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***Pinus halepensis* Mill. litterfall production and decomposition in semiarid and sub-humid climates in Northeast Algeria**

Karima Ghedabnia¹, Soraya Hioun¹, Boudiba Sameh¹, Mohamed Benslama², Louiza Boudiba¹ and Alfred Ngenge Tamfu^{3*}

¹Laboratory of Applied Chemistry and Renewable Energies (LACRE), Echahid Cheikh Larbi Tebessi University, Constantine Road, Tebessa 12002, Algeria

²Laboratory of Soil and Sustainable Development, Badji Mokhtar University of Annaba, Algeria

³Department of Chemical Engineering, School of Chemical Engineering and Mineral Industries, University of Ngaoundere, 454, Ngaoundere, Cameroon

*Correspondence: macntamfu@yahoo.co.uk (A.N. Tamfu)

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Abstract

Litterfall refers to the process by which leaves and other organic materials from the tree canopy fall to the ground, decompose and contribute nutrients to the soil. Plant litters are variable within and amongst forest ecosystems, and litter quality and decomposition affect the functioning of the forest, its productivity and plant growth. It is of ecological relevance to understand the major factors that determine litter production and decomposition in forest ecosystems, which helps provide information necessary for rehabilitation and sustainable forest ecosystem management in general. This study aimed to quantify *Pinus halepensis* litterfall and litter decomposition within the semiarid regions of Tebessa (Bekkaria and Gouraye) and the sub-humid region of Souk Ahras (Gouraye) in northeastern Algeria. Litterfall compounds were measured seasonally, annually, and after two years. During the same seasonal pattern, sub-humid stands receive more litterfall than other stands. Compared to the previous year, litterfall levels rose by 16.20% in Zaarouria and by 20.67% in Bekkaria. Autumn and winter account for the most litterfall due to the highest needle fall. After 1 and 2 years, the percentage of fragments and miscellaneous components in the litter had significantly increased. After 2 years, these processes occurred more frequently the amounts of litterfall collected at Zaarouria, Gouraye, and Bekkaria were respectively 3 to 2.6 and 2.4 times less than their corresponding seasonal and annual yields. Litterfall in sub-humid regions consists of more abundant fragments and miscellaneous items than in semi-arid areas. In sub-humid regions, warmer temperatures and increased moisture levels speed up fragmentation and decomposition processes. These results suggest that high moisture content is the major cause of organic matter decomposition. Temperature is also important, which leads to a very close relationship, and the right balance between them provides a better decomposition. This study can help in afforestation projects as well as monitoring nutrient recycling and rehabilitation of forest ecosystems.

Key words: Aleppo pine; climatic zones; litterfall components; litter decomposition; soil physico-chemical properties

INTRODUCTION

Aleppo pine (*Pinus halepensis* Mill.) is one of the most common Mediterranean plant species. Numerous studies have underlined its significant adaptability to various climatic conditions (Choury *et al.*, 2016; Alfaro-Sánchez *et al.*, 2018). It exhibits remarkable adaptability to various climatic conditions. The circum-Mediterranean area encompasses a variety of bioclimatic stages and geographical ranges, from sub-humid to semiarid. Aleppo ranges from sea level to 300-700 m in the north and up to 1200-1400 m in the south, with latitudes spanning from 45° to 31°N. (Nahal, 1986; Jaouadi *et al.*, 2019; Chambel *et al.*, 2013) (Nahal, 1986; Chambel *et al.*, 2013; Jaouadi *et al.*, 2019). This species grows optimally with an annual rainfall between 300 and 700 mm but can withstand a rainfall range of 200 to 1500 mm (Quézel, 1986), while it's advised to avoid exposure to excessive humidity, frost, and snow (Vennetier *et al.*, 2018). This conifer can grow in various soil types, including poor ones, and on all types of substrates. Aleppo pine is thermophilous and heliophilous, thrives under dry conditions, and is also fire-adapted. The current climatic warming has caused changes in the length and timing of its phenological phases (Vennetier *et al.*, 2011). Mediterranean communities exhibit slow growth and high sclerophylly, which are adaptations to low water and nutrient availability (Sardans & Peñuelas, 2013). Since 1970, a green dam has been extensively planted during reforestation programs for soil protection against desertification and erosion (Madoui *et al.*, 2016; DGS, 2018). *P. halepensis*, the most abundant tree species in Algeria, dominates this green dam barrier, covering 68% (1.158.533 ha) of the country's forests (DGS, 2018), widely distributed throughout the mountains, from the Tell to the Saharan Atlas, and in the Aures, particularly in the Tebessa region (Kadik, 1987).

Litterfall is the process by which fresh, undecomposed plant material including needles, leaves, twigs, nuts, cones, seeds, bark and others fall from trees and other plants to the ground. Litter is classified in three layers, which form on the surface of the O Horizon. These are the L, F, and H layers: L – organic horizon characterized by relatively undecomposed plant material (described above). F – organic horizon found beneath L characterized by accumulation of partly decomposed organic matter. H – organic horizon below F characterized by accumulation of fully decomposed organic matter mostly indiscernible. The litter layer is quite variable in its thickness, decomposition rate and nutrient content and is affected in part by seasonality, plant species, climate, soil fertility, elevation, and latitude (Ochoa-Hueso *et al.*, 2019). The most extreme variability of litterfall is seen as a function of seasonality; each individual species of plant has seasonal losses of certain parts of its body, which can be determined by the collection and classification of plant litterfall throughout the year, and in turn affects the thickness of the

litter layer. The relationship between litter, soil, and climate is a prevalent theme in the literature. In forest ecosystems, litterfall serves as a significant input of organic matter into soil subsystems (Blanco *et al.*, 2006). Litterfall production assessment, based on topsoil and microflora characteristics at a site, is a valuable tool for stand growth, nutrient cycling, and environmental interactions in forest ecosystems (Zhou *et al.*, 2007; Al Omary, 2011; Tesfay *et al.*, 2020). The litter layer plays a crucial role in erosion control, soil structure and fertility maintenance, and moisture retention. The productivity and quality of litterfall from all species is influenced by key factors including climate, soil, and stand characteristics (Pavón *et al.*, 2005; Chomel *et al.*, 2014). The sensitivity of litter decomposition to temperature increases suggests that climate change could impact the capacity of soils to sequester carbon. Soil properties do not appear to control this effect (Gregorich *et al.*, 2017). The Aleppo pine is no exception; its litter production depends on the climate (La Mantia *et al.*, 2013; Grünzweig & Gliksman, 2021), the dynamics of nutrient cycling (Lopes *et al.*, 2015; Segura *et al.*, 2017; Zouidi *et al.*, 2020), the understory vegetation type (Alifragis, 2001; Gliksman *et al.*, 2018), the ecophysiology of the plant beside its interaction with climatic elements and the effect of seasonal variations (Krishna & Mohan, 2017), the soil fertility (Rezgui *et al.*, 2016), the stand age (Alifragis, 2001), and the altitude (Berg *et al.*, 2010). Both abiotic and biotic factors of an ecosystem critically affect stand productivity, as they define the rate of nutrient cycling mediated by the ecosystem's biota (Arianoutsou and Radea, 2000). The physical and chemical properties of the soil play a significant role in how quickly litter decomposes. Texture significantly influences surface area, porosity, permeability, and nutrient-water interactions (Angst *et al.*, 2021). Litter and soil have a reciprocal relationship, so acidification hinders the decomposition process of litter and humus compounds (Tóth *et al.*, 2011). In low-pH soils, decomposition favors fungal growth over plant growth (Grosso *et al.*, 2016).

