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Determination of the Best Diameter-Height Model for the Norway spruce (*Picea abies* L. Karst.) in Kelardasht afforestation (North of Iran)

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Abstract: In order to determination of the most appropriate relation between diameter and height of *Picea abies* L. in Kelardasht affoestation (North of Iran), stand with 18.1 ha^{-1} area, 44 years old, plantation distance 2×2 m was selected. Number of 32 sample plots (inventory network 70×70 m) with circle form and 500 m^2 areas were designed by using of randomized-systematic method for this study. Diameter all of trees and height of witness tree four (number two of the most diameter trees and two of the nearest trees to center of sample plots) were recorded in every sample plots. Results of this research showed that diameter and height mean of stand are 16.86 cm and 18.20 m, respectively. The best appropriate model for aforementioned stand was used $H = 11/9765 + 0/3291D - \frac{87/0541}{D^2}$ that determined as non-linear. Pay attention to aforementioned results the coefficient variance of stand is high because of thinning operations wasn't performed in this stand.

Key words: *Picea abies* L., height, height model, kelardasht

INTRODUCTION

Height inventory of forest stand trees is one of forest inventory necessities for estimation of wood volume, determination of site index, forest stand activity and etc. (Fadaei, 2005). Tree height is one of the effective factors for calculation of volume. Inventory of tree height is possible by using of simple and low cost methods to using of subtle, high cost apparatuses. Height inventory for all of trees is impossible, almost, unless in peculiar conditions and scientific researches (Zobeiry, 2000, 2006).

Therefore, by reason of in forest stand inventory, in every of sample plots, diameter and height some of trees (2 to 4 trees) are recorded as witness trees and by using of these data, height curve on basis of diameter is calculated and generalization to all of trees in study area. In fact, inventory of trees diameter and height are necessity in forest inventory for estimation of wood volume and site index (Fadaei, 2005). Also, these factors are important variables in increment model and wood production (Zobeiry, 2000; Namiranian, 2007). Relation between trees diameter and height is one of the most important component in forest structure (Zobeiry, 2000).

Estimation of trees volumes, site index, explanation of forest stand activity and long succession are need to appropriate diameter-height models (Curtis, 1967; Botkin *et al*., 1972; Karlsson, 2000; Sarkkola *et al*., 2005; Ramming *et al*., 2006). In forest inventory, total height of trees is calculated with using of inventoried diameter of tree at breast height. Tree diameter is measurable simply and low cost but aware of tree height is more difficult and high cost, almost. Therefore, the models that are alone on basis of diameter are the effective on cost (Fadaei, 2005; Namiranian, 2007).

Determinations of height increment models have more effective on prediction of increment changes of uneven aged stands (Lundqvist, 1995; Zobeiry, 2006). Height increment is the important factor in prediction of forest stand stock for the better management of forest resources (Zumrawi, 2003; Zobeiry, 2006; Namiranian, 2007).

Many number of height-diameter models are determined for different species and sites. Fang and Baily (1998) had used 33 height models for tropical forests in the south of china on basis of diameter. Fadaei (2005) has used number of 24 linear and non linear models for determination of relation between diameter at breast height and trees height of *Pinus teada* species in polimbera regions of Talesh (North of Iran).

Pormajidian (1992) and Siahipour *et al*. (2002) had proposed the height-diameter non linear models for *Picea abies* afforestation in Kelardasht region and Guilan province (North of Iran), respectively. In many of researches, non linear models were the most appropriate

for showing of relation between diameter and height because of in high ages, trees have low height increment and in old ages, theirs height increment are fixed, almost. Therefore, linear models aren't used for determination of relation between diameter and height, thus, non linear models are more appropriate for showing this relation.

This study is trying to determination of the most appropriate model in order to achievement to relation between height and diameter at breast height for *Picea abies* L. (Norway spruce) in afforestation of Kelardasht regions, because of diameter and height of stand trees are the foundation and basis for determination of stand volume. Therefore, obtained results in this study are effective in determine of volume stock for *Picea abies* stand of Kelardasht region.

