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Developing A Form Factor Function for Acacia Decurrensin Southwestern Amhara National Regional State, Ethiopia

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Abstract

Volumetric estimation is very important for a sustainable management of forest resources, yield prediction and also to know its growth rates. It is the product of DBH, tree height and form factor. Acacia decurrens Willd is extensively grown as a rotational crop for charcoal and productivity improvement in woodlot of Awi Zone. The objective of the study was to develop a form factor function that can estimate the stem profile of the tree species. Pollanschutz's, F. Evert's, Short Swedish's, Mayer's and Rosset's form factor functions were tested to select the best one. The data were collected at 58 destructed trees from five years aged in two woodlots and one community-managed plantation of A. decurrens during farmers' harvesting. To predict the volume of the species, all the functions were evaluated by Root mean square error (RMSE), mean absolute deviation (MAD), coefficient of variance (CV) and graph behavior of observed form factor. The performance of all functions was almost similar even though we chose Mayer's and Pollanschutz's functions due to their relatively lower values of RMSE, MAD and the nature of the graphs of predicted versus observed form factors are nearly stable. Based on this, 0.4875 was recommended to estimate the above ground stand volume of A. decurrens with a DBH range of 8-14cm for the five years old woodlot in the study site.

Keywords: *Acacia decurrens*woodlot; Awi Zone; Form factor function;

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Introduction

Stand volume estimation is important for decision making and a sustainable management of forest resources. According to Laar and Akea (2007), bole volume estimation is a crucial work in forest inventory because the volume of timber is the basic management unit of forests. Knowing the volume of the wood resources, and their rates of growth (Adekunle *et al*., 2013), yield forecasting is necessary at national and stand levels. The ability to measure tree growth and volume can provide forest owners with an understanding of forest productivity and a basis for planning forest management actions and policies (Philip, 1963). Data needed to estimate tree volume can only be collected through field inventory, but that is time-consuming and expensive. Volumetric measurement of trees requires recording of diameter and height along the bole of each tree. Volume estimates based only on DBH and total height is subject to error resulting from the variation of the stem form of a tree (Socha and Kulej, 2007).

V= g×h×f equation; where "V" is tree volume (in m^3), "g" is basal area at breast height (in m^2), "h" is tree height (in m), and "f" is form factor of a tree, which shapes the cylindrical volume of a tree to its actual form. The form of a stem varies with the height of a tree due to stand density, climate, site quality, and management practices (Heather *et al*., 2000; Laar and Akça, 2007). The form factor is the main determinant factor next to the diameter at breast height and tree height for accurate volume estimation of a species and/or stands (Adekunle *et al*., 2013). Basal area measurement is relatively cheap and easy. However, measuring form factor and height is critical, time-consuming and expensive (Sharma, 2009).

Acacia decurrens Willd (Green wattle) belongs to the family Fabaceae and it grows well in moist and Wet Weyna Dega and DegaAgro-climatic zones of Ethiopia (Tesemma, 2007), inaltitude of 1800 to 2950 meter above sea level (Achamyeleh *et al*., 2016). It has a great potential for charcoal, poles, firewood, and used to stabilize soil (Tesemma, 2007; Priyono *et al*., 2010). It is a fast-growing species where it can reach for rotation within five years in woodlots (Tadele*et al*., 2017). Currently, in the Southwestern of Amhara National Regional State, highlands of Awi Zone, the species is extensively cultivated as rotational crop for charcoal production, rehabilitation of degraded land, production and productivity improvement in the form of woodlot Agroforestry system (Achamyeleh *et al*., 2016; Zerihun *et al*., 2016; Yazie and Anteneh, 2015). *Acacia decurrens* woodlot generates a net present value of 26,682.68 ETB/ha with a benefit-cost ratio of 1.94 and an internal rate of return of 60% (Yazie and Anteneh, 2015) and it is stock produced by the stand. Besides, it improves the soil fertility of the ecosystem including soil organic carbon; due to those economical and ecological advantages of the system is a win-win approach (Tadele *et al*., 2017. unpublished). For example, the area coverage of farmer-managed *A. decurrens* woodlots has been expanded from 720ha in 2009 to 4083ha in 2014 in Fageta Lekoma District (Yazie and Anteneh, 2015).

