Arboriculture & Urban Forestry 2018. 44(5):215–223

Acorn Biomass and Carbon Stock Variation in Five Oak Species Planted in the National Botanical Garden of Iran

Parisa Panahi, Mehdi Pourhashemi, and Maryam Hasaninejad

Abstract. Botanical gardens, as one of the most important urban forests to any region, play an important role in the ecology of human habitats in many ways (e.g., air filtering). The National Botanical Garden of Iran, with an area of 145 ha, includes various woody species with a predominance of oaks (*Quercus* spp.). The size of acorns, fruits of oaks, varies in different species, which can affect their biomass. The biomass and carbon content of acorn components (endocarp, pericarp, and cupule) of four native oak species (*Q. castaneifolia* C.A. Mey., *Q. libani* Oliv., *Q. infectoria* Oliv., and *Q. brantii* Lindl.) and one exotic oak species (*Q. ilex* L.), planted in the National Botanical Garden, were studied to obtain detailed comparative results. Regarding the biomass of acorn components, *Q. libani* and *Q. ilex* showed the highest and lowest values among the study species, respectively. The ranges of carbon content of acorn components were 53.5% (pericarp of *Q. brantii*) to 58% (cupule of *Q. castaneifolia*). These results confirm the variation of biomass and carbon content of acorn components among the oak species studied.

Key Words. Acorn; Botanical Garden; Carbon Stock; Cupule; Endocarp; Exotic; Iran; Native; Oak; Pericarp; *Quercus*.

Urban forests are ecosystems characterized by the presence of trees and other vegetation in association with human developments (Miller 1997; Dwyer et al. 2000). There are many positive incentives or rationales for having urban forest ecosystems within cities, including environmental, social, and economic values. From an ecological function point of view, urban forests play an important role in many diverse aspects: reducing carbon dioxide, reducing air temperature, increasing air humidity, reducing wind speed, absorbing air pollutants, reducing noise levels, and providing shelter to animals and recreational areas for people (Streiling and Matzarakis 2003). The National Botanical Garden of Iran, as one of the most important urban forests in Tehran, Iran, is a valuable collection of woody and herbal species. This garden plays an important role in the ecology of human habitats.

Carbon taken up by the forest canopy is allocated to tree organs for biomass production and respiration (Campioli et al. 2010). On the other hand, carbon allocation within a plant depends on complex rules linking carbon source organs (mainly leaves) and carbon sink organs (mainly the sapwood of stems, branches and roots, and fruits) (Génard et al. 2008). Hence, biomass-related studies have become important for studying ecosystem productivity and carbon budgets (Ryu et al. 2004; Thomas and Malczewski 2007; Saatchi et al. 2011).

Aboveground biomass consists of the biomass of all living vegetation above the soil. The carbon stored in the aboveground living biomass of trees is typically the largest pool. Thus, estimating aboveground forest biomass is the most critical step in quantifying carbon stocks.

Carbon (C) allocation among plant processes (e.g., respiration, biomass production) and organs (e.g., leaves, reproductive organs, and stem) is a key process in the C cycle because it determines the residence time and location of C in the ecosystem (Campioli et al. 2008). For example, C allocated to structural biomass of organs with high turnover and decomposition rate, such as deciduous leaves, returns to the atmosphere within few months to years, whereas C allocated to organs with lower turnover and decomposition rate, such as stem wood, returns to the atmosphere only after decades or centuries (Campioli et al. 2008).

In comparison to other components of forest ecosystems, the biomass of fruits is considered to be small (Mälkönen 1974; Muukkonen 2006) and is sometimes dismissed as negligible. However, the biomass of fruits may play an important role in many ecosystem processes, such as in the nutrient and carbon cycle, due to rapid turnover rate (Muukkonen 2006) at the biomass level.

Members of the genus *Quercus* L. (Fagaceae), including evergreen and deciduous shrubs and trees, have a wide geographical range, occupying vast territories of the Northern Hemisphere in North America, Europe, and Asia (Denk and Grimm 2010; Johnson et al. 2010). *Quercus* is the most common genus of Fagaceae in forests of Iran (Sabeti 1994). Several species of oaks grow abundantly in the Zagros, Arasbaran, and Hyrcanian forests (Sagheb Talebi et al. 2014). During four past decades, native oak species of Iran as well as some exotic oak species, have been planted in the National Botanical Garden of Iran. Today, oak species are one of the most important elements of the garden, distributed throughout the garden.

Fruits of oaks, acorns, are usually associated with an involucre forming a cup around the mature fruit. Acorns are hard, one-seeded, and dry. Due to the woody structure, acorns have a considerable role in biomass production and carbon stock in oak-dominated forests. Acorn production varies from year to year and among species (Lashley et al. 2009; Koenig and Knops 2014).

The biomass and carbon content of acorns may differ because of high variation in morphology among oak species. Some researchers have mentioned the variation in acorn biomass of oak species (e.g., Callahan et al. 2008; Steen et al. 2009; Sánchez-Humanes et al. 2011), but the evidence on acorn carbon content is limited (e.g., Sun et al. 2012). On the other hand, only two reports on acorn biomass (Panahi et al. 2009; Iranmanesh et al. 2013) and one report on carbon stock (Iranmanesh et al. 2013) of native oak species of Iran have been published. The present study gives an account on the mature acorn biomass and carbon stock of five oak species, cultivated in the National Botanical Garden of Iran.

