DENDROBIOLOGY

2022, vol. 87, 101–112

https://doi.org/10.12657/denbio.087.007

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Contrasting foliar and soil nutrients responses to drought induced crown dieback in a *Quercus brantii* forest

Received: 2 August 2021; Accepted: 9 March 2022

Abstract: Evidence has shown that drought-induced crown dieback has significant interaction with soil-plant water and nutrients relationships, but there isn't sufficient knowledge of the water and nutrients connections in declining Persian oak (*Quercus brantii*) trees. To investigate the relationships between crown dieback and leaf nutrients concentrations, leaf water content, soil nutrients concentrations and soil moisture, one of the dieback affected stands was selected. This stand was located in Shalam forested area in northern Ilam province, west of Iran. Persian oak trees were evaluated using a crown dieback classification and divided into four classes with four replicates based on the severity of crown dieback. Sampling from leaves of trees and soil was implemented randomly in four sides of tree crown in August. Trees with moderate to severe declining showed reduced leaf water content (WC) and reduced relative leaf water content (RWC). Leaf N and P concentration of declining trees was significantly (p-value <0.05) more than that of healthy trees. The leaf K concentration of declining trees was significantly (p-value <0.10) more than that of the healthy. The leaf N:P amounts of oak trees was statistically different among crown dieback classes. But no significant differences was observed between the healthy and declining trees in terms of soil N, P, K, Ca and Mg concentrations and soil moisture. It was concluded that drought has effects on the nutrients status in the leaves of Persian oak trees and their changing in the declining trees is for resistance to drought condition, improving water use efficiency and possibly performance of vital activities.

Keywords: crown condition, drought, nutrients, persian oak forests, tree decline

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Introduction

Many tree mortality and crown dieback following severe droughts have occurred in Zagros mountain forests, in west of Iran, during recent years. The results of several studies have confirmed the occurrence of drought and tree mortality in the western forests of Iran (Hamzehpour et al., 2011; Hosseini et al., 2012a; Hosseini et al., 2013b; Hosseini et al., 2014; Hosseini, 2015; Hosseini & Hosseini, 2016; Hosseini et al., 2017a; Hosseini et al., 2017b; Hosseini, 2017c; Aazami et al., 2018;

Hoseinzadeh et al., 2018). For example Hosseini et al (2012a) found that the forest density was reduced at 15.7%, in which 97.65% belonged to *Quercus brantii*. Basal area reduced at 14.23%, in which 95.29% belonged to *Q. brantii*. Mortality was found at most of the diameter classes, but the greatest amount was found at 10 to 25 cm classes and the maximum rate was found at 5, 60, and 75 cm classes. Crown density reduction was about 12.88%. Hosseni et al. (2017a) showed that long-term decrease in rainfall and increase in temperature occurred in the western region of Iran, in the Zagros forests, which led to drought and dust. The term of drought refers to the lack of rainfall over a relatively long period of time as a result of which soil water is depleted and plants are damaged (Kramer, 1983). Drought impacts on vitality of trees through reduce rainfall and reduce soil moisture in the root zone of forest trees and affect them by water shortage stress (Mc Dowell et al. 2008). In other words, drought has most impact on soil and plant nutrient status through its effect on connections between water, soil and plant. There are several evidences indicative the effects of water stress on amounts of nutrients in the forest trees (Sardans et al., 2008a; Graciano et al., 2005; Sardans et al., 2008b; Hosseini, 2017c; Mohammadzadeh et al., 2021). Drought can affect the ability of plants to uptake the nutrients. It can reduce the water content of soil, influence on soil conditions and activity of its enzymes, decrease the photosynthetic and growth rate of plant and reduce its ability to uptake nutrients (Sardans et al., 2008b). Drought can roughen the tree leaves and increase their sclerophilic properties which this property reduces the leaf quality of plants in terms of nutrient content (Feller *et al*. 1999; Bussotti *et al*. 2002; Bacelar *et al*. 2004). Due to drought the nutrient concentrations in some plant organs may increase, which this is happened as a mechanism for drought avoidance (Antolın & Sanchez Dıaz, 1992). However, the results of several studies have shown that the effect of drought on nutrient concentrations within the soil and plant organs varies and depends heavily on the element, species and forest ecosystem (Sardans and Penuelas, 2007; Sardans et al., 2008b). Plant species respond differently to drought which is related to their ability to physiological adapt with drought conditions (Sardans et al., 2008b; Hosseini et al., 2012a; Hosseini et al., 2017a; Hosseini et al., 2018). Hence in more vulnerable species to drought the change rate of nutrients is greater in their bodies (Sardans & Penuelas, 2007). Also in responses of trees to stresses, some elements concentrations decrease in tissues or organs and the others increase for various reasons (Mohammadzadeh et al., 2021; Morillas et al., 2012; Sardans & Penuelas, 2007; Sardans et al., 2008a; Sardans et al., 2008b; Hosseini, 2017c).

