

Assessment of root-shoot ratio biomass and carbon storage of *Quercus brantii* Lindl. in the central Zagros forests of Iran

YOUSEF ASKARI^{1*}, ALI SOLTANI¹, REZA AKHAVAN², PEJMAN TAHMASEBI KOHYANI³

¹Department of Forest Science, Faculty of Natural Resources and Earth Sciences, Shahrekord University, Shahrekord, Iran

²Research Institute of Forests and Rangelands, Agricultural Research Education and Extension Organization (AREEO), Tehran, Iran

³Department of Rangeland and Watershed Management, Faculty of Natural Resources and Earth Sciences, Shahrekord University, Shahrekord, Iran

*Corresponding author: askari.yousef@yahoo.com

Abstract

Askari Y., Soltani A., Akhavan R., Tahmasebi Kohyani P. (2017): Assessment of root-shoot ratio biomass and carbon storage of *Quercus brantii* Lindl. in the central Zagros forests of Iran. J. For. Sci., 63: 282–289.

Assessment of carbon storage build-up in tree stems is a difficult task due to the lack of information on their carbon sequestration potential and allocation in different components. Similarly, high cost and complex methodology for accurate belowground biomass estimation make it in particular problematic. To this end, 18 Persian oak (*Quercus brantii* Lindley) trees from two growth forms in western Iran were destructively sampled to develop biomass and carbon mass prediction. Sampling covered a range of ages (40–145-year-old), sizes (DBH 7–38 cm) and mean crown diameter (1.9–8.55 m). We examined biomass proportion and carbon sequestration quantity at individual tree and growth form levels, which were: coppice and high forest. One-way ANOVA was used to test the significant differences in carbon concentration, biomass and carbon pools between the components of the two growth forms. Results showed that there was a difference in average biomass and carbon sequestration of trees from the two growth forms. The biomass distribution pattern was similar in the two growth forms. Amounts of stored biomass in trunk, stump, branch, twig and foliage were 24.79, 6.01, 63.82, 2.53 and 2.93% of aboveground components for high forest and 16.4, 10.12, 65.83, 4.23 and 3.46% for corresponding coppice trees. The average biomass of the root-shoot ratio in high-forest and coppice trees was determined 0.72 and 0.88, respectively. A general decline in these proportions was detected as the size of trees increased. We recommend a root-shoot ratio of 0.80 to be adopted for Persian oak.

Keywords: carbon sequestration; crown diameter; component; Persian oak; growth form

Persian oak (*Quercus brantii* Lindley) comprises more than 90% of the Zagrosian forests and similarly a major part of its woody biomass storage, however researches on the extent of its above- and belowground biomass storage per tree are still scarce. Assessment of carbon storage build-up in tree stems is a difficult task due to the lack of information on their carbon sequestration potential and allocation in different components. Similarly,

high cost and complex methodology for accurate belowground biomass estimation make it in particular problematic. Nevertheless, the understanding of carbon turnover in forest ecosystems cannot be achieved without having some quantification of these main carbon pools (CAIRNS et al. 1997).

To resolve the problem, it has been demonstrated that a steady allometric relation exists between above- and belowground biomass for each

tree species, which can be used satisfactorily by a range of ecological studies such as tree-based trophic chains, biogeochemical cycles and even climate change (ENQUIST, NIKLAS 2002; REICH 2002; MOKANY et al. 2006). The above- and belowground biomass relationship is commonly described as a root-shoot ratio, where root or belowground biomass is a dependent parameter (BROWN 2002; LI et al. 2003).

As a result of the allometric growth differentiation, the root-shoot ratio often decreases as tree age or size increases. Then the highest values for the ratio are found when seed radicle emergence occurs (RUTHERFORD 1983; MOKANY et al. 2006). This distinctive feature of the ratio makes it worth to study at both the tree level and the stand level. However, the model is more accurate at a tree level. Other well suited ratio applications are carbon sequestration studies in afforestation projects and even-aged stands which are highly dependent on tree species composition, density, site topography, climate and cohort class distribution (VUCETICH et al. 2000; PUSSINEN et al. 2002).

In tree seedlings the ratio may typically average around 0.2 in fertile soils, and increase to 0.4 in infertile soils or after conditioning treatments undertaken in the nursery (ROOK 1971; NAMBIAR 1980; PAYN 1991). However, there are unexpected reports, e.g. root-shoot ratios in *Pinus radiata* D. Don fluctuated between 0.08 and 0.58 in older trees (RITCHIE 1977).

An average root-shoot ratio of 0.32 was reported for the genus *Quercus* sp. and other temperate deciduous broadleaved trees in China forests (LUO et al. 2012). MACDICKEN (1977) concluded that a coefficient of 0.2 could be considered for the root-shoot ratio at a stand level for agroforestry (farm forestry) systems. The same value was reported for *Pinus taeda* Linnaeus in the United States (BEETS et al. 2007). In central Japan, changing root-shoot values between 0.2 and 0.4 were reported for deciduous dicotyledonous trees (CAO, OHKUBO 1998).

