Estimation of fresh sprout biomass based on tree variables of pollarding Turkey oak (*Quercus cerris* L.)

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Abstract Pollarding of oak trees for livestock and animal feeding is a traditional application, and it has been used for centuries from generation to generation in southern and southeastern Turkey. Estimation of the fresh sprout biomass (FSB) potential of pollarded oak forests in high accuracy is important for sustainable forest management. In the present study, 40 trees were sampled from Turkey oak (*Quercus cerris* L.) stands that have been irregularly pollarded for animal husbandry in Adıyaman, southeastern Turkey. In order to estimate FSB, a multiple logarithmic linear model was developed with explanatory variables such as tree diameter at breast height (DBH), total tree height (H), mean sprout length (SL), and mean sprout age (SA), which are in a significant relationship with FSB. Stepwise multiple regression analysis was used to fit this multiple logarithmic linear model and to determine the best independent variable set. As a result of stepwise regression analysis, three models were obtained in which SL, DBH, and SA are independent variables. Model 1 estimates the FSB by taking only SL, Model 2 uses SL and DBH, and Model 3 uses SL, DBH, and SA as independent variables. All models were significant at $p = 0.001$ level. Model 1 explained the variation in FSB by 65%, Model 2 by 81%, and Model 3 by 86%. Inclusion of DBH in the model (Model 2) decreased the mean absolute error (MAE) of FSB by 26% and the inclusion of SA (Model 3) decreased MAE by 43%.

Keywords Animal husbandry · Coppice · DBH · Livestock · Turkey

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Introduction

Pollards and pollarding forest management are of great aesthetical, historical, and natural interest (Rozas 2004). Pollarding has been used for many years and can be carried out for animal feeding, firewood production, or other purposes (Khedri et al. 2017; Smith et al. 2012). Pollarding has been performed in Europe, Asia, Africa, and America, especially for the benefit of leaves and branches, and has been a very important source of income in the farming economy (Franzel et al. 2014;

Geta et al. 2014; Guyassa et al. 2014; Khedri et al. 2017; Lang et al. 2015; Peri et al. 2016). Pollarding forest management probably goes as far as prehistoric times in Europe, although it has been largely abandoned in recent years (Nordén et al. 2018; Rozas 2005; Shahabedini et al. 2018). The product acquired from pollarding forest management is used to provide feed for animal husbandry in areas with poor and difficult conditions for livestock, especially in winter (Ghahramany et al. 2017). The traditional process of pollarding forests is to cut the crowns of trees at a stump height (SH) of 2–3 m to promote the development of new branches and fresh sprouts (Rozas 2004, 2005). This process can be performed regularly or irregularly. Naturally, pollarding application affects the tree architecture and stand structure. After pollarding, the crown area of the tree decreases, and the tree may be stressed and can show abnormal development (Pinkard and Beadle 1998; Ranjbar et al. 2012).

Oaks are the leading tree species in the pollarding forests (Pulido et al. 2001; Rozas 2004; Jazib 2015). In recent years, the effects of pollarding on oak biometric indices and stand characteristics have been investigated (Ghahramany et al. 2017). Oak is also the most widely used tree species in Turkey to aid in animal husbandry and utilization of foliage and branches (Fidan et al. 1998; Mol 1982; Sevimsoy and Sun 1987; Tolunay et al. 2014). Oak pollards are a part of traditional forest management and have a very long history of about 4000 years (Khedri et al. 2017; Rozas 2005). It has been stated that the studies on the foliar biomass or fresh sprout biomass (FSB) of pollarding treatment in oak are limited (Khedri et al. 2017). Accordingly, determination of FSB, which is the main source of animal feed using oak pollards, is essential.

Although there are many literature studies determining the biomasses of trees' stems and woody components, as they contain the world's most common wood products, allometric equations employing tree variables to estimate leaf and fresh sprout biomass in pollards are quite limited in foliar utilization for animal feeding purposes (Shahabedini et al. 2018). Direct measurements of fresh foliar and sprout biomasses are costly and time consuming and sampling is destructive. For this reason, reliable estimation of fresh foliar and sprout biomass without destructive cuts depends on the development of allometric equations based on easily measurable tree variables, such as diameter at breast height (DBH), total height (H), stump height (SH), sprout length (SL), and sprout age (SA) (Shahabedini et al. 2018). Correctly estimated FSB values are greatly needed because they can be used to determine the biological and economic productivity of a forest, the feed capacity for animal nutrition, and forest biomass and carbon stocks (Shahabedini et al. 2018). These equations need to be determined for different tree species with multipurpose use potential and for different regions (Burner et al. 2006).

