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[Research]

Comparison of allometric equations to estimate the above-ground biomass of *Populus alba* species (Case study; poplar plantations in Chaharmahal and Bakhtiari province, Iran)

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ABSTRACT

Carbon sequestration into plants biomass, especially in fast growing trees is an easier and economically way for dropping off Co_2 from atmosphere. This study was carried out in order to investigate above-ground biomass of white poplar (*Populous alba, L.*) plantations that was planted in four different plant spacing (0.5 × 0.5, 1 × 1, 2 × 2 and 4 × 4 m) in Chaharmahal and Bakhtiari province in west of Iran. Selecting the trees was according to diameter classes. After inventory, 10 trees were selected from each density at one hectare area. The tree's characteristics including diameter at breast height (DBH), total height, and crown diameter measured. Then measured trees felled down in order to measure the wet and dry weight of different organs including (whole tree, trunk, main branches, twigs and leaf).The regression analysis was applied to find out a relationship between mass production and poplar characteristics and to develop different allometry models between different organs and their carbon sequestration ability. The results showed that the independent DBH factor in *P. alba*, demonstrated high correlation against all the dependent variables. Height of trees also creates the allometric equations with average accuracy (0.30 - 0.81) against all the dependent variables. The crown diameter in dependent variable almost creates weakest equations. The result also indicated that there is no significant difference among equations of different planting spaces.

Key words: Allometric equation, *Populus Alba*, Non-linear regression, CO_2, Greenhouse gases.

INTRODUCTION

Continuous measurement of the concentration of the greenhouses of carbon dioxide from 1958 to the present years shows a big increase in the concentration of this gas from 315_{ppm} to 380_{ppm} in the atmosphere (Smith *et al.,* 2007). Therefore today`s CO_2 is the most important greenhouse gas and so many problems such as global warming and environmental issues (Backeus, *et al.,* 2005).Trees can absorb the atmospheric carbon during photosynthesis and save it in their structure (Cacho *et al.,* 2003). This stored carbon in the trees and in the forest ecosystems calling plant biomass and this is the most important part of carbon sequestration in the earth. More than 81% of above - ground carbon stored in the tree`s structures of forest ecosystems (Jandl *et al.,* 2007). Forest plantation is a common action in order to restore the degraded forests (Mohammadnezhad Kiasari *et al.,* 2009).

Poplars and their hybrids have displayed the capacity for rapid biomass accretion (Anderson *et al.,* 1983; Pallardy *et al.,* 2003), Ostadhashemi *et al,* (2014) estimated the aboveground biomass and carbon storage in multi-species plantations in Astara County at Guilan province in Iran. They used species - specific equations method and three other generic methods in their study and the result showed significant difference between the mean values of total aboveground biomass estimation obtained by species - specific equations and the three generic methods for *Alnus subcordata*, *Pinus taeda* and *P. nigra*. Results indicated that using generalized methods produced more reliable and accurate estimations for native species than for exotic species for rapid biomass and carbon estimation in order to decide on plantation development in the area. In compare with the other forest species, fast growing species such as poplars (for example white poplar, *Populous alba* L.) have many features that make them highly suitable for afforestation. These characteristics include fast growing, acclimation to different environmental conditions and being suitable for a variety of silviculture systems.

Poplars and theirs hybrid`s shown a great ability to develop themselves biomass (Anderson, *et al.*, 1993; Pallardy, *et al.*, 2003). The direct (destructive) method consists of harvesting the tree to determine biomass through the actual weight of each of its components for example, roots, stem, branches, and foliage (Parresol, 1999). Biomass estimates derived from allometric equations are also an integral component of nutrient budgets (Likens *et al.* 1998) because the biomass of individual tree components (e.g., stem wood, branches, stem bark, foliage, roots, etc.) are multiplied by average tissue nutrient concentrations to estimate nutrient content. Allometry is the description of a property changes on other features (Medhurst *et al.*, 1998). Allometric equations are the mathematics means for estimating the total weight of trees or tree branches through independent variables such as diameter and height that can be measured in the field (Komiyama *et al.*, 2008). In order to estimate the biomass of the tree and its components, the most common form of allometric equation is power model (Y = aXb) (Losi *et al.*, 2003). Y In this equation is the dependent variable like dry weight or carbon content in whole or in part from the tree, and X is independent variables such as diameter and height of the trees. Also "a" and "b" are coefficients of the regression equation (Pajtik *et al.*, 2008).