In Tebessa, pine forests predominate with minimal undergrowth. In a semiarid climate, this study investigates Aleppo pine's capacity to generate greater biomass and slower decomposition rates. These findings are exemplified by a comparison with a sub-humid environment. The significance of a location effect in semiarid regions also merits investigation. The role of plant litter in the resilience and functioning of forest ecosystems in the Tebessa region of Algeria is understudied, and it is relevant to study it to orientate the choice of trees for rehabilitation projects in semiarid and sub-humid areas or in sustainable forest ecosystem management in general. This study aimed to quantify the compounds of *Pinus halepensis* litterfall and litter decomposition in relation to climate in the semiarid regions of Tebessa

(Bekkaria and Gouraye) and the sub-humid region of Souk Ahras (Gouraye) in northeastern Algeria.

1. MATERIAL AND METHODS

1.1. Sites description

The research took place in three Aleppo pine forests, one in Tebessa (Bekkaria and Gouraye) and another in Souk Ahras (Zaarouria), in northeastern Algeria. The approximate distances from Zaarouria to Gouraye and from Gouraye to Bekkaria are 130 km and 30 km, respectively (Figure. 1 and Table 1). The *Pinus halepensis* trees were 6 to 12 m tall, pure-standing *P. halepensis* trees, unscathed by previous fires. The understory is dominated by *Stipa tenacissima* L., *Globularia alypum* L., *Ampelodesmus mauritanicus* (Poir.) T. Durand & Schinz, and *Salvia rosmarinus* Spenn.

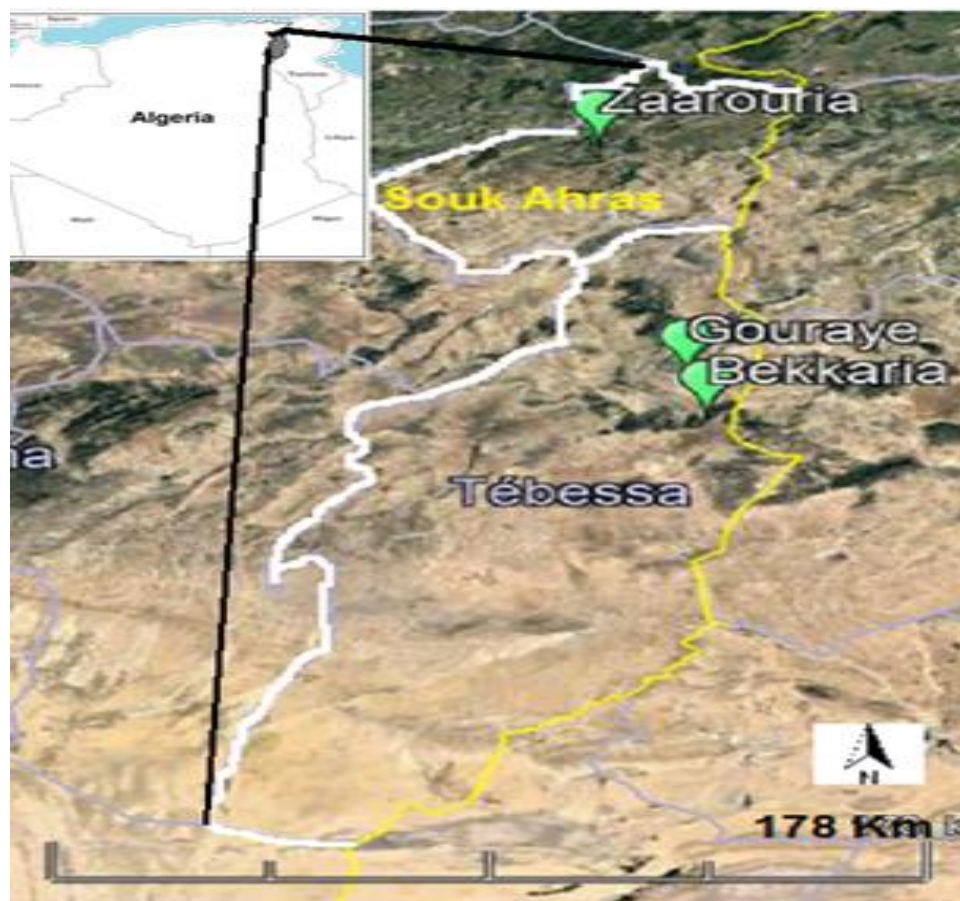


Figure 1: Geographical location of the study areas.

The pattern of precipitation and temperatures revealed a traditional Mediterranean climatic regime, with hot, dry summers and warm, rainy winters. Zaarouria has a Mediterranean climate (Köpper-Geiger classification: Csa), whereas Gouraye and Bekkaria have a semiarid

transitional Mediterranean climate (BSk). Annual rainfall in Tebessa (semiarid) fluctuated between 199 and 610 mm (with an average of 374.3 105.2 mm) between 1993 and 2010, according to climatological data, with the lowest amounts in July and the highest amounts in September. The annual precipitation in Souk Ahras (sub-humid) ranged between 197 and 1180 mm (676.5 ± 232.6 mm on average), with the most rain occurring between November and May and the least in July. During the study period (three years), yearly rainfall in Tebessa and Souk Ahras was 372.2 (first year)/438.6 (second year)/344.7 (third year) mm and 839.6 (first year)/1046.9 (second year)/867.3 (third year) mm, respectively. The rainiest months in Tebessa were October and February, whereas the driest months were June, July, August and September. In both years, the dry season in Souk Ahras lasted from June to August. In January and July, mean monthly temperatures in the research locations varied from 4.9 to 28.7 °C and 1.1 to 29.2 °C, respectively.

Table 1: Characteristics of study areas.

Climate range	Semiarid		Sub-humid
Mediterranean bioclimate	Thermomediterranean		Mesomediterranean
Forest area	Gouraye	Bekkaria	Zaarouria
Location	35°28'52"N 8°11'54"E	35°21'12.42"N, 8°15'19.51"E	36°12'11"N, 7°56'35"E
Altitude (m)	1093	1045	1025
Mean annual temperature (°C)			
Over 20 years (average)	16.23 ± 7.36		15.82 ± 6.78
Past year	16.00		15.38
Present year	16.97		16.12
Annual rainfall (mm)			
Over 20 years (average)	374.4 ± 105.2		676.5 ± 232.6
Past year	438.6		1046.9
Present year	344.7		867.3
Annual rainfall without summer (mm)			
Over 20 years (average)	307.23 ± 95.83		625.02 ± 237.23
Past year	345.80		1015.60
Present year	303.60		852.60
Summer rainfall (mm)			
Over 20 years (average)	67.07 ± 43.11		51.48 ± 34.03
Past year	92.80		34.30
Present year	41.10		14.70
Number of dry months			
Over 20 years (average)	4.32 ± 0.58		3.89 ± 0.66
Past year	6		4
Present year	7		4
Slope angle of study area (%)	2	5	6
Circumference of trees at 1.50 m from the soil (m)*	1.23 ± 0.12	1.28 ± 0.15	1.30 ± 0.11

*mean ± SD (n= 30)

1.2. Sampling of litterfall

Litterfall is measured using litter traps that are placed randomly throughout a study site. The traps are typically 0.5 to 1 meter across and have a mesh screen or netting to contain the litter. Initially, in each forest, three 1 m² squares of litter cover were taken from the experimental areas (all litter) and placed in bags for further sorting in the laboratory. These falls were termed "ancient" (dating over several years); this is used as a baseline to compare the litterfall collected at other times. Then, in each forest, we installed three plots on the forest floor, and each plot was composed of nine squares (1 m²), both randomly distributed. Before the study, all litter was removed from the soil surface in experimental plots, exposing the soil but not disturbing it to preserve existing natural microorganisms. We left 50 cm between two squares and delimited each square with stones. The squares represent three periods of litter recovery (triplicate): (i) after two years (or 24 months) (TL), (ii) after each year (one recovery in past year and another in present year), and (iii) the litterfall collection was at the end of each season [winter (March), spring (June), summer (September), and autumn (December)]. This gives us four different types of times for collecting litterfall. The litterfall was air dried and sorted in the laboratory before being weighed. The litter was separated into six fractions, including needles (N), branches with a diameter $\leq 1 \leq 0.5$ cm (B1), branches with a diameter < 0.5 cm (B2), inflorescences and fragments of pine cones (I), bud scales, pine kernels, fragments, twigs, and bark (F), and the last fraction (M) was made up of miscellaneous materials (indeterminate materials, fine particles).