One of the ways to evaluate the effect of stress on trees is study the changes of elements in different parts of their bodies (Sardans & Penuelas, 2007; Sardans et al., 2008a; Sardans et al., 2008b; Niinemets, 2010; Hosseini, 2017c). In this context, several studies have been conducted in the world (Sardans & Penuelas, 2007; Sardans *et al*. 2008a; Sardans *et al*. 2008b). For instance, in a study Sardans and Penuelas (2007) found that the pattern of nutrients concentration changes varies in different species as well as in different organs of each drought affected species. They showed that drought increased the P concentration of leaf and reduced the P concentrations of wood and root in *Quercus ilex*, but it had no impacts on K leaf and wood contents. Also they reported that the levels of P varied more in *Quercus ilex* and *Arbutus unedo* species and less in *Phillyrea latifolia* species and concluded that different responses of species to drought lead to alters in competitiveness and composition of plant species in the forest. Some studies showed that the responses rate of species to drought in terms of nutrient content is related to their growth rate (Ogaya & Peñuelas, 2007), mortality rate (Ogaya & Peñuelas, 2007), and seed production and regeneration rate (Lloret et al., 2004; Ogaya & Peñuelas 2004). In another study sardans et al. (2008b) found that due to drought the contents of some nutrients in soil were increased which is related to a decrease of soil moisture and decrease of plant uptake capacity.

But a few studies have been done in Iran. For example Rahmani et al. (2009) found that changes in nitrogen and potassium content in dieback elm trees (*Ulmus glabra* Huds.) relative to healthy elm trees could be one of the factors affecting in weakness and dieback of these trees. Also Hosseini (2017c) found that the amounts of nitrogen and phosphorus in the leaves and roots of Persian oak trees changed over time and were higher in declining trees. However, the amount of nitrogen and phosphorus in the soil around the oak trees did not change significantly and stated that drought has a significant effect on the status of these elements in the body of oak trees.

Considering the extent of crown dieback of tree species, especially Persian oak in the forests of western Iran and also considering the ecological position of oak species in these forests, the need for this research is clear. This research tries to study the physiological responses of Persian oak trees to drought induced dieback. So, the aims of present study were; (1) to determine the concentration changes pattern of nitrogen, phosphorus, potassium, calcium and magnesium in the leaves of Persian oak trees in relation to crown dieback and (2) to determine the content changes pattern of nitrogen, phosphorus, potassium, calcium and magnesium of in the root zone soil of Persian oak trees in relation to crown dieback.

