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Evaluation of non-destructive Meyer method for determination of bark volume of beech (*Fagus orientalis* Lipsky) in different geographical aspects

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ABSTRACT
The non-destructive Meyer method was evaluated to determine the bark volume of beech (*Fagus orientalis* Lipsky) stands in north of Iran. The sample size was 185 standing trees collected from 4 geographical aspects (north, south, west and east) aspects. The constant k values and bark thickness (2e mm) of 185 standing trees were used to calculate the bark volume by the Meyer method. In this study, 40 trees were randomly selected from among the felled trees and analyzed for evolution of non-destructive Meyer method. As a result, 668 diameters and 1236 bark thicknesses were measured out of 40 felled trees. The bark volumes were calculated by non-destructive Meyer and sums of integration methods. The results indicated no significant differences in volume estimates based on two methods (P = 0.816, two-tailed test), There were no significant differences in Levene's test for equality of variances between the two methods (P=0.576, two-tailed test). The bark volume variations were significantly different in the geographical aspects. Results of this study can be important for silvicultural planning and natural forest management.

Keywords: *Bark thickness, Beech (Fagus orientalis Lipsky)*, *Meyer method, Silvicultual.*

INTRODUCTION
The Caspian natural forests of Iran also called Hyrcanian forests are located on the southern border of the Caspian Sea. Beech *(Fagus orientalis* Lipsky) is a commercial tree and is common at highlands in the Caspian forest region. It is most common in the cool areas, rich soils and north aspects. The stands in this area are the most valuable and economical forests. The main benefits of these forests are essentially two-fold; on the one hand there is its wood production while on the other hand there are various physical and social effects frequently termed as the forest influence. In many instances the latter transcends the significance of forests as producers of wood. For the forest influence, the Caspian forests are divided into four separate forest management areas. One of these is Guilan influx area with a total of 682500 hectares Bonyad and Rahamnajat (2004); Sarikhani (2001). These forests are harvested, yet we know little about their reproductive capacity, actual numbers, age, size distributions, and relationships with other organisms. To ensure their long-term viability, biologists, ecologists and relevant stakeholders should cooperate to perform detailed studies before, during, and after harvesting (Amateis, 2000). Most of the studies have been carried out only after harvesting. There is still not enough biological information on management of these natural resources to ensure their long-term survival. Therefore, basic biological studies are necessary to determine sustainable harvest levels and management regimes (Laasasenaho *et al*. 2005; Shanley *et al*., 2002).

The Beech is a large tree and common in highlands between altitudes of 800 to 2000 meters. It is most common in north aspects, cool areas and rich soils throughout the Caspian Sea region of Iran (Bonyad, *et al*., 2003). The tree typically reaches a height of 45 meters and a diameter at breast height (dbh) of 120 centimeters (Zobeiry 2003). The beech bark is greenish brown when it is young, but it is gray when it is getting old. A number of forest researchers studied bark thickness and bark volume of trees. Bark thickness and bark volume of tree species have relationships with species, genetic structure, actual numbers, dbh, form, height, age, size distributions, growth rate, biological viability and ecological reproductive capacity (Philip 1994; Sonmez 2007). Zobeiry (2003) reported that bark volume of hornbeam (*Carpinus betelus*) species is 5 percent in northern Iran. Namiranian (2006) reported that bark volume of beech is 6 percent in natural forests of Iran. Hengst and Dawson 1994 studied bark properties of 15 hardwood species in the central hardwood region in north of America. Valipour *et al*., (2009) reported that bark thickness of Lebanon Oak (*Quercus libani* Olive) was related with geographical aspects. Jonsson and Nylinder (1990), studied bark thickness of Pine in the direction of the stem – functions of cross-cutting. Natural forest researchers studied statistical modeling of bark thickness and dbh, form, height, age, and size of tree species (Laasasenaho *et al*., 2005; Farshadfar, 2002; Ojansuu, 1993). The main goal of the study was to use the non-destructive Meyer method in order to determine the bark volume of bark at different geographical aspects in Iranian Caspian forests.

