter content. Total organic carbon represents ~57% of the soil organic matter (Vincent *et al.*, 2019). Regarding the site Hydra, some samples are intercorrelated in terms of conductivity, whereas others are correlated with the soils of other sites.

Analysis of main factors of correlation between chemical and microbial soil properties in the study area

Western Algeria is mainly known for factors like climate, geographical location, anthropogenic activities, overgrazing and fires controlling the vegetation dynamics and structure as it is the core interest of numerous scientific studies about the correlations between these factors and the vegetative cover as in Bouazza *et al.* (2001); Merzouk *et al.* (2009); Belgherbi *et al.* (2018); Allam *et al.* (2019); Djebbouri *et al.* (2022); Aouadj *et al.* (2023a).

However, little attention is given to the impact of the main factors (climate, geographical location, anthropogenic activities, overgrazing, and fires) on the dynamics of forest soil structure and the correlations between soil chemical and microbial properties and these factors. In this regard, this study deals rather with the influence of the main factors on soils' chemical and microbial properties in the region of Fellaoucene (Western Algeria).

The climatic and geographical factors play a key role in developing the correlations between different chemical and microbial properties in the soil of the study area where the air is moist and the weather is less sunny in the Northern sites and areas situated at a high altitude. All these elements have led to an increased moisture rate of the soil and a decrease in the temperature, i.e. a decrease in the mass of aerobic bacteria which resulted in a slowdown of mineralization of organic matter accumulated in the soil as well as an increase in organic carbon and conductivity. Leifeld *et al.* (2009) and Saenger *et al.* (2015) have highlighted that the wet season is cold with less biological activity and therefore, oxygen deficit in the soil is relative and the metabolism of energetic substrates is not exposed to a pronounced activity.

Meanwhile, Southern sites situated

at a low altitude, where the air is dry or less wet, the weather is sunnier and soil temperature is moderate during the day (spring), are characterized by low soil moisture which contributes to increasing mass and aerobic bacteria activity leading to the acceleration of organic matter mineralization and organic carbon release in the form of carbon dioxide (CO_2) which underlines the low content and conductivity in the soil of these sites. According to Valé *et al.* (2007), if the average soil temperature increases by 2 °C and the soil water regime remains unchanged, there would be a 25% increase in mineralization. Furthermore, anthropogenic pressures have played an important role in soil dynamics since correlations between different chemical and microbial properties vary according to the intensity and the type of pressures applied in these sites.

Overgrazing of cattle and sheep, and human exploitation of forests (opening of trails for overgrazing, tourism, medicinal plants collection, deforestation, etc.) are considered among the leading and most severe pressures on Ouled Chaaban, Al-Natour and Ras Al-Taher which have led to the vegetation degradation and the increase of open areas, thereby the soil is more exposed to erosion and compacting (Lahmar & Ruellan, 2007; Allam *et al.*, 2019). These parameters have contributed to the homogeneity of soil dynamics in terms of microbial characteristics (low mass and microbial activity) and a few chemical properties, including conductivity, pH and organic carbon. According to Ighilhariz (2018), in an undisturbed native forest, the structure of bacterial communities in bare soils and rhizospheric soils is similar regardless of the plant species. This can be explained by the difficulty of finding an undisturbed ecosystem and soil unoccupied by living roots. According to Lahmar & Ruellan (2007), we find in the Mediterranean Basin the same environmental conditions and human exploitation of this environment causing the same degradation.

Thus, we can conclude that chemical and microbial properties are similar if the soil is subject to the same disturbance factors with the same intensity.