MATERIALS AND METHODS

Study area: Study area (18.1 ha^{-1} areas) was afforestation with *Picea abies* (L.) in 1965 by total official of natural resources-Noushahr (North of Iran) with plantation distance of 2×2 m. These areas are situated in forest management plan of Mazan Abad. Study area is located on 45 Km southwest far from Chaloos town (Kelardasht region) between 36°29' 54° to 36°29' 52° North latitude and 51°10' 51° to 51°10' 00° East longitude (Fig. 1a-b). The general aspects of these forests are Northern. The average slope of forest field is about 15% (Min. 5% and Max. 27%), the height of forest area at sea level starts from 1250 m and continues till about 1350 m (Mohammadpoor, 2007).

Sampling method: In this study of randomized-systematic method was used. Area of sample plots were 500 m^2 (Zonbeiry, 2000) pay attention to obtained results in previous researches (Pormajidian, 1992; Khodabakhsh, 1998) and also, at least 10 to 15 trees in every sample plots. Numbers of 32 circle form sample plots (with inventory network of 70×70 m) were designed. In this research, intensity of inventory was selected 10.2% (Pormajidian, 1992; Keshavars, 1992; Khodabakhsh, 1998; Haghi, 2002). In every sample plots, diameter at breast high all of trees by using of caliper and height of witness four trees (number two of the most diameter trees and two of the nearest trees to center of sample plots) and totally, height of 128 witness trees in all of areas were recorded by means of suunto clinometer's.

Determination relation between diameter at breast height and height: Different models were proposed for determination of relation between diameter at breast high and forest stand height (Table 2). For evaluation of diameter-high curve, mean square error and R^2 were