The aim of this study was to determine the site-specific acorn biomass, carbon stock, and carbon content of the target species, and to examine if they are significantly different.

MATERIALS AND METHODS

Study Area

The study was conducted at the National Botanical Garden of Iran (35°41’N, 51°19’E) in 2016. The garden was founded in 1968. An area of 145 ha was allocated to the garden in Tehran at an altitude of 1,320 m (Figure 1). The area is flat and slopes gently to the south. The climate is dry with an average annual precipitation of 257 mm, falling between November and May. Temperature reaches as much as 42°C–43°C during July and August. During winter, the temperature may fall to -10°C or lower. The garden consists of some native and exotic collections with different areas. The Hyrcanian and Zagros collections, as symbols of the Hyrcanian and Zagros forests of Iran, are the most important forest collections of the garden. Most of the oak trees are found in these collections. The other individual oak trees are distributed throughout the garden with more density in the Systematic collection.

Study Species

Five oak species were chosen for this study as follows. Four deciduous native oaks of Iran, including chestnut-leaved oak (*Q. castaneifolia*), Lebanon oak (*Q. libani*), Aleppo oak (*Q. infectoria*), and Brant’s oak (*Q. brantii*), as well as one evergreen exotic oak species (*Q. ilex*). All sample oak trees have been planted since 1988. The chestnut-leaved oak is a light-demanding tree and is one of the most productive, valuable, and precious species in the Hyrcanian forests of Iran. Other three native oaks naturally grow in Zagros forests in the west of Iran (Sagheb Talebi et al. 2014). In contrast to the native oaks of Iran studied, *Q. ilex* is an evergreen oak, native to the Mediterranean region. *Quercus ilex* is planted in a number of garden collections, such as the systematic collection.

Figure 1. Map of the National Botanical Garden of Iran (Tehran, Iran), including native, exotic, and subjective collections.

Sampling Procedure

After a garden survey, 15 sample trees were randomly selected for each species. The selected trees were mature and in dominant crown positions. Ten mature and undamaged acorns were selected at random for each sample tree (totally, 150 acorns per species) from different aspects of the crowns or from freshly fallen acorns without regard to acorn size. Samples were placed in plastic bags, and transported to the Forest Research Division laboratory at Research Institute of Forests and Rangelands of Iran. The laboratory is located in the vicinity of the garden.

Laboratory Measurements

Owing to the fact that the C content of acorn components is different, the measurement was done separately. Acorns were divided into three components, including endocarp, pericarp, and cupule (Olson 1974; Figure 2) and labeled. The fresh weight of different components of the acorns was separately weighed by a digital scale with an accuracy of 0.001 g. Then, different components of the acorns were dried in an oven at 80°C to obtain the constant dry weight (Ketterings et al. 2001; Losi et al. 2003). The carbon content of dry biomass samples was obtained by combustion method (Allen et al. 1986).

The normality distribution of variables was assessed by test of Shapiro-Wilk ($P < 0.01$), and one-way ANOVA with Duncan test was used to compare the mean values of variables at the 0.05 probability level.

RESULTS

The normality of data was tested and confirmed. Descriptive statistics of fresh and dry mass of acorn components are given in Table 1. Based on one-way ANOVA analysis, all variables in three acorn components showed significant differences (endocarp fresh mass: $df = 4$, $P < 0.000$, F = 649.527; pericarp fresh mass: $df = 4$, $P < 0.000$, F = 331.074; cupule fresh mass: $df = 4$, $P < 0.000$, F = 381.429; endocarp dry mass: $df = 4$, $P < 0.000$, F = 509.614; pericarp dry mass: $df = 4$, $P < 0.000$, F = 544.949; cupule dry mass: $df = 4$, $P < 0.000$, F = 406.649). In *Q. libani*, the mean values of fresh and dry mass of all acorn components were considerably more than those of the others, so that it was categorized in a separate group. *Quercus ilex* was on the opposite side of *Q. libani*. Other species had an intermediate situation.

The percent of carbon content was calculated for three acorn components (Table. 2). The carbon content of endocarp ranged between 53.8% in *Q. libani* to 57.7% in *Q. ilex*. Also, the carbon content of pericarp ranged between 53.5% in *Q. brantii* to 57.8% in *Q. infectoria*, and for cupule it ranged between 54.2% in *Q. brantii* to 57.9% in *Q. ilex*.

Regarding the carbon content of acorn components, *Q. libani* and *Q. ilex* had the highest and lowest mean values, respectively (Figure 3).