The tree growth form has a notable effect on the root-shoot ratio. Coppicing usually increases the photosynthetic efficiency (TSCHAPLINSKI, BLAKE 1989) and trees may need fewer branches and less foliage for maintenance. KRUGER and REICH (1993) showed that the root-shoot ratio increased in greenhouse-grown English oak seedlings under coppicing treatment. Evidences on the effect of coppicing on the root-shoot ratio are few, however it appears that the subject is common in broadleaves (REICH 2002). No study on either large-root biomass or root-shoot ratios for Zagrosian forests

of western Iran was found in the literature. Based on our knowledge, the potential of carbon storage and root-shoot ratio of high forests and coppice plantations have been examined in numerous studies, while not much on the amount of carbon stored in the above- and belowground tree parts, particularly in Zagrosian forests.

Persian oak covers most of the forests throughout three countries of Iran, Iraq and Turkey. Its versatile growth forms allow it to be seen in both high-forest and coppice growth forms in a single site (TALEBI et al. 2006). Zagrosian forests in the west of Iran (approximately 3 million ha area) include various oak species, which are mostly dominated by *Q. brantii*, *Quercus infectoria* Olivier, and *Quercus libani* Olivier (FATTAHI 1995). This phenotypic plasticity gives *in situ* observers an opportunity to compare the root-shoot ratio between two growth forms of Persian oak, i.e. high forest with trees of seed origin and coppice forest with trees of vegetative origin at different tree ages and sizes.

It is assumed that the young coppice trees are later affected by the stresses, therefore we expect that the root-shoot ratio of small trees in both growth forms would not be different; however, whether the ratio similarity remains the same is the aim of the present study.

MATERIAL AND METHODS

Study area. This study was carried out in the central Zagros region in the west of Iran between the coordinates 50°12'14" to 50°33'25"E and 31°35'05" to 31°58'12"N (Fig. 1). The area mostly consists of hills and mountains of gentle slope. The altitude ranges from 580 to 3,000 m a.s.l. Mean annual temperature and precipitation are 24°C and 694 mm, respectively. The dominant tree species is Persian oak (90%) along with hawthorn (*Crataegus rhipidophylla* Gandoger) and wild almond (*Prunus dulcis*

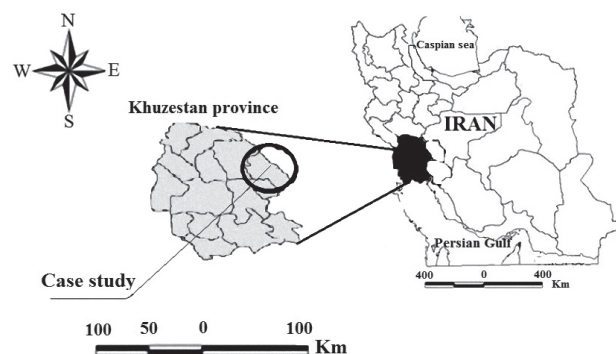


Fig. 1. Location of the study area in the west of Iran

Miller) (FATTAHI 1995). The area is covered by forest, shrub land, agriculture, settlements, villages, riverbeds and water body. The forest density in high and coppice forests is 66.88 and 62.88 tree per hectare, respectively.

Three main orders of soil consist of Mollisols, Entisols, Inceptisols, and Alfisols can be found in the study area (TORAHI, CHAND RAI 2011).

Methods. In the late spring of 2015, 18 Persian oak trees at the identical altitude and aspect were chosen based on stem size (DBH) and crown diameter classes from high and coppice forest trees, respectively (Fig. 2). All trees ($n = 9$) from the coppice growth form produced the same number of shoots. The reason of using crown diameter in coppice trees in this study is that they do not have a single main stem for measurement; therefore crown diameter is used instead of stem diameter in this kind of forests (ZOBEIRI 1994). Then the selected trees were cut down and their trunk was detached.

Tree crowns were defoliated manually and trunks and major branches were debarked. Small branches with leaf scars (twigs) were also dissected. For root measurement, the surface soil around the stump and out to the sub-plot boundaries was excavated. An excavation depth was typically around 6–8 m, including all zones of surface root proliferation. Sampling to the vertical projection of the crown may be relevant. This could be simplified by sampling to a radius equal to the average crown radius (SNOWDON et al. 2002). Stump and all attached underground woody organs (roots) were exhumed and cleaned.

Fresh weight of roots, foliage, twigs, branches, stump and trunks was measured using a battery-powered bascule in the field. An appropriate sample size from each above-mentioned tree components was stored in a sealed container. The entire tissue samples were collected from each part of the trees and representative subsamples were removed using a chainsaw and branch clipper to determine water content. All tissues were dried to constant weight at 80°C. The percentage of carbon in all samples was determined using a combustion method. The combustion method was used to determine carbon concentrations of different tissues (TSI, Inc. 2004). The moisture content percentages were then used to calculate the biomass weight for each tree part. A considerable portion from each tree part was also moved to the lab and its total organic carbon was analysed using the combustion method (MACDICKEN 1977).