1.3. Sampling of soil

The soils are described as shallow (0-50 cm). In the summer, soil samples for evaluating physical and chemical parameters were obtained in triplicate from the same plot sites, down to 40 cm depth for texture and 10 cm depth for soil pH_{H2O} and electric conductivity (EC). All soil samples were air-dried and sieved through 2 mm to get the fine particle component for chemical analysis. The USDA categorization employed the textural triangle to identify soil texture by projecting clay, silt, and sand particle fraction values (Pansu & Gautheyrou, 2006). For soil humidity, the soil water content (SWC) was measured. Samples were dried in the oven at 105 °C for 24 hours. Soil pH_{H2O} and electric conductivity (EC) were measured in the 1:5 soil/water extract. The Kjeldahl method evaluated the total soil nitrogen (N). Total calcium carbonate equivalent (T.CaCO₃) was determined by volumetric calcimetry, and soil organic carbon (C) was analyzed by the Anne method. The rate of organic matter (OM) was estimated by incinerating samples in an electric muffle for 4 hours at 550 °C and converted to carbon content by dividing by 1.72. Active calcium carbonate equivalent (A.CaCO₃) was evaluated by

Drouineau's method. The Olsen method was used to determine available phosphorus (AP) by a molybdate reaction for colorimetric detection (Mathieu and Pieltain, 2003). All analyses were carried out in triplicate.

1.4. Statistical analysis

Normality test and analysis of variance (ANOVA) were used to analyze statistical differences between the means for seasonal litterfall between years and seasons (autumn, winter, spring, and summer). The six fractions of litter were selected as the factors ($p < 0.05$). A three-way ANOVA was performed to evaluate for statistically significant ($p < 0.05$) differences in litterfall amounts between stands, years, and fractions of litter. Chemical soil parameters were used to test for statistical differences ($p < 0.05$) across three sites and two years (two-way ANOVA). Tukey's post hoc test with $p < 0.05$ was used to assess whether there were significant differences in data means obtained from different parameters. The mean weight of total litter and needles, soil chemistry, and annual rainfall after each year were all submitted to a principal component analysis (PCA) with XLSTAT. Version 2014.5.03.

2. RESULTS AND DISCUSSION

2.1. Edaphic data

Edaphic factors include the chemical, physical and biological properties of the soil that result from geological and biological processes or anthropogenic activities. Biological and chemical features of soil as well as their physical properties greatly influence the ecology and evolution of plants and their associated biota. Soil profile distribution of soil organic carbon (SOC) in different soil types depends on the organic matter (OM) and provides information about the carbon dynamics in terrestrial ecosystems, which is also important for understanding climate feedback mechanisms. The amount of litterfall, its decomposition as well as the soil organic matter will depend on the texture and edaphic factors of the soil in question. In the study plots, the soil texture was sandy-clay-loam in Zaarouria (sub-humid), clayey silt in Bekkaria (semiarid), and clayey sand in Gouraye (semiarid). The OM content in our soil samples was low, with the highest values in Zaarouria and the lowest in Gouraye (3.63 to 2.15%). The soil pH ranged from slightly alkaline to neutral (Table 2). The mean electrical conductivity ranged from 688.67 $\mu\text{S cm}^{-1}$ to 613.33 $\mu\text{S cm}^{-1}$ for practically all samples with minor mineral salts present. Soils are moderately to strongly calcareous, with a medium amount of available phosphorus. Significant differences were observed in both sites and interactions, but not across years (Table 3). Total CaCO_3 levels decreased in present year, with a difference between past year and present year of 3.49% in Zaarouria, 2.68% in Bekkaria, and 4.08% in

Gouraye. Active CaCO₃ showed no significant variations between years and sites, but between past year and present year in Zaarouria (Table 2). Nitrogen soil levels were low at all sites, ranging from 0.23 to 0.18% in 2011 and falling to 0.17 to 0.15% in present year. A significant temporal change in this nutrient was found between years (p<0.001). From past year to present year, the C/N ratio increased by 5.24% in Zaarouria but remained unchanged in Bekkaria and Gouraye. In contrast to C/N, AP values were lower in semiarid than in sub-humid stands. The soil texture and porosity affects the amount of decomposed litter and organic matter that is absorbed.

Table 2: Temporal changes in main characteristics soil of *P. halepensis* stands.

Climate Range	Sub-humid		Semiarid			
Site	Zaarouria		Bekkaria		Gouraye	
Trait \ Year	Past year	Present year	Past year	Present year	Past year	Present year
pH _{H2O}	7.13 ± 0.12 b	8.17 ± 0.06 a	7.47 ± 0.15 b	7.33 ± 0.15 b	7.30 ± 0.17 b	7.33 ± 0.23 b
SWC (%)	8.73 ± 4.22 a	7.34 ± 0.10 b	6.37 ± 4.42 b	5.83 ± 0.06 c	5.03 ± 2.12 e	5.43 ± 0.15 d
EC (µS.cm ⁻¹)	868.3± 37.85 a	639.33± 12.90 c	619.0± 6.08 c	688.6± 9.02 b	649.67±8.39 c	613.3± 20.82 c
C (%)	3.49 ± 0.13 a	3.05 ± 0.49 a	2.81 ± 0.47 a	2.41 ± 0.82 a	3.05 ± 0.33 a	2.66 ± 0.71 a
N (%)	0.23 ± 0.01 a	0.15 ± 0.01 d	0.20 ± 0.01 b	0.16± 0.02 cd	0.18 ± 0.01 c	0.17 ± 0.01 cd
C/N	15.25 ± 1.43 b	20.49 ± 0.69 a	14.09 ± 1.63 b	15.06 ± 2.14 b	16.98 ± 1.35 b	15.66 ± 0.70 b
T.CaCO ₃ (%)	24.24 ± 0.62 d	20.75 ± 0.89 e	28.50± 1.82 b	25.82 ± 1.01 c	33.83± 0.10 a	29.75 ± 1.22 b
A.CaCO ₃ (%)	18.60 ± 0.62 a	15.25 ± 0.31 b	14.34± 1.82 b	13.57± 0.25 b	14.42± 0.10 b	14.23 ± 0.02 b
OM (%)	3.49 ± 0.28 a	3.63 ± 0.24 a	3.09 ± 0.05 b	3.02 ± 0.06 b	2.15 ± 0.07 c	2.33 ± 0.15 c
AP (ppm)	27.61 ± 0.66 a	22.27 ± 0.13 b	20.20± 0.07 c	20.14 ± 0.1 c	17.01± 1.53 d	20.50 ± 0.54 c
Soil texture						
Clay (%)	37.66 ± 4.51		35.33 ± 3.25		26.56 ± 3.14	
Silt (%)	36.68 ± 3.17		53.58 ± 3.25		17.86 ± 1.26	
Sand (%)	25.66 ± 2.23		11.09 ± 2.81		55.58 ± 4.51	

SWC: soil water content; EC: electric conductivity; T.CaCO₃: total calcium carbonate equivalent; A.CaCO₃: active calcium carbonate equivalent; OM: organic matter; AP: available phosphorus; N: total soil nitrogen; C: soil organic carbon; C/N: ratio. Data are the mean ± SD (n= 3). a>b>c>d, that corresponds to the respective level of the compared mean values at P< 0.05 (Tukey test).