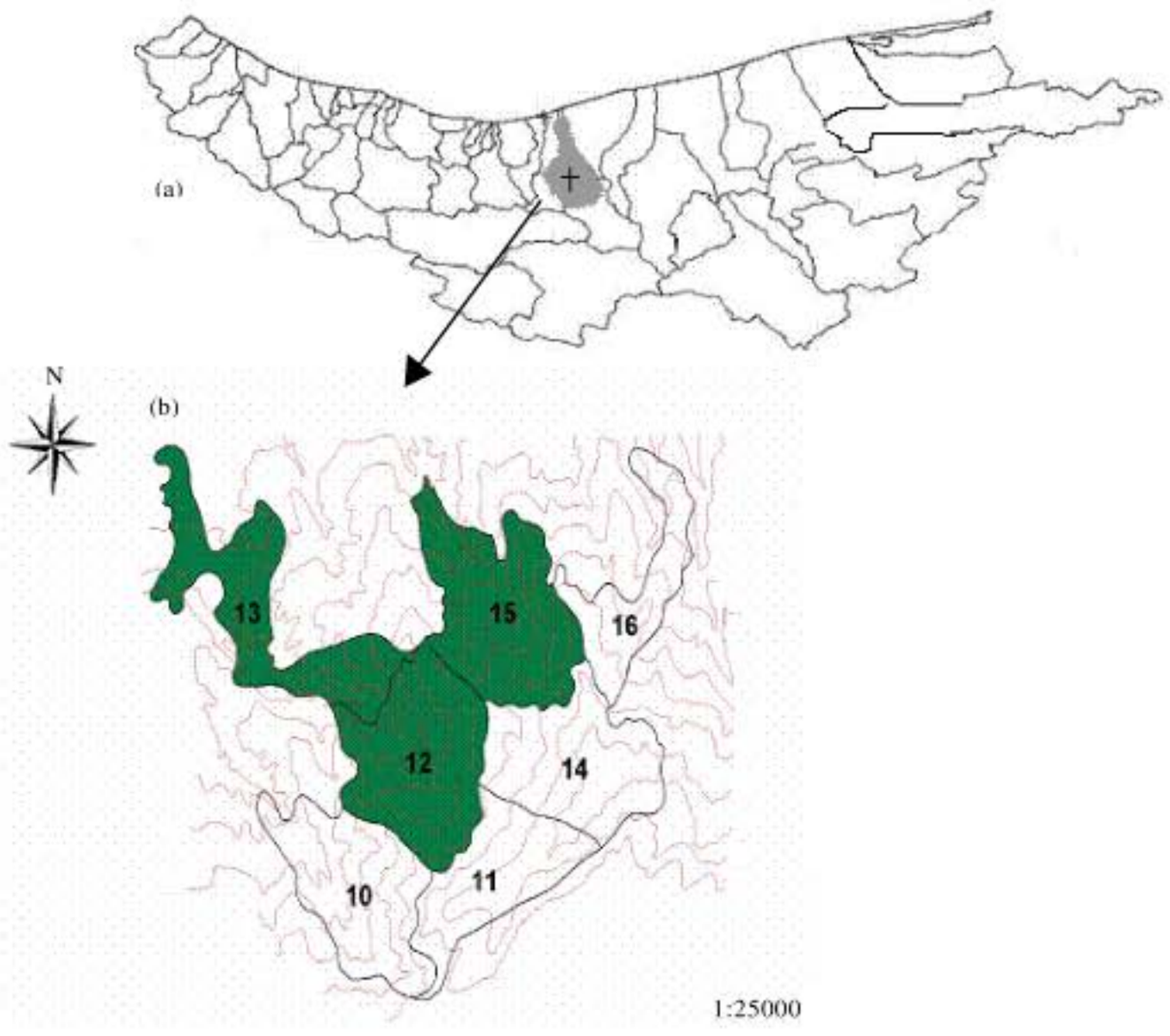

Fig. 1: Position of the study area (a) Mazandaran province and (b) in the North of Iran

calculated in every of models by Eq. 1 and 2 afterwards of data transmission to allocated axes in SPSS software package:

$$MSE = \sum_{i=1}^{n}\left(H_i - \hat{H}_i\right)^2 / n \quad (1)$$

$$R^2 = 1 - \left[\sum_{i=1}^{n}\left(H_i - \hat{H}_i\right) / \sum_{i=1}^{n}\left(H_i - \bar{H}\right)^2\right] \quad (2)$$

where, H_i is observed height, $\hat{H}_i$ is estimated height of tree; $\bar{H}$ height mean of observed trees and n is number of observations.

The model with the most R^2 and the least differences between R^2 and modified R^2, coefficient variances and mean square error are the best regression model (Jalilvand, 2007). Also, in order to selection of the final and appropriate model, distribution of scatter plot of height estimation residual ($\hat{H}$) on basis of diameter at breast high (D) were compared.

RESULTS

Analysis of data showed that diameter mean and diameter average increment in this stand were 16.86, 0.38 cm, respectively. Arithmetic mean of height (18.20 m) and height average increment (0.44 m) for *Picea abies* stand in Kelardasht region were calculated. Also, basal area mean, basal area average increment and growing stock and volume average increment for aforementioned stand were 23.59, 0.54, 193.73 and 4.4 m^3 ha^{-1} year, respectively (Table 1). Form factor of *Picea abies* was obtained 0.46 (Table 1). H/d value is one of the most important factors for judgment of stand sustainable that was calculated 107.95% for studied stand in this study (Fig. 2).

Afterwards of evaluation and comeliness of different models and drawing of scatter plot, the best model was selected for studied stand. Model of number 9 (Table 2, 3) have R^2, modified R^2, coefficient variance, mean square error and distribution of the better scatter plot in comparison with the other models because of this model has a good comeliness in distribution of scatter plots (Fig. 3, 4). The best appropriate model for aforementioned stand was as under (the third equation) by reason of this model display relation between diameter and height with the best manner.

