

Comparative Local Case Study of Coniferous Forest Litter of the "*Pinus halepensis* Mill" in Arid and Semi-arid Areas of Western Algeria

Mohamed ZOUIDI^{a,b*} – Amine Habib BORSALI^{a,b} – Ayoub ALLAM^{a,b} –
Raphael GROS^c – Catherine REBUFA^c – Anne-Marie Farnet DA SILVA^c

^a Department of Biology, University «Dr Moulay Tahar» 20 000 Saïda, Algeria

^b Laboratory "Water Resources and Environment" 20 000 Saïda, Algeria

^c Aix Marseille University, CNRS, IRD, Avignon University, IMBE UMR 7263, Marseille, France

Abstract – Forest tree species produce litter, which is the plant/soil interface that ensures the maintenance of soil fertility whose properties depend on the botanical species considered. The differences of properties are marked in the nature of the decomposition processes and the forms of humus which result from it. In this study, the physicochemical characteristics and biological activity of litter were compared in coniferous plots located in the semi-arid and the arid zones of western Algeria. The objective of this work was to characterize and compare the physical-chemical properties and microbiological characteristics of softwood forest litter in the semi-arid and arid areas of western Algeria. We analyzed the properties of 50 samples of Aleppo pine litter collected from five stations in each zone. Analysis results show a highly significant difference ($p < 0.05$) in the physical-chemical properties between the semi-arid and arid zone: humidity (20.7% – 6.51%), pH (5.98 – 6.14), conductivity (0.42 mS/cm – 0.65 mS/cm), carbon (45.74% – 73.42%), nitrogen (1.17% – 0.86%) and C/N ratio (37.47 – 73.42). A comparison of the mean of microbial biomass and their efficacy reveals what is homogeneous in both zones, with a small difference in basal respiration.

The heterogeneity of these results indicates that such observations still need to be made in other forests of the Algerian territory in order to better understand the functioning of forest ecosystems and the effect of climate on these compartments, especially soil.

decomposition / physicochemical properties / biological parameters / aridity / Aleppo pine

Kivonat – Az Aleppó-fenyő erdei avarjának összehasonlító vizsgálata Nyugat-Algéria száraz és félszáraz területein. Az erdővel borított területek talaj/növény rendszerében a talaj termékenységének fenntartását az erdei fafajok avarprodukciója biztosítja. A termőrétegtépződés folyamatának tulajdonságai jelentősen függenek a fajfajösszetételtől, ebből eredően pedig különbségek jellemzik a bomlási folyamatokat és a keletkező humuszformákat. Jelen tanulmányban avarminták fizikai-kémiai tulajdonságait, valamint a bennük lezajló biológiai aktivitást hasonlítottuk össze nyugat-Algéria félszáraz és száraz övezeteiben fekvő túlelű állományokban. A vizsgálat fő célja a kutatási területekről származó fenyőavar fizikai-kémiai és mikrobiológiai tulajdonságainak jellemzése és összehasonlítása volt. A kutatás során 50 Aleppó-fenyő avarminta tulajdonságait vizsgáltuk minden mintaterületről 5 mintát gyűjtve. Az eredmények szignifikáns ($p < 0,05$) eltérést mutatnak a félszáraz és száraz övezetek mintáinak fizikai-kémiai tulajdonságai között: nedvességtartalom (20,7% – 6,51%),

* Corresponding author: zoiudibologie20@gmail.com; 02 City Sahraoui AEK Youb, DZA-20 000 SAÏDA, Algeria

pH (5,98 – 6,14), vezetőképesség (0,42 mS/cm – 0,65 mS/cm), szén (45,74% – 73,42%), nitrogén (1,17% – 0,86%) és C/N arány (37,47 – 73,42). A mikrobiális biomassza átlagának és hatékonyságának összehasonlítása azt mutatja, hogy mindkét zónában homogének a folyamatok, csak kis különbség van az alaplégzésben. Az eredmények alapján Algéria egyéb erdeiben is vizsgálatokat kell végezni az erdei ökoszisztémák működésének és az éghajlati hatások jobb megértése érdekében, különösen a talajra nézve.