The normality of the data was explored by the Kolmogorov-Smirnov test. Percentage values were

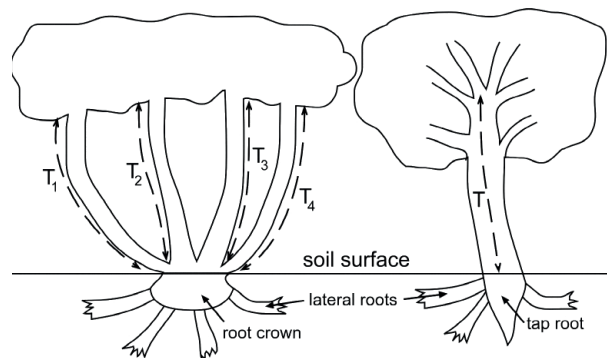


Fig. 2. Differences between the two growth forms of Persian oak. Having several shoots or trunks (T_1 – T_4 in this case) and existence of a major root crown are the characteristic features of a coppice tree (left), and standing on a single trunk (T) as well as a prominent tap root are associated with a high-forest tree

transformed by an arcsin function to normal distribution. One-way ANOVA was used to test significant differences in carbon concentration, biomass and carbon pools between the two growth forms as well as in biomass and carbon concentration between different tree parts.

RESULTS

As the size of the trees increased, plant tissues were partitioned differently in high and coppice trees. In the high-forest growth form, weight of both trunks and branches remained constant at mid DBH and beyond. Even the weight of foliage comparatively decreased in trees of high DBH classes (Fig. 3a). The proportional distribution of biomass at the aboveground tree scale was as follows: trunk 24.79%, branch 63.82%, twig 2.53%, foliage 2.93%. In high-forest oak trees, the relationship between tree DBH (as independent variable) and biomass storage in all components (as dependent variables) was evaluated. R^2 measures were maximal in the branch and the lowest in the foliage component (Fig. 3a).

Table 1 shows the average of dry to fresh weight ratio (DW/FW) as well as the ratio of carbon sequestration in different organs of the high-forest and coppice trees. In fact, the amount of available water in various organs of the tree can be presented according to this ratio. The highest part of the water exists in the leaves, while the lowest in the trunk. Small organs store a large amount of water, while the large organs keep little water. In addition, the evaluation of the potential carbon sequestration requires the exact consideration of carbon amount

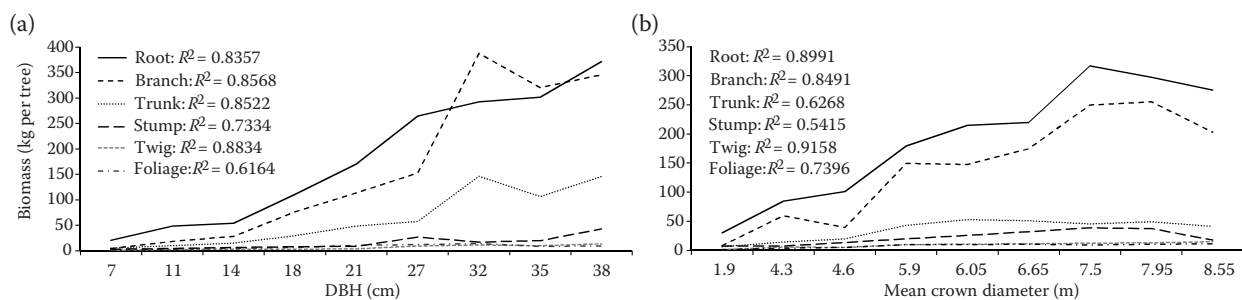


Fig. 3. Biomass production and partitioning in Persian oak trees with high-forest (a), coppice (b) growth form

in tree tissues, which was considered as 50% of tree biomass in most studies (THOMAS, MARTIN 2012). Our results showed that carbon sequestration was variable in different tissues of trees. The average carbon sequestration in different organs of the coppice trees showed no significant differences compared to high-forest trees. However, in this vegetation form, the value of DW was higher than FW compares to the high-forest form. This change was perfectly clear in twigs, however, the rate of the change was not so sensible in the other parts.

Fig. 3b shows the values of aboveground and root biomass at different crown diameters of coppice oak trees. Unlike the high-forest trees, the coppice biomass amount was not in an uptrend. Finally, the total mean aboveground and root biomass was calculated as 217 and 191 kg, respectively. In coppice oak trees, the relationship between tree mean crown diameter and biomass storage in all components was evaluated. R^2 measures were maximal in the root component (Fig. 3b).