For example, the allometric equations for estimating biomass of 98 species of trees, shrubs and herbaceous species were presented by Smith and Brand in 1992. Also the potential of different hybrids of poplar in 5 clones investigated by Fortier *et al.* (2010) to obtain biomass and wood volumes in coastal areas of along rivers in agricultural ecosystems in in Canada. In fast - growing plantations like poplars, several studies conducted in the world and in some studies, planting distance have been proposed as an influencing factor. One of the well - known researches in this area is the Fang *et al.* (2007) that investigated biomass and carbon sequestration of poplars in different plantations density in China.

They results showed the best correlation between carbon storage and biomass of different parts with a diameter at breast height. Parsapour *et al.* (2013) investigated carbon sequestration in Iran and they result showed that the carbon sequestration potential into *P. nigra* species is considerable.

The aim of this study is establishing the allometric equations to predict the total tree and its components biomass based on variables that are easy to measure like DBH.

Furthermore to investigate that which variables are able to create the best correlation in different plant spacing.

MATERIALS AND METHODS

Study area

The study area was located at poplar research station and fast growing trees of Agriculture Research Center and Natural Resources (51° 6' 7" E, 31° 55' 1.7" N) in Chaharmahal and BakhtiariProvince, in west of Iran. The mean annual rainfall is 600 - 700 mm and station average temperature is 11 °C.

Plantation design and establishment

Four areas with different planting density were selected from 10 years old *P. alba* plantations. The surface of areas were 1 hectare Planting densities were 20000, 10000, 2500 and 625 stems per hectare include four plant spacing (0.5 × 0.5, 1 × 1, 2 × 2 and 4 × 4 meter, respectively).

Sample trees selection

According to DBH measuring, trees were divided to 10 diameter classes. From four different planting densities, 40 trees were selected from all diameter classes randomly. The selected trees for cutting had a uniform distribution in different diameter classes.

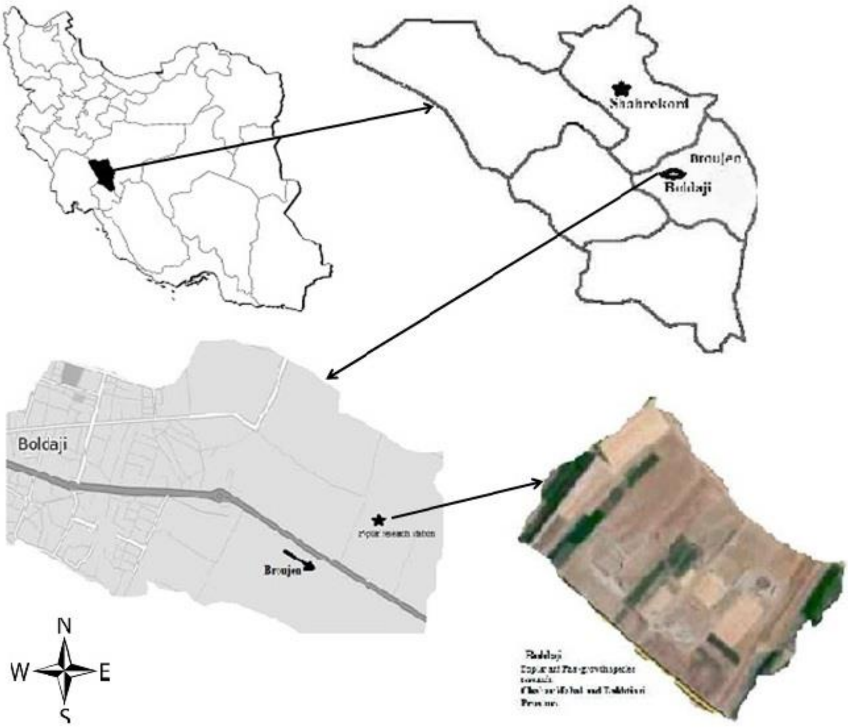

Fig 1. Study area location on the map.