lebontás / fizikai-kémiai tulajdonságok / biológiai aktivitás / szárazság / Aleppó-fenyő

1 INTRODUCTION

Considering the bioclimatic criteria, Algeria includes all the Mediterranean bioclimates from moist to dry. Forest formations are found on virtually all bioclimatic stages. This allows the presence of a great diversity of biotopes occupied by an important floristic richness especially in the forest ecosystems that are found at almost all stages of bioclimatics. Today the Forestry Directorate-General (DGF 2018) estimates this forest heritage at 4.1 million ha, of which 1.420.000 ha consists of forests, 2.410.000 ha of Maquis shrubland, and 280.000 ha of young reforestation. The main tree species are Aleppo pine (*Pinus halepensis*) (69%) and cork oak (*Quercus suber*) (21%). In smaller areas, cedar (*Cedrus satlantica*), maritime pine (*Pinus pinaster*), oak species (*Quercus ilex*, *Q. faginea*, *Q. suberet* *Q. afares*), and eucalyptus are predominant (DGF 2018).

The Aleppo pine forests are mostly present at the semi-arid level, content with 350 mm of annual precipitation, and adapting to any type of soil. Occupying the highest area in Algeria, they are essentially confined to the east and west of the country. The areas of Aleppo pine are found on the coastline, the Tell, the Saharan Atlas, and the Aures Nememcha. In Algeria, the forest has social and scientific functions and, to a lesser degree, an economic function especially in relation to cork oak (*Quercus suber*) (Louni 1994). Algeria is characterized by very diverse and fragile forest ecosystems, incumbent on its geographical position and the significant variations of its climate.

In Algeria, conifers include the majority of forest and pre-forest formations. These are very important economically and ecologically, particularly through their role of protecting the soil from the processes of desertification and erosion, which are very dynamic in the semi-arid and arid regions (Benabadji et al. 2007). These areas are among the most fragile ecosystems in the world due to recurrent droughts and the growing overexploitation of scarce resources. Arid and semi-arid areas occupy about one-third of the earth's land surface and account for roughly one billion human inhabitants, who are often among the poorest in the world (Malagnoux et al. 2007). Forests, trees, and herbaceous plants are essential components of arid-zone ecosystems. At the level of these semi-arid and arid areas, vegetation is continually struggling against harsh climatic factors, and nutrient-poor soil and organic matter (Borsali 2013).

Among various factors, forest/soil relationships can be addressed through the impact of litter on fertility (Dupuy 1998). Litter is the superficial layer that covers the soil. It constitutes the vegetal mass from the leaves (70 to 94%), branches, and stems and forms all the organic matter (Rapp 1969, Mangelot 1980). Many factors may be involved in litter decomposition; physicochemical properties play an especially important role (Lossaint 1959). Indeed, litter plays an important role in soil protection, the storage of mineral elements, and the restitution of these minerals to the soil. The disappearance or destruction of litter is accompanied by a sudden fall in the stock of available mineral elements, which may be a limiting factor for plant growth (Dupuy 1998). The suppression or decrease of protective layers represented by litter and vegetation after a fire subjects the ground to direct sunlight and raises its general

temperature (Raison et al. 1986) because litter plays the role of a sponge that protects the ground and keeps it moist (Faurie 2011).

Through temperature and humidity, the climate directly influences the decomposition of plant debris; however, the climate can also affect the physicochemical and biological properties of litter through its influence on plant community composition and litter quality (Lavelle et al. 1993, Aerts 2006, Pérez et al. 2007). Our objective was to characterize and compare the physical-chemical and microbiological properties of softwood forest litter in semi-arid and arid areas of western Algeria to see if the arid gradient has an effect on these characteristics in order to better anticipate the future of litter in the semi-arid zone due to climate change. The sites were chosen to cover the panel of pedoclimatic conditions corresponding to the semi-arid and arid climates of the western Algeria.

