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Evaluating acorn crops in an oak-dominated stand to identify good acorn producers

Analyse der Eichelernte eines eichendominierten Bestandes um gute Eichelproduzenten zu identifizieren

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Schlüsselbegriffe: *Samendichte, Samenertag, Quercus brantii, Ertragsgrößе, Kronenzahl, Zagroswälder*

Abstract

Acorn production in the Zagros forests of Iran is important for its fundamental role in the natural sexual regeneration of oaks, for human use, and as food for wildlife. The objectives of this study were to examine annual variability in acorn production among individuals of Brant`s oak (*Quercus brantii* Lindl.), the effect of tree quantitative variables as well as weather variables on acorn production and determine whether any pattern in fruiting can be used to identify the good acorn producers. Starting in

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2012, 100 individual Brant`s oaks were selected and their acorn crops were measured by the tree count method during six years (2012-2017). Acorn production performance of each tree and annual acorn crops were ranked as "good", "fair" or "poor". The mean number of acorns per m² crown area (CA) among years and diameter classes and the correlations between 13 weather variables with acorn production was analysed too. During the study period, average annual acorn production per tree ranged from 0 to 2293 acorns. The mean density of acorns per m² CA varied from a low of 1.2 in 2015 to a high of 13.4 in 2016. Acorn crop failures did not occur during our study period. Based on the mean 6-year acorn crop, good, fair and poor producers comprised 35%, 19%, and 46% of the sample trees, respectively. The mean 6-year acorn crop did not vary significantly among diameter classes. Furthermore, two weather variables, spring maximum temperature 1 yr prior to the year of acorn maturation and summer rain during the year of acorn maturation, had positive significant effect on annual acorn production. Our results confirmed that there is great annual variation in acorn production among individuals of Brant`s oak. Because actual good acorn producers represent a small proportion of seed bearing oaks (16%), they should be identified for appropriate management and conservation.

Zusammenfassung

Die Eichelproduktion in den Zagroswälder Irans ist wichtig wegen ihrer fundamentalen Rolle in der Eichenverjüngung, für den menschlichen Gebrauch, und als Futter für Wildtiere. Das Ziel dieser Studie war Untersuchung der jährlichen Variabilität der Eichelproduktion einzelner Brant-Eichen (*Quercus brantii* Lindl.), Analyse des Einflusses quantitativer Baummerkmale sowie Wettervariablen auf die Eichelproduktion und Bestimmung der Fruchtproduktionsmuster, um gut eicheltragenden Bäume zu identifizieren. 100 erwachsene Brant-Eichen wurden im Jahre 2012 ausgewählt und ihre Eichelproduktion wurde mittels Baumzählmethode über sechs Jahren von 2012 bis 2017 gezählt. Die Menge der Eicheln pro Baumes und damit dessen jährliche Produktion wurde mit "gut", "genügend" oder "schwach" bewertet. Die durchschnittliche Anzahl der Eicheln pro m² Kronenfläche (CA) wurde nach Beobachtungsjahr und Durchmesserklassen analysiert. Die durchschnittliche Anzahl der Eicheln per Baum variierte zwischen 0 und 2293. Die durchschnittliche Anzahl der Eicheln pro m² CA variierte zwischen 1.2 im Jahr 2015 und 13.4 in 2016. Während dem Untersuchungszeitraum wurde keine Missernte registriert. 35% der Bäume wurden als gut, 19% als genügend und 46% als schwach eicheltragend bezeichnet. Die durchschnittliche jährliche Eichelproduktion nach Durchmesserklassen war statistisch nicht significant. Zwei Wettervariablen, hingegen, nämlich Frühlingsmaximaltemperatur im Jahr vor der Eichelreife und Sommerniederschlag während der Eichelreife, zeigten einen positiven signifikanten Einfluss auf die Eichelproduktion. Unsere Ergebnisse bestätigen eine grosse Variation der Eichelproduktion zwischen einzelnen Brant-Eichen. Da die aktuell guten Samenproduzenten nur einen kleinen Teil (16%) aller samenproduzierenden Eichen darstellen, solten diese für weitere geeignete Managementmaβnahmen identifiziert und verwendet werden.

1. Introduction

Acorn production is a foundational process of oak (*Quercus*) forest ecosystems (Rose et al., 2012; Olson et al., 2015). Aside from its obvious importance in the sexual reproduction of oaks, acorns are also a primary food source of many vertebrate and invertebrate species (McShea and Healy, 2002; Greenberg and Warburton, 2007). Acorn production is sporadic and hard to predict (Sander, 1990; Auchmoody et al., 1993). It is highly variable among oak species, individual trees, locations and years (Sork et al., 1993; Shibata et al., 2002; Pons and Pausas, 2012). Masting is characteristic of acorn production in many oak stands, meaning that large crops are produced once every few years when trees become synchronous in their acorn production (Janzen, 1971; Silvertown, 1980). Periodicity in masting is characteristically variable and the length of the period between heavy mast crops is not necessarily constant.