Cutting and Sampling Procedures

Selected trees were cut and divided into various components including the trunk, branch (more than 1 cm-diameter), twig (branches less than 1 cm diameter) and leaf (Sohrabi & Shirvani, 2012). The wet mass of each tree component was measured in the field. The leaf and twig samples were dried at 75 º C for 24 hours. The trunk and branch were dried at 80 º C for 48 hours.

Then all components were weighted in order to estimate moisture content.

Equation (1) was used to determine the components dry weight (Bakhtiarv & Sohrabi, 2012).

$$WDC = \frac{WFc * WDs}{WFs} \quad \textbf{(1)}$$

WDC is dry weight of each component of the tree.

WFc is wet weight of each tree.

WDs dry weight of each sample.

WFs is wet weight of each sample.

Statistical Analysis

Data normality was examined by Kolmogorov–Smirnov test. Regarding data normality, allometric relations modeling was conducted using power regression by least squares method. Past studies, have been showed that the power non-linear regression model provide the best results among allometric equations to different trees, shrubs and herbaceous species by the equation $Y=b_0X^{b_1}$ (Smith & Brand, 1992).

All data were analyzed using the SPSS version 19 and Minitab version 16.

RESULTS

Allometric equations of 0.5×0.5 meter planting space

In 0.5×0.5m planting space, the tree DBH with 0.85 to 0.97 coefficient factors had highly correlation with other organ's biomass, and tree height with 0.5 to 0.81 coefficient factor, had fairly good correlation with other organ's biomass, while tree crown with 0.3 to 0.6 coefficient factors had low correlation with other organ's biomass.

The results of different component biomass are shown in Table1.

Correlation between height and branch skin was not significant in 1 × 1 m planting density, but all other in-dependent variables had significantly correlation to the other organ's biomass. The results of allometric equation of DBH, height and crown diameter with other tree organs biomass are shown in Table 2.

Allometric equations of 2 × 2 meter planting space

Estimated - biomass model between crown diameter to trunk weight, trunk skin, leaf, branch and branch skin, was not significant in 2 × 2 m planting density, but other in dependent variable had significantly correlation to different tree organ's biomass. The results of allometric equation of DBH, height and crown diameter with other tree organs biomass are shown in Table 3.

Table1. The results of DBH, height and crown diameter allometric equation of (*P. alba* L.) species related to different organs biomass in 0.5 × 0.5 m plantation spacing.

F	Standard error	R^2	Allometric equation	Dependent variable
318.132***	0.137	0.972	$y = 0.011d^{2.385}$	Crown biomass
32.06***	0.391	0.775	$y = 3.04h^{4.245}$	
**20.68	0.462	0.686	$y = 7.576c^{0.893}$	
*8.185	0.867	0.444	$y = 0.002d^{2.418}$	Leaf biomass
**13.458	0.492	0.538	$y = 3.104h^{5.291}$	
ns 5.27	957.0	0.322	$y = 0.006c^{3.780}$	
*** 27.120	0.184	0.930	$y = 0.013d^{1.972}$	Sub branch biomass
** 21.38	0.385	0.694	$y = 0.001h^{3.41}$	
*** 32.90	0.327	0.780	$y = 2.90c^{0.795}$	
**54.60	0.334	0.896	$y= 0.001d^{2.534}$	Branch skin biomass
** 66.22	0.706	0.499	$y= 8.159h^{4.55}$	
**497.13	0.5950	0.581	$y = 0.02c^{0.930}$	
*** 305.114	0.265	0.926	$y= 0.002d^{2.768}$	Branch biomass
*** 77.33	0.454	0.785	$y= 1.303h^{5.059}$	
**01.14	0.636	0.591	$y= 3.49c^{0.995}$	
*** 145.93	0.214	0.911	$y = 0.010d^{2.013}$	Trunk skin biomass
**17.81	0.429	0.641	$y = 0.001h^{3.042}$	
** 50.17	0.426	0.647	$y =2.39c^{0.757}$	
*** 8.221	0.161	0.961	$y =0.027d^{2.332}$	Trunk biomass
*** 22.40	0.350	0.813	$y = 6.287h^{4.260}$	
* 79.16	0.489	0.637	$y = 16.277c^{0.85}$	