2 MATERIALS AND METHODS

2.1 Study areas

2.1.1 Semi-arid area

The Jebel Sid Ahmed Zeggai forest is located 4.5 km west of Saida province; it is part of the mountains of Saida, which are the eastern extension of the mountains of Dhaya, which belong to the Atlas Tellian (*Figure 1*). This forest covers an area of 2232 hectares on a limestone brown soil dominated by 90% Aleppo pine. Other plant species present are: are lentisk (*Pistacia lentiscus* L), cade juniper (*Juniperus oxycedrus*), evergreen oak (*Quercus ilex*), and esparto grass (*Stipa tenacissima*). This forest is extremely dense (2000 plant ha⁻¹) and has significant regeneration. Aleppo pine has an average age of 50 years with an average height of 6 to 8 m. From a climatic point of view, the forest benefits from a semi-arid climate (T min = 3 °C, P = 344.6 mm) located on superior stage of the Mediterranean vegetation (T min > 3 °C, 200 < P < 400 mm); the seasonal regime of the zone is of the HAPE type (Winter, Autumn, Spring, Summer) and has 6 months of drought (Zouidi et al. 2019).

2.1.2 Arid area

The Jebel Antar Forest is located in the commune of Mecheria in the east of Naama province (*Figure 1*). This forest is a piedmont area of Jebel that plays a protective role against the desertification of the area. It is a mass afforestation with an area of 1000 ha on a calcimagnesian soils. Aleppo pine is used as the main species at a rate of 95% with a density of 1600 plant/ha. Cypressus (*Cupressus*), betoum (*Pistacia atlantica*), white retem (*Retama raetam*), esparto grass (*Stipa tenacissima*), and white wormwood (*Artemisia herba-alba*) are also found in this forest. Today, Aleppo pine trees have an average height of between 3 and 5 m. The area has recently encountered several factors of degradation due to desertification and urbanization with the consequence of a radical transformation of the affected plant formations. The forest benefits from an arid climate (T min = 2 °C, P = 203.5 mm) located on a superior stage of the Mediterranean vegetation (T min > 2 °C, 100 < P < 300 mm). The seasonal regime is type APHE (autumn, spring, winter, summer) with 8 months of drought (Zouidi et al. 2018).