Materials and methods

Study area

This research was done in Shalam forested area (33°37'N, 46°27E) as a part of the Zagros forests located in north of Ilam province, Western Iran (Fig. 1). This region has a Mediterranean to semi-Mediterranean climate with cold winter (Asakereh, 2007). Summers are hot and dry and there is no rainfall in this season (mid-spring to mid-late autumn). In spring, it usually rains in April and May. The average annual temperature in the region is 16 °C and the average annual rainfall is 509 mm (Asakereh, 2007). Meteorological data for this study were available from the climate station of Ilam (about 10 km apart from the study area). Total annual precipitation and dust events (number of days with dust) were investigated. This area is located on eastern aspect of Shalam Mountain and its topography conditions at the sampling sites were homogenous in slope, aspect, and elevation. The bedrock was limestone and the soil classes with respect to the US soil taxonomy classification was entisols. Persian oak (*Quercus brantii* var. persica Lindl) is the dominant tree species accompanied by other tree and shrub species, such as *Pistacia atlantica*, *Acer monspessulanum*, *Crataegus pontica* and *Amygdalus orientalis*. About 95.26% of the stand density and 93.60% of the basal area was belonged to this species (Table 1). The average canopy cover was 32.52%, of which 31.47% belonged to Persian oak species (Table 1) (Hosseini et al., 2012a; Hosseini et al., 2013a; Hosseini et al., 2017a).

Table 1. Stand density, basal area, canopy cover and tree diameter in the study area (Hosseini et al., 2013a)

Variable	Stand (mean±SD)	Oak (mean±SD)
Density (trees/ha)	225±152.3	214.3±145.8
Basal area (m²/ha)	13.4±6.1	12.6±5.7
Canopy cover (%)	32.5±16.9	31.5±16.3
DBH (cm)	28±8.2	27.9±8.1

Research methods

Crown dieback classification of Persian oak trees were evaluated with respect to the percentage of

Fig. 1. Location of study site – Shalam Mountain in the northern half of Ilam province, in the west of Iran

Fig. 2. Persian oak trees with crown dieback classes: healthy, weak, moderate and severe (respectively from left to right)

crown dieback, conducted as follows: (1) healthy: less than 5%; (2) low: 5–33%; (3) moderate: 34–66%; and (4) severe: more than 66% of the crown (Kabrick et al., 2008; Hosseini et al., 2017a; Hosseini et al., 2018) (Fig. 2). For each class, four tree replications were selected (a total of 16 trees were sampled). The selected trees were all in form of standard and had approximately the same or similar DBH (about 30 to 35 cm). Given the direct relationship between DBH and tree age, it can be said that the selected trees were almost in the same age. Leaf samples were randomly taken from the four main sides of tree crown and from end branches at the middle part of the crown. From each tree 20 mature leaves were removed, collected in bags and transferred to the laboratory for analysis of leaf elements. Also for each tree, five leaves were taken from south side of tree crown for morphological traits and water status. Soil samples were taken from holes with depth of 70 cm in the four cardinal sides of each tree and combined them together (a total of 16 combined soil sample were collected). Composite soil samples were transported to the laboratory for analysis of elements and moisture status. Leaf samples were immediately weighed by a digital scale to measure their fresh weight. Then the leaves were immersed in water to reach saturation and their saturation weight was measured. After drying the leaves in the oven at 70 °C for 24 h, their dry weight was also measured. Then, using equations 1 and 2, the leaf water content (WC) and the relative leaf water content (RWC) were calculated (Barr and Weatherley, 1962; Cowling and Campbell, 1983).

$$WC = ((FW - DW) / FW) \times 100 \quad (1)$$

$$RWC = ((FW - DW) / (TW - DW)) \times 100 \quad (2)$$

FW corresponds to the leaf fresh weight, TW to the leaf turgid weight measured after 12 h of incubation in deionized water at 4 °C in the dark, and DW to the dry weight (24 h at 70 °C). Soil samples were immediately weighed to measure their fresh weight and oven-dried soil samples weighed for dry weight. Then the percentage of soil moisture was calculated using the equation 1.

After the extraction process, the concentrations of leaf and soil nutrients including nitrogen, phosphorus, potassium, calcium and magnesium were measured. Total soil nitrogen was measured using Kjeldahl method ((McGill & Figueiredo, 1993). Absorbable soil phosphorus was measured using Olsen method and spectrophotometer (model 64-2088-80, manufacturer of LKB Biochrom United Kingdom) (Jones, 2001). Leaf nitrogen and phosphorus were measured by Kjeldahl (Issac & Johnson, 1984) and Olsen method by spectrophotometer (Jones, 2001) respectively. Soil and leaf potassium, calcium and magnesium were measured using atomic absorption method and by spectrophotometer (Issac & Johnson, 1984; Wang et al., 2004).