MATERIALS and METHODS

This study was conducted at four different geographical aspects in the Shafarud forest, north of Iran. The study area is located at the latitude of 37° 30' 5" to 37° 30' 8" N and 48° 50' 3" to 48° 50' **7**" W. 185 trees were selected among the stand trees within 5 cm dbh interval classes at the four different geographical (north, south, west and east) aspects. In this study, north, south, west and east aspects are denoted with I, II, III and IV, respectively. The elevation of non-destructive Meyer method requires felling numerous trees within each geographical aspect. For this propose, 40 trees from among the felled trees were randomly selected. We used calipers to measure the diameter in centimeters at ground level, 0.5, 1.0, 1.3, meters, and every 3 meters along the felled stems up into the canopy. The procedure was repeated for several trees within each geographical aspect. Tree volume (with or without bark) was determined by measuring the cross-sectional area and length of sections of felled trees and by applying the Smalian or Huber formulas. At each point where the diameter was measured, two small rectangular sections of bark, 180 degrees from each other, were awed out. The bark thickness was measured with vernier calipers, resulting in 668 diameter measurements and 1236 bark thickness measurements. The Meyer method (1946) relies on a single equation expressing the relationship between the bark thickness and the diameter (or the diameter under-bark (d) and the diameter over-bark (D). The diameter under- double bark thickness (B) is subtracted from the diameter over-bark (d = D−B). A regression coefficient (k) is then calculated by the equation: k=d / D. Assuming the ratio d/D to be constant for the length in question, the constant k can be used to calculate the bark volume by the non-destructive equation1: $V_b = V_D \times (1 - k^2)$, where V_D equals volume over-bark Meyer (1946). We used equation 1 to calculated bark volume of standing stems of beech in this study. Meyer cautions against applying k values obtained from small diameter trees to larger diameters and suggests grouping by size class. For this purpose, measured trees are grouped into 2 size classes (15 - 50 and 51+ cm dbh). Another potential problem is whether a given ratio is applicable at various heights of the same tree. Meyer, however, found no significant difference in measured and calculated values of k over approximately twenty meters of hemlock stem. From the sums of integration method (SIM) for felled stems, we calculated the bark volume of each measured stem section using the Smalian or Huber equation. The volumes of individual sections were calculated, and then summed to obtain the total bark volume for the lengths measured. Bark volumes for each tree were tallied and the average was calculated for each size class of geographical (north, south, west and east) aspects.

RESULTS

A null hypothesis (H_0) tested the bark variations at four main geographical study sites (north, south, east and west aspects). Meyer (1946), cautions against applying k values obtained from small diameter trees to larger diameters and suggests grouping by size class. For this purpose, measured trees were grouped into 2 size classes (15 - 50 and 51+ cm dbh) in each geographical study area. The constant k values and bark thickness (2e mm) variation of 185 standing trees were calculated in different geographical aspects as shown in Table 1.

Table 1. Sample size and k values in different geographical aspects.

Sample size		k values		bark thickness		
aspects	Abbreviation	15-50 cm dbh	50+ cm dbh	k_{15-50}	k_{51+}	2e mm
North	I	25	25	0.9586	0.9697	16.8 ± 2.34
South	II	24	23	0.9711	0.9781	15.3 ±2.17
East	III	23	22	0.9525	0.9765	15.1 ± 2.49
West	IV	21	22	0.9514	0.9639	15.5 ±2.09
Total	-	93	92	0.9528	0.9688	15.9 ± 3.19

The k values were used to calculate bark volume by the Meyer method (equation 1). An analysis of variance (ANOVA) test was performed to test k value variations at different geographical aspects. These values were significant (P = 0.043, two-tailed test). We found no significant difference in Levene's test for equality of variances between the study sites (P = 0.158, two-tailed test). The following polynomial equation ($y = 3E\text{-}05\ x^3 + 0.005\ x^2 + 0.546\ x - 4.046$, $R^2 = 0.826$) describes the relationship between double bark thickness (2e mm) and dbh (cm) of *Fagus orientalis* Lipsky in Caspian Sea area (Fig. 1).