Table 3: Two-way ANOVA results to test differences between sites and experimental years in the physico-chemical characteristics of soil (n = 3).

Parameter		pH _{H2O}		EC		SW		C		N	
	Df	F	P	F	P	F	P	F	P	F	P
Site	2	7.39	0.008	68.80	<0.001	296.63	<0.001	2.48	0.127	3.619	0.059
Year	1	17.82	<0.001	51.72	<0.001	80.62	<0.001	2.68	0.127	68.762	<0.001
Site*Year	2	24.43	<0.001	92.92	<0.001	43.98	<0.001	0.001	0.999	17.333	<0.001
Parameter		C/N		T.CaCO ₃		A.CaCO ₃		OM		AP	
	Df	F	P	F	P	F	P	F	P	F	P
Site	2	14.073	<0.001	170.39	<0.001	24.259	<0.001	96.287	<0.001	121.85	<0.001

Year	1	2.182	0.165	69.13	<0.001	14.310	0.003	1.188	0.297	3.52	0.085
Site*Year	2	4.153	0.043	0.97	0.406	6.584	0.012	0.966	0.408	57.28	<0.001

df: degrees of freedom. Bold numbers are statistically significant. See more abbreviations in Table 2.

Edaphic factors affect the movement of air and water/dissolved chemicals through soil, as well as conditions affecting germination, root growth, and erosion processes as well as the changes in chemical and biological processes, which may be further governed by climate, landscape position, and land use (Jat et al., 2018). Thus, a range of soil physical properties when altered by climate change variation from sub-humid to semiarid zones can trigger a chain reaction that leads to soil environmental fluctuations, organic matter contents, which may greatly influence growth and production of crops resulting from overall litterfalls. Soil organic matter helps in nutrient and energy cycling, water storage, improves soil physical condition, climate regulation, fosters soil biodiversity, and regulates ecosystem functions (Ghimire et al., 2024). This also affects electrical conductivity, soil water content, soil organic matter as well as mineral and elemental contents notably carbon, nitrogen and phosphorus. Furthermore, OM is a vital part of the terrestrial carbon pool and soils can serve as a potential sink for the atmospheric carbon. Carbon content in soil that is stored in the organic form is three times more than that of the atmosphere and five times more than in biotic pools like plants, animals, and microorganisms.

2.2. Amounts of seasonal litterfall for different fractions

Litterfall is usually sorted into two or three fractions after it is collected. This can be classified as foliar and nonfoliar or leafs, wood, and fruit cones/seeds fractions of litterfall. Litterfall was analyzed as pooled samples or per fraction. The plausible ranges of element concentrations in litterfall are greater than for foliage. The different components of litterfall such as leaves, branches, flowers, fruits, and other materials, can be separated into categories based on their size or other characteristics. The needles were the most frequent portion in all sites among the other fractions in Aleppo pine litter (Figure 2). The sum of the seasonal litterfall of needles revealed Zaarouria was highest in past year (237.46 g/m²) and present year (374 g/m²) corresponding to 46.54% (past year) and 66.32% (present year) of total litterfall, followed by Bekkaria with past to present year litterfall of 157-254 g/m² (41.29-62.54%) and Gouraye with past to present year litterfall of 203-201 g/m² (45.32-48.29%). Fragments were the second-most important product fraction throughout all seasons. Only 7 of the 24 readings per site presented fragments at Zaarouria and Gouraye, and only 4 at Bekkaria. However, the amount

of these fragments for each stand is nearly the same. There were no significant changes across sites or years (Figure 2 and Table 3). However, the result appeared significantly at the end of the winter compared to other seasons ($F_{3,48} = 5.971, P < 0.001$, Table 4). The quantity of needles that fell each season varies across years, with a winter peak in all stands except in Gouraye in autumn of present year (Figure 2, Tables 4 and 5). However, comparing falling needles to the total litter for each season reveals that the percentage is often higher in the winter of past year and spring of present year (Figure 3). In the seasonal and annual trials, the overall falls present before the study (three months or a year before) were eliminated to focus on litterfall fractions that fell to the ground after each season or each year. Each fraction of litterfall varies during the year. The findings show that the phenology of the species and the climate both had a significant impact on the variety of plant fallout.

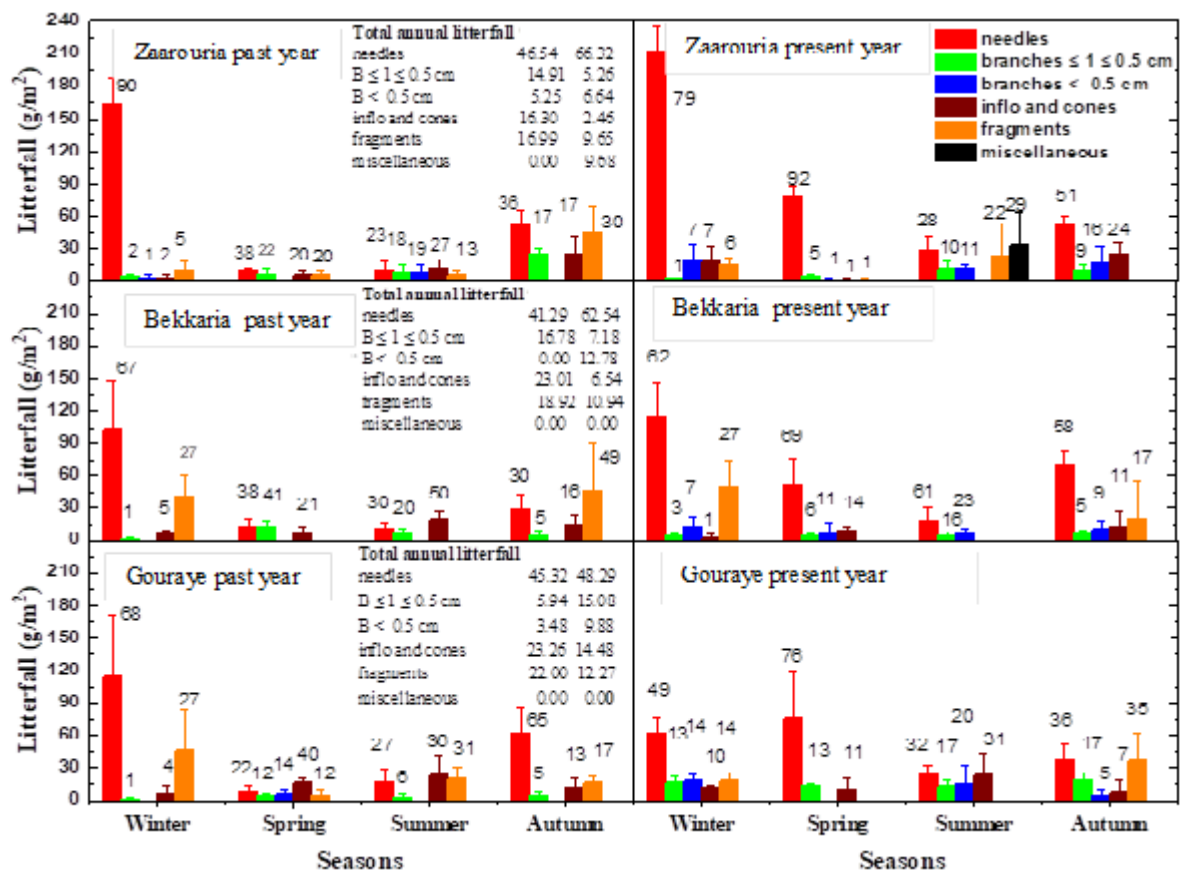


Figure 2: Comparison of different fractions of litterfall collected each season (g/m^2 and %) in Zaarouria (sub-humid), Bekkaria, and Gouraye (semiarid) stands in past year (first column) and present year (second column). Values are mean \pm SD ($n = 3$). The number above each histogram is the percentage of each fraction compared to the total litterfall of the season.