Since the classification of these two vegetation forms was accomplished in different ways, there was no possibility for pair comparison; however, the comparison of the average amount of carbon storage at the same organs in both vegetation forms was performed using an independent t -test. Results showed that there were no statistical differences between the same various parts in terms of biomass and carbon sequestration amounts

($P < 0.05$) (Fig. 4). However, the carbon and biomass root-shoot ratio was higher in coppice trees (0.88) followed by high trees (0.72). Branches had the highest amount while foliage and twigs had the lowest amount of biomass and carbon storage.

In other words, the root amount of coppices was higher than that of high forests, while the amount of carbon allocation and shoot biomass in coppices was lower than that of high forests (Fig. 5). This is due to a continuous pruning of coppice trees in response to feeding animals and other consumptions by forest dwellers and villagers in the studied area.

The overall (both on land and roots) averages of carbon balance were approximately close to each other in both vegetation forms (i.e. 200 and 213 kg for coppice and high forest, respectively).

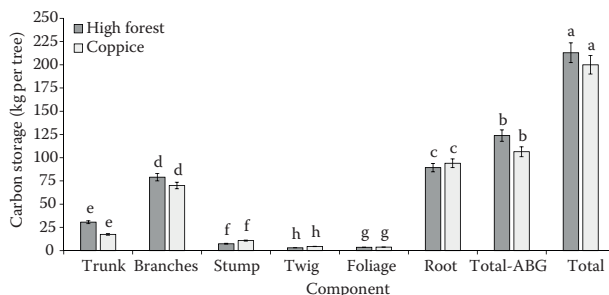


Fig. 4. Carbon storage in different tree components of the two forms of Persian oak

ABG – aboveground biomass

Table 1. Mean dry to fresh weight ratio (DW/FW) and carbon concentration \pm standard deviation in different parts of the high-forest and coppice trees

Component	High forest		Coppice	
	mean (DW/FW)	carbon concentration (%)	mean (DW/FW)	carbon concentration (%)
Trunk	0.68 \pm 1.03 ^a	48.83 \pm 1.0 ^a	0.67 \pm 0.94 ^a	48.75 \pm 1.05 ^a
Stump	0.68 \pm 0.94 ^a	49.01 \pm 1.1 ^a	0.68 \pm 0.91 ^a	48.97 \pm 0.90 ^a
Branches	0.62 \pm 0.67 ^b	49.10 \pm 0.95 ^a	0.63 \pm 0.85 ^a	49.00 \pm 0.81 ^a
Twig	0.57 \pm 0.92 ^c	48.50 \pm 1.2 ^a	0.61 \pm 0.99 ^a	48.42 \pm 1.1 ^a
Foliage	0.53 \pm 0.60 ^c	47.15 \pm 1.3 ^b	0.53 \pm 0.72 ^b	47.05 \pm 1.05 ^b
Roots	0.63 \pm 0.57 ^b	48.97 \pm 1.0 ^a	0.66 \pm 0.77 ^a	48.90 \pm 0.96 ^a

values in the same row followed by the same letter are not significantly different ($P < 0.05$)

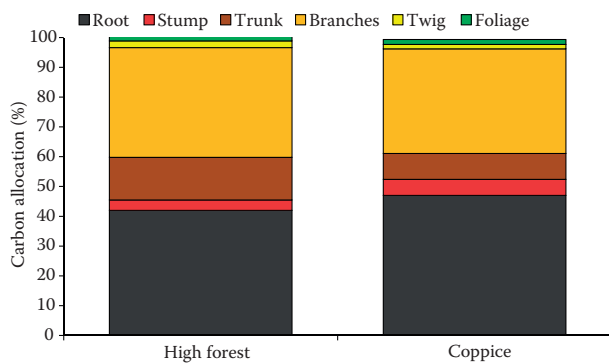


Fig. 5. Proportions of carbon allocation in different components of a tree

Figs 6a, b show relationships between root-shoot ratios by DBH and mean crown diameter at coppice and high-forest forms. This amount has a descending status from small to large diameters in high-forest trees. However, in coppice trees, it is first ascending and then comes to uniform.

DISCUSSION

An average coppice oak tree in this study had a significantly higher mean root-shoot ratio (0.88) than high-forest trees (0.72). In fact, root-shoot ratios for both growth forms were higher than the range of 0.20–0.30 ratios found in most temperate forest trees, even when high forests trees are excluded (RODIN, BAZILEVICH 1967; SANTANTONIO et al. 1977; LUO et al. 2012).

The root-shoot ratio in both high-forest and coppice forms had a nearly descending trend from small to large diameter classes, so that it reached its maximum amount in the small diameter classes and minimum amount in the larger ones (Figs 6a, b). This changing pattern is seen in all trees and shrubs of the regions with suitable precipitation for creation a forest (ASSMANN 1970; PRETZSCH 2010).