Table 1: Statistic characteristics for picea abies in Kelardasht region at 44 years old

Statistic characteristics	Mean	SD	SE	Coefficient Variance (%)	Increment annual mean
No. per hectare	982	38.80	13.90	3.95	-
Diameter (cm)	16.86	3.67	0.22	21.76	0.38
Height (m)	18.20	1.98	0.35	10.89	0.41
Basal area (m^2 ha^{-1})	23.59	1.10	0.11	4.66	0.54
Volume (m^3 ha^{-1})	193.73	9.20	0.99	4.79	4.40
Form factor	0.46	0.03	0.01	6.5	-

Table 2: Utilized models for determine relation between diameter-height in different studies

No.	Model	Reference
1	$\hat{H} = (D^2/(a + bD + cD^2)) + 3/1$	Curtis (1967), Carus (2004)
2	$\hat{H} = ae^{b/d}$	Buford (1986)
3	$\hat{H} = a\text{-}be^{-cd}$	Bailey (1979)
4	$\hat{H} = aD^b$	Huang and Titus (1992), Arabatzis and Burkhart (1992)
5	$\hat{H} = a/(1 + be^{-cD})$	Carus (1994)
6	$\hat{H} = a + bLnD$	Soares and Tome (2002)
7	$\hat{H} = aD/(b + D)$	Soares and Tome (2002)
8	$\hat{H} = a+(b/F)$	Soares and Tome (2002)
9	$\hat{H} = a + bD + cD^2$	Carus (2004)
10	$\hat{H} = ae^{-b-cd}$	Fadaei (2005)
11	$\hat{H} = a/(1 + e^{b-cD})^{1/D}$	Fadaei (2005)
12	$\hat{H} = (a + bD)/(1 + cD + dD^2)$	Fadaei (2005)
13	$\hat{H} = a\ (b\text{-}e^{-cD})$	Fadaei (2005)
14	$\hat{H} = aD^{bD}$	Fadaei (2005)
15	$\hat{H} = ae^{bD}$	Fadaei (2005)
16	$\hat{H} = (ab + cD^d)/(b + D^d)$	Fadaei (2005)
17	$\hat{H} = a + bD + (c/D^2)$	Fadaei (2005)

D: Diameter at breast height (cm); $\hat{H}$: Estimation of tree height (m); Ln: Natural logarithm; a-e: Equation coefficients

Table 3: Estimated parameters of diameter-height models for picea abies species

Model No.	a	b	c	d	R^2	R^2_{adj}	CV (%)	MSE
1	-4.1219	0.0559	5.0068	0.0985	0.893	0.892	9.95	0.385
2	33.9397	0.1503	0.0318	-	0.897	0.896	9.95	0.376
3	26.2648	6.8577	0.0003	-	0.870	0.868	9.88	0.476
4	6.5600	2.1588	0.1050	-0.0010	0.898	0.896	9.95	0.375
5	87.6676	0.8700	-0.0038	-	0.896	0.895	9.94	0.381
6	32.1708	-3.6789	-	-	0.887	0.886	9.94	0.414
7	12.3437	0.0194	-	-	0.892	0.891	9.88	0.396
8	-2.9071	-0.5640	2.0802	-0.1019	0.898	0.896	9.95	0.375
9	11.9765	0.3291	-87.0541	-	0.897	0.897	9.90	0.375
10	10.9514	474.5627	8.3325	-0.2318	0.870	0.895	9.95	0.376
11	26.2725	-6.8587	-	-	0.897	0.869	9.88	0.476
12	29.7987	1.7373	0.0511	-	0.889	0.896	9.95	0.376
13	-1.7713	6.7721	-	-	0.883	0.888	9.90	0.406
14	29.1925	11.4368	-	-	0.889	0.882	9.99	0.428
15	-1.7714	6.7721	-	-	0.877	0.888	9.70	0.406
16	1.0000	-0.9910	0.9671	-	0.877	0.875	9.99	0.446
17	5.9158	0.3794	-	-	0.896	0.895	9.96	0.383