Data analysis

The Kolmogorov-Smirnov test was used to assess normality of data. Homogeneity of variances was evaluated by Levene's test. Quantitative values of nutrients including nitrogen, phosphorus, potassium, calcium and magnesium for leaf and soil samples were calculated and compared among classes of crown dieback. To investigate the leaf and soil nutrients status in relation with crown dieback intensity One Way ANOVA in SPSS software was used. Means comparisons were done by Duncan test. Also to investigate the leaf water status in relation with crown dieback, quantitative values of Leaf fresh weight, Leaf dry weight, Leaf water content and Relative leaf water content were calculated and compared among classes of crown dieback using the Kruskal–Wallis H test.

Results

Climate status

Climate data obtained from the Meteorological station of Ilam (the nearest station to the study area)

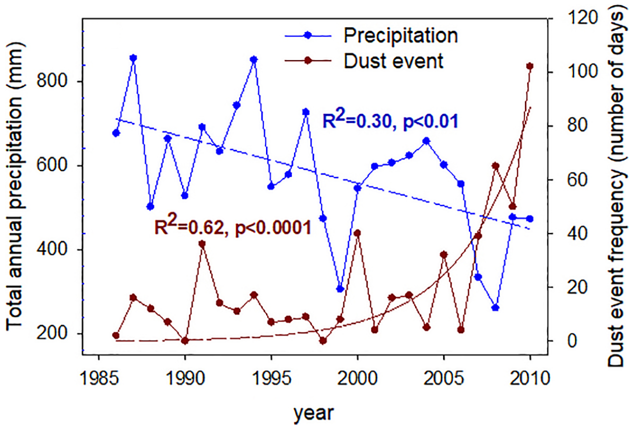

Fig. 3. Local data obtained from the Ilam city meteorological station. Total annual precipitation (linear regression, upper inset) and dust events (exponential regression, bottom inset) of the local dataset showed significant trends during the time span investigated (1986–2010) (Hosseini et al., 2017a)

showed a significant decline in total annual precipitation ($R2$ = 0.30, p<0.01), with extreme drought events in 1999, 2007 and 2008 (Fig. 3). Moreover, dust events showed a significant exponential trends ($R2$ = 0.62, p<0.0001), with increasing number of days with dust mainly from the year 2000 onward (Fig. 3).

Soil nutrients status in relation with crown dieback

Analysis of variance (Kruskal-Wallis test) showed that the studied soil elements have no significant differences among crown dieback classes (Table 2). Soil moisture showed no statistically differences among crown dieback classes (Table 2). The ratios of C:N, C:P and N:P had no statistically differences among crown dieback classes (Table 2).

Leaf nutrients status in relation with crown dieback

The amounts of nitrogen and phosphorus had significant difference among crown dieback classes. The amount of nitrogen and phosphorus were statistically higher in severely declining trees than the healthy trees (Table 3). Potassium was significantly differed among crown dieback classes at Level of 90% and the highest amount of potassium was found in severe crown dieback class. Calcium and magnesium showed no statistical difference among crown dieback classes. The amount of leaf N:P was statistically differed among crown dieback classes (Table 3).

Table 2. Means comparison of soil macro elements concentration (Mean±SD) in contrasting crown dieback classes of Persian oaks (n = 4 replicates per class)

