LITTERFALL PRODUCTION OF OAK FORESTS IN NORTHWEST TUNISIA

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(Received 22nd Jan 2018; accepted 1st May 2018)

Abstract. Litterfall is considered a key process in determining the carbon and nutrient cycle of the forest ecosystems, and in controlling the main respiration substrates on the forest floor. Litterfall and its seasonal changes were measured monthly for one year, in two sites and three stands of oak forests in Northwest Tunisia. The results show that the total annual litterfall varied significantly according to forest types ($P<0.01$) in the range of 7.71–9.89 t ha^{-1} yr^{-1}. Litterfall of *Quercus suber*, *Quercus canariensis* and mixed stand occur mostly in autumn, winter, spring and summer seasons, respectively. An annual decay coefficient is calculated from litter accumulation data, which varies according to the site and the stand. The decomposition rate is more pronounced in the *Quercus canariensis* stand, followed by the mixed stand and a slow decomposition in *Quercus suber* stand.
Keywords: *forest ecosystem, Quercus canariensis, Quercus suber, decomposition, annual decay coefficient*

Introduction

In the biogeochemical cycle of organic matter and mineral elements, litterfall plays an important part in the relations of soil, vegetation and surrounding environment, constituting one of the essential ecological phenomena in the wooded ecosystems (Vitousek et al., 1995).

The environmental signals activate a series of events leading to the fall of the leaves. The fallen leaves on the soil degraded by the microorganisms allow the recycling of the constituents of the plant material, which are uptaken again by the tree.

The fall of the leaves is not considered as a great loss for the tree because their metabolism is slowed down due to ceased photosynthesis and their constituents are recycled and reused.

Litter dynamics play an important part in the return of nutrients to the forest soil. It is considered an important component in the accumulation of soil organic matter (SOM). It is also one of the major inputs of C to the soil and an important C source for SOM (Sayer, 2006). Therefore, litterfall is a key parameter in measuring and predicting soil C sequestration (Liski et al., 2005) and one of the most important variables in the global C cycle (Janssens et al., 2003). The litterfall is characterized by a regular rate from one year to another.

The estimation of the foliar proportion of litter is, however, directly tributary of the other components of the litter whose production is rather variable from one year to another because it depends on events which occur with irregular time intervals. Such factors are likely to vary the annual litterfall (Ben Yahia et al., 2016).

The fall of the leaves is considered a very important periodic event in these forests. It represents approximately 65% of the total litterfall (Vogt et al., 1986) and it contributes to the mobilization of the organic matter. The litterfall is influenced by climate variability and latitude. Berg and Meentmeyer (2001) observed that litterfall is positively correlated with annual evapotranspiration or other climatic indices including average air temperature. Litterfall decreases with the increase in latitude (Bray and Gorham, 1964).

In Tunisia, few studies have been made on the leaf fall and decomposition of organic matter in forests. In this context, the aim of our study is to analyse the seasonal variation of litterfall in *Quercus canariensis* and *Quercus suber* forest in Northwest Tunisia and to estimate the decay coefficient from the litter stock.

Materials and methods

Study area

The study was carried out in a natural oak forest site in Northwest Tunisia, the site of Khroufa (36° 55.5’ N; 08° 56’ E) and the site of Ain Zena (36° 46.98’ N; 8° 43.79 E). These sites belong to the forest subdivision of Tabarka and Ain Draham, respectively (*Fig. 1*).

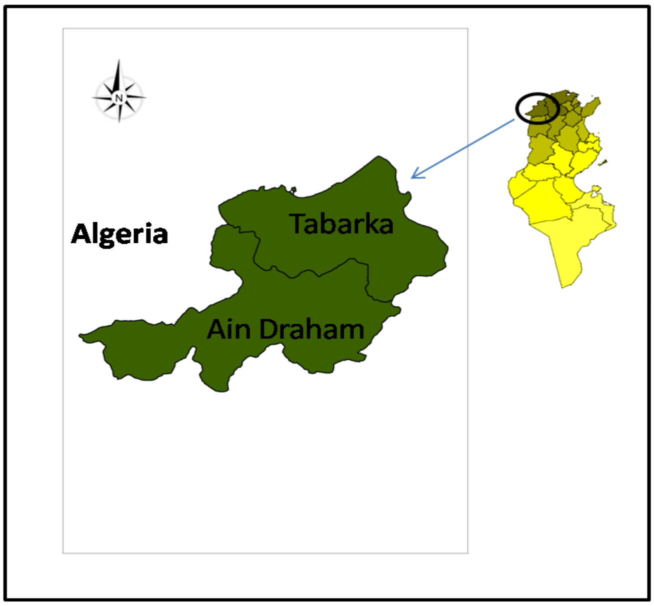

Figure 1. *Study area in Northwest Tunisia*

The climate of Khroufa forest is characterized by mild winters while the climate of Ain Zena forest is described as having temperate winter with snowy precipitations (*Fig. 2*).