Pollarding of oaks for livestock in eastern and southeastern Turkey, including the research area of the present study, has been the traditional utilization for many years and has been a tradition from generation to generation. Although this type of utilization is a well-known fact, it is not a legally planned application in terms of forest management. The pollarding cuts are unplanned and made randomly by the local habitants and livestock holders; for this reason, irregular forest structures have resulted due to freehand cuts, spatially and temporally. A highly accurate estimation of the current biomass potential of pollarded Turkey oak forests under this special utilization is important for sustainable forest management, especially because a study of this context has not been documented in Turkey. The present study aimed to develop models to estimate FSB of irregularly pollarded Turkey oak (*Quercus cerris* L.) stands according to tree variables in the southeast of Turkey. Multiple logarithmic linear models were tested by taking the FSB as the dependent variable and DBH, H, SL, and SA as the independent tree variables.

Material and method

Study site

The study area is located between 38°10′45″–39°15′02″ north latitudes and 39°15′45″–37°25′29″ east longitudes in the Adıyaman Province in the southeast of Turkey (Fig. 1). The area is under the influence of the Southeastern Anatolian continental climate, in which summers are very hot and dry and winters are colder. The annual mean temperature is 17.0 °C and the annual rainfall is 835.4 mm. The average altitude is 678 m a.s.l. and the main geological parent material of the research area is limestone. Soils are clay-textured with high lime content. Detailed information for the research area was presented by Saglam et al. (2020).

Clear-cut coppicing is the simple forest management method used to produce foliar fodder for animal husbandry, especially in intensive grazing areas. These clear-cut coppices are managed as pollarding forests in eastern and southeastern Turkey, and the main tree species is generally oak. The difference in treatment of this method from standard coppicing is the cutting height of the trees: in clear-cut coppicing, this is 1.5–2 m from the ground (Fig. 2). Coppice and pollarded forests dominated by Turkey oak (*Quercus cerris* L.) cover 122,212 ha in the study area (Saglam et al. 2020).

Pollarding oak coppices has also been used for the production of wood sticks as well as foliage production. Pollarding is the process of removing the foliated crown-fresh sprouts of the tree by handle cuts, as in coppice stands. Fresh sprouts and fresh leaves are the main components for the assimilation-photosynthesis potential of a tree, and they directly affect the primary growth functions of a tree, such as crown development, diameter increments, branching, and height growth. The complicated question in the research area is as follows: How often are the cuts for pollarding made? The Turkish General Directorate of Forestry does not put pressure on the local population regarding this issue, although the pollarding of oak for animal feeding is completely illegal. In other words, the pollarding practice has been used for years, despite its illegal nature. Also, the use of foliated branches and fresh sprouts completely depends on the preferences of the shepherd or the person who is pollarding the tree. It is likely that trees with more branches and green leaves and that are easier to cut are preferred. Thus, the current utilization and pollarding treatment are completely different from that of the neighboring countries and are country- and site-specific.

Data sampling

The field study was conducted between July and August 2013. Forty healthy trees with different DBH, H, and sprout structures were randomly selected and sampled based on the stand type maps and field observations in order to represent the pollarding coppice of different ages in the study area. Descriptive statistics of sampled trees are given in Table 1. DBHs of the sampled trees vary between 6.6 and 32 cm and total heights between 2.6 and 6.2 m (Table 1).

DBH, H, and SH of selected trees were measured. Then, the sprouts were cut and the lengths were measured. The average sprout age for each tree was obtained by counting the annual rings of all sprouts, and their fresh weights were determined by weighing the sprouts. Measured tree variables are shown in Fig. 3.

Data analysis

Pearson correlation analysis was performed to assess the correlation between FSB and tree variables such as DBH, H, SH, SL, and SA. A correlation matrix
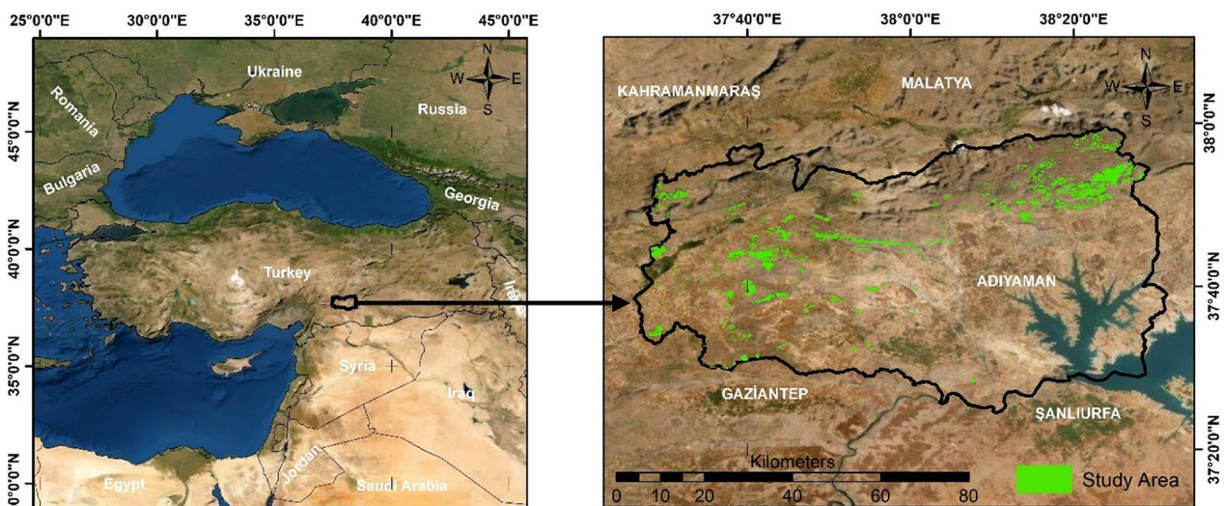

Fig. 1 Study area

including Pearson correlation coefficients and significance levels was obtained from this analysis.