*** Highly significant, (99.9), significantly high (99), significant (95) and ns no significant.

Allometric equations of 1×1 meter planting space

Table 2. The results of DBH, height and crown diameter allometric equation of (*P. alba* L.) species related to different organs biomass in 1×1m plantation spacing.

F	Standard error	R^2	Allometric equation	Dependent variable
*** 7.55	275.0	859.0	$y = 0.040d^{1.945}$	Crown biomass
*579.8	0.540	0.457	$y = 0.002h^{2.838}$	
403.16* *	0.445	0.631	$y = 8.306c^{1.048}$	
** 41.22	0.320	0.704	$y = 1.449d^{0.882}$	Leaf biomass
* 820.5	0.475	0.349	$y = 0.003h^{2.508}$	
41.22**	0.320	0.702	$y = 1.449h^{22.418}$	
*** 815.36	0.328	0.799	$y = 0.20d^{1.941}$	Sub branch biomass
* 801.6	0.588	0.399	$y = 0.001h^{2.573}$	
**465.14	0.477	0.599	$y = 4.104c^{1.055}$	
* 4.6	0.859	0.375	$y = 0.002d^{2.057}$	Branch skin biomass
ns1.09	0.801	0.010	$y = 0.001h^{2.029}$	
*68.8	0.798	0.461	$y = 0.317c^{1.367}$	
*** 89.31	0.368	0.744	$y = 0.015d^{1.966}$	Branch biomass
** 8.11	0.522	0.545	$y= 0.00h^{3.219}$	
***52.11	0.526	0.539	$y= 3.3c^{1.037}$	
*** 97.57	0.312	0.868	$y = 0.006d^{2.162}$	Trunk skin biomass
** 49.17	0.483	0.647	$y = 3.816h^{3.624}$	
*** 60.33	0.378	0.784	$y = 2.26c^{1.273}$	
*** 75.136	0.229	0.938	$y = 0.019d^{2.532}$	Trunk biomass
** 93.21	0.503	0.699	$y = 5.366h^{4.23}$	
*** 251.70	0.311	0.885	$y = 20.041c^{1.516}$	

*** Highly significant, (99.9), significantly high (99), significant (95) and ns no significant.

Allometric equations of 4×4 meter planting space

In 4×4 m plantation spacing, allometric equation of all independent variables to tree component biomass, showed significant correlation. Results showed that DBH with 0.85 to 0.96 coefficient factor had highly correlation to some tree organ's biomass and the other two independent variables (height and crown diameter) with 0.5 to 0.86 coefficient factor had significant correlation to the others. The results of allometric equation of DBH, height and crown diameter with the other organ's biomass are shown in Table 3.

Table 3. The results of DBH, height and crown diameter allometric equation of (*P. alba* L.)Species related to different organs biomass in 2×2 m plantation spacing.