Each of the two study sites consists of three stands. The dominant species in stand 1, 2 and 3 are *Quercus canariensis* (*QC*), *Quercus suber* (*QS*) and *Quercus canariensis* and *Quercus suber* (mixed), respectively (*Fig. 3*). A detailed description of the sites is indicated in *Table 1*.

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DOI: http://dx.doi.org/10.15666/aeer/1603_28992908

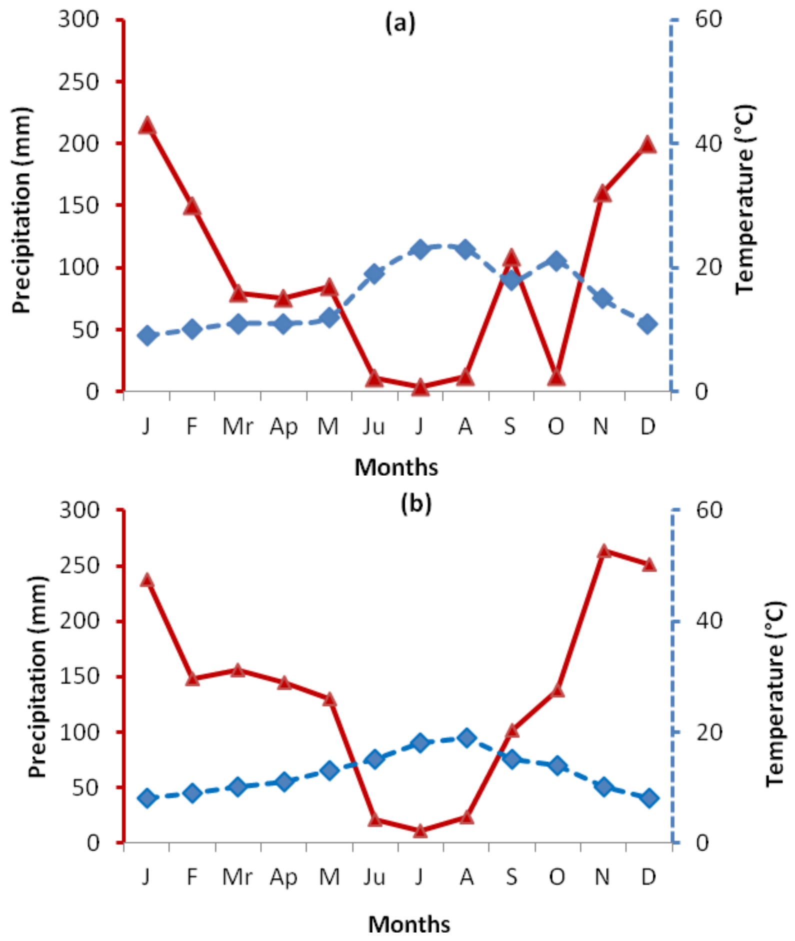

Figure 2. *Ombrothermic diagram of Bagnouls and Gaussen (P = 2 T) for the year 2011 for the two sites (a) Khroufa and (b) Ain Zena*

Table 1. *Characteristics of the study sites*

Sites	**Khroufa**			**Ain Zena**		
Stands	**1**	**2**	**3**	**1**	**2**	**3**
Coordinates	36°55'27.0''N 08°57'03.7''E	36°55'53.8''N 08°56'37.7''E	36°55'35.4''N 08°56'26.6''E	36°44'09.4''N 08°51'38.1''E	36°44'59''N 08°52'11.8''E	36°44'23.4''N 08°52'05.7''E
Altitude (m)	530 - 590	430 - 465	500 - 530	850 - 870	800 - 820	820 - 845
Soil type	Cambisols humic	Cambisols humic	Cambisols humic	Luvisols	Luvisols	Luvisols
Natural vegetation	*Q. canariensis*	*Q. suber*	*Q. canariensis + Q. suber*	*Q. canariensis*	*Q. suber*	*Q. canariensis + Q. suber*
Plant associations	*Erica arborea, Arbutus unedo*	*Erica arborea, Myrtus communis, Pistacia lentiscus, Phillyrea angustifolia, Smilax aspera*	*Erica arborea, Myrtus communis, Pistacia lentiscus*	*Erica arborea, Arbutus unedo*	*Erica arborea, Myrtus communis, Pistacia lentiscus, Phillyrea angustifolia, Smilax aspera*	*Erica arborea, Myrtus communis, Pistacia lentiscus*