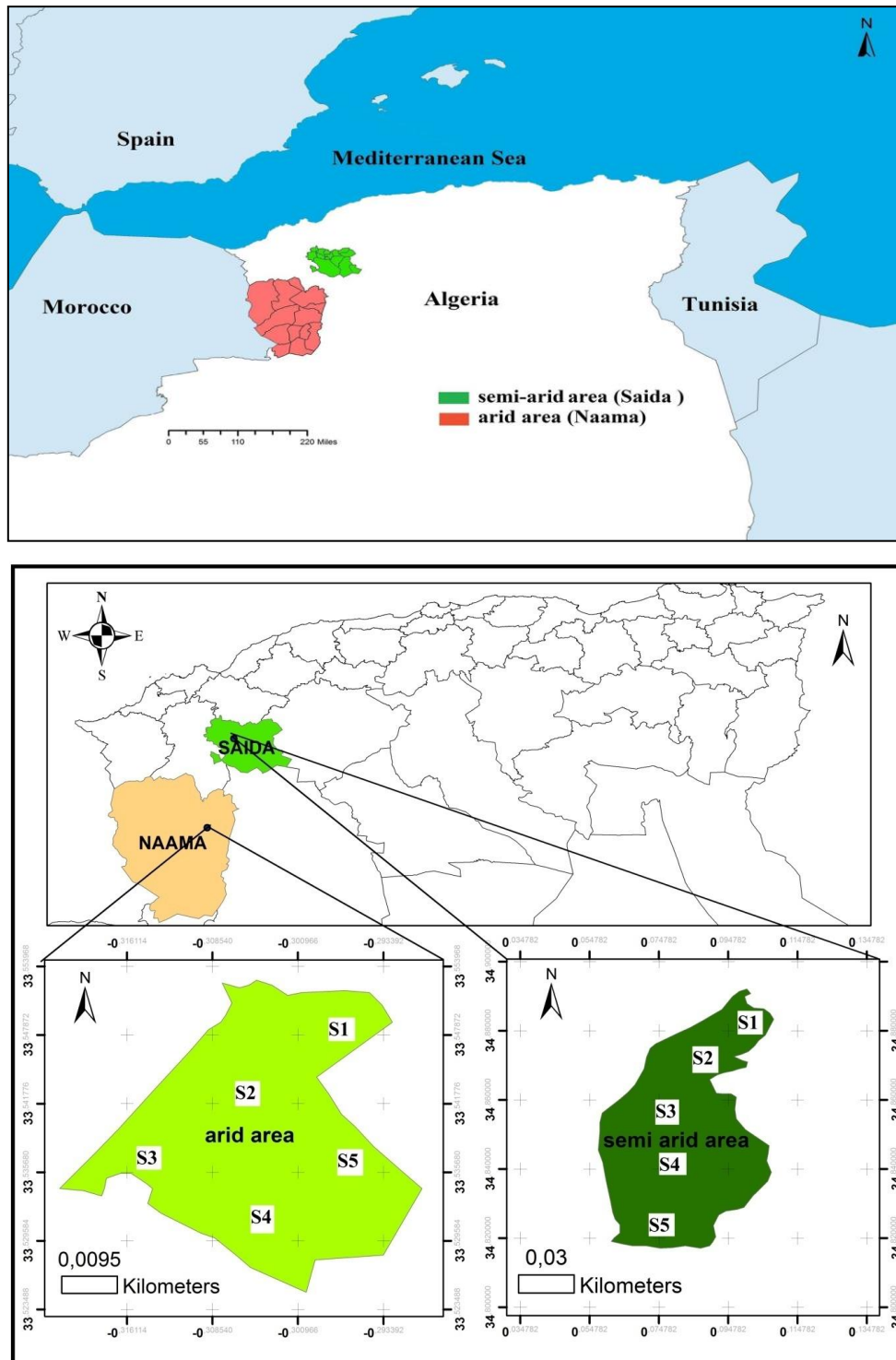


Figure 1. Geographical situations of study areas

2.2 Litter Sampling

Five sampling stations were selected for each zone (*Table 1*). Five samples were randomly collected at each station. All stations are located at altitudes between 970 and 1280 m with a similar exposure (N). Samples of approximately 1kg of litter (OL horizon) were collected under the canopy of *Pinus halepensis* Mill. in March 2016. Each sample was sorted manually to remove any shellfish shells, pebbles, or twigs.

Table 1. Geographical and characterizations of the study stations

Areas	Station	Altitude (m)	Latitude	Longitude
semi-arid area	S 01	975	34°52'13.7" N	00°05'09.5" E
	S 02	1067	34°51'22.3" N	00°04'40.9" E
	S 03	1146	34°50'29.5" N	00°04'57.6" E
	S 04	1160	34°49'31.8" N	00°05'22.6" E
	S 05	1081	34°49'23.7" N	00°04'33.8" E
arid area	S 01	1080	33°32'02.3" N	00°19'13.1" W
	S 02	1140	33°32'23.7" N	00°18'25.1" W
	S 03	1119	33°32'51.6" N	00°17'55.0" W
	S 04	1085	33°31'52.7" N	00°17'55.3" W
	S 05	1108	33°31'52.7" N	00°18'25.6" W

2.3 Physicochemical Analyses

Litter water content was determined by measuring fresh weights and weights after oven-drying (80°C) for 24h (Alarcón-Gutiérrez 2007). The pH and conductivity of the samples were measured on a litter suspension obtained by mixing 5 g of litter with 100 mL of distilled water. The measurement was carried out 2 h after using a pH meter (Métrohm, Herisau, Switzerland) (Alarcón-Gutiérrez 2007). Total organic carbon (COT) and total nitrogen (TN) were measured as follows: kiln-dried initial litter subsamples and each microcosm litter were sprayed in a ceramic mortar and analyzed by combustion in an analyzer Elemental, FlashEA 1112, Thermo Fisher; the calculated C/N ratio then presents a chemical character that may show the decay rate of plant debris (Gloaguen –Touffet 1982).