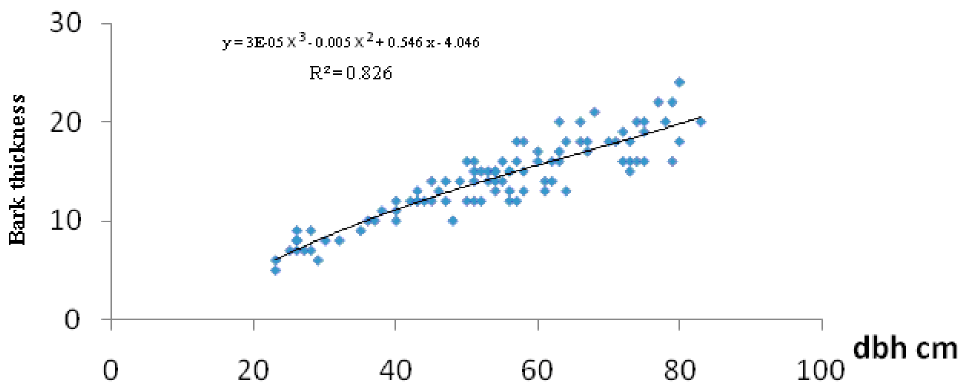

Fig. 1. Polynomial regression between double bark thickness (2e mm) and dbh (cm) of measured trees.

The results indicate that the bark thickness of beech (*Fagus orientalis* Lipsky) was significantly different (P = 0.018, two-tailed test) in different geographical aspects. The bark thickness was maximum in north the aspects and minimum in the south aspects. Two variables: dbh cm and bark thickness (2e mm) were measured from each sample standing trees. The local volume table was used to calculate the volume of sample trees. The analysis of variance (ANOVA) test was performed to test the volume variations of measured standing trees in different aspects (Jerrold, 1999). The results indicate that the mean volume of measured trees was significantly different (P = 0.001, two-tailed test) in different geographical aspects (Table 2).

Table 2. Mean volume of 185 measured trees in different geographical aspects.

Geographical aspects	samples size	volume of measured trees m^3	mean volume of measured trees m^3
North	50	31.60	2.632 ± 0.158
South	47	96.96	2.063 ± 0.144
East	45	81.18	1.804 ± 0.145
West	43	94.39	2.195 ± 0.132
Total	185	404.13	2.185 ± 0.153

For evolution of non-destructive Meyer method, 40 trees of Beech (*Fagus orientalis* Lipsky) were randomly selected among the felled trees. A total tree volume (with or without bark) is determined by measuring the cross-sectional area and length of sections of felled trees and by applying either the Smalian or Huber formulas. As a result, 668 diameters and 1236 bark thickness were measured. Sums of integration method (SIM) and the nondestructive Meyer method (NMM) were used (as two methods) to calculate the bark volume of each of the 40 felled trees (Table 3).

Table 3. Bark volume calculation using sums of integration and the nondestructive Meyer methods n = 40.

bark volume variation (m^3)							
Saple n.	Aspect	SIM method m^3	NMM method m^3	Sample n.	aspect	SIM method m^3	NMM method m^3
1	North	0.146	0.135	21	east	0.075	0.072
2	"	0.119	0.119	22	"	0.073	0.076
3	"	0.089	0.084	23	"	0.098	0.103
4	"	0.199	0.188	24	"	0.137	0.131
5	"	0.179	0.176	25	"	0.082	0.087
6	"	0.388	0.376	26	"	0.099	0.095
7	"	0.288	0.274	27	"	0.151	0.147
8	"	0.199	0.198	28	"	0.148	0.135
9	"	0.411	0.344	29	"	0.153	0.157
10	"	0.072	0.062	30	"	0.123	0.121
11	South	0.042	0.045	31	west	0.139	0.143
12	"	0.059	0.066	32	"	0.184	0.201
13	"	0.075	0.072	33	"	0.146	0.135
14	"	0.153	0.157	34	"	0.028	0.031
15	"	0.123	0.121	35	"	0.146	0.144
16	"	0.188	0.176	36	"	0.288	0.276
17	"	0.193	0.187	37	"	0.288	0.244
18	"	0.087	0.091	38	"	0.397	0.298
19	"	0.219	0.215	39	"	0.035	0.037
20	"	0.425	0.398	40	"	0.188	0.187

The means of the bark volumes calculated by sums of integration method (SIM) and the nondestructive Meyer method (NMM) were $\overline{X}_1 = 0.163 \pm 0.036$ and $\overline{X}_2 = 0.176 \pm 0.031$ respectively. We found no significant differences in volume estimates employing the two methods for calculating bark volume (P = 0.816, two-tailed test) nor did we find significant differences in Levene's test for the equality of variances between the two methods (P = 0.576, two-tailed test). An analysis of variance (ANOVA) test was performed to test bark volume variations in the four geographical study areas (north, south, east and west aspects). The results indicate that these values are significantly different in the geographical aspects. The results of this research can be important in forest research, biometrics, planning and management.