Nevertheless, a sudden reduction in the rate of biomass accumulation in both aboveground and belowground parts of both high-forest and coppice forms of *Q. brantii* trees could mean a full compatibility of this tree to the harsh and stressful conditions of central Zagros forests.

High root-shoot ratios had been previously achieved for *Quercus* sp., *Fraxinus angustifolia* Vahl and *Castanea sativa* Miller (RUIZ-PEINADO et al. 2012). Different values reported in the literature suggest that root-shoot ratios may not be static relationships; and it may depend on tree age (PEICHL, ARAIN 2007), species, i.e. hardwood or softwood (KURZ et al. 1996) as described in this study; or surrounding abiotic factors (CAIRNS et al. 1997). For these reasons, more data from different sites and developmental stages would be needed to support the values presented here. Our findings are in contradiction to the results of RUIZ-PEINADO et al. (2012), who measured the root-shoot ratio for *Quercus canariensis* Willdenow, *Quercus faginea* Lamarck, *Quercus ilex* Linnaeus, *Quercus pyrenaica* Willdenow, and *Quercus suber* Linnaeus as much as 0.490, 0.357, 0.323, 0.353 and 0.31 respectively, in a forest stand in Spain.

One reason for the higher root-shoot biomass ratios for coppice trees in our study is the consideration of the multi-stemmed structure of the tree, since trees are commonly considered as discrete units (originated from seeds) in most root-shoot reports. Mean root-shoot ratios of other clonal *Quercus* Linnaeus tree species were high when the whole root system of multi-stemmed trees was excavated: 1.2 and 0.91 for *Q. ilex* (CANADELL, RODA 1991; SERRADA et al. 1992), 3.5 for *Quercus coccifera* Linnaeus (CAÑELLAS REY DE VIÑAS, SAN MIGUEL AYANZ 2000), and 2.2 for *Quercus aquifolioides* Rehder (ZHU et al. 2012). Another reason explaining high ratios of these studies and of *Q. brantii* here is the resprouting nature of the species. Resprouters

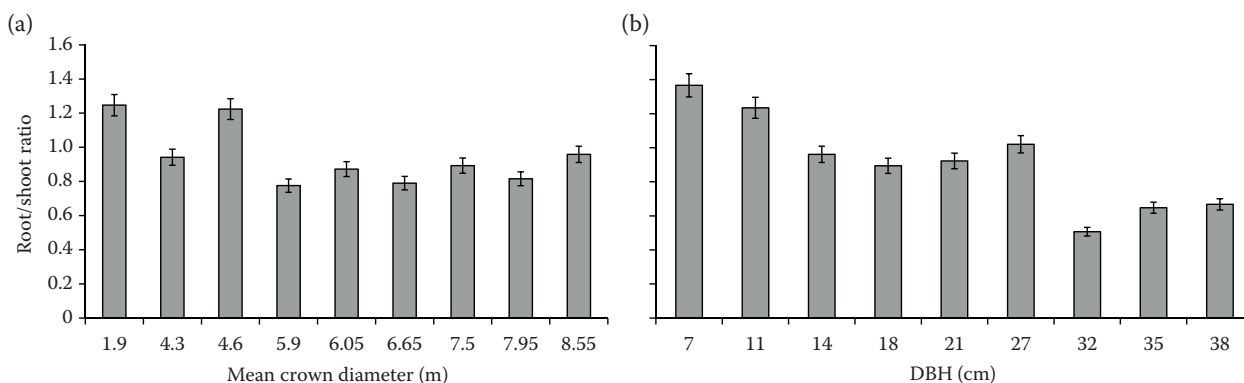


Fig. 6. The relationships between the root-shoot ratio and mean crown diameter in coppice trees (a), DBH in high-forest trees (b)

allocate more biomass into roots than seeders under similar growing conditions (BOND, MIDGLEY 2001; CLARKE et al. 2013).

The difference in root-shoot ratios between high-forest and coppice trees in this study may probably arise from frequent wood harvest in the coppice trees. On the other hand, shortage in water availability in companion with poor soil content would significantly drop raw supply for the photosynthetic demand on a crown level (BRAY 1963; WHITTAKER, MARKS 1975; HIROSE, KITAJIMA 1986).

In our study, the crown biomass proportion for Persian oaks was similar (more than 40%) to Mediterranean species like *Q. ilex*, *Q. suber*, *Ceratonia siliqua* Linnaeus and *Q. canariensis* as well as it was higher than 35% of Eurosiberian species like *Alnus glutinosa* Linnaeus and *Fagus sylvatica* Linnaeus (LUO et al. 2012). The value was also higher than corresponding measurements in softwood tree species like *Pinus halepensis* Miller or *Pinus uncinata* De Candolle (RUIZ-PEINADO et al. 2012). The highest root-shoot ratio reported for European oak seedlings was less than 0.4 (NORBY et al. 1986; CASTELL et al. 1994).