2.4 Biological analysis

Basal respiration ($\mu\text{g C-CO}_2/\text{g dry litter}$) was measured according to the protocol described by Anderson and Domsch (1978) to assess the physiological state of the microbial communities of litter; 3 grams (dry equivalent) of fresh litter stored at 4 °C were weighed in a glass vial (117 ml). The vials were closed with a hermetically sealed plug immediately after the replacement (4 minutes) of their internal atmosphere via a stable CO_2 concentration atmosphere, and incubated 4 hours at 25°C. After incubation, an aliquot of atmosphere of the vial (1 ml) was injected using a syringe into a gas chromatograph (Chrompack CHROM 3 – CP 9001). The chromatograph was equipped with a TCD detector and a filled column (Porapack) in which helium circulates at a flux of 60 mL/h. The values obtained were adjusted to 22°C according to the law of the gases perfect at $Q_{10} = 2$. Ambient CO_2 concentrations were subtracted from the CO_2 concentrations measured after incubation to obtain the amount of CO_2 produced by the heterotrophic microorganisms contained in the sample. Microbial biomass was estimated by the glucose-induced respiration method (Anderson – Domsch, 1978). A mixture of talc and glucose (1 000 $\mu\text{g carbon/g}$ of litter) was added to the three grams (dry equivalent) of litter. An incubation of 100 minutes was performed to achieve a maximum rate of induced respiration. The vials were closed with an airtight stopper immediately after the replacement (4 minutes) of their internal atmosphere by an atmosphere of stable CO_2 concentration, and then incubated for 90 minutes at 22°C. The CO_2 concentration of the vials was analyzed with gas chromatography and corrected in the same way as previously described for basal respiration. Induced respiration rates were converted to microbial biomass values using the equation given by Beare et al. (1990). The metabolic quotient ($q\text{CO}_2$) was calculated as the ratio of basal respiration/microbial biomass to Anderson and Domsch (1985).

2.5 Data analysis

The student *t*-test was used to compare the results of the physicochemical and microbiological properties of litter between the semi-arid and the arid areas using Sigmaplot 14 software.

3 RESULTS

3.1 Physicocemical characteristics

The evaluation of litter quantities of Aleppo pine litter taken from one square meter shows a good production of litter with high moisture in the semi-arid zone (1493 gr/m²; 20.70%) compared to the litter in our arid zone, which presents quantities (906.4 gr/m²) with low moisture (6.51%). The comparison of the averages reveals this difference is significantly high between the two zones ($p < 0.001$). Conductivity and pH are elevated in the arid zone (6.14 for the pH and 0.65 mS/cm for the conductivity). The pH is low acid (pH greater than 5) in our semi-arid zone with a low conductivity (0.42 mS/cm) and presents a significant difference between the two zones ($p < 0.001$). On the basis of the results, a carbon concentration and a high C/N ratio were recorded in the arid zone (73 for the C/N ratio; 73.42% for the carbon) in contrast to the concentration of nitrogen, which presents a significant average in our semi-arid zone (1.17%) more than the arid zone (0.86%). The statistical study based on the comparison of the means (student's *t* test) shows a highly significant difference ($P < 0.001$) of these parameters (*Figure 2*).

3.2 Microbial properties of litters

The microbial parameter averages of litters are recorded in table 02. Based on the comparison of biological parameter averages of litter, we recorded a high basal respiration in the semi-arid zone (97.78 µg de C-CO₂ /h/g) compared to the arid zone, which presents an average of 85.42 µg of C-CO₂ /h/g. Statistical analysis of the results shows a notably small difference ($t = 2.14$; $p < 0.05$) of this microbial basal respiration (BR) between these two zones. It should be noted that the average of microbial biomass (BM) and metabolic quotient (qCO_2) are high in our semi-arid zone (BM - 4.31 µg of carbon microbial/g ; qCO_2 - 23.67 µg of C-CO₂/h/g). However, the bacterial biomass and the metabolic quotient did not show any noteworthy difference between the two zones ($p > 0.05$).

Table 2. Microbiological properties of forest litter in arid and semi-arid areas.