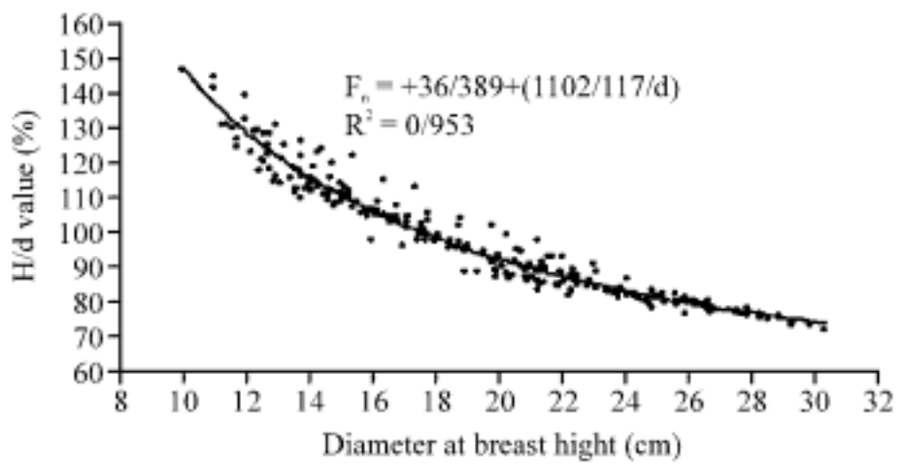

Fig. 2: Scatter plot and H/d curve for stand

$$F_n = \frac{\bar{h}}{d} \times 100 = \frac{18/20}{16/86} \times 100 = 107/95\%$$

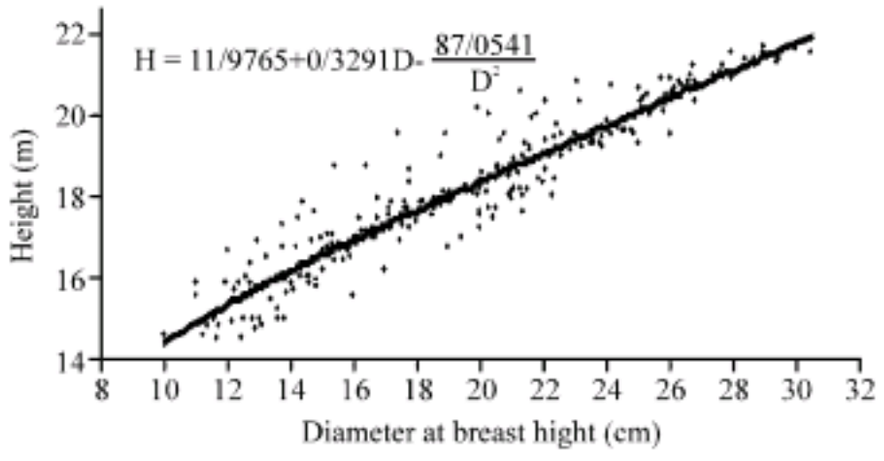

Fig. 3: Relation between diameter at breast height and height of trees in picea abies stand