For other species, in the case of *F. sylvatica* (a value of 0.163 according to the results of this study) LEBAUPE et al. (2000) found a very similar value (0.15) in France. In the same way, the value found for *Q. ilex* (0.357) was similar to the value reported by CANADELL, RODA (1991) in Cataluña, northeastern Spain (0.41). In other cases, the results vary slightly from other studies, such as the case of poplar in which FEDERICI et al. (2008) reported a value of 0.21 in Italy. MOKANY et al. (2006) presented root-shoot ratios according to vegetation categories, including oak forests where a value of 0.295 was found. Moreover, others like CAIRNS et al. (1997) and MOKANY et al. (2006) did not find any differences between mixtures of (softwood and hardwood) species; when Spanish species are concerned, the differences between groups are substantial: a mean value of 0.466 for hardwoods (from 13 species in the Iberian peninsula) and a mean value of 0.265 for softwood species found by RUIZ-PEINADO et al. (2012).

The root-shoot ratio often decreases with increasing plant age or size as a result of differences in the allometric growth of roots and shoots (RUTHERFORD 1983; MOKANY et al. 2006), when we detected such a trend in high-forest and coppice oaks.

Moreover, on a more general scale, the process of carbon sequestration was different in vegetation forms of high and coppice forest of oaks at a stem level over time (HOCHBICHLER 1993; BRUCKMAN et al. 2011).

Carbon concentrations differ by tree forms and components. Carbon content of tree components varies (Table 1). The average carbon concentration including all tree parts was higher in high forest followed by coppice. The mean carbon concentration was found very close to 50% of biomass often used to estimate carbon storage from dry biomass. KRAENZEL et al. (2003) reported the range of 45.2 to 50.4% of carbon storage in different tree components, which was confirmed by the present study.

SMIT et al. (1996) considered the lack of macronutrients, especially nitrogen and sulphur for *Castanea pumila* Miller and low water for *Combretum erythrophyllum* Sonder coppices, as the cause of this reaction, if any coppice competition existed. Similar results were reported for a sharp drop in growth due to food shortages in the coppice forests of *Quercus petraea* (von Mattuschka) Lieblein (ANDRE, PONETTE 2003), lack of symmetric increase in crown diameter (which is synonymous with an increase in the number of shoots) and increase in biomass accumulation in shoots and roots of coppice trees.

This recent reason means that the rapid growth in coppice trees likely causes the rapid accumulation of tissues in need of food, especially in twigs and small branches; which in the case, the photosynthetic leaves would not have the ability of feeding the new tissue mass. Therefore, the basis of methods for mass thinning of coppice oak is principally an adjustment of the ratio of trees crown to their height in the Mediterranean region (MONTES et al. 2004).

CONCLUSIONS

In this study, biomass and carbon storage as well as the ratio of root biomass to the aboveground components of oak trees were evaluated in a part of Zagrosian forests in the west of Iran. In fact, oak trees are found in two vegetation forms of high forest and coppice in the studied area.

While root-shoot ratios varied markedly among the studies reviewed in this paper, these variations were predominantly due to sampling and methodological limitations. We recommend a root-shoot ratio of 0.80 to be adopted for Persian oak.

We assume that the warm and dry climate is a limiting factor in the study region; hence coppicing has the advantage of a fully functional root system after harvesting, facilitating rapid resprouting even under conditions of low precipitation and drying topsoil.

The reason for a high value of this ratio for young Persian oak trees may be due to their almost constant exposure to exploitation stress for firewood. Resprouters allocate more biomass into roots than seeders under similar growing conditions.

It is important to consider different carbon storage patterns among the growth forms of trees. Some species store more carbon in the soil while the others store more carbon in their living tissues. Each species, due to the characteristics of physiology, phenology and morphology, may need to be managed in different ways.