Variable	Means Comparison					
	F	Sig.	healthy	low	moderate	severe
Soil moisture (%)	0.724	0.557	5.38	4.82	4.67	4.36
Carbon (%)	0.203	0.891	1.203±0.60	1.197±0.52	1.027±0.43	0.963±0.24
Nitrogen (%)	0.204	0.891	0.103±0.06	0.1±0.04	0.09±0.03	0.08±0.02
Phosphorus (ppm)	0.560	0.656	4.5±1.67	5.6±1.44	4.4±1.06	4.6±0.061
Potassium (mg/kg)	1.24	0.356	188.33±23.63	156.67±46.19	230±78.10	215±35
Calcium (%)	1.98	0.194	3.87±0.23	2.67±0.46	2.93±0.92	3.2±0.69
Magnesium (%)	1.04	0.423	1.6±1.06	1.47±0.23	1.07±0.46	0.8±0.40
C:N	1.71	0.242	11.91±0.73	11.99±0.27	11.33±0.32	12.06±0.29
C:P	0.345	0.794	0.26±0.12	0.21±0.04	0.23±0.07	0.21±0.05
N:P	0.306	0.821	0.023±0.01	0.017±0.00	0.020±0.01	0.017±0.00

Table 3. Means comparison of leaf macro elements concentration (Mean±SD) in contrasting crown dieback classes of Persian oaks (n = 4 replicates per class; 20 leaves per tree)

Variable	Means Comparison					
	F	Sig.	healthy	low	moderate	severe
Nitrogen (%)	7.480	0.010**	1.233±0.06[c]	1.403±0.50[b]	1.44±0.92[b]	3.2±0.52[a]
Phosphorus (%)	4.187	0.047**	0.11±0.00[c]	0.227±0.16[b]	0.547±0.23[a]	0.263±0.07[b]
Potassium (%)	2.989	0.055*	0.642±0.05[b]	0.633±0.13[b]	0.767±0.03[a]	0.783±0.28[a]
Calcium (%)	0.991	0.455[ns]	1.13±0.12	1.46±0.31	1.61±0.35	1.46±0.50
Magnesium (%)	1.639	0.256[ns]	0.80±0.00	0.533±0.23	0.533±0.23	0.467±0.23
N:P	3.286	0.050**	11.21±0.52[a]	7.854±4.25[b]	3.55±3.70[c]	13.13±5.62[a]

Analysis of variance was done by one-way ANOVA F test. Different letters indicate significant differences (p<0.05** and p<0.10*) for means comparison.

Table 4. Means comparison of leaf water status in contrasting crown dieback classes of Persian oaks (n = 4 replicates per class; 5 leaves per tree)

Variable	Means Comparison					
	H	P-value	healthy	low	moderate	severe
Fresh weight (g)	2.800	0.060	1.020	0.941	0.898	0.796
Dry weight (g)	1.230	0.746	0.574	0.573	0.568	0.550
Leaf water content (%)	2.941	0.050	43.780[a]	39.050[ab]	36.750[ab]	30.870[b]
Relative leaf water content (%)	3.920	0.037	73.710[a]	72.840[ab]	67.420[b]	67.310[b]

Analysis of variance was done using the Kruskal-Wallis H test. Different letters indicate significant differences ($p<0.05$) for means comparison among crown dieback classes.

Leaf water status in relation with crown dieback

Leaf fresh weight and Leaf dry weight showed no statistical differences among crown dieback classes (Kruskal–Wallis test; Table 4). Leaf water content and Relative leaf water content were statistically lower in severely declining trees than the healthy trees (Table 4).