Microbial analysis	Student <i>test-t</i>	Semi-arid area	Arid area
Basal respiration at 22°C (µg of C-CO ₂ /h/g)	2.14*	97.78 ± 17.39	85.42 ± 22.98
Microbial biomass (µg of Carbon microbial/g)	1.73ns	4.31 ± 0.90	3.94 ± 0.54
Metabolic quotient (qCO_2) (µg of C-CO ₂ /h/g)	0.753ns	23.67 ± 6.51	22.17 ± 7.57

This table records the average values ± deviation; Microbial properties of soils; the *p* value of independent test is presented with its threshold of significance (*: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$; ns: not significant).

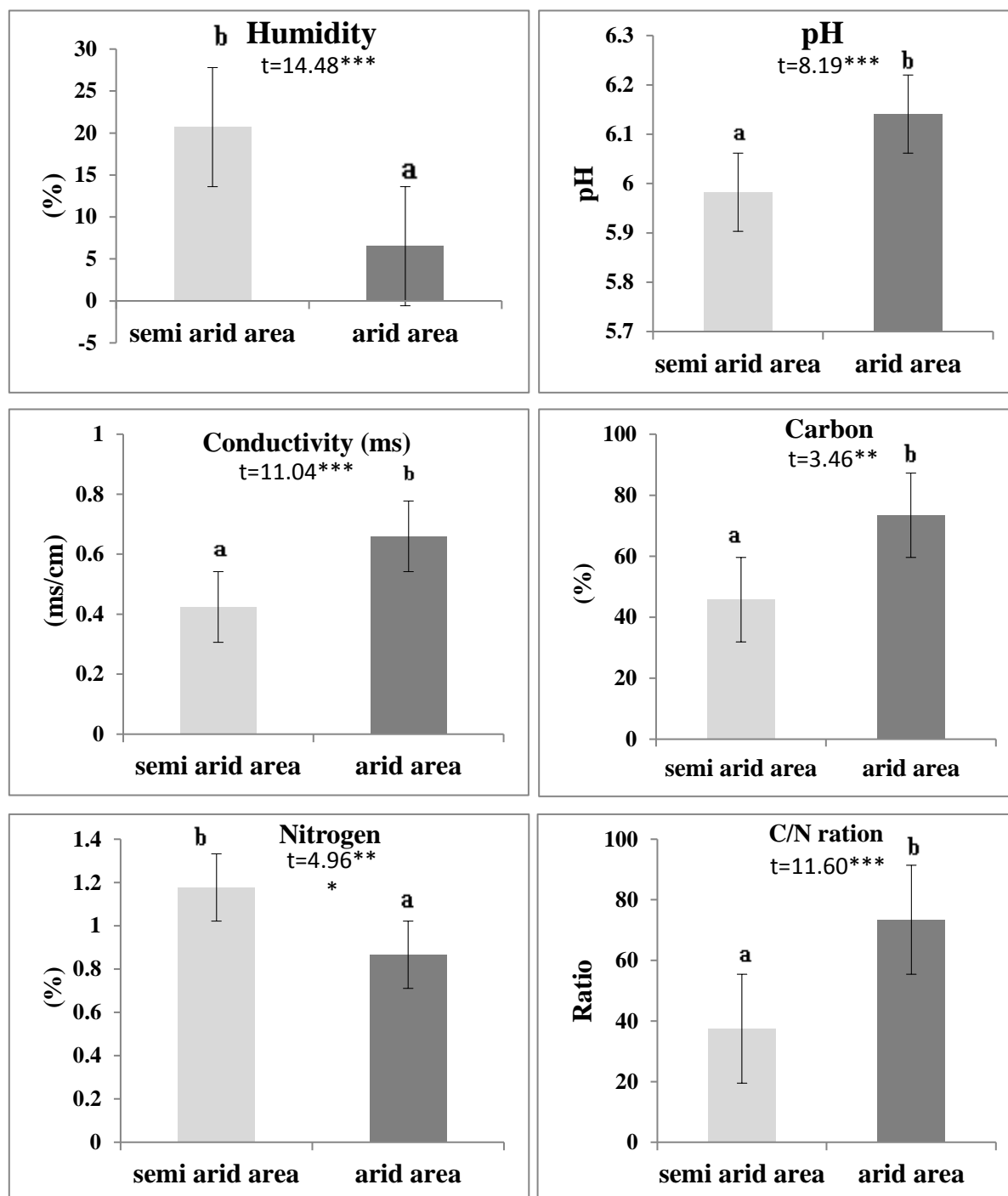


Figure 2. Physicochemical parameters of litter in semi-arid and arid areas. Averages \pm standard deviations. The t-value of the Student's test is presented with its significance threshold (*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$, ns: not significant)