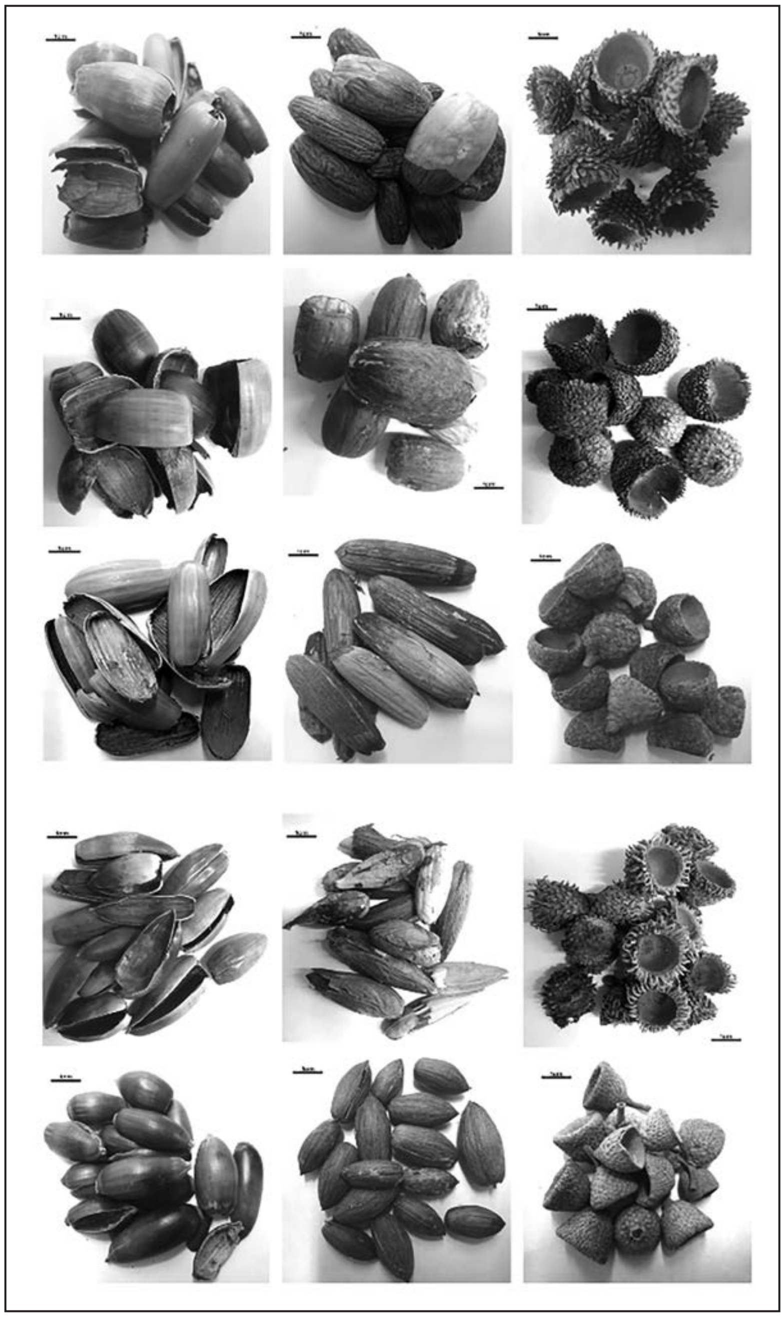

Figure 2. Acorn components of the oak species studied (left column: pericarps; center: endocarps; right: cupules). Species from top to bottom: *Q. castaneifolia, Q. libani, Q. infectoria, Q. brantii,* and *Q. ilex*).

DISCUSSION

This research focused on acorn biomass and carbon content of different oak species, which usually receives less attention. In other words, researchers considered one of the main ecological roles of botanical gardens as one of the most important urban forests. The National Botanical Garden of Iran occupies a vast area in one of the most pollutant cities of the world. In this situation, the ecological role of gardens is more valuable. The garden includes a lot of trees with different sizes and ages, and oaks are the dominant species. This healthy collection is normally considered as a big source for absorbing carbon dioxide from the atmosphere.

Since the forest trees produce seeds with different sizes, their role in carbon sequestration differ significantly. Among tree species, some of them produce large seeds, which could be seen in conifers and some broadleaved species such as oaks. Regarding the biomass production, acorns have two advantages in comparison with other seeds: large size and woody components. Besides, an oak tree produces considerable amount of acorns, especially in mast years. The number of acorns produced per tree ranges from zero to more than 7,000 (Christisen and Kearby 1984; Sork 1993; Pulido 1999; Pourhashemi et al. 2011). In a given area, the number of acorns produced per year may range from zero to more than 650,000/ha, (Auchmoody et al. 1993; Healy et al. 1999; Guariguata and Sáenz 2002). Some researchers have mentioned

Table 1. Descriptive statistics (mean ± SD and range) of acorn components fresh and dry mass. Significant differences in mean fresh and dry mass are denoted by different letters among species.