However, the volume of *A. decurrens* trees, woodlots, and stands have been estimated from the product of measured DBH, tree height and a constant form factor value of 0.44 as a blanket recommendation for all DBH classes of a species (Amhara Forest Enterprise, Personal communication during Nov. 03, 2016). This is supposed to be the main source of error, which reduces the income to households and/or the government by underestimating the wood volume. This is because volume estimation using the same form factor function is not ideal for all species. For example, Gezahegn (2015) developed a form factor function for 20 broadleaved tree species which dominated four natural forests in Amhara. However, it was not produced for commercial and plantation tree species including *A. decurrens* tree and stands in Southwestern of the region except for *JuniperusProcera*in Arsi by (Mamo *et al*.,1995). In general, there is a limited experience of tree form factor function development in Ethiopia (Gezahegn, 2015). The objective of this study was to develop a form factor function that can help estimate the stem profile of *Acacia decurrens* tree and woodlot stands in Southwestern of the Amhara region.

Materials and Methods

The study areas: The study was conducted in AnkeshaGuagusa and FagetaLekoma districts that are found in Awi Zone, Amhara National Regional State, Ethiopia (Figure 1). Ankesha Guagusa District is geographically located at 36º36'18" and 36º59'33" east and (10º57'23" to 11º11'21" north while FagetaLekoma District is located at 10º31'46" and 10º41'32" north and 36º40'01" to 37º05'21" east (Kebede, 2014). The elevation of the study area ranges from 1800 to 2900 m a.s.l. (Achamyeleh *et al*., 2016). The farming system of the highland part of Awi Zone including the study districts is a mixed cropping system mainly potato and livestock husbandry. However, recently, the major components of livelihood of the households are Bamboo as furniture and *Acacia decurrens* woodlots in the form of charcoal and fuelwood. The income and fuelwood source of the study districts, as well as the Administrative Zone, are highly dependent on *Acacia decurrens* woodlot products (Yazie and Anteneh, 2015). Based on the reports by Central Statistics Agency (2015), Fageta Lekoma District has a total population size of 146,848, of which 90.5% are rural inhabitants whereas AnkeshaGuagusa District has a total population size of 233,257, of which 92.6% are rural inhabitants.

Sampling Methods

Based on the existing extensive production system of *A. decurrens*, two woodlots were purposively selected in AmeshaShenkuri Kebele found in Fageta Lekoma District and one community-managed plantation in Tuleta Kebele situated in AnkeshaGuagusa District (Figure 1).

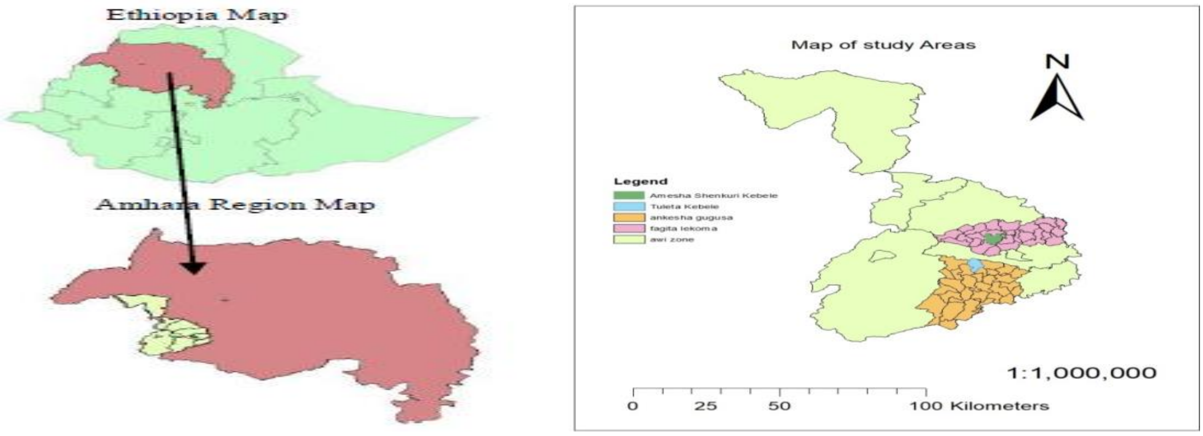


Figure 1; Location of the study areas

The age and spacing of the sampled sites/stands were five years and 0.75m x 0.75m, respectively. Sampled trees were selected purposively depending on their diameter at breast height (1.3m) that is ≥8cm. During data collection, trees having multiple stems, broken tops and branches and clear cankers or crooked boles were not included because those trees do not show its real stem form. Based on these defined criteria, the data were collected by using a destructive method, after following the farmer's harvesting time of woodlots for charcoal production (Figure 2A, 2B, and 2C).