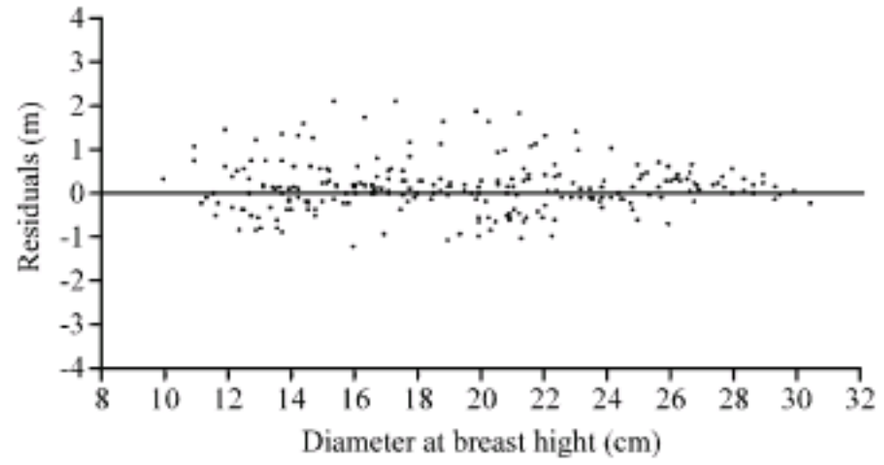

Fig. 4: Distribution of estimated height residuals on basis of diameter at breast height

$$H = 11/9765 + 0/3291D - \frac{87/0541}{D^2} \quad (3)$$

where, H, tree height (m) and D; diameter at breast high (cm).

DISCUSSION

Pay attention to the important of *picea abies* L. and also, extensive areas that are afforested with this species in these years, therefore, determination of increment models are necessitate for more attention to this species. Determination of these models helps to the better management of forest. Obtained models will present increment and the effective factors on theirs. These models will show the best alternative and also, it is possible to prediction of forest future and succession (Zobeiry, 2000, 2006; Namiranian, 2007).

Tree heights are effective for determination of height annual increment, site quality, stand structure (Fahlvik *et al*., 2005; Strand *et al*., 2006; Kantola *et al*., 2007) and stand competition (Cobb *et al*., 1993; Zobeiry, 2006). Determination of trees height model is as important factor for determine of trees reaction to site conditions and regeneration methods (Makitalo, 1999; Saksa *et al*., 2005; Eerikainen *et al*., 2007).

Pormajidian (1992) proposed $\hat{H} = 0/494746+0/91913d - 0/123d^2$ for *Picea abies* at 29 years old for kelardsht region. Siahipour *et al*. (2002) proposed $H = 0/0257d^2+ 1/5418d-3/59$ ($R^2 = 0.9775$), $H = 0/0139d^2+0/1739d^2+ 0/1739d-22295$ ($R^2=0.9956$), $H = 0/44d^2+0/9963d-0/4155$ ($R^2= 0.9827$) for Piseson, Oroston, Rik regions, respectively, in Guilan province at 27 years old.

The results of Table 3 showed that coefficient variances of models are high and R^2 is low, relatively, because of high h/d value of stand due to didn't perform cultural operations and stand thinning, on time. In fact, prevention of thinning operation in appropriate time following increase of competition and high increment for achievement to light factor (Chrimes, 2004; Hunzinker and Brang, 2005; Laasasenaho *et al*., 2005; Paulina *et al*., 2007), that this subject is following irregular height increment and is effective on R^2 and coefficient variance of stand.

Thinning operations is following reduction of competition, increase of volume and diameter increment in stands (Sarvas, 1944; Nilson and Lundqvist, 2001; Motta, 2003; Chertov *et al*., 2003; Cunninghami *et al*., 2006; Saarsalmi *et al*., 2007), therefore, coefficient variance and R^2 of stand will change, also. Finally, this subject is mentionable that calculated model in this research, is just applicable for 44 years old, because of height curve right away in different ages thus we have special model for every of age classes (Veronica *et al*., 2007).

Also, height models of *Picea abies* L. are well studied and results for models have been reported by Karlsson (2000), Eid and Tuhus (2001), Gobakken and Nasset (2002), Chertov *et al*. (2003), Mottav (2003), Sakkola *et al*. (2005), Leasasenaho *et al*. (2005), Hunziker and Brang (2005), Fahlvik *et al*. (2005), Rammig *et al*. (2006), Strand *et al*. (2006), Cunningham *et al*. (2006), Fehrmann and Kleinn (2006), Kantola *et al*. (2007), Saarsalmi *et al*. (2007), Eerikainen *et al*. (2007), Seifert (2007), Paulina *et al*. (2007) and Hosseini and Jalilvand (2007).

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