A stepwise multiple regression analysis was employed to estimate FSB by using tree variables as an independent variable, which shows a significant relationship with FSB as a result of correlation analysis. Stepwise regression analysis, a combination of backward elimination and forward selection, is one of the most widely used methods in variable selection and determination of the final model, as it is simple and easy to apply (Ghani and Ahmad 2010; Li et al. 2019). For this reason, it was decided that the multiple log-linear model was suitable.

The multiple log-linear model was developed based on the relationship between dependent variables and independent variables. A stepwise multiple regression analysis was used to fit the multiple log-linear model and to select the best set of independent variables. The multiple log-linear model can be represented as follows:

$$\ln(Y) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_n X_n + \varepsilon \qquad (1)$$

where the $\ln(Y)$ is the natural logarithm of the fresh sprout biomass, X_1 to X_n are the independent variables, ε is the error terms, and $\beta_0 - \beta_n$ are the regression coefficients.

The model prediction values obtained on a logarithmic scale should be back-transformed to the original scale by multiplying with a correction factor to correct the systematic bias caused by logarithmic transformation. For this purpose, a correction factor was calculated
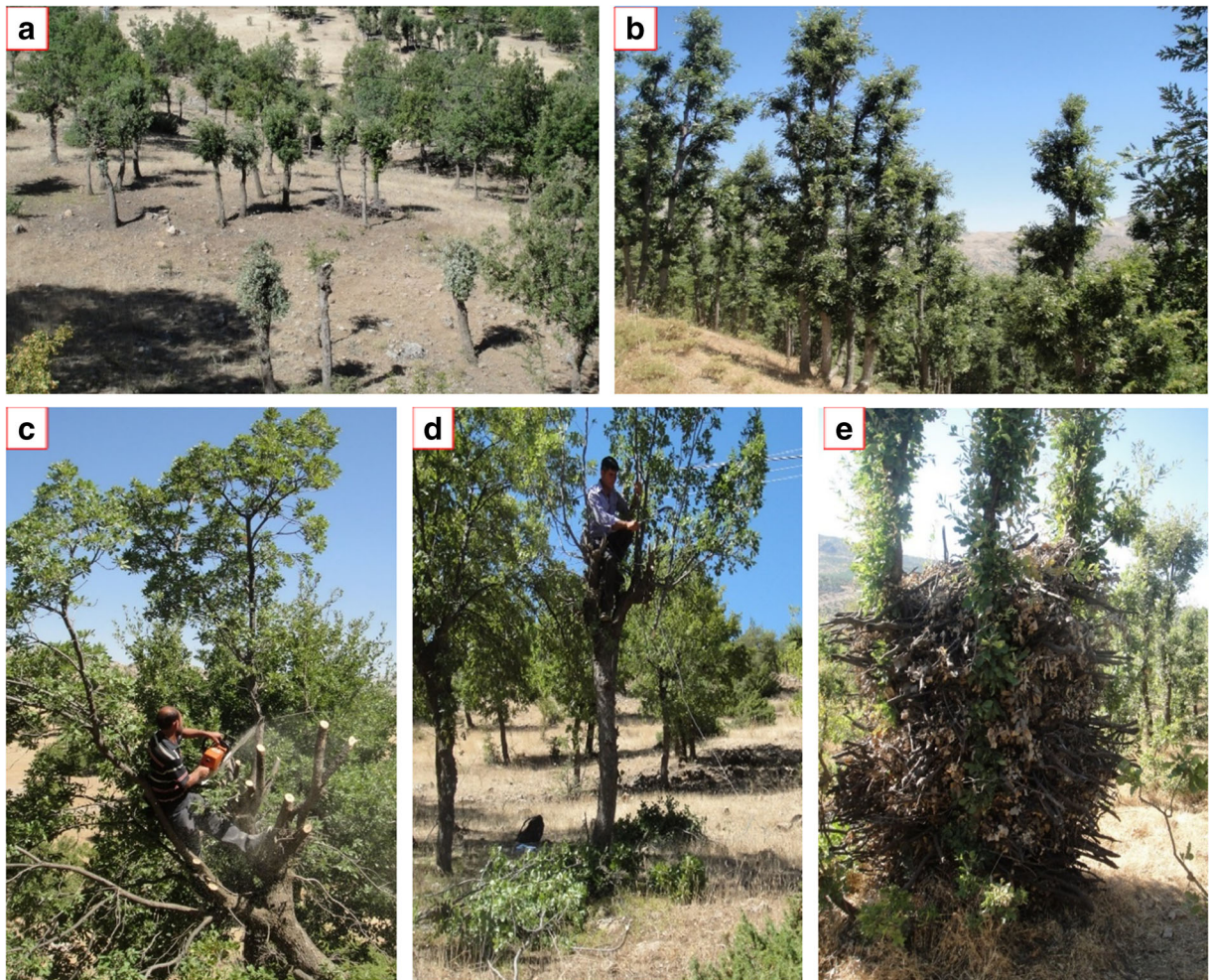