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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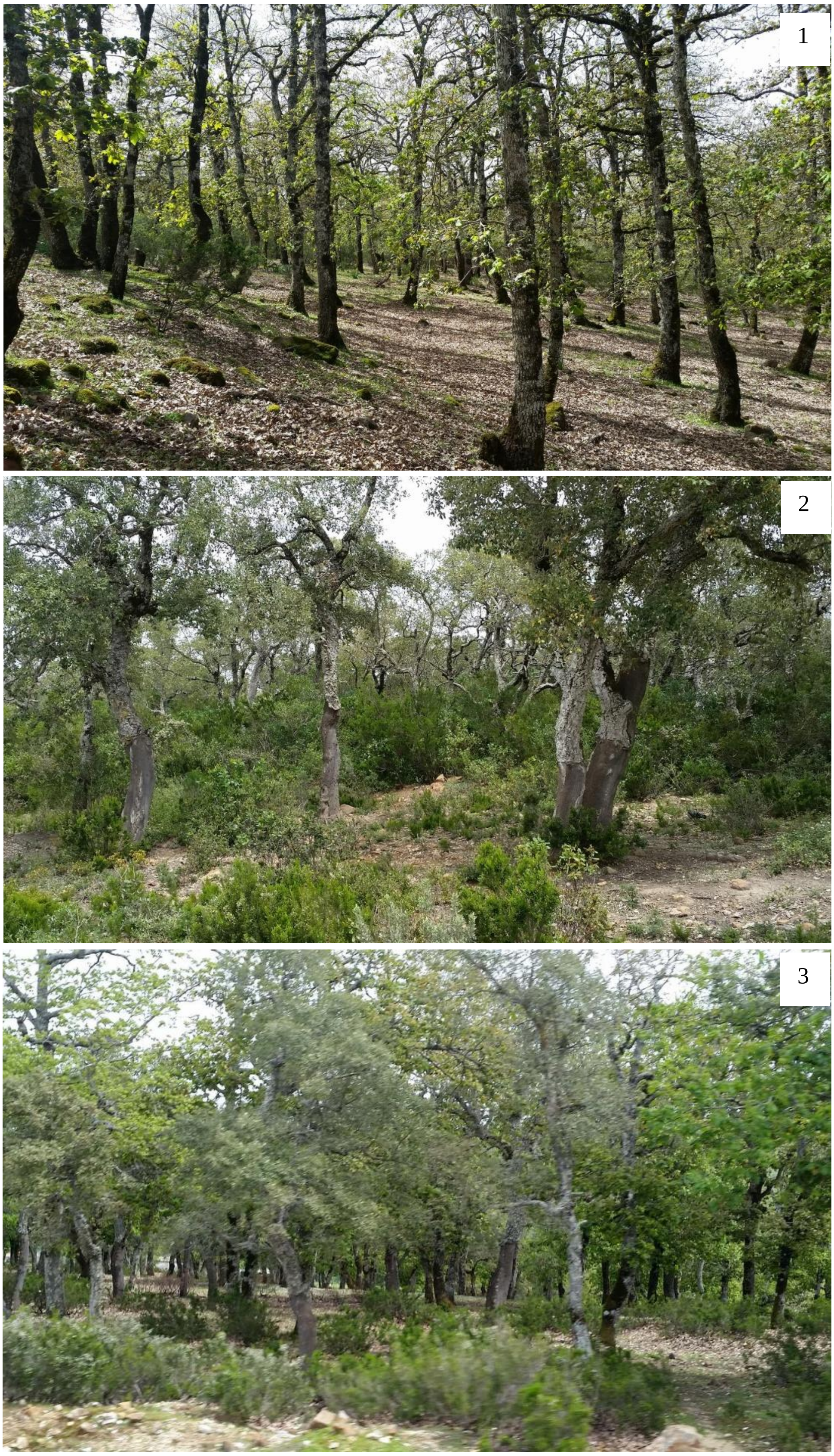

Figure 3. *Photos of the different stands studied (1, 2 and 3)*

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Quercus suber and *Quercus canariensis* are important forest species in the Mediterranean region, specifically in Tunisia. They cover 69.870 ha and 6614 ha, respectively

Litterfall collection

Litterfall was collected monthly throughout a year (from June 2011 to May 2012) for two species (*Quercus Canariensis* and *Quercus Suber*) at all sites and stands.