Data Collection Techniques

A total of 58 destructed trees of *A. decurrens* were sampled in both districts. For calculation purposes, data of the stump heights and DBH at 1.3m in centimeters, total tree height, and height to live crown in meters were measured. Based on the cultural practice of farmers of Awi Zone, the minimum top diameter threshold for the terminal leader and branch were determined to be 4.5cm, due to the purpose of woodlots harvested that is for charcoal production, the rest top part less than 4.5cm diameter was used for firewood. Starting from the base, the diameter of all sample trees was measured at every 2 meters interval sectional length. Diameter (cm) and length (m) of each branch were measured by using Caliper and measuring tape.

Figure 2; Field data collection (B and C) on *A. decurrens* woodlot in Agroforestry system (A) of Awi Zone; the data were collected during farmers' harvesting times

Data Analysis

Calculation of observed form factor

The measured DBH readings in cm were converted into the meter. Then, the calculation of cylindrical volume for each section and branches of a tree was accomplished using Huber's formula;

$$Vi = \frac{\pi Di^2}{4} * Hi\text{-------Equ. 1.}$$

Where the Vi = volume of the section, Di = diameter of the section, Hi = length of the section,

π= 3.14. Then, all sectional and branch volumes of a tree were summed up.

The cylindrical volume of each sampled trees was calculated as;

$$V = \frac{\pi DBH^2}{4} * H\text{---------Equ. 2.}$$

Where V = volume of a tree, DBH = diameter at breast height of a tree, H = total height of a tree. Then, the observed form factor of a tree was calculated as:

$$Obs.ff = \frac{\sum_{i=1}^{n}(Sec.\ Vol)}{cylinder.Vol} \quad \text{---------- Equ. 3.}$$

Where Obs. ff = the observed form factor of a tree, ∑(sec.vol) = sum of n sectional volume of a tree and cylinder. Vol = is the cylindrical volume of a tree.

Table 1: Diameter at a height of 1.3 m (DBH, cm), total height (Ht, m), and observed form factor (FF) for *A. decurrens* in woodlots of Agroforestry system in Awi Zone.

Variables	Samples	Mean	Standard deviation	Minimun	Maximum	The C (%)	Altitude (m.a.s.l)	Slope Rang (%)
DBH	58	9.874	1.3266	8	13.7	13.44	1800-2900	5-25
Ht		12.8	1.4	9.8	15.3	10.9		
FF		0.4875	0.0423	0.369	0.603	8.68		

Selection of Form Factor Equations

The use of the same equation for all tree species is not ideal. Therefore, five commonly used different form factor equations were selected to obtain the coefficients which are used as the bases for volume calculations (Gezahegn, 2015; Tensin*et al*., 2016). The statistical analyses were performed by using the R statistical software of version 3.1.3. A non-linear regression model with 5% a significance level was used to compute each equation.

Selected equations for this study were:

A. Pollanschutz's form factor function (Pollanschutz, 1965).

$$f = b_1 + b_2 * \ln^2(\mathrm{DBH}) + b_3 * \frac{1}{H} + b_4 * \frac{1}{\mathrm{DBH}} + b_5 * \frac{1}{\mathrm{DBH}^2} + b_6 * \frac{1}{\mathrm{DBH} * H} + b * \frac{1}{\mathrm{DBH}^2 * H} \quad \text{Equ. 4.}$$

Diameter at breast height (DBH) and height (H) in decimeters

B. F. Evert's (Australian) form factor function (Evert, 1976).

$$f = a + b_1 * \frac{1}{\mathrm{DBH}^2 * H} + b_2 * \frac{1}{H} + b_3 * \frac{1}{\mathrm{DBH}^2} \quad \text{Equ. 5.}$$