References

- Andre E., Ponette Q. (2003): Comparison of biomass and nutrient content between oak (*Quercus petraea*) and hornbeam (*Carpinus betulus*) trees in a coppice-with-standards stand in Chimay (Belgium). *Annals of Forest Science*, 60: 489–502.
- Assmann E. (1970): *The Principles of Forest Yield Study: Studies in the Organic Production, Structure, Increment, and Yield of Forest Stands*. Oxford, New York, Toronto, Sydney, Braunschweig, Pergamon Press: 506.
- Beets P.N., Pearce S.H., Oliver G.R., Clinton P.W. (2007): Root-shoot ratios for deriving below-ground biomass of *Pinus radiata* stands. *New Zealand Journal of Forestry Science*, 37: 267–288.
- Bond W.J., Midgley J.J. (2001): Ecology of sprouting in woody plants: The persistence niche. *Trends in Ecology & Evolution*, 16: 45–51.
- Bray J.R. (1963): Root production and the estimation of net productivity. *Canadian Journal of Botany*, 41: 65–72.
- Brown S. (2002): Measuring carbon in forests: Current status and future challenges. *Environmental Pollution*, 116: 363–372.
- Bruckman V.J., Yan S., Hochbichler E., Glatzel G. (2011): Carbon pools and temporal dynamics along a rotation period in *Quercus* dominated high-forest and coppice with standards stands. *Forest Ecology and Management*, 262: 1853–1862.
- Cairns B., Carlson B.E., Laxis A.A., Russell E.E. (1997): An analysis of ground-based polarimetric sky radiance measurements. In: Goldstein D.H., Chenault D.B. (eds): *Polarization: Measurement, Analysis, and Remote Sensing*, San Diego, July 27, 1997: 387–398.
- Canadell J., Roda F. (1991): Root biomass of *Quercus ilex* in a montane Mediterranean forest. *Canadian Journal of Forest Research*, 21: 1771–1778.
- Cañellas Rey de Viñas I., San Miguel Ayanz A. (2000): Biomass of root and shoot systems of *Quercus coccifera* shrublands in Eastern Spain. *Annals of Forest Science*, 57: 803–810.
- Cao K.F., Ohkubo T. (1998): Allometry, root/shoot ratio and root architecture in understory saplings of deciduous dicotyledonous trees in central Japan. *Ecological Research*, 13: 217–227.
- Castell C., Terradas J., Tenhunen J. (1994): Water relations, gas exchange, and growth of resprouts and mature plant shoots of *Arbutus unedo* L. and *Quercus ilex* L. *Oecologia*, 98: 201–211.
- Clarke P., Lawes M., Midgley J., Lamont B., Ojeda F., Burrows G., Enright N., Knox K. (2013): Resprouting as a key functional trait: How buds, protection and resources drive persistence after fire. *New Phytologist*, 197: 19–35.
- Enquist B.J., Niklas K.J. (2002): Global allocation rules for patterns of biomass partitioning in seed plants. *Science*, 295: 1517–1520.
- Fattahi M. (1995): *Investigation of Zagros Natural Resources and the Important Factors of Demolition*. Tehran, Research Institute of Forests and Rangelands: 57.
- Federici S., Vitullo M., Tulipano S., De Lauretis R., Seufert G. (2008): An approach to estimate carbon stocks change in forest carbon pools under the UNFCCC: The Italian case. *iForest – Biogeosciences and Forestry*, 1: 86–95.
- Hirose T., Kitajima K. (1986): Nitrogen uptake and plant growth. I. Effect of nitrogen removal on growth of *Polygonum cuspidatum*. *Annals of Botany*, 58: 479–486.
- Hochbichler E. (1993): Methods of oak silviculture in Austria. *Annals of Forest Science*, 50: 583–591.
- Kraenzel M., Castillo A., Moore T., Potvin C. (2003): Carbon storage of harvest-age teak (*Tectona grandis*) plantations, Panama. *Forest Ecology and Management*, 173: 213–225.
- Kruger E.L., Reich P.B. (1993): Coppicing affects growth, root-shoot relations and ecophysiology of potted *Quercus rubra* seedling. *Journal of Plant Physiology*, 89: 751–760.
- Kurz W., Beukema S., Apps M. (1996): Estimation of root biomass and dynamics for the carbon budget model of the Canadian forest sector. *Canadian Journal of Forest Research*, 26: 1973–1979.
- Lebaube S., Le Goff N., Ottorini J.M., Granier A. (2000): Carbon balance and tree growth in a *Fagus sylvatica* stand. *Annals of Forest Science*, 57: 49–61.
- Li Z., Kurz W.A., Apps M.J., Beukema S.J. (2003): Below-ground biomass dynamics in the carbon budget model of the Canadian forest sector: Recent improvements and implications for the estimation of NPP and NEP. *Canadian Journal of Forest Research*, 33: 126–136.
- Luo Y., Wang X., Zhang X., Booth T., Lu F. (2012): Root:shoot ratios across China's forests: Forest type and climatic effects. *Forest Ecology and Management*, 269: 19–25.
- MacDicken K.G. (1997): *A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects*. Winrock International Institute for Agricultural Development: 91.
- Mokany K., Raison R.J., Prokushkin A.S. (2006): Critical analysis of root-shoot ratios in terrestrial biomes. *Global Change Biology*, 11: 1–13.
- Montes F., Cañellas I., del Río M., Calama R., Montero G. (2004): The effects of thinning on the structural diversity of coppice forests. *Annals of Forest Science*, 61: 771–779.