Discussion

Crown dieback is an indicator of health or stress within the tree (Dobbertin, 2005; Hosseini, 2015; Hosseini et al., 2018; Hosseini et al., 2017b). However, studies have illustrated that crown dieback along with reduced tree growth are two complementary indicators that their accuracy are increased by their simultaneously presence (Dobbertin, 2005; Ogaya & Penuelas, 2007). Depending on the stress kind and its severity and extent, crown dieback and reduced tree growth can occur before or after each other. For example, in drought stress first the reduced tree growth happens and then crown dieback occurs (Dobbertin, 2005). Of course in the present study drought was the primary and underlying factor (Hosseini et al., 2017a; Hosseini et al., 2018; Hoseinzadeh et al., 2018; Aazami et al., 2018; Asakereh, 2007). Although in this study, the growth rate of oak trees has not been measured and only the rate of their crown reduction has been considered, but according to the findings of Dobbertin (2005), it can be said that before the occurrence of crown dieback, growth decline has been done in oak trees. Of course, the rate of growth reduction within trees is directly related to the rate of their crown dieback (Dobbertin, 2005), which based on this it can be said that more growth reduction has occurred in Persian oak trees with severe crown dieback. The rate of tree growth reduction is a reflection of the tree's ability reduction to uptake water and minerals from the soil, so crown dieback is occurred by tree weakening (Dobbertin, 2005; Ogaya & Penuelas, 2007; Sardans & Penuelas, 2007; Sardans et al., 2008a). As a result, intraspecific variability in sensitivity to stress, uptake of water and nutrients, and growth reduction rate is appeared in Persian oak trees (Hosseini et al., 2017a; Hosseini et al., 2018; Hosseini, 2017c). Some studies in the Zagros forests have shown signs of widespread decline in Persian oak trees, including crown dieback and tree death (Hamzehpour et al., 2011; Hosseini et al., 2012a; Hosseini et al 2017a), but understanding how and why trees show decline depends on understanding the physiological process. Different behavior of declining and healthy trees have received increasing attention, mainly focused on physiological response of tree species to abiotic and biotic stressors (McDowell et al., 2008; Allen et al., 2010).

We found that the soil water content and the soil nutrients concentrations showed no significant changes among crown dieback classes. Our results suggest that there was the same amount of nutrients and moisture within the all soil samples which indicates that all studied oak trees have the same opportunity to receive water and nutrients. These results are consistent with the findings of Hosseini (2017c) regarding the lack of significant changes in the amounts of soil elements in the crown dieback classes. But at the same time, we found that the concentration of nitrogen, phosphorus and potassium in the leaves of declining Persian oak trees was more than that of healthy trees. Thus in Persian oak stands high mortality rates may be associated with nitrogen and phosphorus imbalances in the tree (Morillas et al., 2012; Hosseini, 2017c). Considering the significant changes of leaf nutrients compared to the lack of significant changes of soil nutrients in relation with canopy dieback of Persian oak trees, our results suggest that the concentration of leaf nutrients are better indicators than that of soil nutrients, because they indicate better the nutrient status of the tree during a growing season or more (Townsend et al., 2007).

The changes in leaf nutrients concentration among crown dieback classes can be attributed primarily to disorders of soil – plant water relations (Hosseini, 2017c; Utrillas et al., 1995). Because in this study the relative leaf water content (RWC) of declining oak trees was less than that of healthy trees. This result is consistent with the findings of Martinez-Villata et al (2002) about crown dieback of *Quercus ilex* trees which they concluded that crown dieback of *Q. ilex* trees is due to disrupting soil – plant water relations.

Changing of nutrients concentrations in the leaves of Persian oak trees is likely referred to physiological mechanisms of Persian oak trees and their responses to stress such as drought (Hosseini, 2017c). Oak trees (*Quercus* spp.) are adapted to drought-prone sites by an ability either to avoid, or to tolerate, water stress, or both (Corcuera et al., 2002; Niinemets, 2015; Gomez-Aparicio et al., 2008; Laureano et al., 2016). Persian oak trees studied here responded plastically as regards foliar morphology, to cope with water stress (Corcuera et al., 2002; Laureano et al., 2008; Villar & Merino, 2001; Aranda et al., 2005; Ogaya & Penuelas, 2006). Foliar traits are known to be good indicators for the ability of drought-adapted species to respond to decreases in rainfall under climate change (Niinemets & Keenan, 2014; Sperlich et al., 2015, Ogaya & Penuelas, 2006; Setayeshmehr & Ganjali, 2013).

Increasing of nitrogen and phosphorus concentrations within the leaves of declining Persian oak trees could be due to the concentration effect (Sardans & Penuelas, 2007; Sardans et al., 2008a). By this mechanism, water and nutrients absorbed by the roots of dieback trees are directed to their remaining healthy and active branches (Sardans & Penuelas, 2007). Thus, probably the N and P concentrations are increased in leaves.