Each oak tree has an inherent capacity for acorn production (Grisez, 1975; Beck, 1993; Sork et al., 1993), but only a relatively small proportion of oak trees are inherently good acorn producers (Christisen and Kearby, 1984; Healy et al., 1999; Greenberg, 2000). Whether an oak tree reaches it genetic potential in acorn production is dependent upon various environmental factors such as weather and soil, or other exogenous factors such as stand density and inter-tree crown competition, and insect and wildlife predation on oak flowers and developing seed (Sharp and Sprague, 1967; Christisen and Kearby, 1984; Sork et al., 1993; Fernández-Martínez, 2012; Kelly et al., 2013).

Zagros forests extend along the Zagros Mountain range in the west and south of Iran, and cover an area of over six million hectares (equivalent to 44 percent of Iran's forests). The continuous Zagros forests are distributed across ten provinces from northwestern (West Azerbaijan province) to southern (Fars province) Iran (Sagheb Talebi et al., 2014). Currently, there is no commercial wood production in these forests, but they are valued for other forest services such as water supply, production of by-products such as gall and manna, and prevention of erosion (Pourhashemi et al., 2004). Due to the large dependence of local communities on these forests, socio-economic issues in these forests are also important and complicated.

The dominant genus in the Zagros forests is oak (*Quercus*), with three species occurring across the region. Lebanon oak (*Q. libani* Oliv.) is widespread in the northern range of the Zagros Mountains (West Azerbaijan and Kurdistan provinces). Gall oak (*Q. infectoria* Oliv.) is widely distributed in West Azerbaijan, Kurdistan, Kermanshah and Lorestan provinces. It is usually found on northern slopes, but at lower elevations than Lebanon oak. Brant's oak (*Q. brantii* Lindl.) is the dominant oak species in the Zagros forests, being located mainly in the southern and central areas (Sagheb Talebi et al., 2014). It is more resilient and tolerant to environmental stresses than either of the other two oak species, and hence, it occurs across a wider range of aspects and elevations (Sagheb Talebi et al., 2014). The distribution of Brant's oak continues into

Armenia to the north, and Turkey, Iraq, and Syria to the west (Oldfield and Eastwood, 2007; Panahi et al., 2012). The regeneration origin of most oaks in these forests is vegetative by coppice, and trees of direct seed-origin are only found in certain locations.

In the Zagros forests, like many oak forests in the temperate regions of the world, acorns play an important role in feeding wildlife and domestic animals. The life of some animal species, like the Iranian squirrel (*Sciurus anomalus* Gmelin), is heavily dependent on acorn crops. Acorns are also a mainstay of domestic animal feed rations. In addition, acorns are traditionally used for food such as bread by the local residents of the Zagros forests. Therefore, the potential capacity of individual trees to produce acorns and the actual annual production is an important driver affecting how these forests are managed.

Our knowledge of acorn production patterns in Zagros oak forests is limited. Previous reports showed that production is highly variable, both within years and among individuals (Panahi et al., 2009; Parvaneh et al., 2011; Pourhashemi et al., 2012, 2013, 2015). While the Zagros forests are very important and sensitive forest ecosystems (Pourhashemi et al., 2004; Sagheb Talebi et al., 2014), and they have experienced widespread degradation by various factors such as traditional overharvesting of timber, unsustainable collection of acorns, deforestation for agriculture, overgrazing, and road and dam construction. More specifically, unmanaged cutting of oak trees without regard for their inherent acorn production potential results in the inadvertent loss of valuable mast producing individuals. In addition, sustainability of oak forests is uncertain because of a failure in oak seedling establishment despite acorn production, which has been occurring over the past decade (Sagheb Talebi et al., 2014). Without oak regeneration to eventually replace mature oaks in the overstory, oak forests and all their associated social and ecological goods and services, including those dependent on acorn production, are in peril.

The objectives of this study are to examine: (1) the variability in acorn production among individual trees and years, (2) the effect of tree dimensions and weather on acorn crop, and (2) determine if fruiting patterns can be used to identify relatively good acorn producers in a stand. Knowing what trees are the good acorn producers improves managers and landowners ability to better manage to maximize acorn production in individual trees, and to sustain acorn production and oak forests in the Zagros for future generations.

2. Materials and methods

2.1. Site description

The study was conducted at Darsafe Forest (33˚07´34" N, and 48˚12´07" E), a natural oak forest located in the city of Poldokhtar, Lorestan Province, western Iran. Elevation at the study site ranges from 1414 to 1460 m. The study area holds pure stands of Brant`s oak on slightly slope hillsides which is covered with one-layered coppice stand consisted of scattered oak trees. Traditionally, the area is under-cultivated with wheat and barley by the local people. *Pyrus* spp., *Crataegus* spp., *Pistacia atlantica* Desf., *Acer monspessulanum* L., *Daphne mucronata* Royle., *Amygdalus* spp., *Lonicera nummularifolia* Jaub. & Spach., *Cotoneaster nummularia* Fisch & C. A. Mey. and *Cerasus microcarpa* C. A. Mey. are other woody elements of the stand. The forest floor is bare and without vegetation because of plowing the soil for production of annual crops within decades. Presence of local livestock (sheep and goat) in forest causes severe soil compaction and problem for establishment of ground vegetation and tree seedlings. Therefore, no oak regeneration is found on forest floor. The traditional forest management by local communities in the past decades has formed coppice trees but with a single stem. In this method which is common in some parts of Zagros forests, only one shoot is favored to lead the height growth fodder for local cattle. Hence, after a few decades the remained shoot turns to a single stem coppice tree. The consequence of this management system is forming of open oak stand with scattered trees and a canopy cover less than 25%. Most of the oak trees are old and the abundance of trees older than 100 years is significant, but the frequency of trees between 50 and 100 years is higher than in other age classes. Therefore, trees has wide crown with considerable height and diameter at breast height of the tree while all other shoots are cut off with the purpose of producing fuel wood.