Variable	Descriptive statistic	Species: *Q. castaneifolia*	*Q. libani*	*Q. infectoria*	*Q. brantii*	*Q. ilex*
Endocarp fresh mass (g)	Mean ± SD	6.2 b ± 0.9	15.4 e ± 2.3	7.68 c ± 1.1	9.1 d ± 0.9	2.57 a ± 0.41
	Range (min–max)	4.9–8.82	10.41–19.36	5.44–10.15	6.54–10.74	1.76–3.31
Pericarp fresh mass (g)	Mean ± SD	1.68 b ± 0.38	5.11 d ± 1.5	1.92 b ± 0.35	4.4 c ± 0.55	0.4 a ± 0.07
	Range (min–max)	0.99–2.58	2.23–7.7	1.29–2.9	3.11–5.56	0.29–0.56
Cupule fresh mass (g)	Mean ± SD	2.84 b ± 0.49	9.46 d ± 2.8	1.1 a ± 0.2	3.52 c ± 0.42	0.7 a ± 0.11
	Range (min–max)	2.09–4.08	5.01–13.68	0.84–1.77	2.91–4.24	0.56–1.01
Endocarp dry mass (g)	Mean ± SD	4.22 b ± 0.8	8.91 d ± 1.23	4.33 b ± 0.64	5.64 c ± 0.89	1.63 a ± 0.28
	Range (min–max)	2.26–6.48	5.87–11.06	3.2–5.71	3.51–7.36	1.03–2.22
Pericarp dry mass (g)	Mean ± SD	1.14 b ± 0.25	3.36 d ± 0.7	1.26 b ± 0.19	1.98 c ± 0.24	0.29 a ± 0.04
	Range (min–max)	0.71–1.62	2.27–4.74	0.89–1.65	1.4–2.49	0.21–0.38
Cupule dry mass (g)	Mean ± SD	1.77 c ± 0.36	6.04 d ± 1.7	0.79 b ± 0.11	2.04 c ± 0.28	0.33 a ± 0.06
	Range (min–max)	1.22–2.54	3.13–9.75	0.61–1.1	1.53–2.74	0.24–0.47

Table 2. Carbon content (mean ± SD and range) of acorn components.

Variable	Descriptive statistic	Species: *Q. castaneifolia*	*Q. libani*	*Q. infectoria*	*Q. brantii*	*Q. ilex*
Carbon content of endocarp (%)	Mean ± SD	57.4 ± 0.2	56 ± 1.4	56.5 ± 0.7	56.7 ± 0.7	57.3 ± 0.2
	Range (min–max)	57.2–57.6	53.8–57.2	55.1–57.6	55.5–57.2	57.1–57.7
Carbon content of pericarp (%)	Mean ± SD	57.5 ± 0.3	55.8 ± 1.1	57.7 ± 0.1	56 ± 1.4	56 ± 0.5
	Range (min–max)	57.1–58	54.5–56.9	57.6–57.8	53.5–56.7	55.5–56.7
Carbon content of cupule (%)	Mean ± SD	57.1 ± 1	55.5 ± 0.9	57.6 ± 0.3	55.6 ± 0.9	57.4 ± 0.5
	Range (min–max)	55.4–58	54.3–56.3	57.2–57.8	54.2–56.8	56.6–57.9

that the acorn biomass could reach more than 15 kg per tree (Panahi et al. 2009; García-Mozo et al. 2012) and 800 kg/ha in bumper and good years (Christisen and Kearby 1984; Drake 1991).

Regarding the biomass of acorn components, *Q. libani* had the highest values among the study species (Table 1). Acorns of *Q. libani* are bigger than the others (Djavanchir Khoie 1967; Sabeti 1994; Figure 2). On the other hand, biomass of acorn components was in the lowest values in *Q. ilex* because of the small size of the acorns (de Rigo and Caudullo 2016).

Most researchers estimate carbon by assuming the carbon content of dry biomass to be a constant 50% by weight (e.g., Montagnini and Porras 1998; Das et al. 2016). However, other authors have used a carbon concentration of 45% by weight (Whittaker and Likens 1973). Limited research (e.g., Cañellas et al. 2008; Li et al. 2015) has used other rates. Occasionally, carbon is measured directly by combustion method or a carbon analyzer (e.g., Kraenzel et al. 2003; Iranmanesh et al. 2013). In the current study, researchers calculated the carbon content of acorns directly by the combustion method, which is a very accurate method. Based on the results, carbon stock (percent) was different among the study species and acorn components (Table 2). The maximum and minimum mean values of carbon content were observed in the pericarp of *Q. infectoria* (57.7%) and the cupule of *Q. libani* (55.5%), respectively. In addition, the ranges of this variable were 53.5% (pericarp of *Q. brantii*) to 58% (cupule of *Q. castaneifolia*) among acorn components of the study species. In a same research in Zagros forests of Iran, the acorn biomass of the seed-originated *Q. brantii* trees was six times more than that of coppice ones, and the carbon content was 40% of its dry weight (Iranmanesh et al. 2013). The mean value of carbon content of 21 oak (*Q. variabilis*) populations in eastern China was calculated to be 43.6% (Sun et al. 2012) as well.