In each of the experimental years, rainfall amounts were more than twice as high in the sub-humid sites as they were in the semiarid ones. As opposed to sub-humid areas, semi-arid

areas like Tebessa get generally three times as much summer rainfall, which arrives in the form of severe and infrequent thunderstorms. The cumulative fallout that we collected every three months showed a significant difference that might be related to past years' precipitation totals, particularly during the dry seasons. Mediterranean regions are susceptible to early drought; thus, an early growing season is necessary to take advantage of the water stored from the previous winter (Thabeet *et al.*, 2009). The water from melting snow in the Zaarouria forest, which was weak at Gouraye and Bekkaria but had frost spells, helped the soil in addition to the rain. The predominant component of fallout was needles, which fell throughout the year in winter, followed by autumn in past year and spring in present year in the three sub-humid areas. The current climate of global warming has resulted in phenologic changes in the Mediterranean regions, including increased *P. halepensis* needle fall in the summer and early fall, as well as weak fall in the spring (Jiménez and Navarro, 2016; Pacheco *et al.*, 2018). It usually happens in the summer for brown needles, with the highest quantity in July; additionally, in February for other fractions (Rapp, 1989; García-Plé *et al.*, 1995). The precipitation rates and temperature were responsible for repeated needle falls, but we can have others that are specific to the location. According to Arianoutsou and Radea (2000), the amount of needle litter produced by Aleppo pine in Spain, Greece, and France, as well as other Mediterranean areas, was respectively 96%, 71.7%, and 69.6% of the total annual mass of litter production, which varied from 150 to 530 g/m²/year. In comparison, our needle falls had a maximum of 66.32% and a minimum of 41.29%. Here, the comparison is limited to the annual quantity of needles that fall than those found in each season. In biological terms, spring, summer, and the dry season in Algeria begin much earlier than in southern Europe. Climate change, on the other hand, is causing the needle to fall earlier and more frequently. This is due to climate change, which is making the Mediterranean region hotter and drier, putting pressure on Aleppo pines. The needle fall of Aleppo pine can have a number of ecological effects, including an increase in soil organic matter, which can help to improve soil fertility and provide nutrients to macro-fauna. The litter is increased by small branches falling at random, with winter being the most characteristic season for twig fall, as mentioned by Jiménez and Navarro (2016), resulting from heavy rains, high winds, or thunderstorms.

The total quantities of inflorescence and pine cone fragments that fell in both years for each site were low (0.56 to 7.63 g/m² each season with more inflorescence than cone fragments and 7.6 to 21.7 g/m² per year for the sum of the season mean values) (Figure 2). This compound fluctuated seasonally, although it was strongest near the conclusion of the fall and winter seasons. The most was collected at the end of fall in Zaarouria, but at the end of summer in both

years for Gouraye and Bekkaria. The analysis of variance revealed no significant differences between seasons, years, or sites (Table 4). Other litter components, such as inflorescences, are defined by the plant cycle, which is fixed in phenological time, as opposed to cone fragments, which are determined by several factors, including age, biotic factors, and climate. Furthermore, collecting litter every three months penalizes the degrading process, as indicated by the practically complete absence of mixed litter. The total amount of litterfall collected in each season revealed high quantities of each component in the following order: needles, fragments > inflorescence, and cone fragments. Branches are more in sub-humid than in semiarid. It should also be noted that the closeness of Gouraye and Bekkaria showed low litter production variability due to similar latitude, altitude, and climate, as reported between local scales according to Qin *et al.* (2020). The overall collection after each year showed various phenologic differences and revealed that the litterfall does not decompose all at once and rapidly into a larger quantity of fragments and then to miscellaneous.

Twigs with a diameter of less than 0.5 cm were seen in Zaarouria and Gouraye, with a peak near the end of autumn and significant values (Figure 2, Tables 4 and 5). However, the Tukey test indicated the lowest quantities of all sites in the winter of 2011. There were no significant variations in inflorescence years or cone pieces ($F_{6,48} = 3.205$, $P = 0.009$). Given that the present year was practically void of fall for all sites (Figure 2, Tables 4 and Table 5), branch diameter greater than 0.5 cm was clearly significant only between years ($F_{1,48} = 14.853$, $P = 0.001$). The statistical examination of the present year results indicated only a highly significant seasonal difference with winter falls. Miscellaneous was the least parameter involved in litterfall quantity and was only present in Zaarouria at the end of summer of the present year (Figure 2). This fraction found in a single square out of the nine replicates is much more likely a finer fractionation of the fragments. Comparison of the means of needle fall and total litterfall by seasons (g/m^2) and % of needle fall to total litterfall is given on figure 3. The so-called miscellaneous fraction was added later in Figure 4 with the fragments, given the very short time of three months for an advanced process of litter degradation.

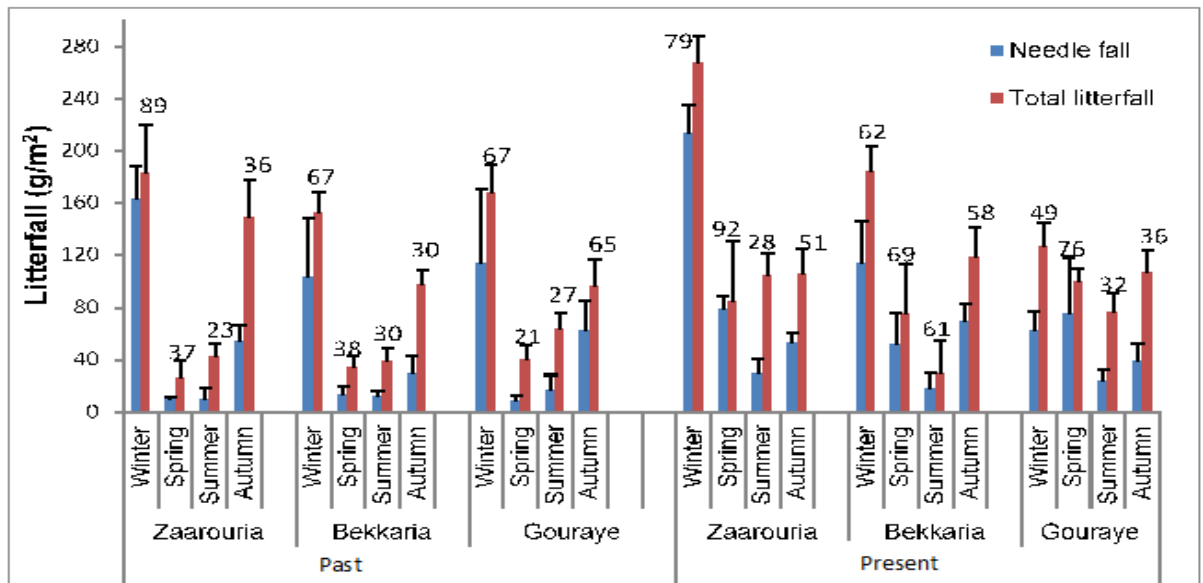


Figure 3: Comparison of the means of needle fall and total litterfall by seasons (g/m²) and % of needle fall to total litterfall in Zaarouria (sub-humid), Bekkaria, and Gouraye (semiarid) stands in past year and present year. Values are mean ± SD (n = 3).