Fig. 2 Pollarding applications in study area, Adıyaman-Turkey. **a** Degraded structure of pollarded Turkey oak (*Q. cerris*) stand, **b** tree architecture after pollarding, **c** pollarding cuts with chainsaw, **d** handle pruning of fresh sprouts, and **e** clamp of pruned-pollarded sprouts

Table 1 Descriptive statistics of sampled trees

Variables	Mean	Std. dev.	Min.	Max.
DBH (cm)	19.6	6.8	6.6	32
H (m)	4.1	1	2.6	6.2
SH (m)	2.7	0.6	1.9	4
SL (m)	1.4	0.8	0.1	3
SA (year)	6	4	1	15
FSB (kg)	42.5	42.1	4	155

H total tree height, *SH* stump height, *SL* sprout length, *SA* sprout age, *FSB* fresh sprout biomass, *DBH* diameter at breast height

according to the article of Marklund (1987) and Cienciala et al. (2008) as shown below:

$$Cf = \sum_{i=1}^{n} Y_i \Big/ \sum_{i=1}^{n} e^{\widehat{ln Y_i}} \qquad (2)$$

where Y_i and $\widehat{Y}_i$ represent the observed and fitted values, respectively, and *n* is the number of sample trees.

Thus, using this method, the mean observed value is equal to the estimated value (Cienciala et al. 2008), and the estimation values obtained on a logarithmic scale can be back-transformed to the original scale as shown below:

Fig. 3 Tree variables used to estimate the fresh sprout biomass on pollarding Turkey oak

$$\widehat{Y} = Cf.\exp(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n) \qquad (3)$$

The goodness-of-fit statistics were calculated to evaluate and compare the performances of models obtained by stepwise multiple regression analysis. While the adjusted coefficient of determination (Adj.R^2) and Akaike information criterion (AIC) were on a logarithmic scale, root mean square error (RMSE) and mean absolute error percentage (MAE %) were calculated using original scales as shown below:

$$RMSE = \sqrt{\frac{\sum \left(Y_i - \widehat{Y}_i\right)^2}{n - p}} \qquad (4)$$

$$MAE \ (\%) = \frac{\sum \left|Y_i - \widehat{Y}_i\right| / n}{\overline{Y}} 100 \qquad (5)$$

where Y_i and $\widehat{Y}_i$ represent the observed and fitted values, respectively, *n* is the number of sample trees, $\overline{Y}$ represents mean value, and *p* is the number of parameters. Statistical analyses were performed on R Software Version 3.6.1 (R Core Team 2019).

Results

Data of 40 sampled trees were used to determine the relationships between FSB and tree variables to develop models for estimating FSB in pollarding oak coppices.

Table 2 features the correlation matrix, which includes the Pearson correlation coefficients and significance levels obtained as a result of the correlation analysis performed to evaluate the relationships between FSB and tree variables.

As a result of the correlation analysis, tree variables (DBH, H, SL, SA) except for SH had a significant relationship with FSB at the $p = 0.01$ significance level. In descending order of significance levels, SL ($r = 0.714$), DBH ($r = 0.694$), SA ($r = 0.665$), and H ($r = 0.578$) show a high correlation with FSB. Furthermore, the relationships between FSB and tree variables, which are significant as a result of correlation analysis, are provided in graphs in Fig. 4.

A multiple logarithmic linear model was developed based on the relationships between FSB and tree variables to estimate FSB. In this model, FSB is a dependent variable, and explanatory tree variables as DBH, H, SL,
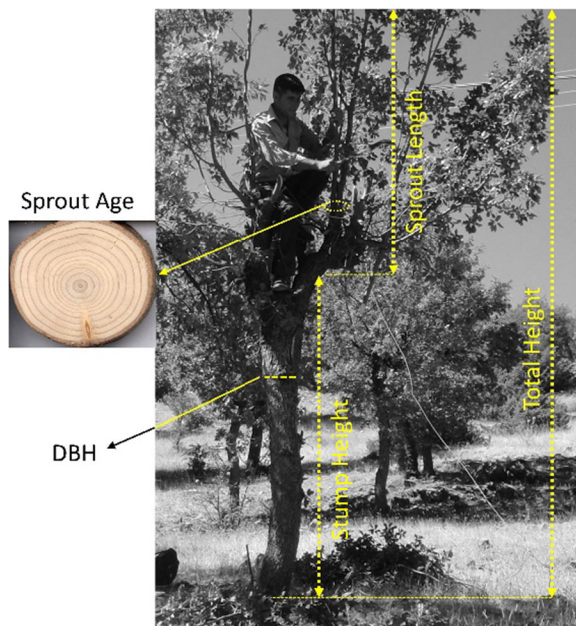
Table 2 Correlation matrix including Pearson correlation coefficients and significance levels