Diameter at breast height (DBH) in centimeter and height (H) in decimeters

C. Short Swedish's form factor function

$$f = a + b_1 * \frac{1}{H} + b_2 * \frac{H}{\mathrm{DBH}} + b_3 * \frac{H}{\mathrm{DBH}^2} \quad \text{Equ. 6.}$$

Diameter at breast height (DBH) in centimeter and height (H) in decimeters

D. Mayer's form factor function

$$f = a + b_1 * \frac{1}{\mathrm{DBH}^2 * H} + b_2 * \frac{1}{\mathrm{DBH} * H} + b_3 * \frac{1}{\mathrm{DBH}} + b_4 * \frac{1}{H} + b_5 * \frac{1}{\mathrm{DBH}^2} \quad \text{Equ.7.}$$

Diameter at breast height (DBH) in centimeter and height (H) in decimeters

E. Rosset's form factor function (Rosset, 1998)

$$\ln(f) = a + b * \ln(\mathrm{DBH}) + c * \ln(H) \quad \text{Equ.8.}$$

Diameter at breast height (DBH) in centimeter and height (H) in meters

Comparison of Models

Based on the following criteria, all functions (Equ. 4- 8) were evaluated and then compared by using the non-linear regression model developed via R statistical software, version 3.1.3.

I. Root mean square error (RMSE) has been mostly used to describe well the model goodness of fit with the lower value (Chai and Draxler, 2014), calculated as:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{ffi}-\mathrm{fi})^2}{n}} \quad \text{-------Equ. 9.}$$

Where ffi is observed form factor, fi is predicted form factor and n is the sample number.

II. Mean Absolute Deviation (MAD) - it describes the average distance between each datum point and the mean (Pham-Gia and Hung, 2001) where the lower the value, it is the preferred one. It is calculated as;

$$\mathrm{MAD} = \frac{\sum_{i=1}^{n}|\mathrm{ffi}-\mathrm{fi}|}{n} \text{------ Equ. 10.}$$

III. The coefficient of variance (CV %) can be used to compare the distributions obtained in different units (Abdi, 2010), how large the standard deviation (SD) concerning the mean of the data. The lower the CV, the smaller the residuals relative to the predicted value, which is suggested as a good model fit and it is calculated as;

$$\mathrm{CV}(\%) = \frac{\mathrm{SD}}{\mathrm{mean}} * 100 \quad \text{------ Equ. 11.}$$

Finally, the graphical illustration for residuals and the behaviors of observed and predicted form factor versus DBH and tree height for the selected functions were handled for further validation.

Results and Discussions

Comparison and validation of functions

Based on the findings of the present study, statistical fitting criteria for comparison of all 5 form factor functions, the RMSE (0.0369) and MAD (0.0266) of Mayer's and Pollanschutz'sfunctions being approximately equal; however, the coefficient of variance (CV%) of Meyer's function (4.12%) and Pollanschutz's (4.13%) is slightly greater than that of others (Table2). Even though we further checked the sum rank of all criteria, Mayer's and Pollanschutz's functions were ranked first and second, respectively as compared to others.

Furthermore, the graphical presentation of the observed form factor and that of predicted by Mayer's and Pollanschutz's functions against the diameter at breast height (cm) and tree height (m) indicated a relatively stable and almost similar than the other functions (Figure1 and 4). Based on these reasons, Mayer's and Pollanschutz's form factor functions were selected as alternative functions to estimate the stem profiles of *Acacia decurrensWilld* tree in the study site. According to the reports by Tenzin *et al*. (2016), Pollanschutz's function was selected for commercial trees like; (*Abiesdensa* (fir), *Piceas pinulosa* (spruce), *Pinus wallichiana* (bluepine), *Tsuga dumosa* (hemlock), *Pinus roxburghii* (chirpine), *C. tribuloides*, *Quercus glauca*, *Quercus lanata* and *Quercus lamellosa*) species in Bhutan. These findings are in line with our results. In contrast, Mayer's function is ranked as the third next to the Pollanschutz's and Short Swedish's function. Similarly, Gezahegn (2015) revealed that the F. Evert's (Australian) function has been selected for 20 broadleaved tree species dominated in 4 selected natural forests of the Amhara National Region, Ethiopia. The graph of residuals versus diameter at breast height (cm) and tree height (m) illustrated the normal distribution and almost the same for the selected functions, which supports our decision to select the best one (Figure 3).