2.2. Weather

Annual rainfall ranges from 250 to 513 mm, with a 15-year (2003-2017) mean of 368 mm that falls mainly between November and May. The maximum amount of precipitation falls in winter (156.7 mm = 42.6%) and autumn (141.6 mm = 38.5%). Only 0.7% of total precipitation (2.5 mm) occurs in summer. Within the study period, February is registered as the most humid month (63.5 mm) while July as the driest month (0.1 mm). The mean annual temperature is 23.3ºC. Maximum temperatures may reach 48ºC in August. During the winter, temperatures may fall to -4ºC or lower.

2.3. Geology and Soil

Geological formation of the study area is a part of wrinkled Zagros and belongs to the tertiary and partly is covered by quaternary sediments. Bedrock is mostly hard and calcareous which is often broken. In these parts, soil depth and root system is deep which improves the fertility of the soil. In rocky and gravely areas with continuous bedrock, soil fertility tree density is low. In general, soils of the area are Inceptisol with loam-clay texture and pH of between 7.7 and 7.9.

2.4. Acorn counting

Starting in 2012, we selected 100 mature Brant`s oaks using stratified random sampling method. For this purpose, diameter at breast height (dbh) range of Brant`s oaks in the studied site divided into diameter classes with 10 cm intervals, and then 100 Brant`s oak trees were selected, somewhat there were at least 5 trees in each diameter class. Selected individuals were larger than 15 cm in dbh and sufficiently distant to avoid crown contact with neighboring trees. This spatial configuration of oaks is the result of traditional utilization and tending of the forests. Sample trees were numbered and their quantitative variables (diameter at breast height, height and crown length) measured. We also measured crown width using eight radii along established azimuths from the tree base to the canopy drip line, and computed crown area as an octagon from the measured radii.

We counted acorns on sample oak trees each fall, 2012-2017, using tree count method (Gysel, 1956). Because oak trees in this study are short, acorns can be easily counted, and this method provides an accurate determination of acorn number. We counted all acorns on the crown of each tree between mid-September and early October prior to acorn fall.

2.5. Statistical analysis

To standardize comparisons among different sized trees, acorn number per tree was converted to acorns/m² crown area (CA) by dividing acorn number of each tree by its crown area (Christisen and Kearby, 1984; Rose et al., 2012). Acorn production performance of each tree was ranked as "good", "fair" or "poor" by comparing its 6-year mean number of acorns/m² CA to the 6-year mean of the stand. Good producers had means equal to or greater than the 6-year mean number of acorns/m² CA for the stand; fair producers had means less than the 6-year mean but equal to or greater than 60% of the stand mean; and poor producers had means less than 60% of the 6-year stand mean (Healy et al., 1999; Greenberg, 2000). Annual acorn crops were also ranked as poor, fair or good by comparing the mean number of acorns/m² CA for a given tree in a particular year to the 6-year average of that tree. All mature acorns were included in analyses regardless of their condition (sound, animal or insect-damaged). Data from six trees in the original sample were eliminated from analyses because these trees were cut during the study period.

Normality distribution of variables was assessed using the Shapiro-Wilk test ($p < 0.01$). The mean number of acorns/m² CA among years was tested using the Wilcoxon non-parametric test and pairwise comparisons were done using the Friedman test. The mean number of acorns/m² CA among diameter classes was tested by Kruskal-

Wallis non-parametric test and pairwise comparisons were done using the Mann-Whitney U test. Furthermore, the differences of quantitative variables of sample trees (height, crown length and crown area) and the mean of them among diameter classes were tested by One-Way ANOVA and Duncan. We extracted 13 weather variables to explain variation in the annual mean acorn crop (Table 1). Correlations between weather variables were generally not high. Only two Pearson correlation coefficients (spring maximum temperature with summer maximum temperature, $r = 0.72$; spring maximum temperature with winter cold 1 yr prior to the year of acorn maturation, $r = 0.66$) were significant at the $p < 0.01$ level. This relatively low collinearity among variables allowed us to examine the relationship between weather and acorn crop using a stepwise regression of the 13 weather variables on the mean annual acorn crops. Statistical significance is reported at the $p < 0.05$ level unless otherwise stated.

Table 1: Description of weather variables used in Pearson correlation test

Tabelle 1: Beschreibung der Wettervariablen verwendet im Pearson-Korrelationstest.