	FSB	DBH	SH	H	SL	SA
FSB	1					
DBH	0.694^{**}	1				
SH	0.055^{NS}	0.033^{NS}	1			
H	0.578^{**}	0.464^{**}	0.648^{**}	1		
SL	0.714^{**}	0.582^{**}	0.052^{NS}	0.794^{**}	1	
SA	0.665^{**}	0.493^{**}	0.161^{NS}	0.594^{**}	0.650^{**}	1

** Correlation is significant at the 0.01 level. *NS* non-significant

and SA have significant relationships with FSB according to correlation analysis.

$$\ln(Y) = \beta_0 + \beta_1 DBH + \beta_2 H + \beta_3 SL + \beta_4 SA \qquad (6)$$

Stepwise multiple regression analysis was used to fit this multiple log-linear model and to determine the best independent variable set. As a result of the stepwise regression analysis, three models were obtained in which SL, DBH, and SA were independent variables. In Model 1, only SL is included; in Model 2, SL and DBH are included; and Model 3 estimates FSB by taking SL, DBH, and SA as independent variables. As the H had no effect on the estimation as a result of the stepwise regression analysis, it was not used as an independent variable in any of the models.

The coefficients of the models and the significance levels of these coefficients are given in Table 3. The coefficients were found to be statistically significant since the significance levels of the model coefficients for the t values are $p < 0.05$.

The goodness-of-fit statistics of the models are given in Table 4. The developed models are significant at $p = 0.001$ significance level. Model 1 explains the variation in FSB by 65%, Model 2 by 81%, and Model 3 by 86%. The variation explained in FSB increases by 24% if DBH is included in the model (Model 2) and by 31% with the inclusion of SA (Model 3).

Among the models, the one using only SL as an independent variable (Model 1) estimated FSB with the highest error of RMSE of 33 kg and MAE of 50%. The mean absolute error rate (MAE%) decreased to 37% with the inclusion of DBH in the model and to 28% with the entry of SA. Model 3, which was developed as the final model with a stepwise multiple regression analysis, explained the variation in FSB with the highest rate (86%) and the lowest error (RMSE = 19 kg,

MAE = 28%) and used SL, DBH, and SA as explanatory variables. Furthermore, Model 3 also had the lowest AIC with 51.1. For this reason, Model 3, which estimated FSB of trees in pollarding oak coppices according to SL, DBH, and SA, can be used reliably. The distributions of standardized residuals according to the predicted ln (FSB) and explanatory variables did not show any systematic trend, and standardized residuals generally ranged from −2 to +2 in the final model as obtained from stepwise multiple regression analysis (Fig. 5).

Discussion

In previous studies, the effects of pollarding on the biometric indices (such as DBH, H, trunk height, crown area, crown diameter, and health) of oak trees were documented (Khedri et al. 2017; Ranjbar et al. 2012; Valipour et al. 2014). Pollarding creates different single-tree biomass values through different structure formations from the normal growth process of the tree, as in the coppice forests.

In the research area, the pollarded oak forests were likely previously managed as coppice because until 2006, deciduous forests, mainly oak forests, were mostly managed as coppice in Turkey (Makineci et al. 2015; Ozdemir et al. 2019; Saglam et al. 2020). Similar to the coppice forest management in oak pollards, the FSB (leaves and fresh crowns) of the tree is cut. As stated before, the pollarding cuts in the research area are irregular and there is no planned and enrolled information. However, it is well known that these pollarding cuts have been made for years (OGM 2014; Saglam et al. 2020) and pollarding affects tree biomass values. Since the main utilization method in the field is cutting the fresh sprouts with leaves, determining and modeling the FSB into relationships with different tree variables has a special importance. FSB demonstrated significant correlations with DBH, H, SL, and SA. In order to estimate FSB with the help of these variables, a stepwise multiple regression analysis was performed to fit the logarithmic multiple linear model to select the best independent variable set. As a result of the stepwise regression analysis, three models with SL, DBH, and SA as independent variables were obtained.