Different values of carbon content have been reported for the fruits of other species (e.g., Geiger et al. 1989; Ogawa and Takano 1997; Campioli et al. 2010; Priyadi et al. 2014; Li et al. 2015) or other

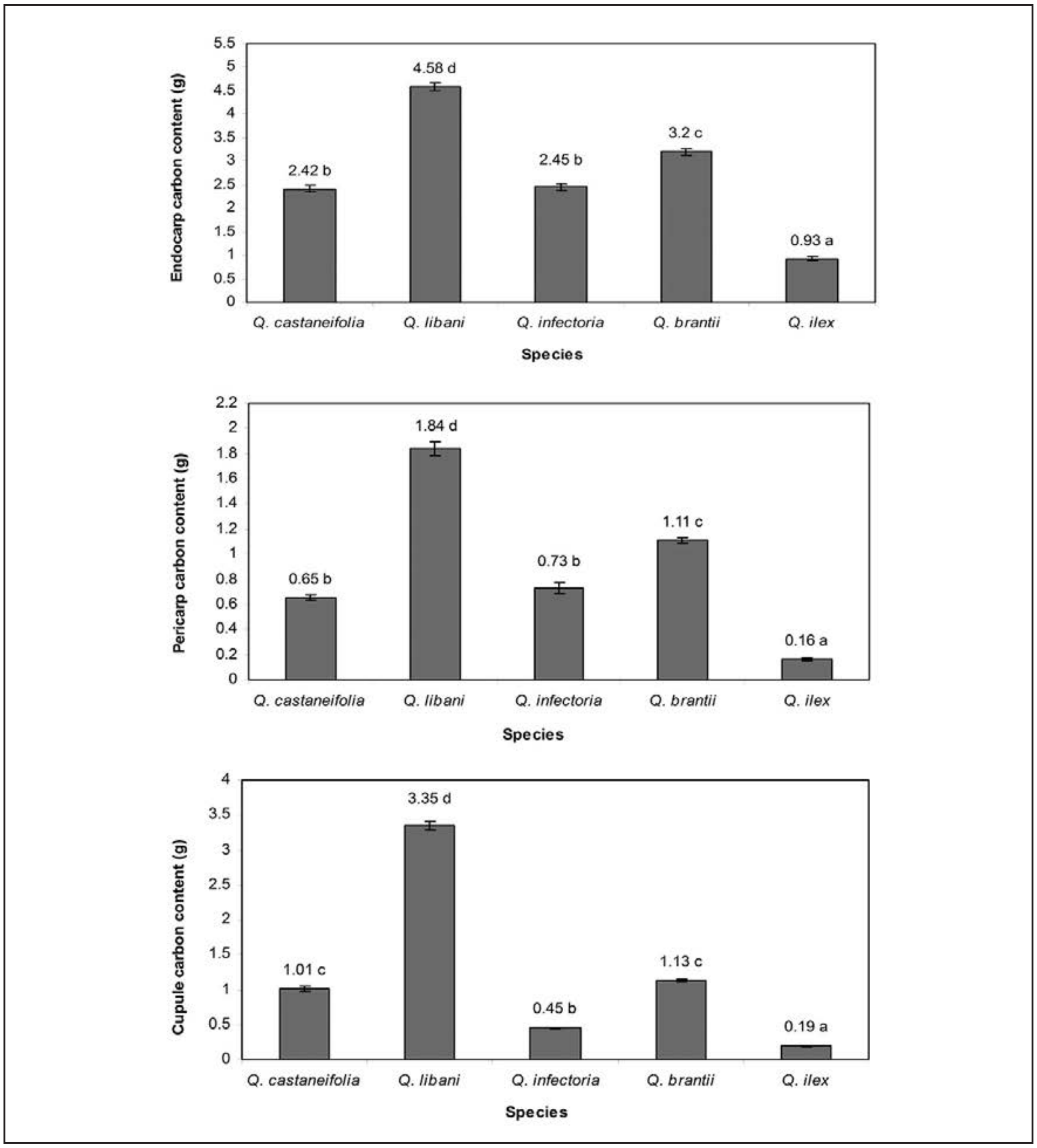

Figure 3. Carbon content (g) of acorn components. Significant differences in mean carbon content are denoted by different letters among species.

organs of oak species (e.g., Thomas and Malczewski 2007), but it is difficult to compare the results with those of previous studies because of the differences in studied species or organs. This study focuses exclusively on carbon content related to acorns.

These results present a detailed comparative analysis of biomass and carbon content of acorn components among five oak species. Based on the grouping of the variables, a clear differentiation was observed in the study characteristics among the species studied, especially in *Q. libani* and *Q. ilex*. Finally, the study authors propose to repeat the same research in other sites and on other oak species to complete the results.

Acknowledgments. The authors wish to thank the authorities of Research Institute of Forests and Rangelands for providing the facilities for this research. We also thank the authorities of Forest Laboratory, Research Institute of Forests and Rangelands. Thanks are due to Dr. Jamzad, Dr. Sadeqzade, Mr. Vahdatian, and Mr. Azarsa for their collaboration.

LITERATURE CITED

Allen, S.E., H.M. Grimshaw, and A.P. Rowland. 1986. Chemical analysis. pp. 285–344. In: P.D. Moore and S.B. Chapman (Eds.). Method in Plant Ecology. Blackwell Scientific Press, Oxford, London, UK.

Auchmoody, L.R., H.C. Smith, and R.S. Walters. 1993. Acorn production in northern red oak stands in northwestern Pennsylvania. USDA Forest Service, Research Paper NE-680:5.

Callahan, H.S., K. Del Fierro, A.E. Patterson, and H. Zafar. 2008. Impacts of elevated nitrogen inputs on oak reproductive and seed ecology. Global Change Biology 14:285–293.

Campioli, M., B. Gielen, A. Granier, A. Verstraeten, J. Neirynck, and I.A. Janssens. 2010. Carbon allocation to biomass production of leaves, fruits, and woody organs at seasonal and annual scale in a deciduous and evergreen temperate forest. Biogeosciences Discuss 7:7575–7606.