Variable	Description
Spring maximum temperature	Spring maximum temperature during the time of pollination calculated as the mean maximum daily temperature during 5-25 April of the year of acorn maturation
Spring maximum temperature (-1)	Same as above except calculated for previous year, when pollination occurs
Spring rain	Mean daily rainfall during 5-25 April of the year of acorn maturation
Spring rain days	Number of days with rain during 5-25 April of the year of acorn maturation
Spring rain days (-1)	Same as above except measured 1 yr prior
Summer maximum temperature	Mean daily temperature for the period of 1 April-30 July during the year of acorn maturation
Summer maximum temperature (-1)	Mean daily temperature during 1 May-30 September during year prior to acorn maturation
Summer maximum temperature (-2)	Same as above but 2 yr prior
Summer rain	Mean daily rainfall for the period of 1 April-30 July during the year of acorn maturation
Summer rain (-1)	Mean daily rainfall during 1 May-30 September of previous year
Summer rain (-2)	Same as above but 2 yr prior
Winter cold	Mean minimum daily temperature during 16 November-15 March of the year of acorn maturation
Winter cold (-1)	Same as above but 1 yr prior

3. Results

Descriptive statistics of quantitative variables and acorns of sample trees are given in Table 2. Considering the range and mean height and diameter at breast height, sample trees were determined that mostly were large trees (dbh > 50 cm) with considerable height. Analysis of the crowns of the sample trees showed that their crown is large and voluminous. By comparing the crown length and total height of the sample trees, we found out that a considerable proportion of tree height is allocated to the crown.

Table 2: Descriptive statistics of quantitative variables and acorns of sample trees

Tabelle 2: Zusammenfassung der quantitativen Merkmale der untersuchten Bäume

Variable	Range	Mean (±SE)
DBH (cm)	35-95	58.1 (1.33)
Height (m)	6-16	10.1 (0.2)
Crown area (m^2)	28.3-271.6	110.5 (4.8)
Crown length (m)	3.8-12.5	7.6 (0.2)
Average number of acorns per tree	0-2293	576 (55.3)
Average number of acorns/m^2	0-22.3	4.8 (0.57)

Individual sample trees varied in acorn production among years (Figures 1a, b, c). Whereas some trees produced a lot of acorns in a given year (e.g. trees No. 57, 90 and 95 in 2016), others produced few (e.g. trees No. 46 and 23) or none (e.g. trees No. 80 and 84). In addition, some trees showed little variability in acorn production among years (e.g. trees No. 34 and 52) whereas production fluctuated widely in others (e.g. trees No. 19 and 95).

Acorn production of some trees was remarkably high in some years, so that prolific trees had a significant share in the stands. Based on the 6-year mean number of acorns/m^2 CA, average acorn density of 14 trees (14.9%) was more than twice than that of stand, and 44.7% of the total acorn production was contributed by them. Among these 14 trees, six (6.4%) had produced more than three times the average amount of acorns than that of the stand, accounting for 23.6% of the total stand acorn production. Two trees (trees No. 66 and 90) had averaged more than four times the amount of acorns than that of stand, producing 9.3% of the total stand acorn production.