The results show that DBH is an important variable for FSB estimation. While Model 1 estimated FSB according to only SL, MAE% decreased from about 50 to 36% with the addition of DBH to the model
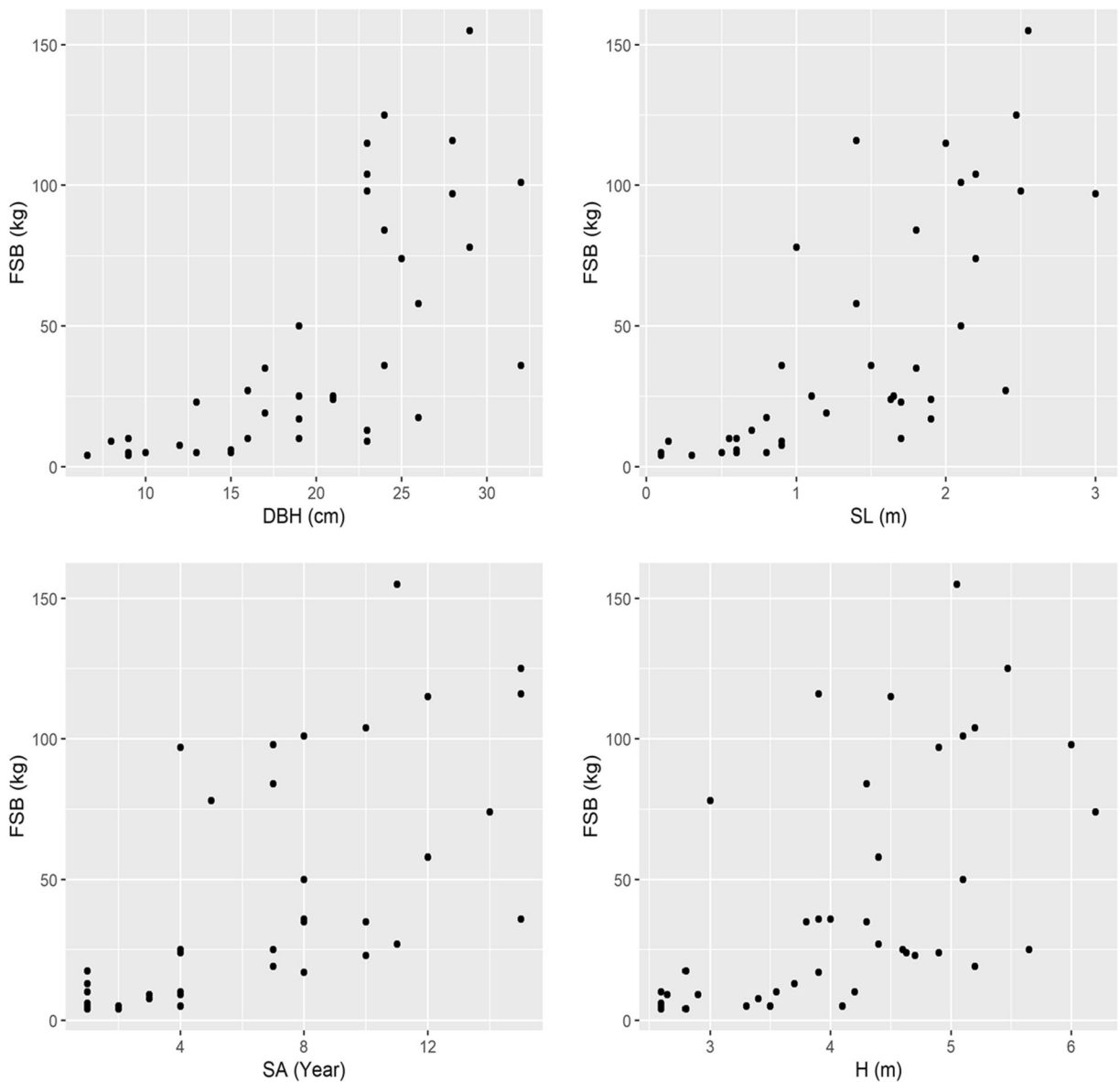
Fig. 4 The relationship between FSB and tree variables, which are significant as a result of correlation analysis

(Model 2). In addition, DBH showed the highest correlation ($r = 0.694$) with FSB after SL. Indeed, similar findings are presented in the literature on this subject.

DBH alone is a good predictor to estimate leaf biomass (Bayen et al. 2016; Calvo-Alvarado et al. 2008; Salis et al. 2006; Wang 2006). The correlation coefficient between the leaf biomass and the stem diameter at 20 cm height is 0.66 of *Jatropha curcas* species in Burkina Faso (Bayen et al. 2016; Shahabedini et al. 2018).

In pollarding Lebanon oak (*Quercus libani* Oliv.) stands, the diameter increment was estimated as 3.5 mm per year (Ghazanfari et al. 2003); in reality, it was measured annually as 3.41 mm in the pollarded stands despite it being 2.20 mm in less-disturbed stands. In Gall oak (*Quercus infectoria* Oliv.), the diameter increments were 2.23 mm per year in pollards and 1.14 mm in less-disturbed stands (Ghahramany et al. 2017). These results showed the direct effect of pollarding on DBH.