Table 4: ANOVA of total litterfall in the global study and for each fragment at the end of season.

Source of variation	Df	Overall	Source of variation	Df	N	B1	B2	I	F	M	
Site (S)	2	*	Site	2	***	*	ns	ns	ns	*	
Year (Y)	1	*	Year	1	**	ns	***	ns	ns	ns	
Season (Se)	3	***	Season	3	***	***	*	*	***	*	
Total litterfall (T)	5	***	S * Y	2	**	***	ns	ns	ns	*	
S * Y	2	*	S * Se	6	***	**	ns	**	ns	**	
S * Se	6	*	Y * Se	3	***	ns	*	ns	ns	*	
Y * Se	3	*	S * Y * Se	6	***	**	*	ns	*	**	
S * T	10	***	Erreur	48							
Y * T	5	***	Homogenous groups								
Se * T	15	***									
S * Y * Se	6	**	Site	Zaarouria a			Bekkaria b			Gouraye ab	
S * Y * T	10	***	Year	Past year a				Present year b			
S * Se * T	30	***	Season	Winter a		Spring c		Summer c		Autumn b	
Y * Se * T	15	***	Fraction	N a		B1 c	B2 c	I c	F b	M d	
S * Y * Se * T	30	***									
Erreur	288										

Needles (N), branches $\leq 1 \leq 0.5$ cm (B1), branches < 0.5 cm (B2), inflorescences and cone fragments (I), fragments (F), miscellaneous (M). * Significant at $P < 0.05$; ** Significant at $P < 0.01$; *** Significant at $P < 0.001$; n.s: not significant. $a > b > c > d$, that corresponds to the respective level of the compared mean values and is statistically significant at $P < 0.05$.

Table 5: Homogenous groups of the Tukey test for fractions of litter between sites, years, and seasons.

Fraction	Site			Year		Season			
	Zaarouria	Bekkaria	Gouraye	Past year	Present year	Winter	Spring	Summer	Autumn
Needles	76.43 a	51.37 b	56.29 b	69.08 a	53.65 b	136.22 a	39.60 bc	18.44 c	51.19 b
Branches $\leq 1 \leq 0.5$ cm	6.15 b	8.70 a	9.48 a	7.32 ns	8.90 ns	5.06 b	8.11 ab	7.8 ab	11.46 a
Branches < 0.5 cm	8.93 ns	6.84 ns	4.96 ns	11.34 a	2.48 b	8.89 ab	3.10 b	10.11 a	5.56 ab
Inflorescences, cone fragments	11.78 ns	9.5 ns	15.87 ns	12.71 ns	12.07 ns	9.11 b	8.15 b	14.78 ab	17.51 a
Fragments	14.05 ns	22.27 ns	17.87 ns	21.18 ns	14.95 ns	29.96 a	2.31 b	9.14 b	30.84 a
Miscellaneous	4.17 ns	00.00 ns	00.00 ns	00.00 ns	2.77 ns	00.00 b	00.00 b	5.55 a	00.00 b

ns: not significant. $a > b > c > d$, that corresponds to the respective level of the compared mean values at $p < 0.05$.

2.3. Seasonal and annual total litterfall

Figure 2 shows the contribution of Aleppo pine fractions in g/m^2 and percentage for each season, site, and year, as well as a comparison in percent of the yearly sum of seasonal fractions. The sum of needles in seasonal fall was the main component of the litter in all locations, followed by fragments in Zaarouria and branches (B1) in the other stands (Figure 4).

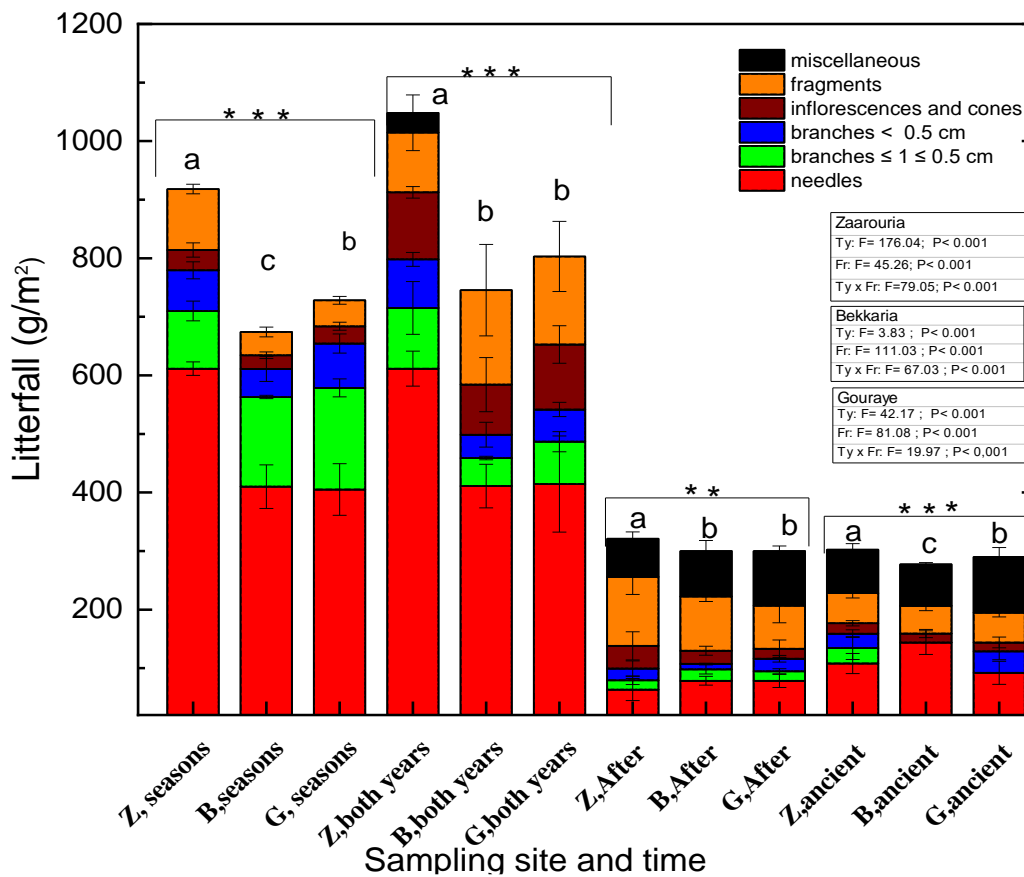


Figure 4: Amounts of total litterfall fractions (g/m^2) in three stands of *P. halepensis*: Z: Zaarouria (sub-humid), B: Bekkaria, and G: Gouraye (semiarid). Seasons: the sum of eight seasons. Both years: sum of the litter collected in past and present years. After: litter collected once after two years. Ancient: present litterfall in the forest at the beginning of the study. ANOVA for each site. Values are mean \pm SD ($n = 3$); Ty: cumulation type; Fr: fractions; F: f value of ANOVA; *** Significant at $P < 0.001$; $a > b > c > d$, that corresponds to the respective level of the compared mean values and are statistically significant at $P < 0.001$.