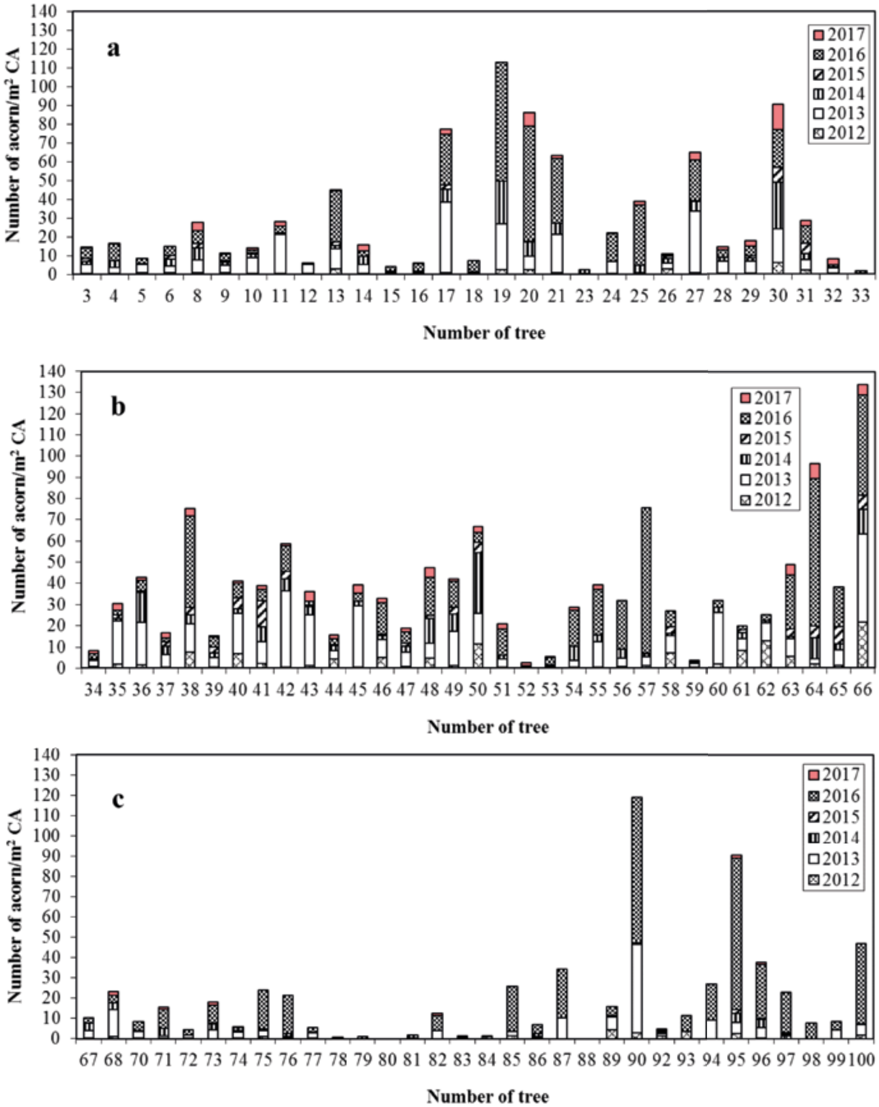

Figure 1: The annual acorn production per tree during the study period (2012-2017). To better determine the acorn production condition of the sample trees, Figure 1 was divided into three parts a, b and c. The data from six trees (trees No. 1, 2, 7, 22, 69, and 91) which had cut during the study period were eliminated from analyses.

Abbildung 1: Die jährliche Eichelproduktion pro Baum während dem Untersuchungszeitraum (2012-2017). Zwecks Übersichtlichkeit wurde die Abbildung in drei Teilen a, b und c geteilt. Die Daten von sechs Bäumen (Bäume Nr. 1, 2, 7, 22, und 91), die während der Studie entnommen wurden, wurden aus der Analyse entfernt.

Acorn crop failures, i.e., when > 50% of the trees did not produce any acorns, did not occur during our study period (Table 3). However, we observed 41 trees that failed to produce acorns in 2015. In 2016 we observed the greatest number of trees (n = 88) that produced acorns, while in 2015 we observed the lowest number of trees (n = 53) that produced acorns.

Table 3: Portion of non-producers during the study period (2012-2017)

Tabelle 3: Anteil der nicht eicheltragenden Bäume während dem Untersuchungszeitraum (2012-2017)

Year	Non-producers	
	Number	Percent
2012	12	12.8
2013	13	13.8
2014	15	16
2015	41	43.6
2016	6	6.4
2017	38	40.4

The number of acorns/m² CA differed significantly among study years ($Z = 7.11$; $p = 0.000$), therefore, we categorized years into classes (Figure 2). Mean values for acorns/m² CA varied from 1.2 in 2015 to 13.4 in 2016. The maximum value of annual acorns/m² CA from individual trees ranged from 12.6 in 2015 to 75 in 2016. Acorn production in the highest production year (2016, mean number of acorns/m² CA = 13.4) was 11 times more than that of the lowest production year (2015, mean number of acorns/m² CA = 1.2), and about 3 times more than the 6-year average. The best year (2016) and the poorest year (2015) accounted for about 46% and 4%, respectively of the 6-year total acorn collection. Coefficients of variation in mean annual acorn production ranged from 120% for 2013 to 188.7% for 2015.

Frequency of acorn production varied among individuals. During the study period, two trees (trees No. 80 and 88) failed to produce acorns, while 39 trees (41% of all individuals) produced acorns each of the six years. The number of trees that failed to produce acorns for one, two, three, four and five years was 23, 15, 3, 9 and 3, respectively. Therefore, the majority of individuals produced acorns most years.

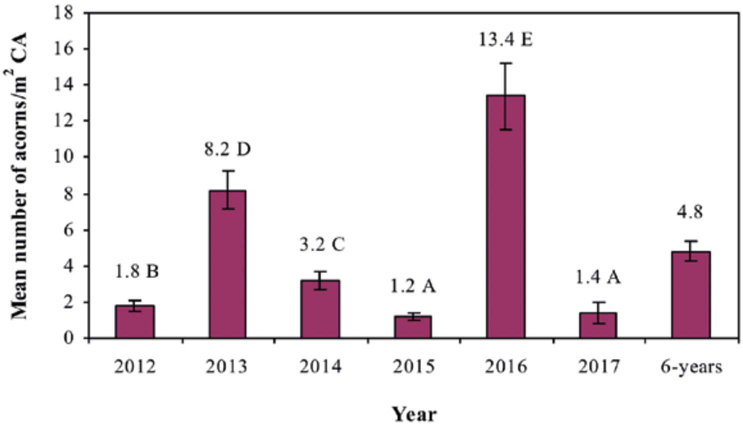

Figure 2: Variation of acorn production (mean ± SE) during the study period. Significant differences in mean acorn density are denoted by different letters among years

Abbildung 2: Variation der Eichelproduktion (Mittelwert ± Standardfehler) während Untersuchungszeitraum. Signifikante Unterschiede in der durchschnittliche Eichelanzahl nach Jahren sind mit unterschiedlichen Buchstaben bezeichnet.

We scored the best acorn producers in 2016 and 2014, which included about one third of the total sample trees in any one year. We observed the fewest number of good acorn producers (26.1%) in 2012. Interestingly, although the year 2015 was the lowest acorn production year, the proportion of good acorn producers in this year (27.7%) was a little more than that of 2012. In 2015, we observed no fair producers and most trees (72.3%) were poor acorn producers. Overall, there were more trees in the poor acorn producer class than in the fair and good classes. In the lowest acorn production years (2015 and 2012), the difference between the poor acorn producers to good acorn producers was higher than in years of good acorn production (Figure 3a).