In stressed trees that suffer from crown dieback, photosynthesis and respiration are usually reduced and increased respectively (Niinemets & Keenan, 2014; Ogaya & Penuelas, 2006). Declining oak trees probably have absorbed N and P to compensate the reduction in photosynthesis (Sardans & Penuelas, 2007; Sardans et al., 2008a). Moreover due to reduce of metabolic activity and stop moving produced material, these elements have not consumed and their concentrations increased in healthy leaves (Alizadeh, 1990). Increase of respiration in the leaves of declining trees leads to the breakdown of DNA and RNA molecules in the ATP process, which causes to an increase in the concentration of phosphorus in the leaves, and also leads to the breakdown of carbohydrates and proteins and produce of nitrogen compounds, which causes to an increase in the concentration of nitrogen in the leaves (Alizadeh, 1990).

Another reason for concentration changes of nutrients in the leaves of Persian oak trees is referred to their performance and behavior especially under stress condition (Antolin and Sanchez-Diaz, 1992; Ebadi khazineh ghadim et al., 1999; Paoli et al., 2005; Hawkesford et al., 2012; Huber & Jones, 2012). Nutrients have special effects on the water absorption and water regime of plants (Egilla et al., 2005; Graciano et al., 2005; Sardans et al., 2008b). Nitrogen causes plants absorb more water, and increase water content of tissues and evapo-transpiration of plants (Ebadi khazineh ghadim et al., 1999; Graciano et al., 2005). In sudden drought condition the amount of nitrogen is increased in roots and reduced in leaves due to low transition from root to the upper part of the plant, but under constant conditions of water shortage, amount of nitrogen in leaves and roots is more than usual (Dhindsa & Cleland, 1975). In this condition, converting of nitrogen compounds in roots and upper parts of plant is stopped due to reduce of protein synthesis (Dhindsa & Cleland, 1975). Considering the above, in this study Persian oak trees have absorbed more amount of nitrogen to counter drought stress and to absorb more water from soil, so the amount of nitrogen has increased in leaves (Farquhar et al., 2002; Setayeshmehr & Ganjali, 2013; Sperlich et al., 2015); or maybe due to reduction of photosynthetic activity and protein synthesis, the absorbed nitrogen is accumulated in leaves (Farquhar et al., 2002; Hosseini et al., 2018). Increasing nitrogen concentration in plants under drought stress is probably a drought tolerance strategy. This strategy would make it possible to react rapidly to changes in soil water availability (Susiluoto & Berninger, 2007; Sardans et al., 2008a; Niinemets, 2015; Laureano et al., 2016). Accordingly, in this study the declining Persian oak trees which have poorer water relations and experience more drought stress, increasing of nitrogen in their leaves is likely a drought tolerance strategy in response to reduced water uptake (Hosseini, 2017c).

Leaf phosphorus content was statistically higher in severely declining Persian oak trees than that of the healthy ones. Increasing of p concentration due to drought has been reported in some studies (Utrials et al., 1995; Diaz & Roldan, 2000; Samarah et al., 2004). Increasing the leaf phosphorus concentration is related to increase of water use efficiency and reduce of dilution effect which is a mechanism to cope with drought (Sabate & Gracia, 1994; Penuelas & Estiarte, 1998; Diaz & Roldan, 2000; Samarah et al., 2004; Graciano et al., 2005; Egilla et al., 2005; Sardans & Penuelas, 2007; Hosseini, 2017c). Phosphorus has a notable role in the growth of plants and its availability to absorb is related to the availability of water (Hosseini, 2017c; Hawkesford et al., 2012; Vitousek et al., 2010; Diaz and Roldan, 2000; Sundareshwar et al., 2003; Wissuwa, 2003; Paoli et al., 2005). So it can be said that increasing of phosphorus in leaves of declining Persian oak trees indicates tree effort to move the phosphorus from soil to leaves to improve their water use efficiency and cope with crown dieback.