Annual litterfall in Zaarouria, Bekkaria, and Gouraye was higher in the present year by 33.57%, 37.26%, and 23.17%, respectively, than in the past year. The ANOVA revealed that the total litterfall values were significantly higher in seasons ($F_{3,288} = 49.748$, $P < 0.0001$) and fractions ($F_{5,288} = 160.314$, $P < 0.0001$) than in both years ($F_{1,288} = 5.286$, $P = 0.0221$) and sites ($F_{2,288} = 4.364$, $P = 0.014$). The total amounts of cumulative litterfall harvested seasonally during the two study years revealed that Zaarouria had significantly higher values than Gouraye and Bekkaria, with respective mean total values of 918.17, 703.54, and 759.59 g/m^2 (Figure 4).

A close production was found in Gouraye (385.27 and 373.8 g/m^2), Bekkaria (369.18 and 376.3 g/m^2), and Zaarouria (300 and 376.53 g/m^2) at the end of each 12-month period (Figure 4). Miscellaneous were present just at Zaarouria. In the past year, a significant difference in the fall was detected. The values for all stands will be very close in the following year. In the case

of Zaarouria, a comparison of the cumulative seasons gathered separately from the sum of the two-year collection revealed a stronger cumulative effect in terms of inflorescence.

PCA revealed two main ordination axes that together accounted for 83.31% of the variation. The qualitative parameters of soil, litter, and rainfall are established by the distribution of the stands during the research years inside the plane specified by two axes, as illustrated in Figure 5. The first axis of PCA was responsible for 53.11% of the total variation.

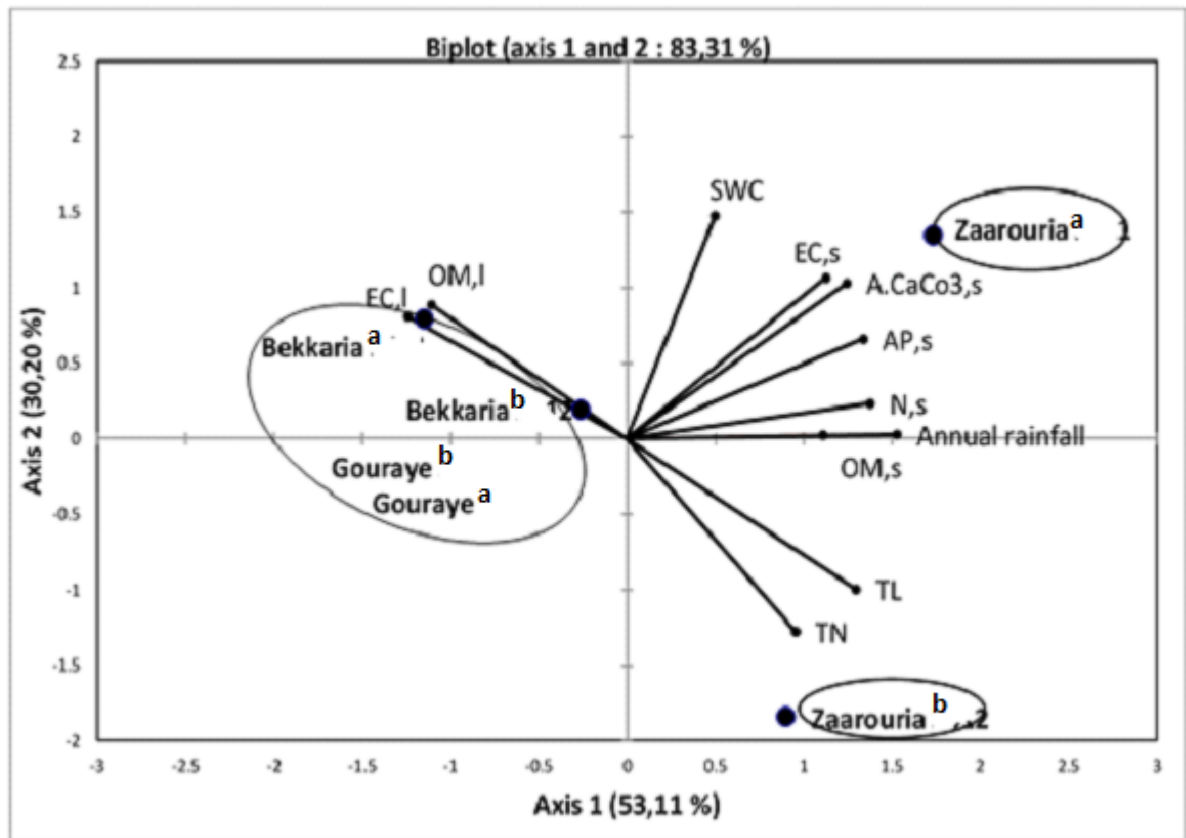


Figure 5: Biplot of the first and second axes obtained from the study of Aleppo pine stands (sub-humid: Zaarouria and semiarid: Bekkaria and Gouraye) in 2011 and 2012 using total litterfall production (TL), total needle fall (TN), annual rainfall, organic matter in soil and litter (OM,s and OM,l), electric conductivity in soil and litter (EC,s and EC,l), organic nitrogen in soil (N,s), soil water content (SWC), active calcium carbonate equivalent in soil (A.CaCO_{3,s}), and available phosphorus in soil (AP,s). a (past year) b (present year)

Litter OM increased in semiarid stands (Bekkaria and Gouraye); nevertheless, Zaarouria (past year) provided an excellent illustration of rainfall, soil, and total litterfall moving in the opposite direction. The soil water content and total needle fall for Zaarouria in the present year were both positively correlated with the second PCA axis, which explained 30.20% of the overall variation. The total fall of litter after two years without removal and the litter found at the study sites before the experimentation revealed that the formation of miscellaneous layers

and the time required for litter decomposition are partly linked to climate. According to Krishna and Mohan (2017), climate has direct and indirect effects on soil chemical and physical properties, as well as a significant role in litter decomposition. In older plots, the humification process is already visible, leading to a higher quantity of miscellaneous, with continued usage and renewal of the litter through fallout depending on weather and biotic factors. The accumulation of litterfall in the experimental site over time revealed that the layer of fragments is thicker than the layer of needles, in contrast to the blocks, which got only two years of litterfall. The decrease in needles, which made up the majority of the litter, demonstrates the transformation of intact to fragmented compounds. Needle tissues degrade faster than other lignified components in litterfall. All the stands showed decomposition, with different rates between sites. Berg *et al.* (2010) found that the decomposition resulted in a mass needle loss ranging from 47 to 83%, with an average of 67%, and the periods ranging from 3.0 to 5.4 years, with an average of 3.9 years, were long enough to allow estimates of decomposition limit values. After three years, an average of 53% of the litter had decomposed, which is a comparable result (Chomel *et al.*, 2014). However, all the cited studies were on the northern side of the Mediterranean area, which is characterized by warm, dry summers and mild, wet winters. According to Dubreux and Sollenberger (2020), many factors affect litter decomposition, such as litter quality, temperature, moisture, soil particle size, and nutrient availability. At Zaarouria, the soil texture is quite balanced. Gouraye has a lighter, more porous texture than the other soils and keeps less water, although it is still suitable. Bekkaria's soil has a heavy texture that makes it highly water-retentive, but also quite compact and impermeable. Seasonal fluctuations in soil activities are caused by the important effects of soil humidity throughout the year on soil activity and chemistry (enzymes and microbiological variables) (Baldrian *et al.*, 2010). As Angst *et al.* (2021) found, in comparison to the soil rich in sand, the high contents of silt and clay-sized mineral particles in the clay-rich soil offered favorable conditions for a more efficient microbial use of the litter material (high pH and high C usage efficiency). Layers of organic debris keep water in runoff and block nutrients in the biogeochemical nutrient cycle. Due to the decomposition of pine needles by the micro-fauna, the litter left up for a year is less acidic. The speed of degradation and the fraction of recalcitrant residue that define the buildup of soil organic matter are determined by the structural properties and chemical composition of litter (Berg *et al.*, 2010). Despite OM litter's richness, decomposition takes time and is heavily influenced by temperatures, humidity, and the presence of appropriate microfauna. In the previously mentioned edaphic and climatic conditions, one year is insufficient to provide accessible nitrogen nutrients. The nitrogen in litter appears to be