Campioli, M., H. Verbeeck, R. Lemeur, and R. Samson. 2008. C allocation among fine roots, above, and belowground wood in a deciduous forest and its implication to ecosystem C cycling: A modelling analysis. Biogeosciences Discuss 5:3781–3823.

Cañellas, I., M. Sánchez-González, S.M. Bogino, P. Adame, C. Herrero, S. Roig, M. Tomé, J.A. Paulo, and F. Bravo. 2008. Silviculture and carbon sequestration in Mediterranean oak forests. pp. 317–338. In: F. Bravo, R. Jandl, V. LeMay, and K. von Gadow (Eds.). Managing Forest Ecosystems: The Challenge of Climate Change. Springer, Netherlands.

Christisen, D.M., and W.H. Kearby. 1984. Mast measurement and production in Missouri (with special references to acorns). Missouri Department of Conservation Terrestrial Series 13:34.

Das, D.J., A. Saxena, and P.S. Roy. 2016. Surface area based above ground woody forest biomass carbon estimation: A case study of Kolasib District, Mizoram, India. Tropical Ecology 57(3):583–599.

Denk, T., and G.W. Grimm. 2010. The oaks of western Eurasia: Traditional classifications and evidence from two nuclear markers. Taxon 59:351–366.

de Rigo, D., and G. Caudullo. 2016. Quercus ilex in Europe: Distribution, Habitat, Usage and Threats. In: J. San-Miguel-Ayanz, D. de Rigo, G. Caudullo, T. Houston Durrant, and A. Mauri (Eds.). European Atlas of Forest Tree Species. Publications Office of the European Union, Luxembourg: e014bcd+

Djavanchir Khoie, K. 1967. Les chênes de l'Iran. Ph.D. Thesis. Univ. of Montpellier, Faculty of Science, Montpellier, France. 221 pp.

Drake, W.E. 1991. Evaluation of an approach to improve acorn production during thinning. 4–6 March 1991:429–441. In: L. McCormick, H. Gottschalk, and W. Kurt (Eds.). Proceeding of the 8th Central Hardwood Forest Conference, University Park, U.S.

Dwyer, J.F., D.J. Nowak, M.H. Noble, and S.S. Sisinni. 2000. Connecting people with ecosystems in the 21st century: An assessment of our nation's urban forests. General Technical Report PNW-GTR-490. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon, U.S. 483 pp.

García-Mozo, H., E. Dominguez-Vilches, and C. Galán. 2012. A model to account for variations in holm-oak (*Quercus ilex* subsp. *ballota*) acorn production in southern Spain. Annals of Agricultural and Environmental Medicine 19(3):403–408.

Geiger, D.R., W.J. Shieh, and R.M. Saluke. 1989. Carbon partitioning among leaves, fruits, and seeds during development of *Phaseolus vulgaris* L. Plant Physiology 91:291–297.

Génard, M., J. Dauzat, N. Franck, F. Lescourret, N. Moitrier, P. Vaast, and G.Vercambre. 2008. Carbon allocation in fruit trees: From theory to modeling. Trees 22(3):269–282.

Guariguata, M.R., and G.P. Sáenz. 2002. Post-logging acorn production and oak regeneration in a tropical montane forest, Costa Rica. Forest Ecology and Management 167:285–293.

Healy, W.M., A.M. Lewis, and E.F. Boose. 1999. Variation of red oak acorn production. Forest Ecology and Management 116(1–3):1–11.

Iranmanesh, Y., S.G.A. Jalali, Kh. Sagheb-Talebi, S.M. Hosseini, and H. Sohrabi. 2013. Allometric equations of biomass and carbon stocks for *Quercus brantti* acorn and its nutrition elements in Lordegan, Chaharmahal va Bakhtiari. Iranian Journal of Forest and Poplar Research 20(4):551–564. (in Persian with English abstract)

Johnson, P.S., S.R. Shifley, and R. Rogers. 2010. The Ecology and Silviculture of Oaks, Second edition., CABI, Wallingford, Oxon, UK.: 600 pp.

Ketterings, Q.M., R. Coe, M. van Noordwijk, Y. Ambagau, and C.A. Palm. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting aboveground tree biomass in mixed secondary forests. Forest Ecology and Management 146:199–209.

Kraenzel, M., A. Castillo, T. Moore, and C. Potvin. 2003. Carbon storage of harvest-age teak (*Tectona grandis*) plantations, Panama. Forest Ecology and Management 173:213–225.

Koenig, W.D., and J.M.H. Knops. 2014. Environmental correlates of acorn production by four species of Minnesota oaks. Population Ecology 56(1):63–71.

Losi, C.J., T.G. Siccamaa, R. Condit, and J.E. Morales. 2003. Analysis of alternative methods for estimating carbon stock in young tropical plantations. Forest Ecology and Management 184:355–368.

Lashley, M.A., J.M. McCord, C.H. Greenberg, and C.A. Harper. 2009. Masting characteristics of white oaks: Implications for management. 31 October–04 November 2009:21–26. In: A.G. Eversole, K.C. Wong, M.D. Smith, and B. Davin (Eds.). Proceedings of the Sixty-third Annual Conference of Southeastern Association of Fish and Wildlife Agencies, Atlanta, Georgia, U.S.