Table2: Comparisons of all five Form Factor functions: Root Mean Square of Error (RMSE), Mean Absolute Deviation (MAD) and Coefficient of Variance (CV).

Species	DBH Ranges(cm	Mean	Form Factor functions	RMSE	Rank	MAD	Rank	The CV(%)	Rank	Sum (Rank)
Acacia	8-14	0.487	Pollanschutz's	0.0369	1	0.0266	1	4.13	5	7(2)
decurren		5	F. Evert's	0.0397	5	0.0293	5	2.79	1	11(5)
sWilld			Short Swedish's	0.0382	3	0.0291	3	3.58	3	9(3)
			Mayer's	0.0369	1	0.0266	1	4.12	4	6(1)
			Rosset's	0.0392	4	0.0291	3	3.08	2	9(3)

Figure 3; the relationship between observed form factor and that of predicted for each equation (A-E) against Diameter at 1.3 m (DBH in cm) and tree height (m).

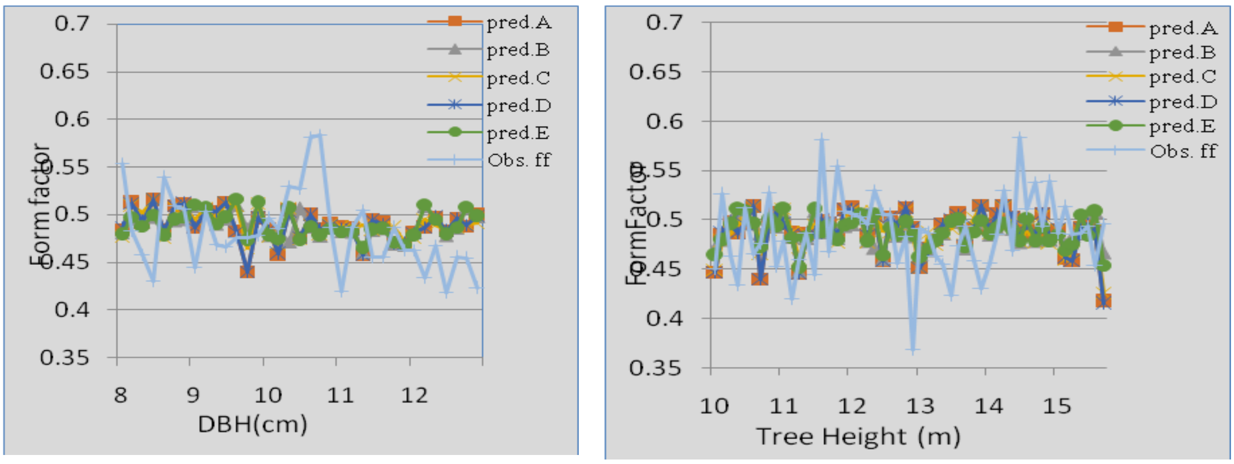


Table 3; Value of Coefficients of Mayer's and Pollanschutz's functions selected to estimate the stem profiles of *A. decurrens*in Awi Zone.

Model	Coefficients								
	a	b_1	b_2	b_3	b_4	b_5	b_6	b_7	R^2(%)
Mayer's	-2.8123	34386.1174	-6841.0190	67.4640	325.4936	-332.2623	-	-	22.56
Pollanschutz's	-	-3.7823	0.0700	329.7478	76.0959	-358.6584	-6920.9161	34753.7747	22.57