Five plots are established at each stand to measure the litterfall. Five litter traps in each plot (1 m^2 collecting surface) were installed and located randomly at each plot.

The samples were collected from the five traps and transported to the laboratory, where they were dried at 75 °C for 48 h, and weighed each month throughout a whole year. The samples were sorted into four components: leaves, twigs, fruits and flowers. Twigs with a diameter of more than 2 cm were discarded.

After calculating for each plot the litter quantity per litter trap and per year for each fraction, an average value per plot were used to extrapolate litterfall per hectare and per year.

Data analysis was performed using SAS software: Statistical significance of differences between means of different variables were determined by the Student Newman Keuls (SNK) test using a significance threshold of 5%.

Results

The litterfall of the two species in the two study sites was estimated. The results show that the dynamics of the litterfall differ significantly with time, sites and stand (*Table 2*). In the pure *Quercus canariensis* stand, we noted that the litterfall is highly important during the months of January, February and March.

We noticed that the fall of the leaves and twigs in the pure *Quercus canariensis* stands in the Khroufa and Ain zena sites are important in winter season (*Fig. 4*).

Table 2. *Variance analysis of the different fractions of the litterfall. Correlation is significant at the 0.05, 0.01 and 0.001 level. (*P < 0.05, **P < 0.01, ***P < 0.001)*

Variables	Leaves	Twigs	Flowers	Fruits	Total litterfall
Sites	0.43	22.09***	0.71	54.97***	2.31
Stands	17.20***	3.41*	33.94***	16.51***	8.86**
Times	27.67***	8.42***	10.94***	9.03***	22.87***

We observed in the two sites that in the pure *Quercus suber* stand, the highest number of falling leaves was observed during May and June.

At Khroufa's site, the highest number of falling twigs is in June, November and January, whereas it is higher in the summer at Ain Zena's site. The maximum number of leaves dropped in the mixed *Quercus canariensis* and *Quercus suber* stands, is in May, January and March in Khroufa, while in Ain zena stands, the highest number of leaves fallen occur from May to July.

The fall of the twigs is intense during winter and summer season in Khroufa and Ain Zena, respectively (*Fig. 4*).

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Leaf litter contributes to total litterfall, substantially. The percents of leaf litter vary slightly among forest types in a range of 77.3–85%, followed by twigs.

Regarding fruits and flowers (mentioned as other in *Fig. 4*), there is a significant difference among stands and times ($P < 0.001$), it is observed that the rates are very low in the two sites and stands. The fall of flowers generally occurs during summer months.

For fruits, the values found are low, especially, in Ain Zena stand; this is probably due to the cattle action in this station.