Based on the 6-year mean of good, fair and poor acorn producers, the percentage of poor producers outweighed the other production categories. Good and poor producers composed 35% (n = 33) and 46% (n = 43) of the sample trees, respectively. The percentage of fair producing trees (19%) was much less than the other categories. Assessment of year-to-year mean acorn production/m² CA of the 33 best producers showed that 18 trees produced fewer acorns than the annual acorn production in some years. Therefore, 15 trees were considered to be consistently good producers in our study.

Mean annual acorn production by good, fair and poor producers is shown in Figure 3b. Good producers had a higher range in mean annual number of acorns/m² CA (5.5-33.4) compared to fair (0.8-10.5) and poor producers (0.1-3.2).

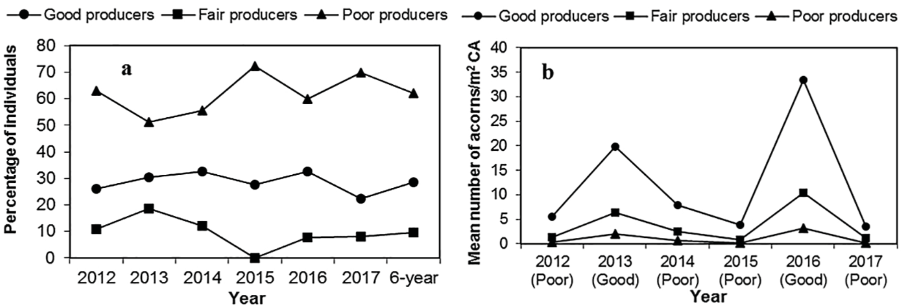

Figure 3: (a) Proportion of good, fair and poor acorn producers during the study period (2012-2017); (b) Mean annual acorn production by good, fair and poor producers during good and poor overall years of production

Abbildung 3: Anteil guter, genügender und schwacher Eichelproduzenten pro Jahr im Untersuchungszeitraum (a) und durchschnittliche jährliche Eichelproduktion von guten, genügenden und schwachen eicheltragenden Bäumen während der guten und schlechten Produktionsjahren (b).

Although the 6-year mean of number of acorns/m² CA suggested differences among diameter classes, the differences were not statistically significant (Figure 4). The absolute largest acorn production occurred in the 45-54.9 cm diameter class, where trees averaged 6.7 acorns/m² CA. This exceeded nominally the smallest collection, which was observed in the 35-44.9 cm diameter class, where mean number of acorns/m² CA was 2.3. Differences in acorn production were relatively minor in trees with diameters above 55 cm.

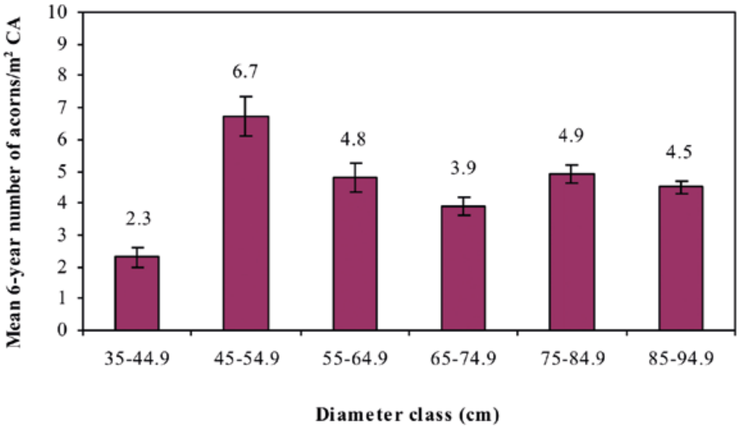

Figure 4: Mean (±SE) 6-year (2012-2017) number of acorns/m² CA by diameter class (χ2 = 11.221; p = 0.058)

Abbildung 4: Durchschnittliche Anzahl der Eicheln pro m² Kronenfläche (± Standardfehler) nach Durchmesserklasse (χ2 = 11.221; p = 0.058).

There were significant differences between crown area ($F = 5.024$, $p = 0.000$), crown length ($F = 3.621$, $p = 0.005$) and height ($F = 2.536$, $p = 0.034$) of sample trees among diameter classes (Table 4). In order to proof, whether the quantitative parameters (tree height, crown length and crown area) of trees within the second diameter class (dbh = 45-45.9 cm) show a significant difference with other diameter classes, mean values of the mentioned parameters were compared among the diameter classes. Results indicated, however there was a significant difference between the mean values (Table 4) but the values of crown length and tree height in the second diameter class were less than that of other diameter classes.

Table 4: Mean values of crown area, crown length and height of sample trees among diameter classes. Significant differences (p < 0.05) are denoted by different letters.

Tabelle 4: Durchschnittliche Kronenfläche, Kronenlänge und Kronenhöhe der Probebäume nach Durchmesserklassen. Signifikante Unterschiede (p <0.05) sind durch unterschiedliche Buchstaben gekennzeichnet.