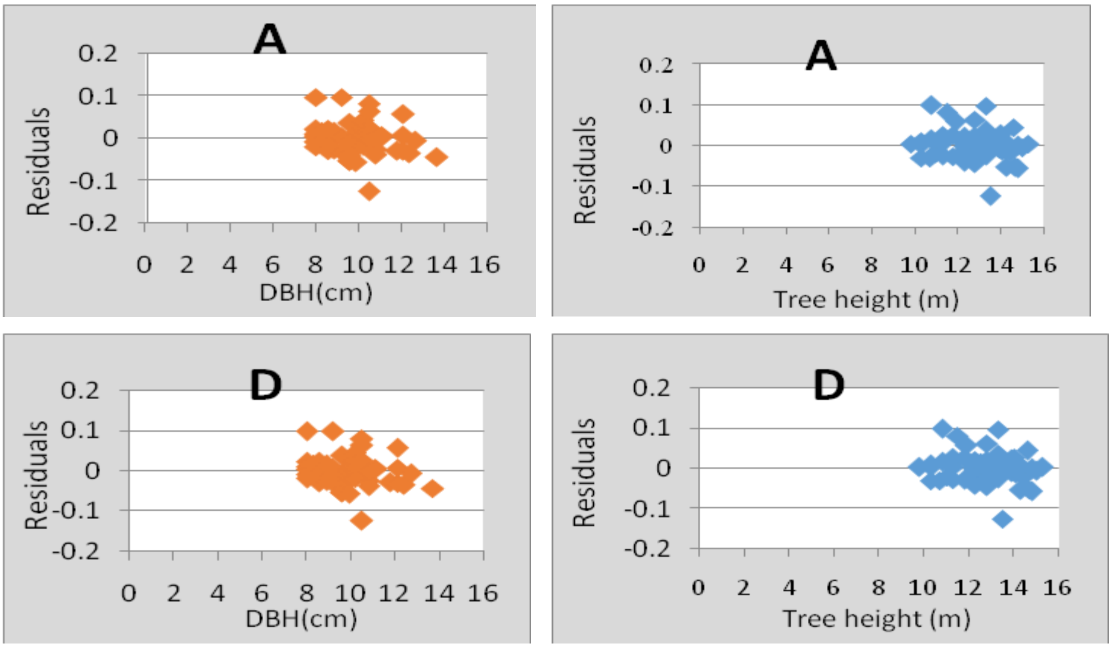
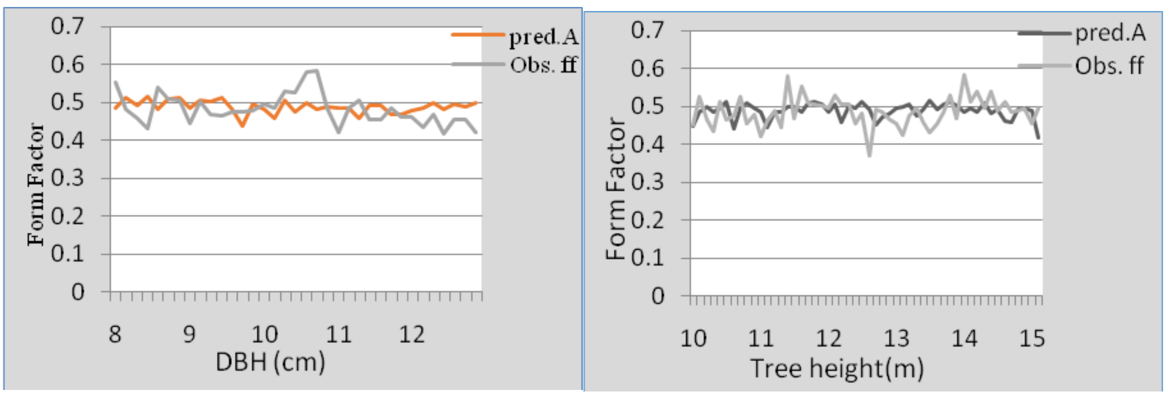


Figure 4; Distribution of residuals against Diameter at Breast Height (DBH in cm) and Tree Height (m) of *A. decurrens* by the selected (Pollanschutz's (A) and Meyer's (D)) functions.