Table 3 Estimated coefficients and significance levels of models obtained by stepwise multiple regression analysis

Model	Parameter	Estimated coefficients	Standard error	t	p
1	Intercept	1.535	0.220	6.986	<0.001
	SL	1.198	0.139	8.618	<0.001
2	Intercept	0.541	0.241	2.244	<0.05
	SL	0.781	0.127	6.139	<0.001
	DBH	0.080	0.014	5.622	<0.001
3	Intercept	0.549	0.207	2.652	<0.05
	SL	0.536	0.127	4.203	<0.001
	DBH	0.072	0.012	5.733	<0.001
	SA	0.078	0.021	3.753	<0.01

The highest leaf area and specific leaf area (Gill et al. 1998; Pinkard et al. 1999) were found in the first year after pollarding compared to those in the second and third years in the study carried out with Lebanon oak stands. Accordingly, a greater leaf area increases the diameter increment by providing higher photosynthesis potential, and this difference is significantly higher than that in the previously cut and uncut trees. In other words, the tree diameter increases in the first year following the pollarding cuts. However, pollarding naturally decreases the crown volume with a decrease in leaf area (Pinkard and Beadle 1998). Uncut-undisturbed trees naturally have thicker branches at the top (branches get thicker instead of DBH increment), more dry branches (increased respiration), and denser stands (light competition), all of which cause a decrease in DBH increment (Ghahramany et al. 2017). As stated before in our study, pollarding treatment does not take place with a planned and regular system and it is not clear how often it occurs.

Mac Cracken and van Ballenberghe (1993) determined the leaf and sprout biomass using equations based on DBH in seven different woody species, and R^2 was between 0.16 and 0.76 with an error of ±20% from actual values (Burner et al. 2006). In the present study, the coefficients of determination ($R^2 = 0.65–0.86$) of the models developed for FSB estimation were more reliable than the ones cited above (Burner et al. 2006).

The relationship between dry leaf biomass and the crown height-crown diameter (CHxCD) was higher than in the present study with $R^2 = 0.94$ in the models developed for post-pollarded stands of *Quercus brantii* in Iran, which is relatively close to the research area (Shahabedini et al. 2018). In our study, there was no statistically significant relationship between FSB and SH. Contrary to our results, it was stated that stem cutting height (0, 15, 30, and 45 cm) was effective on height growth of pollards in fast-growing species such as *Leucaena leucocephala* and *Robinia pseudoacacia* (Youkhana and Idol 2008).

In addition, the relationship was found as $R^2 = 0.54$ with the addition of the crown to the model in the estimation of leaf biomass of Lebanon oak pollards (Shahabedini et al. 2018). Tobin et al. (2006) documented that the allometric relationship in leaf biomass estimation using only DBH was 0.72, while R^2 was 0.91 with the addition of the crown height (CH) in the *Picea sitchensis* stands in Ireland (Shahabedini et al. 2018). In our study, the coefficient of determination of the model was obtained as approximately $R^2 = 0.81$ using SL and DBH as independent variables. The pollarding Turkey oak stands in the research area were very sparse, as can be seen in the figures (Figs. 2 and 3). Shahabedini et al. (2018) indicated that sparsely growing trees have different architectures. As a matter of fact, the canopy

Table 4 The goodness-of-fit statistics of models obtained by stepwise multiple regression analysis

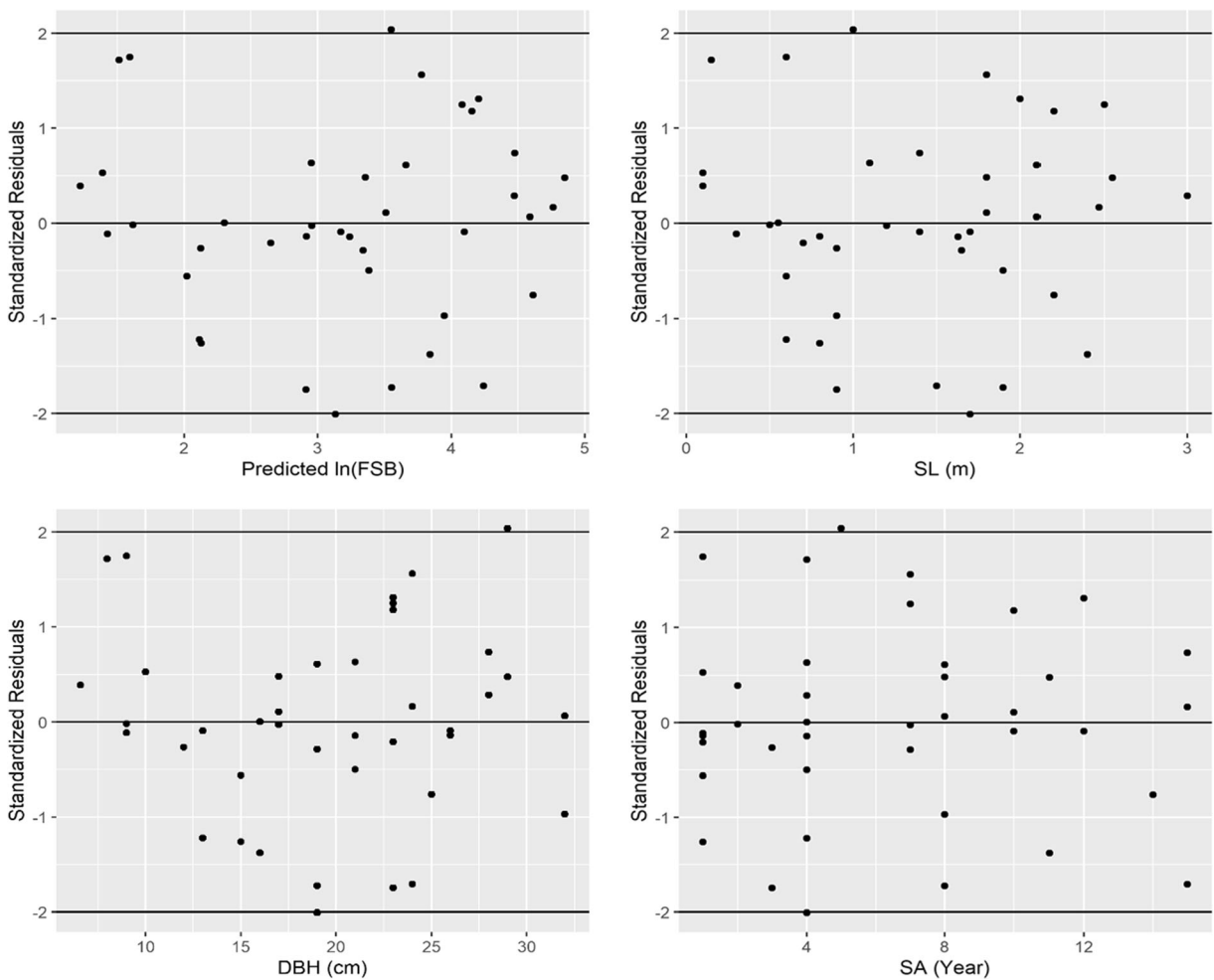| Model	Adj.R^2	RMSE (kg)	MAE (%)	F	AIC	Cf
$\ln(Y)=\beta_0+\beta_1 SL$	0.653	32.7	49.7	74.27[***]	85	1.174
$\ln(Y)=\beta_0+\beta_1 SL+\beta_2 DBH$	0.808	25.7	36.6	82.85[***]	62.3	1.123
$\ln(Y)=\beta_0+\beta_1 SL+\beta_2 DBH+\beta_3 SA$	0.858	18.7	28.1	79.46[***]	51.1	1.104