4 DISCUSSION

Forest litter is mainly composed of softwood leaves, needles, and dead wood. It forms a source of energy and essential elements for the metabolism of microbial communities. Our study reveals there is an effect of the arid gradient on the production of *pinus halepensis* litter, which is more important in the semi-arid zone compared to the arid zone. This is certainly due

to forest density as well as climatic and edaphic conditions specific to each area. Several scientists have shown that litter production is controlled by climatic and edaphic factors that regulate production and forest stand density (Puig – Delobelle 1988, Mutabesha 2009). Litter in arid forests is susceptible to winds, and according to Kumada et al. (2008), it is natural that this weather effect removes a significant amount of litter.

The work presented in this research concerns the quality of litter in two areas on two different bioclimatic stages (arid and semi-arid). The moisture measurements highlight the footprint of the climatic stage on each zone. In fact, litter in the semi-arid zone has a more significant proportion of moisture than litter in the arid zone, which indicates that the wilted leaves of *Pinus halepensis* retain more water in the semi-arid zone. Air and rainfall are more important in this area when it comes to soil moisture (344 mm/year) than it is in the arid area where there is less rain (203 mm/year) and, therefore, less water in the soil and litter (Zouidi et al. 2018, Zouidi et al. 2019). It should also be stressed that water evaporation of leaves in the semi-arid zone is low as it is in the arid zone where temperatures and periods of drought are longer and more pronounced. In addition, the low density of species trees and herbaceous species are non-existent in the arid zone, which facilitates the loss of water from the litter and soil. Consequently, the water content of the litter and the dead plants depend solely on physical phenomena such as exchange by capillarity with the soil and in equilibrium with the moisture content (in vapor form) of the atmosphere located in immediate contact with the litter (Trabaud 1976). High temperatures with reduced plant cover in the arid zone also reduce soil moisture by increasing evaporation (soil and litter) and perspiration (Tardif 2013).

The pH of litter in both the semi-arid zone (5.98) and the arid zone (6.14) are low in acid ($\text{pH} > 5$). Softwoods, and especially pine, are considered acidifying species (Gobat et al. 2003, Lagacé 2009); in fact, the litter acidifies during decomposition and its pH gradually rises to 6 after 3 months (Lossaint 1959). The pH is more acidic in the semi-arid zone because there is less leaching that will limit the pluviolessivats loaded with phenols (which can deproton and therefore generate a higher acidity) (Bernhard-Reversat 1972). On the other hand, this is also probably due to the higher CaCO_3 content in the arid zone, which acts like a ‘tampon’ and, therefore, causes a small increase the pH (Zouidi et al. 2018). Litter in the arid zone may remain saline compared to litter in semi-arid areas. This result is probably related to the nature of soil and the presence of minerals in soils in this arid zone (Zouidi et al. 2018). The difference in carbon levels between the two zones can be explained in the following manner: the high percentage in the arid zone can be explained by the pedoclimatic variation between the two study areas, which influences the significant photosynthetic activity of the conifers, especially in the presence of solar radiation in the arid zone that lasts all year as shown by Puig and Delobelle (1988). Changes in carbon levels, therefore, reflect the climatic or edaphic variations of an annual cycle with a lag of a few months. Forest litter fallout and decomposition are key processes in the formation of carbon (C) and nutrient cycling in terrestrial ecosystems. These processes determine the amount of carbon stored in the humus (Berg et al. 2001, Sabine et al. 2014). Carbon stocks will increase if litter production (carbon input) increases. With regard to litter production, it is closely related to the rainfall regime. The lack of rainfall in the arid zone (8 months dry) is accompanied by falling leaves, which translates into increased litter production (Paul – Clark 1996, Dupuy 1998). This also explains the significant amount of carbon in the arid zone, which has a seasonal rainfall regime that is less than that of the semi-arid zone. This causes pine trees to shed their needles and increases litter production. The accumulation of organic carbon in the humus of the closed conifer formation can be explained by the quality of the litter composed of recalcitrant materials to the microbial decomposition such as tannins and polyphenols (Berg 2000, Prescott et al. 2000). Nitrogen levels remain low, especially in arid zones. This can be explained by the very slow decomposition of the Aleppo pine litter; indeed, several studies have confirmed that