F	Standard error	R^2	Allometric equation	Dependent variable
*** 2.142	0.221	0.947	$y= 8.69d^{3.02}$	Crown biomass
*4.8	0.670	0.511	$y = 8.12h^{3.49}$	
6.6*	0.709	0.453	$y = 0.17c^{1.79}$	
*** 3.64	0.352	0.899	$y = 1.45d^{3.24}$	Leaf biomass
* 8.5	0.808	0.419	$y = 2.04h^{3.49}$	
7.2ns	0.917	0.250	$y = 0.25h^{1.47}$	
*** 33	0.346	0.805	$y = 7.81d^{2.28}$	Sub branch biomass
* 1.8	0.522	0.504	$y = 5.27h^{2.83}$	
** 5.17	0.439	0.686	$y =0.03c^{1.80}$	
* 9.69	0.466	0.897	Y=0.05d4.47	Branch skin biomass
* 9.5	1.103	0.425	Y= 0.081h4.83	
3.3ns	1.227	0.289	Y= 0.002c2.17	
*** 7.63	0.466	0.897	$Y= 0.02d^{5.24}$	Branch biomass
* 7.5	1.103	0.425	$y = 0.04h^{5.64}$	
9.2ns	1.277	0.289	$y = 8.69c^{3.02}$	
*** 7.63	0.260	0.788	$y =0. 004d^{1.62}$	Trunk skin biomass
** 1.13	0.348	0.621	$y = 0.02h^{2.26}$	
359.2ns	0.496	0.288	$y =0.16c^{0.75}$	
*** 8.68	0.217	0.896	$y = 0.07d^{2.06}$	Trunk biomass
** 2.18	0.371	0.695	$y= 5.366h^{2.85}$	
1.5ns	0.526	0.387	$y = 20.041c^{1.16}$	

*** Highly significant, (99.9), significantly high (99), significant (95) and ns no significant.

Table 4. The results of DBH, height and crown diameter allometric equation of (*P. alba L.*) species related to different organs biomass in 4 × 4m plantation spacing.

F	Standard error	R^2	Allometric equation	Dependent variable
*** 94.258	0.236	0.960	$y = 0.011d^{2.776}$	Crown biomass
*6.16	0.777	0.63	$y = 0.006h^{3.761}$	
** 46.29	0.630	0.760	$y = 0.974c^{2.124}$	
*** 39.79	0.318	0.897	$y = 0.011d^{2.073}$	Leaf biomass
** 68.28	0.492	0.755	$y = 0.003h^{3.559}$	
** 85.16	0.766	0.638	$y = 0.006h^{3.780}$	
*** 0.33	0.346	0.805	$y = 81.7d^{28.2}$	Sub branch biomass
* 1.8	0.552	0.504	$y = 27.5h^{83.2}$	
** 5.17	0.439	0.638	$y = 3.00c^{80.1}$	
*** 4.133	0.319	0.936	$Y= 0.002d^{2.695}$	Branch skin biomass
* 09.21	1.899	0.587	$y = 0.002h^{3.377}$	
***89.60	0.058	0.869	$y =0 .106c^{2.217}$	
*** 86.634	0.171	0.983	$y= 0.010d^{3.14}$	Branch biomass
*** 38.20	0.030	0.691	$y = 0.001h^{4.353}$	
***81.38	0.033	0.808	$y = 0.317c^{2.448}$	
*** 63.136	0.253	0.938	$y = 0.011d^{2.161}$	Trunk skin biomass
** 09.21	0.584	0.691	$y = 0.05h^{3.073}$	
** 90.20	0.566	0.689	$y = 0.363c^{1.607}$	
*** 2.29	0.232	0.973	$y = 0.023d^{2.516}$	Trunk biomass
** 94.22	0.627	0.742	$y = 0.10h^{3.565}$	
** 42.28	0.578	0.753	$y = 1.334c^{1.914}$	

*** Highly significant, (99.9), ** significantly high (99) and * significant. (95).

DISCUSSION

Carbon sequestration into plant biomass is an easiest and economically most practical way for dropping off CO2 from atmosphere (Parsapour *et al.*, 2013). In large regions of the world, biomass is a very important source of energy. The global bioenergy market based on forest biomass is growing rapidly and Allometric equations are the powerful means to estimate the biomass of the forest trees (Lohmender, 2012). The results of this study showed that there is a Highly correlation between tree DBH and the biomass of different organs of *P. alba* species. The reason could be due to the cylindrical trunk of this species (Madejon *et al.*, 2004). In accordance with other studies, the additional inclusion of trees DBH and height in allometric biomass equations could reduce the standard error of estimate particularly for predictions of stem wood and aboveground woody biomass. In contrast, crown diameter models aren`t that much exact (Antonio *et al.,* 2007). Parsapour *et al,* (2013) investigated the allometric equations for estimating biomass in four poplar species at Charmahal & Bakhtiari province and the results of their study showed that there are significant correlations to predict biomass for the whole tree's organs at each species. The independent DBH values, in *P. alba* and *P. alba* × *P. euphratica* demonstrated high correlation against all the dependent variables that is completely accordance to this study.