Diameter class (cm)	Variable		
	Crown area (m^2)	Crown length (m)	Tree height (m)
35-44.9	163.52 a	6.75 b	9.46 ab
45-54.9	117 ab	6.81 b	9.31 b
55-64.9	124.56 ab	7.73 ab	10.01 ab
65-74.9	80.14 bc	8.96 a	11.35 a
75-84.9	66.27 c	7.80 ab	10.44 ab
85-94.9	91.64 bc	9.04 a	11.38 a

Results of the stepwise multiple regression showed that variables associated particularly strongly with annual acorn production were spring maximum temperature 1 yr prior to the year of acorn maturation ($F = 16.5$; $r^2 = 0.68$; $p = 0.043$) and summer rain during the year of acorn maturation ($F = 10.1$; $r^2 = 0.65$; $p = 0.039$).

4. Discussion

Despite the widespread distribution and importance of Brant's oak throughout the Middle East (Iran, Turkey, Iraq, and Syria) and Armenia (Oldfield and Eastwood, 2007; Panahi et al., 2012), there was previously no adequate information on acorn production and variation over time for this species. Although a longer-term perspective, i.e., more that 6 years, is important in understanding and managing acorn production due to the high annual variation and periodicity of mast crops, this research provides valuable information in the mid-term about acorn production in Brant's oak that will help us to better conserve and manage the species for the variety of goods and services it provides to meet social needs, maintain ecological integrity, and sustain forest productivity.

We clearly observed year-to-year variation in individual trees and total stand acorn production. There never was a complete failure in stand acorn production in all six years of study. Some trees produced small amounts of acorns even in years of poor production. A portion of the sample trees produced more than 60 acorns/m² CA, whereas others did not produce any acorns.

Climate can affect acorn production of oak trees in various forms. The most damages on seed production process occur between two stages of flowering and fertility (Ceccich & Sullivan, 1999). Since the formation of pollens and growth of pollen tubs requires relatively high temperature, if the temperature drops significantly in this stage, fertility will be disturbed or it will be damaged severely. Moreover, in wind pollinated species, continuous rainfall during the pollination period can negatively affect the seed production process. In this relation, different results have been reported for different oak species (Ceccich & Sullivan, 1999). Summer drought is also one the factors that affects negatively the acorns formation and maturity, which is reported in different studies on Mediterranean oaks (Espelta et al., 2008; Carevic et al., 2010). In our study, we found out that the temperature in previous spring of one year before masting and summer precipitation in the masting year have significant positive effect on acorn production. Since Brant's oak is traditionally included in the Subgenus *Quercus*, Section *Cerris* which exhibits a biennial pattern of maturation (Djavanchir Khoie, 1967), the spring before masting year coincides with flowering and male flower production in this species, but the complete maturity of acorns happens in the summer of the masting year. Hence, the results of our study confirm the important role of weather factors in acorn production.

Generally, good acorn production at the stand level occurred in years when individual trees were producing at their highest levels and a high number of the trees in the sample were producing acorns. The opposite was true in years of low acorn production in the stand (Healy et al., 1999; Greenberg, 2000; Greenberg and Warburton, 2007). We identified the years 2013 and 2016 as good crop years during the study. In contrast, the year 2015 was the poorest year in acorn production. In 2015, the number of non-producing trees was at a maximum value (n = 41) for the study period at the same time that a considerable proportion of trees (n = 68) produced fewer acorns than the mean of the population.

Long-term acorn production in native oak trees of the Zagros forests of Iran has not yet been fully described. Mean acorn counts/m² CA for Brant's oak have been reported to range from 6.2 in a 3-year study in Kermanshah forests (Pourhashemi et al., 2015) to 11.3 in a 1-year study in Kurdistan forests (Pourhashemi et al., 2013). Our 6-years results (average = 4.8) were similar to the Kermanshah forest study, but much lower than the Kurdistan study of one year. Differences may be due to length of the study period and year of study (e.g., one year, 2010, in Kurdistan forests and 6 years, 2012 to 2017, in our study), differences in stand and hence tree characteristics (e.g., crown size) and other socio-ecological conditions that affect tree health and productivity.

We observed significant differences in acorn production among years; for example, 2013 and 2016 were quite productive in relation to other years. The acorn crop in 2016 (mean 13.4 acorns/m² CA) was considerably more than that in 2013 (mean 8.2 acorns/m² CA). The mean number of acorns/m² CA in 2016 was about 3 times more than the mean 6-year acorn crop. Evidences of cyclic acorn production were observed in this study; however the time period examined was not long enough to make a definitive comment on whether masting occurred and at what frequency. Healy et al. (1999) pointed out that within short intervals other factors like weather could obscure mast cycles. It seems that Brant's oak is capable of producing large crops at 3 year intervals (e.g. good crops in 2013 and 2016). Unfortunately, there are no long-term studies on acorn production in Zagros oaks in Iran that can be compared with our results. The only similar research that can be used for comparison was by Pourhashemi et al. (2015) who reported a good acorn crop in 2010 (mean 10.7 acorns/m² CA) during a three year study (2009-2011) in Kermanshah forests, and lesser crops of 1.6 and 6.3 acorns/m² CA occurring in 2009 and 2011, respectively. Species-specific cycles in acorn production in other oak species of the world have reported masting intervals that commonly vary between 2 to 6 years (e.g. Sork et al., 1993; Koenig et al., 1994; Abrahamson and Layne, 2003).