- Nambiar E.K.S. (1980): Root configuration and root regeneration in *Pinus radiata* seedlings. *New Zealand Journal of Forestry Science*, 10: 249–263.
- Norby R.J., O'Neill E.G., Luxmoore R.J. (1986): Effects of atmospheric CO₂ enrichment on the growth and mineral nutrition of *Quercus alba* seedlings in nutrient-poor soil. *Plant Physiology*, 82: 83–89.
- Payn T.W. (1991): The effects of magnesium fertiliser and grass on the nutrition and growth of *P. radiata* planted on pumice soil in the Central North Island of New Zealand. [Ph.D. Thesis.] Christchurch, University of Canterbury: 119.
- Peichl M., Arain M.A. (2007): Allometry and partitioning of above- and belowground tree biomass in an age-sequence of white pine forests. *Forest Ecology and Management*, 253: 68–80.
- Pretzsch H. (2010): *Forest Dynamics, Growth and Yield: From Measurement to Model*. Berlin, Springer-Verlag: 664.
- Pussinen A., Karjalainen T., Mäkipää R., Valsta L., Kellomäki S. (2002): Forest carbon sequestration and harvests in Scots pine stand under different climate and nitrogen deposition scenarios. *Forest Ecology and Management*, 158: 103–115.
- Reich P.B. (2002): Root-shoot relations: Optimality in acclimation and adaptation or the “Emperor’s new clothes”? In: Waisel Y., Eshel A., Kafkafi U. (eds): *Plant Roots: The Hidden Half*. New York, Marcel Dekker: 205–220.
- Ritchie I.M. (1977): Some observations on the roots of *Pinus radiata* on coastal sand dunes in the Manawatu. In: Neall V.E. (ed.): *Soil Groups of New Zealand. Part 2. Yellow Brown Sands*. Lower Hutt, New Zealand Society of Soil Science: 169–171.
- Rodin L.E., Bazilevich N.I. (1967): *Production and Mineral Cycling in Terrestrial Vegetation*. London, Oliver and Boyd: 288.
- Rook D.A. (1971): Effect of undercutting and wrenching on growth of *Pinus radiata* D. Don seedlings. *Journal of Applied Ecology*, 8: 477–490.
- Ruiz-Peinado R., Montero G., del Río M. (2012): Biomass models to estimate carbon stocks for hardwood tree species. *Forest Systems*, 21: 42–52.
- Rutherford M.C. (1983): Growth rates, biomass and distribution of selected woody plant roots in *Burkea africana-Ochona pulchra* savanna. *Vegetatio*, 52: 45–63.
- Santantonio D., Hermann R.K., Overton W.S. (1977): Root biomass studies in forest ecosystems. *Pedobiologia*, 17: 1–31.
- Serrada R., Allué M., San Miguel A. (1992): The coppice system in Spain. Current situation, state of art and major areas to be investigated. *Annali dell’Istituto Sperimentale per la Selvicoltura*, 23: 266–275.
- Smit G.N., Rethman N.F.G., Moore A. (1996): Review article: Vegetative growth, reproduction, browse production and response to tree clearing of woody plants in African savanna. *African Journal of Range & Forage Science*, 13: 78–88.
- Snowdon P., Raison J., Eamus D. (2002): *Protocol for Sampling Tree and Stand Biomass*. Sydney, Australian Greenhouse Office Publication: 67.
- Talebi M., Sagheb-Talebi K., Jahanbazi H. (2006): Site demands and some quantitative and qualitative characteristics of Persian oak (*Quercus brantii* Lindl.) in Chaharmahal & Bakhtiari province (western Iran). *Iranian Journal of Forest and Poplar Research*, 14: 67–79.
- Thomas S.C., Martin A.R. (2012): Carbon content of tree tissues: A synthesis. *Forests*, 3: 332–352.
- Torahi A.A., Chand Rai S. (2011): Land cover classification and forest change analysis, using satellite imagery – a case study in Dehdez area of Zagros Mountain in Iran. *Journal of Geographic Information System*, 3: 1–11.
- Tschaplinski T.J., Blake T.J. (1989): Photosynthetic reinvigoration of leaves following shoot decapitation and accelerated growth of coppice shoots. *Journal of Plant Physiology*, 75: 157–165.
- TSI, Inc. (2004): *Combustion Analysis Basics: An Overview of Measurements, Methods and Calculations Used in Combustion Analysis*. TSI, Inc.: 35.
- Vucetich J.A., Reed D.D., Brey Meyer A., Degórski M., Mroz G.D., Solon J., Roo-Zielinska E., Noble R. (2000): Carbon pools and ecosystem properties along a latitudinal gradient in northern Scots pine (*Pinus sylvestris*) forests. *Forest Ecology and Management*, 136: 135–145.
- Whittaker R.H., Marks P.L. (1975): Methods of assessing terrestrial productivity. In: Lieth H., Whittaker R.H. (eds): *Primary Productivity of the Biosphere*. New York, Springer-Verlag: 55–118.
- Zhu W.Z., Xiang J.S., Wang S.G., Li M.H. (2012): Resprouting ability and mobile carbohydrate reserves in an oak shrubland decline with increasing elevation on the eastern edge of the Qinghai-Tibet Plateau. *Forest Ecology and Management*, 278: 118–126.
- Zobeiri M. (1994): *Forest Inventory (Measurement of Tree and Stand)*. Tehran, University of Tehran: 401.

Received for publication December 29, 2015

Accepted after corrections May 16, 2017