Li, S., J. Su, W. Liu, X. Lang, X. Huang, C. Jia, Z. Zhang, and Q. Tong. 2015. Changes in biomass carbon and soil organic carbon stocks following the conversion from a secondary coniferous forest to a pine plantation. PLoS ONE. DOI:10.1371/journal.pone.0135946.

Mälkönen, E. 1974. Annual primary production and nutrient cycle in some scots pine stands. Helsinki, Finland. Finnish Forest Research Institute: 84–87.

Miller, R.W. 1997. Urban Forestry: Planning and Managing Urban Greenspaces, second edition. Prentice Hall, New York, New York, U.S. 502 pp.

Montagnini, F., and C. Porras. 1998. Evaluating the role of plantations as carbon sinks: An example of an integrative approach from the humid tropics. Environmental Management 22(3):459–470.

Muukkonen, P. 2006. Forest inventory-based large-scale forest biomass and carbon budget assessment: New enhanced methods and use of remote sensing for verification. Ph.D. Thesis. Department of Geography, Faculty of Science, Univ. of Helsinki, Finland. 49 pp.

Ogawa, K., and Y. Takano. 1997. Seasonal courses of CO_2 exchange and carbon balance in fruits of *Cinnamomum camphora*. Tree Physiology 17:415–420.

Olson, D.F. 1974. *Quercus* L. Oak. No. 450:692–701. In: C.S. Schopmeyer (Ed.). Seeds of Woody Plants in the United States. USDA Forest Service Agriculture Handbook.

Panahi, P., Z. Jamzad, and M. Pourhashemi. 2009. Acorn production of Zagros forests oaks and their qualitative characteristics in Zagros section of National Botanical Garden of Iran. Journal of Forest and Wood Products 62(1):45–57. (in Persian with English abstract)

Pourhashemi, M., M. Zande Basiri, and P. Panahi. 2011. Estimation of acorn production of gall oak (*Quercus infectoria* Olivier) in Baneh forests by Koenig visual method. Iranian Journal of Forest and Poplar Research 19(2):205–220. (in Persian with English abstract)

Priyadi, A., S. Sutomo, I.D.P. Darma, and I.B.K. Arinasa. 2014. Selecting tree species with high carbon stock potency from tropical upland forest of Bedugul-Bali, Indonesia. The Journal of Tropical Life Science 4(3):201–205.

Pulido, F.J. 1999. Herbivorismo y regeneración de la encina (*Quercus ilex* L.) en bosques y dehesas. Ph.D. Thesis. Universidad de Extremadura, Cáceres, Spain. 146 pp.

Ryu, S.R., J. Chen, T.R. Crow, and S.C. Saunders. 2004. Available fuel dynamics in nine contrasting forest ecosystems in North America. Environmental Management 33:87–107.

Saatchi, S.S., N.L. Harris, S. Brown, M. Lefsky, E.T.A. Mitchard, W. Salas, and B.R. Zutta et al. 2011. Benchmark map of forest carbon stocks in tropical regions across three continents. 108(24):9899–9904. In: S.E. Trumbore and C.A. Irvine. (Eds.). Proc. of the National Academy of Sciences of the United States of America.

Sabeti, H. 1994. Forests, Trees, and Shrubs of Iran, second edition. Yazd, Iran, University of Yazd. 876 pp. (in Persian)

Sagheb Talebi, Kh., T. Sajedi, and M. Pourhashemi. 2014. Forests of Iran: A Treasure from the Past, A Hope for the Future. Springer, Netherlands. 152 pp.

Sánchez-Humanes, B., V.L. Sork, and J.M. Espelta. 2011. Trade-offs between vegetative growth and acorn production in *Quercus lobata* during a mast year: The relevance of crop size and hierarchical level within the canopy. Oecologia 166:101–110.

Sork, V.L. 1993. Evolutionary ecology of mast-seeding in temperate and tropical oaks (*Quercus* spp.). Vegetatio 107/108:133–147.

Steen, C., R. Jensen, L. Vangilder, and S. Sheriff. 2009. Hardmast production in the Missouri Ozarks: A preliminary report of acorn production on MOFEP. Resource Science Division, Missouri Department of Conservation: 11.

Streiling, S., and A. Matzarakis. 2003. Influence of single and small clusters of trees on the bio-climate of a city: A case study. Journal of Arboriculture 29:309–316.

Sun, X., H. Kang, H. Du, H. Hu, J. Zhou, J. Hou, X. Zhou, and C. Liu. 2012. Stoichiometric traits of oriental oak (*Quercus variabilis*) acorns and their variations in relation to environmental variables across temperate to subtropical China. Ecological Research 27:765–773.

Thomas, S.C., and G. Malczewski. 2007. Wood carbon content of tree species in Eastern China: Interspecific variability and the importance of the volatile fraction. Journal of Environmental Management 85:659–662.

Whittaker, R.H., and G.E. Likens. 1973. Carbon in the Biota. 16–18 May 1973:281–302. In: G.M. Woodwell and E.V. Pecan (Eds.). Carbon in the Biosphere, Proceedings of the 24th Brookhaven Symposium in Biology. United States Atomic Energy Commission, Upton, New York, U.S.