Fig. 5 Standardized residuals according to the predicted ln (FSB) and explanatory variables for the final model (Model 3)

crown is more lateral, and the vertical distribution of branches is less stratified in pollarded trees growing in open environment compared to trees grown in dense stands (Shahabedini et al. 2018). In the application of pollarding, the branches are cut frequently and the foliated crown biomass shows a rather fluctuating trend. For this reason, the crown height and area constantly change. Although the crown is reformed with new sprouts 3–4 years after cutting, the estimation of leaf biomass is determined less accurately than other biomass components (Kenzo et al. 2009; Sawadogo et al. 2010). However, many factors such as soil type, forest structure, density, age, and climatic conditions are influential on biomass (Shahabedini et al. 2018).

In addition, tree species is very important in natural leaf biomass formation. The mean mass of the leaf stacks in *Q. libani*, *Q. brantii*, and *Q. infectoria* species was found to be about 63.9 kg/tree, and no significant difference was found in terms of diameter classes in Iran (Khedri et al. 2017), while the average FSB was 42.5 kg/tree in the present study. As Burner et al. (2006) stated, some deciduous tree species develop a crown slowly after pollarding while those of others develop rapidly (Burner et al. 2006). These results can be interpreted in that different results can be seen in different oak species and site conditions are influential on sprout productivity and growth.

In pollarding, the sprouts in oaks reach an average of 80 cm height in 5 years (Rozas 2003; Rozas 2004). This situation is similar to the previous pollarding studies in Europe. In the present study, the average sprout age was 6 and the average sprout length was 140 cm, which was higher than those in Rozas (2004).

In the estimation of FSB in the present study, inclusion of the sprout age (SA) to the model (Model 3) increased the explained variation by about 6% and decreased the estimation error by about 8%, compared to Model 2 (DBH and SL). Although a young structure consisting of new sprouts is formed at the top after pollarding, there is an old and developed root system below that supports it. However, new sprout formation is stronger and growth capability is higher in young trees compared to in old ones (Shahabedini et al. 2018).

Conclusions

As a result, FSB showed a very high relationship with DBH, SL (CH), and SA. However, as previously stated, the pollarding is irregular in the research area. Especially in summer, adverse effects such as grazing affect sprout productivity, as the research area is in relatively degraded and harsh growing conditions (summer drought, cold and long winters, low rainfall in the vegetation period, grazing pressure). So, Turkey oak may show relatively little crown development.

As these forests are mostly used for grazing and livestock, destructive effects from grazing (soil compaction, erosion, and reduced soil fertility) can be seen, as in many European pollards. Accordingly, productivity is very low in the forests of the research area. In addition, pollarding significantly affects the nutrient cycle, reducing ecosystem productivity and sustainable regeneration management by losing leaf mass depending on the cutting frequency.

In the present study, only 40 trees from a single species were sampled once in a specific region. Research to determine different biomass components, along with the effects of pollarding in different sites and forest areas with different species and characteristics, will be necessary to obtain more detailed information.

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