DISCUSSION

The bark volume calculations are dependent on the accurate determination of the bark thickness. Potential error is minimized in smooth-barked species such as Beech (*Fagus orientalis* Lipsky) and is greater for species with great variation in bark texture, such as some species of oak, poplar and pine (Atha, *et al*. 2005; Bennett, 1965). The sums of integration and Meyer methods employed for measuring the bark volume are also subject to bias. The most accurate method is to remove a section of bark and measure the thickness with a caliper ruler, as done in this study. Even assuming accurate bark thickness measurements, the precise bark volume calculations are inherently difficult because the shape under consideration is that of a hollow cylinder which not only tapers, but does so at one angle on the inside and another on the outside (Atha, *et al*., 2005). This is true when the diameter over-bark and diameter under-bark are not constant as in the case of species including oak, pine and spruce (Loetsch 1973). Calculus methods such as the equation for rotational volume (employed in this study) are the most accurate means of measuring the volume of such shapes, with the precision depending on the number of data points taken along the length in question. Most commercial timber operations rely on volume tables based on a few measurements and employ algebraic equations based on the average cross-sectional areas and assuming an overall paraboloid shape (Jonsson and Nylinder 1990).

Our findings in this study are in agreement with that of other natural forest researchers. The constant k values calculated for each of the 2 size classes (k_{15-50} and k_{50+}) were significantly different in the four geographical aspects. The Meyer method is more accurate when trees are normally shaped and trees are grouped by size class. In this study, measured trees are grouped by size class for more accuracy of constant k values. The bark thickness measurements were taken from 185 trees within each geographical aspect to obtain reasonable confidence in an average bark thickness for that size class. The constant k values were calculated and used in the non-destructive Meyer method. As a result, 668 diameters and 1236 bark thicknesses were measured. The results obtained using the nondestructive Meyer method were not significantly different from that obtained using the sums of integration method. The results of this study showed that the percentage of bark volumes were maximum in small diameter trees and minimum in those with larger diameters. The greater bark volume in the north and west aspects may be due to ecological variations in these aspects. Our findings are coordinated with other natural forest researchers, findings (Mahinpoor, 2002; Valipour, *et al*., 2009; Atha, *et al*., 2005; Laasasenaho, et al., 2005; Farshadfar, 2002; Ojansuu, 1993 and Kleinbaum, et al., 1988). These results can be important for silvicultural planning, and natural forest management.

The results of this study provide reliable estimates for the current bark thickness and volume of *Fagus orientalis* Lipsky in the Caspian Sea area in the north of Iran. It is also shown that bark volume may be accurately determined by using the non-destructive Meyer method. We suggest that the researchers employing the Meyer method can obtain bark volume data simply and accurately for broadleaved and conifer species. These results can be important for forest planning and management.

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ارزیابی روش مایر برای تعیین حجم پوست گونه راش در جهت های مختلف جغرافیائی

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چکیده

در این بررسی از روش مایر برای تعیین حجم پوست درختان در درختان سر پا در جنگل های شمال ایران استفاده گردید. تعداد 185 اصله درخت سر پا در چهار جهت جغرافیایی (شمالی، جنوبی، شرقی و غربی) برای اندازه گیری ضخامت پوست انتخاب شدند. ضخامت پوست (2e mm) تعداد 185 اصله درخت سرپا در قطر برابر سینه اندازه گیری شد و مقدار k برای هر یک از درختان مورد اندازه گیری محاسبه گردید. برای ارزیابی صحت و دقت روش مایر، تعداد 40 اصله درخت از بین درختان قطع شده بصورت تصادفی انتخاب شدند. از 40 اصله درخت قطع شده، تعداد 668 مورد قطر و1236 مورد ضخامت پوست اندازه گیری و ثبت گردید. حجم پوست درختان، به دو روش شامل روش مایر و روش معمولی و سنتی محاسبه گردید. نتایج این بررسی نشان می دهد که واریانس بین دو روش اختلاف معنی داری ندارند (P=0/576) و همچنین برآورد حجم با این دو روش اختلاف معنی داری (P= 0/816) وجود ندارد . با توجه به این نتایج می‌توان از روش مایر برای محاسبه حجم پوست درخت سرپا (بدون قطع) استفاده کرد. این نتایج آن می تواند در مدیریت جنگل و جنگلشناسی مورد استفاده قرار گیرد.