Parisa Panahi (corresponding author)
National Botanical Garden of Iran
Botany Research Division
Research Institute of Forests and Rangelands
Agricultural Research, Education and Extension Organization (AREEO)
Tehran, Iran
email: panahi@rifr-ac.ir

Mehdi Pourhashemi
Forest Research Division
Research Institute of Forests and Rangelands of Iran
Agricultural Research, Education and Extension Organization (AREEO)
Tehran, Iran

Maryam Hasaninejad
National Botanical Garden of Iran
Botany Research Division
Research Institute of Forests and Rangelands
Agricultural Research, Education and Extension Organization (AREEO)
Tehran, Iran

Résumé. Les jardins botaniques, constituant en soi une forêt urbaine des plus importantes pour toute région, jouent un rôle important dans l'écologie des habitats humains par leurs diverses fonctions (par exemple, pour la filtration atmosphérique). Le Jardin botanique national d'Iran, avec une superficie de 145 hectares, comprend une diversité d'espèces ligneuses avec une prédominance pour les chênes (*Quercus* spp.). La dimension des glands, les fruits des chênes, varie selon les différentes espèces, ce qui peut affecter leur biomasse. La biomasse et la teneur en carbone des constituantes du gland (l'endocarpe, le péricarpe et la cupule) de quatre espèces de chêne indigènes (*Q. castaneifolia* C.A. Mey., *Q. libani* Oliv., *Q. infectoria* Oliv., et *Q. brantii* Lindl.) et une espèce introduite (*Q. ilex* L.), plantés dans le Jardin botanique national furent analysées afin d'obtenir des données détaillées comparatives. En ce qui a trait à la biomasse des constituantes des glands, *Q. libani* et *Q. ilex* ont respectivement démontré la plus haute et la plus basse valeur parmi les espèces étudiées. Les fourchettes de la teneur en carbone des constituantes des glands furent de 53.5% (péricarpe du *Q. brantii*) à 58% (cupule du *Q. castaneifolia*). Ces résultats confirment la variation de la biomasse et de la teneur en carbone des constituantes des glands parmi les espèces de chêne étudiées.

Zusammenfassung. Botanische Gärten, die zu den wichtigsten urbanen Waldflächen in jeder Region gelten, spielen auf vielen Wegen eine wichtige Rolle in der Ökologie von humanen Habitaten (z.B. Luftfilterung). Der National Botanical Garden of Iran mit einer Fläche von 145 ha beherbergt verschiedene holzige Arten mit einer Prädominanz von Eichen (*Quercus* spp.). Die Größe der Eicheln, der Eichenfrüchte, variiert bei den unterschiedlichen Arten und kann ihre Biomasse beeinflussen. Von vier einheimischen Eichenarten species (*Q. castaneifolia* C.A. Mey., *Q. libani* Oliv., *Q. infectoria* Oliv., und *Q. brantii* Lindl.) und einer exotischen Eichen species (*Q. ilex* L.), die in dem National Botanical Garden gepflanzt wurden, wurde die Biomasse und der Kohlenstoffanteil von Eichelbestandteilen (Endokarb, Perikarb und Cupula) studiert, um vergleichbare detailierte Ergebnisse zu erhalten. Bezüglich der Biomasse der Eichelbestandteile zeigten *Q. libani* und *Q. ilex* die höchsten und niedrigsten Werte unter allen untersuchten species. Die Bandbreiten des Kohlenstoffanteils der Eichelbestandteile waren 53.5% (Perikarp von *Q. brantii*) bis 58% (Cupula von *Q. castaneifolia*). Diese Ergebnisse bestätigen die Variation von Biomasse und Kohlenstoffanteil der Eichelbestandteile bei den untersuchten Arten.

Resumen. Los jardines botánicos, como uno de los bosques urbanos más importantes de cualquier región, desempeñan un papel importante en la ecología de los hábitats humanos de muchas maneras (por ejemplo, el filtrado de aire). El Jardín Botánico Nacional de Irán, con un área de 145 ha, incluye varias especies leñosas con predominio de robles (*Quercus* spp.). El tamaño de las bellotas y frutos varía en diferentes especies, lo que puede afectar su biomasa. La biomasa y el contenido de carbono de los componentes de la bellota (endocarpio, pericarpio y cúpula) de cuatro especies nativas de roble (*Q. castaneifolia* CA Mey., *Q. libani* Oliv., *Q. infectoria* Oliv., y Q. *brantii Lindl.)* y una especie exótica *(Q. ilex L.),* plantada en el Jardín Botánico Nacional, fueron estudiadas para obtener resultados comparativos detallados. Con respecto a la biomasa de los componentes de la bellota, *Q. libani* y *Q. ilex* mostraron los valores más altos y más bajos entre las especies estudiadas, respectivamente. Los rangos de contenido de carbono de los componentes de la bellota fueron 53.5% (pericarpio de *Q. brantii*) a 58% (cúpula de *Q. castaneifolia*). Estos resultados confirman la variación de la biomasa y el contenido de carbono de los componentes de la bellota entre las especies de roble estudiadas.