Nevertheless, among the main degrading factors that characterize Ain El Kabira, Karkoum Sidi Boumediene and Ain Manchar are fires and cattle overgrazing. Our results show clearly their role in the homogeneity of these soils and in developing the correlation between different chemical and microbial properties where we have recorded high microbial biomass and basal respiration rates as well as a decrease in moisture, organic matter, carbon and conductivity compared with other sites. Indeed, in the research study of Borsali *et al.* (2012) on post-fire restoration of physical, the chemical and microbial properties of Algerian forest soils indicate that the peak microbial biomass would be the result of a hyper stimulation of microbial growth during the first 8 years which would lead to very low carbon content in these soils. Furthermore, herbaceous plant growth with branches, leaves and shrubs generated after fires encourage plenty of breeders to use these lands for livestock grazing to easily control cattle and their excrement in the whole sites. Consequently, we suggest that this organic matter input, mainly excrements of animals grazing over post-fire herbaceous plants may have fostered microbial growth which implies encouraging rapid resilience of microbial biomass. It is likely that animal feces and urine may have supplied recently burned soils with organic carbon and total nitrogen resulting in the stimulation of biological mineralization of reluctant organic matter and coal (Borsali *et al.*, 2012). The acceleration of mineralization of soil's organic matter subsequent to labile organic matter input is a process broadly described in the literature and known as the "priming effect" (Kuzyakov *et al.*, 2000; Bell *et al.*, 2003).

The chemical and microbial characteristics of this soil in S. Fellaoucene and El Hyadra developed a relative correlation as

compared to the different soils investigated; this is probably the result of exposure to different degrading factors since the last fire in both sites occurred in 2014 in addition to anthropogenic pressures, as well as cattle overgrazing observed in these two sites.

The obtained results reveal high rates of moisture, organic matter, carbon and conductivity as well as a decrease in microbial characteristics (microbial biomass, basal respiration, qCO_2). In the context related to litter incineration and mineralization of the soil organic matter, fine particle erosion may increase (Neary *et al.*, 2005) and contribute to the lowering of the soil capacity to retain water (Fayos, 1997). In addition, the first visible effect of fires on soils' chemical properties is usually the loss of organic matter (Guénon *et al.*, 2011; Allam *et al.*, 2020).

However, the increase in the measured rate of moisture and organic matter in soils excludes these hypotheses. Despite a restructuration of water and organic matter content following the last fire, via consequent input of fresh organic matter under the form of litters of roots (Johnson & Curtis, 2001), either from carbon input resulting from plants carbonization during the fire or from animal excrements in post-fire herbaceous plant growth (Borsali *et al.*, 2012), anthropogenic pressures and overgrazing in burned lands leave a bare soil without plant reconstitution. Mathieu (2020) indicated that overgrazing leads to plant destruction and other related issues, mainly soil grading as roots grow slowly in compacted soil, altering the formation and the stability of aggregates which reduce gas soil exchanges, permeability and capillary properties and results in the soil becoming sensitive to erosion (waterborne and wind). Deforestation and overgrazing are usually mentioned as the leading causes of soil erosion (Lahmar & Ruellan, 2007; Allam *et al.*, 2021; Aouadj *et al.*, 2023b) which may reduce or modify, in the long term, the returning of soil microbial properties. According to Six *et al.* (2004), aggregation dynamics, organic matter composition and stabilization along with soil biological activity are related. Furthermore, aggregate formation and stability depend on several factors, especially roots, fauna, microorganisms, mineral binders and environmental variables, including freeze-thaw cycles, wetting-drying, and fires.

Conclusion

This study revealed that the dynamics of soil chemical and microbial properties in Djebel Fellaoucene are strongly affected by climatic, geographical and anthropogenic factors as well as pastoral uses of forests and fires. The results and the comparisons between soils show correlations and significant similarities between different soils depending on these factors.

The soils at Southern sites are characterized by an increase in mass and microbial activity despite the plant destruction (caused by fires and pastoral use), burning of organic matter after the fires, and a decrease in water content. Organic inputs from animal excreta in these sites can enhance the efficiency and activity of microorganisms.

The aforementioned facts show that the issue of soil degradation is widespread in the study area but lacks documentation. Severity and intensity risks are barely assessed due to landscape heterogeneity and complexity, multiple disturbances and their variable intensity, different degradations, microclimate, interrelation among soils, plants, climate and anthropogenic activity as well as climate change.

Intense anthropogenic activities, several types of livestock overgrazing mainly through soils which have recently been burned have caused disruptions of soil microbial properties and a low activity despite an increase in organic matter and moisture content. In these conditions, mi-

crobial resilience is reinforced in the long term in these forest soils.

In perspective, we propose the rehabilitation of abandoned soils to rebuild the production potential of water and soils, improve their resilience to future hazards and increase their sustainability.

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