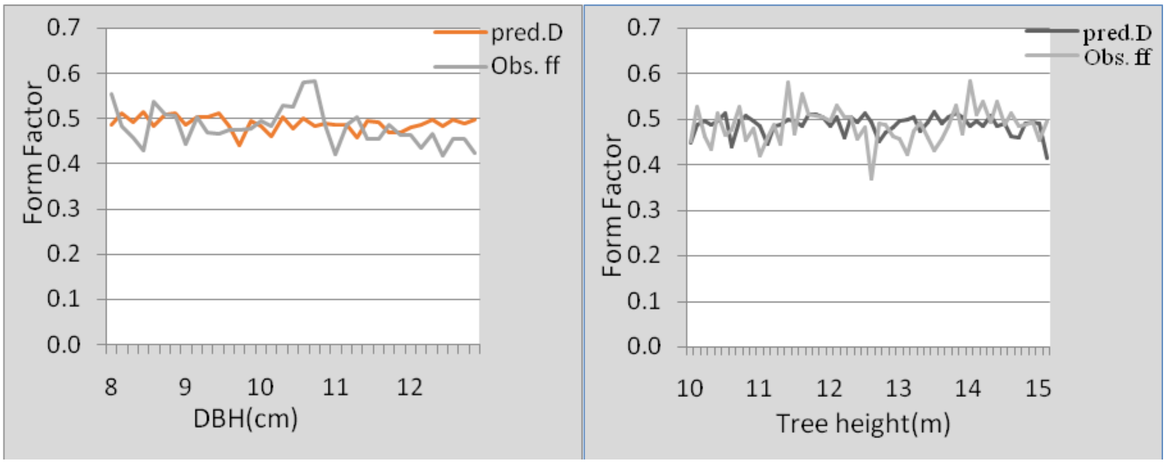


Figure 5: The relationship between observed form factor versus predicted for the selected Mayer's (Pred.D) and Pollanschutz's (pred. A) functions against the Diameter at breast height (DBH at 1.3m) and tree height (m).

Predicted Form Factor

Our result reveals that the trend of the predicted form factor of *A. decurrens* gradually decreases with increasing DBH and height inline with the findings of Mamo *et al*. (1995) on the form factor of *JuniperusProcera* in Arsi part of Ethiopia, Hassan *et al*. (2012) on *Cupressus sexperience*L. *var horizentalis*inthe north of Iran, Lei *et al*. (2012) on spruce-fir mixed stands at Changbai Mountains in China and Neto *et al*. (2016) on *Tectonagrandis*in Brazil.However, the findings of Tensin *et al*. (2016) who did for nine commercial trees

of Bhutan and Gezahegn (2015) for 20 broad-leaved trees of the selected natural forests in Ethiopia reported as form factor had shown a constant trend when DBH reaches the maximum. This may be due to *A. decurrens*does not reach its growth potential (maximum DBH) as a result of short rotation periods of woodlots/ stands (commonly five years) (Figure 3). According to the report by Intia*et al*. (2016) for *Pinus taeda* stands, the form factor is greatly affected by the age of the stand. If the age of stand extended, the species will reach its growth potential and the graph may show a constant trend. The findings of Joao*et al*.(2017) also showed that the form factor values of *Pinus taeda L.* decreased as the spacing increased.For functions of goodness to fit, the predicted form factor by the selected functions is approximately equal to that of the observed which is 0.4875 for a DBH class of 8-14cm. Amhara Forest Enterprise uses 0.44 form factor value to estimate the volume of *A. decurrens* plantations in Amhara (AFI, personal communication during Nov. 03, 2016) and 0.8 in Indonesia (Priyono*et al*., 2010). Estimating a tree and stand volume of *A. decurrens* in Southwestern of Amhara by using the form factor of 0.44 (AFI) may lead to an error due to underestimating. Thus, using 0.4875 (the finding of the present study) is relatively more appropriate to increase the estimated volume of the species.

Conclusions and Recommendations

Meyer's and Pollanschutz's functions are relatively efficient to estimate the stem profile of *A. decurrens*woodlot/plantation in the Amhara Region. Both functions were recommended to be used alternatively to determine A. *decurrens* form factor at the given DBH and tree height in the study sites. The estimated mean Form Factor of *A. decurrens*was 0.4875 to estimate the volume of *A. decurrens* woodlot as a correction factor for a diameter range of 8-14cm. However, as the research was conducted on the woodlots with different site and management practices, further experimental research should be done to test the effect of density and age of *A. decurrens* on its wood volume and stem form.

Conflict of Interests

The authors declare that they have no conflict of interests

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