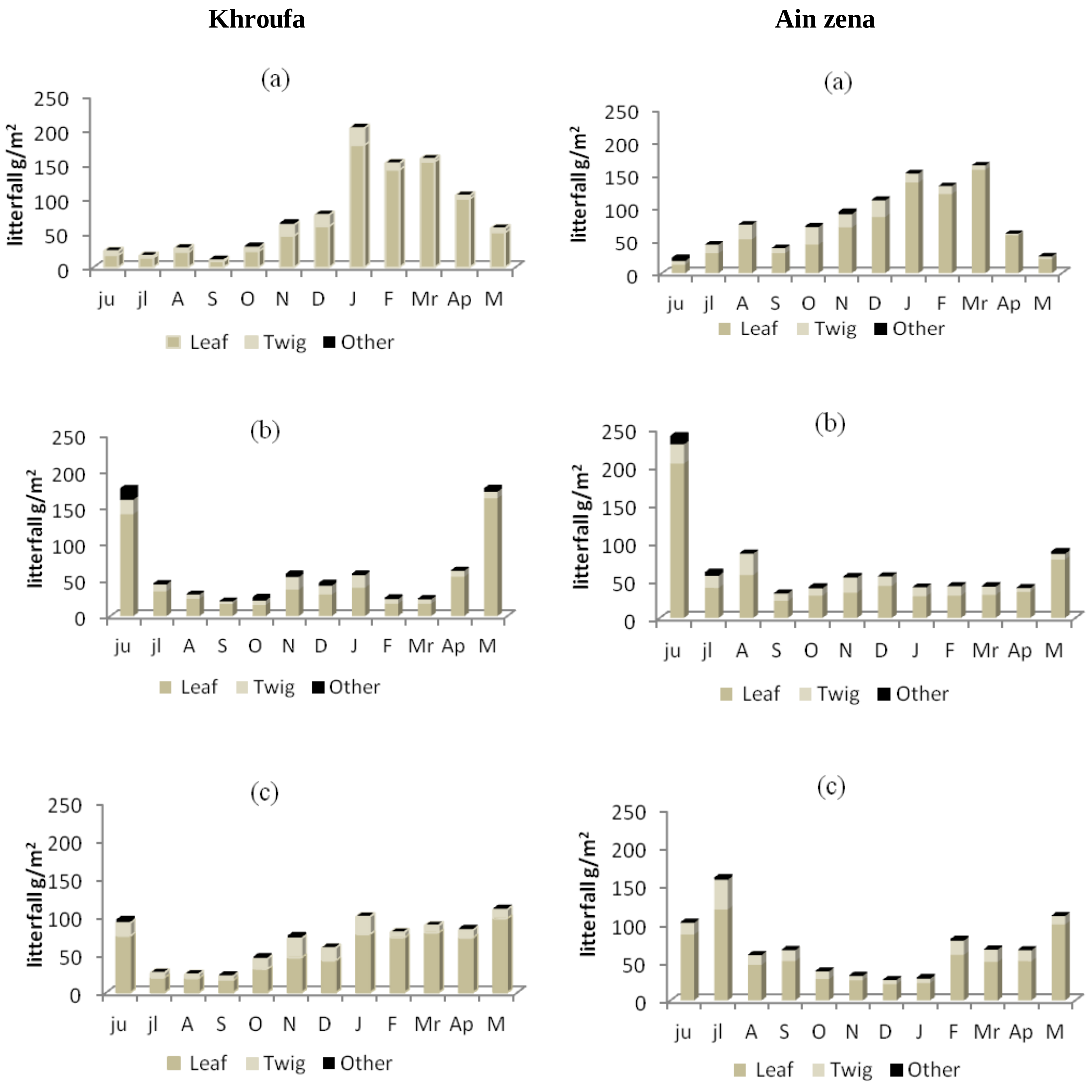

Figure 4. *Monthly variation of litterfall in (a) stand 1, (b) stand 2 and (c) stand 3 in Khroufa and Ain Zena sites in northwestern Tunisia*

The total litterfall is the most pronounced in the pure *Quercus canariensis* stand, it is on the order of 9.33 t ha^{-1} yr^{-1} and 9.89 t ha^{-1} yr^{-1} respectively at Khroufa and Ain Zena sites, moderate in the mixed stand (8.18 and 8.45 t ha^{-1} yr^{-1}) and low in *Quercus suber* stand (7.71 and 8.26 t ha^{-1} yr^{-1}) (*Table 3*).

APPLIED ECOLOGY AND ENVIRONMENTAL RESEARCH 16(3):2899-2908.
http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Litter decomposition rate

Mass balance techniques are used to estimate litter decomposition for the whole ecosystem. The mass balance for the aboveground litter decomposition, suggests that annual litter decomposition should equal the annual input of fresh litter as long as the mass of stock litter stored in the ecosystem remains constant (Olson, 1963; Schlesinger, 1997).

The coefficient $k = \frac{A}{L}$ (for which A = annual litterfall and L = litter stock) can be used to estimate the percentage of litter decomposed by year. Thus, it is possible to obtain the necessary time for the litter to disappear to 100% (in the absence of input).

The results obtained (*Table 3*) highlight that the decomposition rate is higher in Khroufa site than Ain Zena. Similarly, the decomposition rate is more pronounced in *Quercus canariensis* stand; this rate reached 99% yr^{-1} at Khroufa and 81% yr^{-1} at Ain Zena sites, followed by the mixed stand (90.1% yr^{-1} and 75% yr^{-1}) and, finally, a slow decomposition in *Quercus suber* stand 75% yr^{-1} and 67% yr^{-1}).

Table 3. *Annual litterfall, litter decomposition rate (k) and time of 100% litter decomposition for the different sites and stands*

Sites	Stands	Annual litterfall ($t\ ha^{-1}\ yr^{-1}$)	k (% yr^{-1})	Time of 100% litter decomposition (days)
Khroufa	QC	9.33	99	369
	Mixed	6.45	90.1	405
	QS	6.06	75	487
Ain Zena	QC	9.89	81	451
	Mixed	8.45	75	487
	QS	8.26	67	545

Discussion

The litter input of the present study (7.71 to 9.89 t ha^{-1} yr^{-1}) in the forest stands is higher than the values of 5 t ha^{-1} yr^{-1} recorded by Selmi (1985); and other studies carried out on the oak forests of the Mediterranean Basin.