The leaf potassium content statistically increased in declining Persian oak trees, which it suggested that K has been more absorbed by declining oak trees in order to improve water use efficiency or defense mechanisms (Hawkesford et al., 2012; Sardans and Penuelas, 2007). It is likely that the reduction of photosynthesis and metabolic activities in persian oak trees leads to K accumulation in the leaves (Egilla et al., 2005; Sardans & Penuelas, 2007). Because Hosseini et al. (2018) found that the leaf area of declining Persian oak trees has decreased, which indicate a reduction in their growth and metabolic activity. Potassium is essential to increase leaf LMA (Sardans & Penuelas, 2007). In this case, Hosseini et al. (2018) found that the leaf LMA amount of declining Persian oak trees has increased.

Some Studies have shown that leaf dry weight is increased during the time due to thickening of cell wall (Heidari Sharif Abad, 2001). The role of potassium, often, is the production of epidermal cells with thick cell wall which are more resistant against diseases (Salardini, 1987). Potassium enhances the water absorption by plant (Heidari Sharif Abad, 2001) and its availability to absorb is indirectly related to water availability (Sardans & Penuelas, 2007). Potassium is an essential nutrient for plant growth and development which is effective in dry matter production (Cadish et al., 1993). The benefits of potassium during drought stress through its effects on leaf osmotic potential, inflammation potential, cell size and leaf water content is known (Jensen et al., 1992). The enough amount of potassium makes improvement of water use efficiency and accumulation of dry matter under drought conditions (Jensen & Tophoj, 1985). Plants which have enough potassium, they needs less water for synthesis of organic matter. It is likely due to the reduction in transpiration, because potassium is rapidly absorbed (Sabaghpour, 2006). Some studies have reported that potassium increases the dry weight of leaves, stems and roots (Singh et al., 1997). Under water stress condition, leaf area is significantly reduced due to reducing of leaf water content (Sperlich et al., 2015; Sabaghpour, 2006; Ogaya & Penuelas, 2006). By loss of water, the relative water content in the leaves decreases, but potassium increases the relative water content in the leaves, thereby helping the plant to perform a variety of physiological processes, such as photosynthesis, enzymatic activity and biochemical metabolism with optimal efficiency (Umar et al., 1993).

Conclusions

Variations in leaf nutrients content and leaf water content were observed among contrasting crown dieback of Persian oak trees. The drought induced tree mortality and crown dieback in the study area had significant and strong effect on leaf nitrogen, phosphorus and potassium. We attribute this intra-species variability among crown dieback classes, to acclimation of foliar morphology with drought and following tree mortality occurred in this area. More changes of nitrogen, phosphorus and potassium than the other studied elements within the leaves of Persian oak trees is referred to the defense mechanisms of this species which has absorbed more amounts of these elements to cope with the occurred stresses, to absorb more water from soil and to prevent further crown dieback. However, the leaf water contents of declining oak trees were lower than that of healthy trees. So, we suggested that Persian oak with respected to significant changes of some elements in its leaves, has no considerable ability to absorb some nutrients and use them in vital activities, so it is a sensitive species to stress, especially to drought. In general it was determined that Persian oak trees with contrasting crown dieback had similar status in terms of soil water content and macro elements, but were different in terms of leaf water content and macro element contents. On this basis it can be said that crown dieback of oak trees is directly linked to the amount of water shortage within the tree (decreasing RWC and SD), but has no clear relationship with the amount of soil moisture shortage. So it can not be evaluated the rate of stress within the tree by measuring moisture and nutrient status of soil. Thus the rate of water and elements stresses within the tree is indicative of tree crown condition.

Acknowledgements

Authors would thank the lab manager of Tarbiat Modares University for him assistance during nutrients analyses and also would thank the head of Ilam Agricultural and Natural Resources Research and Education Center for assistance during field work.

Funding

This study was funded by Tarbiat Modares University for nutrient analyses in laboratory and Ilam Agricultural and Natural Resources Research and Education Center for field sampling. But no funding was received to assist with the preparation and submission of this manuscript.

Financial interests

The authors declare that they have no financial interests.

Conflict of interest

The authors declare that they have no conflict of interest.

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