decomposition is influenced by the initial concentrations of mineral nitrogen (Aerts 1997, Kaspari et al. 2008, Wieder et al. 2009) and total litter nitrogen, which decreases with decomposition (Gloaguen – Touffet 1982, Qasemian et al. 2012). According to Salleles (2014), the source of nitrogen for plants in low-input (unfertilized) ecosystems such as arid zones is mainly derived from litter decomposition and the mineralization of soil organic matter. As a result, litter plays an essential role in the recycling of nitrogen in the forest ecosystem (Salleles 2014). When litter is subjected to favorable climatic conditions (temperature and humidity), it has a high initial nitrogen content (Kurz-Besson 2000). This is one of the key factors that regulate the decay rate of plant debris, as pointed out recently (Taylor et al. 1989). Conifers are characterized by acidifying litter which, due to their composition, cause a slowing of the biodegradation of humification with a C/N ratio generally greater than 50 (Duchaufour, 1980). The C/N ratio in the semi-arid zone translates into the capacity of a litter to be decomposed more or less rapidly in the arid zone. This shows a very slow decay. This report is only a general indication of the potential of litter to decay (Taylor et al. 1989). A strong C/N ratio of the initial litter was correlated with a low rate of decay and increased with the age of the needles in place, corresponding to nitrogen depletion and lignin enrichment (Gloaguen – Touffet 1982, Lagacé 2009).

The results showed that microbial biomass remains homogeneous and low in both the arid and semi-arid zones as a result of lack of water and high temperatures. As some authors have reported in their work (Sabaté et al. 2002, Papa et al. 2008), the most important factors affecting soil microbial biomass are precipitation and temperature. In addition, studies on forest ecosystems have shown significant decreases in fungal and bacterial biomass during drought periods (Krivtsov et al. 2006, Borsali et al. 2017). Salinity is a factor influencing the activities of microorganisms, particularly in arid and semi-arid areas (Toberman et al. 2008). Basal respiration remains weakly variable between the two zones and depends on water availability, temperature, and biochemical composition of litters such as lignin, cellulose, hemicellulose, and C/N ratio (Arunachalam et al. 1998).

5 CONCLUSION

Forest litter is the plant-like interface in the forest that protects the soil and ensures that fertility is maintained through the production of nutrients. The aim of this study was to demonstrate the differences between litters in semi-arid and arid areas and to determine any imprint of exposure to bioclimatic stages on the physicochemical and biological properties of resin litter. The results showed a significant difference in all physicochemical parameters ($p < 0.05$) and particularly in moisture where a 14.19% difference between the two areas was recorded. The differences for carbon and nitrogen, both of which promote decomposition and ensure the life of decomposing organisms, were 27.68% and 0.49%, respectively. The pH of the two semi-arid and arid zones shows that acidifying litters are mull or mild humus ($\text{pH} > 5$); this acidity is a character of conifers and in particular Aleppo pine. The decrease in the moisture content of the arid forest litter (6.51%) caused an increase in carbon (73.42%) content and, consequently, the elevation of the C/N ratio (73%) and the slow decay of the litter. Litter degradation in the arid zone is slower than in the semi-arid zone. This is due to the pedoclimatic factors of the arid zone (mother rock nature, precipitation erosion, drought, and salinity). The forests dominated by Aleppo pine from both zones produce poor quality litters that are difficult to degrade. In these zones litter possess low activity and low microbial biomass, with an average of 4.12 μg of carbon microbial/ g.

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