The litterfall of the *Quercus suber* is about 5.6 t ha^{-1} yr^{-1} in Portugal and Spain (Sa et al., 2001; Caritat et al., 2006). In May and June, the peak of the leaf fall changes depending on the year (Bellot et al., 1992; Caritat et al., 1996; Martin et al., 1996). The fall of leaves at the end of spring may be due to an adaptation to the hydric deficit that can occur during the dry season (July and August), in the Mediterranean areas (Escudero et al., 1987).

However, the estimation of the proportion of leaf litter is directly dependent on other components of litter (Ben Yahia et al., 2016). The input is variable from one year to another because it depends on events that occur at irregular intervals. Therefore, some factors are likely to vary the annual litter production. The high values found in our study are probably due to higher temperatures and lower precipitation.

Dendroclimatological studies in Tunisia and Morocco (Aloui, 1982; Raouane, 1985) have shown that *Quercus canariensis* has a greater sensitivity to precipitation than to

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temperatures. But on the other hand, it is indifferent to the physico-chemical nature of the soil.

Our study shows that the fall of the twigs takes place in winter for *Quercus canariensis* stand and at the beginning of summer and winter for the two others stands. This may vary from one study to another since the twig fall depends significantly on wind and storms. According to Caritat et al. (2006), the fall period takes place mostly at the beginning of springtime and at the end of autumn, and it varies a lot depending on the year as observed for the same species in Sicily (Leonardi et al., 1992).

According to Pérez-Suarez (2009), the strong seasonality in leaf-litterfall recorded in other ecosystems with a variety of deciduous and evergreen species (West, 1985; Berg and Meentemeyer, 2001; Liu et al., 2001) has been attributed to interactive effects of weather patterns (e.g. drought), species phenology (Binkley et al., 1992; Liu et al., 2001; Berg and Meentemeyer, 2001) and the temporal distribution of precipitation events (Liu et al., 2004).

For the decomposition rate, the values observed for *Quercus canariensis* stand at Khroufa indicate that the decomposition of litter is relatively fast (369 days), which can be explained by the climatic conditions favorable to the decomposers and the biological activity in this stand. On the other hand, it has been found that there is a significant difference with the coefficients found following the decomposition experiment using the litterbag method.

Van Wesemael (1992) studied decomposition in the Mediterranean forests of Italy (Tuscany) by the litterbag method, and found a rate of decomposition respectively equal to 50% yr^{-1} and 47% yr^{-1} in *Quercus cerris* and *Quercus suber* after one year of decomposition.

This difference highlights the critical importance of mesofauna, prevented from acting by using litterbag method (Bernhard, 1970).

The decomposition rate of *Quercus canariensis* and *Quercus suber* reached 1.69 yr^{-1} and 1.1 yr^{-1} in Southern Spain (Aponte et al., 2012). Moreover, the decomposition of *Quercus serrata* is rapid over time. For instance, according to Pandey et al. (2007) the decomposition rate is 2.37 yr^{-1} and the half life time is 107 days.

These high values are due to the climate characterized by an alternation of dry and wet periods which play an essential part in the regulation of decomposition rates (Tripathi and Singh, 1992) by changing microbial communities in the process of organic matter decomposition (Arunachalam et al., 1997).

Conclusion

The examination of the seasonal variation of litterfall at different oak forests in Tunisia shows that there are no differences between the two study sites of Khroufa and Ain Zena; the only difference is between stands. This could be related to the differences phenological alterations of the species studied. The results suggested that total annual litterfall vary significantly according to forests, with a range of 6.06–9.89 t ha^{-1} yr^{-1}, and that leaf litter is the main component.

In *Quercus suber* the observed links between leaf fall and climatic variables are as they were be expected in typical Mediterranean forests, in which low rainfall and high temperatures favor leaf fall in spring. As for deciduous species, the opposite is true.

Our results will help develop litterfall models in response to climate change in the future studies.

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In addition, the litterfall is an important phase in the biogeochemical cycle of nutrients that ensure the productivity of ecosystems. The knowledge of the quantities of biomass returning to the soil and the released minerals allow, with other criteria such as decomposition rate, to give an idea about their use by plants and to determine the excesses or deficiencies in a given ecosystem.

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