Identifying the good acorn producers was one of the main goals of this research. As mentioned before, producing acorns almost every year and high levels of acorn production are two main characteristics of these trees. We observed that only a small proportion of oak trees in forest stands are good, consistent acorn producers with the above characteristics. This places the utmost emphasis on their value and the importance of identifying and preserving these trees.

Currently, there are no criteria that can be used to identify good producing trees in a single forest inventory. However there are certain tree characteristics that can be used to identify potential good producers based on their influence on a tree's ability to attain its genetic potential to produce acorns. The first criterion used to identify good acorn producers was described by Sharp (1958) as "sound, uncrowded trees, possessing uniform symmetry of crown and growing in a dominant position in the stand or in openings". However, all of the trees in our study met this criterion of Sharp, and there were good, fair, and poor producers among them. About a decade later, Sharp and Sprague (1967) recommended that it is better to identify good acorn producers each year and make them in a way that long-term trends in production can be assessed. Identifying good acorn producers, requires long-term observation that may be difficult and costly to implement. Maybe for some oak species and in some habitats, it is possible to achieve this goal in a shorter time; however, it seems that for most oak species studies should be done for at least 10 years. For example, Sharp and Sprague (1967) did not observe a good white oak acorn crop until the sixth year of their study. Johnson (1994) pointed out that it takes at least 5 years to identify good acorn producers. Healy et al. (1999) found that an average of 87%, 94%, and 98% of the good acorn producers were correctly recognized in periods of 3, 4, and 5 years, respectively in the eastern United States. For red oak species, they reported that it is possible to identify most of the good acorn producers by recording individual acorn production for 3 years. Our observations over a 6-year period showed that 15 trees could be considered as good producers. Decreasing the study period to 3 years would not change the number of good acorn producers that we identified, but further reductions in the period of observation would affect the correct identification of good acorn producers. Therefore, Healy's et al. (1999) recommendation of 3-5 years being the best period for monitoring of acorn production to identify good acorn producers is acceptable for Brant's oak based on our research.

In some oak species, it is known that as tree diameter increases, acorn production also increases, reaching a maximum before production begins declining in old senescing trees (Downs and McQuilkin, 1944; Goodrum et al., 1971; Dey, 1995; Greenberg, 2000). It seems that the positive relationship between tree diameter and acorn production is due to the usually strong correlation between tree diameter and crown size (Martínik et al., 2017). The relationship between diameter, age, and crown size as related to acorn production is complex, varies by species, and other factors such as stand density and its management throughout a tree's development, and site quality. Some studies have indicated that it may take up to 25 years for oak trees to reach sexual maturity and that significant acorn production occurs between the ages of 40 and 50 (USDA, 1974; Sander, 1990; Carbonero et al., 2002). Perhaps the beginning of flowering and maturation of oak trees and the time it takes for acorn production to be fully expressed accounts for some of the weak correlation between metrics of tree size and acorn production. In our research, acorn production of trees increased with increasing dbh to a maximum above which production remained almost stable across the upper diameter classes. The maximum value of acorn production occurred in the 45-54.9 cm diameter class (mean 6.7 acorns/m² CA). The trees in this class produced 3 times more acorns than the lowest observed diameter class (35-44.9 cm). For trees with dbh > 55 cm, acorn production decreased to a mean of 4.5 acorns/m² CA up to the largest diameter class (85-94.9 cm). Thus, our observed tree size associated with maximum acorn production was similar to other oak species from around the world (e.g., Downs and McQuilkin, 1944).

As already mentioned, however there was a significant difference between the mean values but the values of crown length and tree height in the second diameter class (dbh = 45-54.9 cm) were less than that of other diameter classes. For example, the crown surface of trees in the first diameter class (dbh = 35-44.9 cm) and in third class (dbh = 55-64.9 cm) was higher than that of trees in the second diameter class. Hence, it seems that the presence of trees in the second diameter class coincides with the time of full maturity of trees in the study area, after which the acorn production decreases.

The most important conclusions from this study are the need for more detailed, and longer studies to explain acorn production patterns in Zagros forests of Iran, and the importance of identifying and conserving good acorn producers in these forests. Traditional use of Zagros oak forests by residents has likely had negative effects on acorn production by eliminating good acorn producers through harvesting and damage to remaining oaks by grazing and other practices that reduce crown size and tree health. Many valuable seed trees have been cut for timber and especially for fuel. This research quantified the low proportion of good acorn producers in a sample stand in the Zagros forest region, which is even more significant given that the study stand is one of the best stands in the Zagros currently. Only 16% of oak trees in the study stand were good producers. The fact that they account for the majority of the annual acorn crop in good and poor years, makes their loss all the more important. It is likewise as important to do similar research on other oak species in the Zagros forests to obtain information on acorn production, its variability among species, years and locations, and develop guidance for identifying the good acorn producers. It is a serious alarm call to foresters that they consider adequate measures to protect and conserve individual oaks that are good acorn producers and that they take steps to improve acorn production potential by working with local residents to implement sustainable land use practices that promote oak health, growth, longevity, and regeneration. The awareness of the importance of identifying and conserving good acorn producing trees needs to be made known to local residents, who can help ensure the sustainability of oak forests and acorn production in such an important forest region in Iran.

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