unavailable to microorganisms that first invade it (De Santo *et al.*, 2009; Chae *et al.*, 2019). As reported by Akpor *et al.* (2006), soil macro-organisms play a key role in litter mixing, which can be increased by MO. The water-soluble substances in the litter were the primary energy source for the decomposers during the early stages of decomposition, Litter that is too dry or too wet can also inhibit decomposition (Chae *et al.*, 2019; Venn *et al.*, 2019). According to Zhoo *et al.* (2020), calcium, magnesium, and condensed tannins indicate litter mass loss. It's known that the climatic effects, particularly rain, are crucial, but with the collaboration of soil and its microfauna on the litter. Litter levels and fractions demonstrate the locality effect as well as the effects of different rainfall, temperatures, and soil characteristics on the three locations, particularly between first Bekkaria and Gouraye (semiarid) and second Zaarouria (sub-humid). When all factors are considered, local factors are more critical than climatic factors for the growth of Aleppo pine in the study area (Vennetier *et al.*, 2018).

2.4. Total litterfall before and at the end of the study

Significant differences between locations were found in the litterfall collected at the study sites before the experimentation (referred to as "ancient") and that accumulated after the two years of observation (referred to as "after") (Figure 4). Furthermore, the litter amounts were lower than 50% compared to the two preceding cases of accumulation. After two years, litterfall demonstrates that quantities and rankings vary from site to site. At first, in sub-humid by g/m^2 , we had $F (117.85) > M$ and $N (64.90; 63.46) > I (38.85) > B1$ and $B2 (19.80; 16.02)$. For semiarid, Bekkaria, we had $F (92.89 \text{ g/m}^2) > N$ and $M (78.54; 77.43) > I$ and $B2 (22.39; 19.39) > B1 (9.36)$. Another ranking was observed at Gouraye with $M (93.27 \text{ g/m}^2)$, N and $F (78.26; 73.56) > B1$, I , and $B2 (21.37; 17$ and $16.49)$. In previous litterfall collection, the ranking system provided below was used, and we found in sub-humid $N (108 \text{ g/m}^2) > M (74.35) > F (51.36) > I (38.85) > B1$ and $B2 (26-24)$. We noted in semiarid for Bekkaria, $N (143.63 \text{ g/m}^2) > M (70.22) > F (47.55) > I (15.44)$ with another ranking for Gouraye M and $N (95.24; 92 \text{ g/m}^2) > F (50.89) > B2 (36.81) > I (15)$. Through the ANOVA, significant variations in total litterfall between stands were noted (Figure 4).

Needles, pieces, and other random items are the litter's main constituents. Total litter fall comparisons between semiarid and sub-humid sites from seasonal and annual testing after one and two years did not show any differences. After two years, we observed that the cumulative quantities from the other experiments showed no variation between the sites (Table 6).

Table 6: Litterfall yield (g/m²) after each season, year, and two years in three Aleppo pine forests.

Sites	Zaarouria (sub-humid)			Bekkaria (semiarid)			Gouraye (semiarid)		
	Seasonal	Year	2 years	Seasonal	Year	2 years	Seasonal	Year	2 years
Autumn	148.83			97.13			96.67		
Winter	183.43			153.27			168.33		
Spring	26.67			34.33			40.67		
Summer	43.00			39.33			63.63		
Past year	401.93	477.61		324.06	314.26		369.30	415.30	
Autumn	105.33			119.17			107.00		
Winter	268.00			184.00			127.00		
Spring	85.33			75.33			100.00		
Summer	108.00			30.00			76.00		
Present year	566.66	570.67		408.50	431.29		410.00	409.99	
Past to present year	968.59	1048.28	320.87	732.56	745.55	299.98	805.30	825.29	300.00

According to García-Plé *et al.* (1995), it is difficult to compare data from different pine stands since litterfall levels depend on a range of interrelated elements, including climate (rainfall, temperature, winds, etc.), soil (nutrient availability, etc.), and the nature of the forest (age, structure, etc.). Understanding the rate of litter degradation is difficult because many factors influence it. Climate, litter quality, the kind and quantity of the decomposing organisms, and the physical and chemical properties of the soil all play a significant role in the complicated phenomenon of litter fragmentation in the decomposition process (Coûteaux *et al.*, 1996; Krishna & Mohan, 2017). Plant fallout accumulates on the soil in real time, forming a mulch that protects and saves the ecosystem's water during the driest months. The global decomposition pattern, however, was not described by the average yearly temperature or precipitation alone. Among soil compounds, texture is the most significant, as it stimulates nutrient and water dynamics, porosity, permeability, and surface area. Soil moisture can also limit soil fauna (Homet *et al.*, 2021) and directly modulate the microbial decomposition process by affecting the activation energy of compounds in the litter (Suseela, 2019). Slow decomposition rates cause organic matter and nutrient stocks to accumulate in the soil. As a result, the rate of fresh litter decomposition increases as temperatures and precipitation rise (Salah & Scholes, 2011). OM can also increase the population density of soil macroorganisms, which plays a significant role in litter mixing and decomposition (Akpör *et al.*, 2006). According to Bullock (2005), temperature, rainfall, and seasonal variations can all have a significant impact on the existence of microorganisms and the rate of decomposition.

3. CONCLUSION

Litterfall is a fundamental ecological process that influences carbon and nutrient cycling as a result of the decomposition of aboveground litter into the soil. Litter is considered essential for the maintenance of soil fertility in terrestrial ecosystems. The seasonality of litterfall is tightly related to vegetation, climate, season and other minor factors like humidity, temperature, rainfall, topography in conjunction with soil water retention capacity. This study reports seasonal and annual patterns of litterfall production from *P. halepensis* from two geo-climatic zones (semiarid and sub-humid) of Algeria. According to our research, the litterfall of Aleppo pine is seasonal and dependent on a number of variables, including the availability of water. According to measurements of litterfall across short (seasons) and long (years) time periods, precipitation appears to have a greater impact on biomass output than temperature. Compared to the semiarid locations, the sub-humid site produced much more litter components. Additionally, it took longer than a year to build the fine particle layer in order to improve the fragmentation and decomposition of litter compounds at all sites by micro-fauna. The findings also suggest that more favorable conditions and biotic and abiotic interactions are required for the creation of a fine fraction by fragmentation and decomposition. Various conditions can increase rates of leaf and branch fall, which can be seen as adaptations to avoid transpiration water losses and cope with water stress. Variability in litterfall production with climatic and seasonal changes can alter forest and plant growth as well as nutrient cycling and soil properties. Therefore this work could be used to guide afforestation projects and monitor soil erosion and properties.

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