Allometric equations of four different species in Mobarakeh plantation in Isfahan Province at Iran has been investigated by Bkhtiary & Sohrabi (2011). Results showed high correlation between independent variables and needle leaf biomass. While in this study, correlation between independent variable and leaf of white poplar was fairly good. It is may be relevant to the volume of needle leaves. This study obviously cleared that in fast growing species such as white poplar, most carbon sequestration is stored in trunk but in coniferous tree, partly of absorbed-carbon is kept to needle leaves. Therefore, fast growing species such as poplar have better compatibility with coniferous species. Although in this study planting space had not strongly affect carbon sequestration, but wider planting space showed higher value of carbon sequestration. This study also showed that biomass estimation of tree woody organs has higher accuracy than non woody organ such as leaf twigs. By allometric equation which can be attributed to this issue that the branch and leaf changes are more dependent on habitat (Socha & Wezyk, 2007). Ebrahimi *et al.,* (2012) investigated the effects of initial spacing on some allometric characteristics of 12-year-old *Quercus castaneifolia plantation* in Central Mazandaran. Trees were planted in 5 different layouts (1 × 1, 1.5 × 1.5, 2 × 2.5, 2 × 3 and 4 × 4 m). The results showed that the best plantation spacing in this research station was 2m×3m. Statistically, about 95% of the changes in sediment yield was due to the effect of increased dry land farming area in the basin (R_2= 0.95, $\alpha < 0.05$). Therefore, the results shows fairly good correlation between height and crown diameter of tree and the biomass of tree, it is similar to the results of Socha & Wezyk, (2007). Fang *et al* (2007). Assumed that power nonlinear regression model shows the best result for biomass estimation of poplar species that is accordance to this study.

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مقایسه معادلات آلومتریک در تخمین رویه زمینی صنوبر کبوده (*Populus alba*)

(مطالعه موردی: صنوبر کاری‌های استان چهار محال و بختیاری)

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چکیده

ترسیب کربن در بیوماس گیاهان، به ویژه گیاهان تند رشد آسان‌ترین و اقتصادی‌ترین روش برای جذب دی اکسید کربن از جو زمین است. این مطالعه به منظور بررسی زی توده روی زمینی صنوبر کبوده (*Populus alba*) که با چهار فاصله کاشت (۰/۵ ×۰/۵، ۱×۱، ۲×۲ و ۴×۴ متر) در استان چهار محال و بختیاری و در غرب ایران کشت شده بودند صورت گرفت. انتخاب درختان بر اساس کلاسه‌های قطری صورت گرفت. بدین صورت که پس از آماربرداری تعداد ۱۰ اصله درخت از هر قطعه یک هکتاری انتخاب شد. مشخصه های درختان از جمله قطر برابر سینه، ارتفاع درختان و قطر تاج درختان اندازه‌گیری شد. سپس درختان منتخب جهت محاسبه‌ی وزن‌تر و سپس وزن خشک اندام‌های درختان (شامل تنه، شاخه، سرشاخه، پوست و برگ) قطع شد. از معادلات رگرسیونی برای ایجاد رابطه بین بیوماس و مشخصه‌های درختان و ارائه مدل‌های آلومتری وزن خشک اندام‌های گیاهی و پتانسیل ذخیره کربن آنها استفاده شد. نتایج نشان داد متغیر مستقل قطر برابر سینه بهترین معادلات را با ضریب تعیین بالای ۰/۸۵ ایجاد می‌کند. متغیر ارتفاع معادلاتی با دقت متوسط ایجاد کرد (۰/۸۱-۰/۳۰). قطر تاج ضعیف‌ترین معادلات را با ضرایب تعیین غالباً کمتر از ۰/۶ ایجاد کرد. نتایج همچنین اختلاف قابل ملاحظه‌ای در مورد دقت نتایج در چهار فاصله کاشت نشان نداد.

*مولف مسئول