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Biomass and Carbon Allocation of 10-Year-Old Poplars (*Populous alba* L.) Plantations in the South West of Iran

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Abstract

This study was carried out to investigate above-ground biomass of white poplar (*Populous alba* L.) plantations by four different plant spacing (0.5 × 0.5, 1 × 1, 2 × 2 and 4 × 4 m) in south west of Iran. After taking inventory, 10 trees were selected from each density section at one-hectare area (totally 40 stems). The tree's characteristics including diameter at breast height (DBH), total height, and crown diameter were measured. Then measured trees were felled down in order to measure the wet and dry weight of their different organs. After sampling from all the parts, carbon stock in the structure of this biomass species was obtained and the results showed that the most amount of biomass among the components per hectare is related to the bole wood and most amounts of biomass was related to the 0.5 × 0.5 m and 1 × 1 m planting spaces.

Keywords: CO_2; Carbon sequestration; Plant spacing; White poplar; Climate change; Dry weight

Introduction

Climate change from anthropogenic emissions of greenhouse gases, such as CO_2, is believed by some to be one of the most significant environmental concerns of the 21st century. Essex and forests contribute up to 70% of terrestrial carbon (C) fixation Waring and Schlesinger and are a major sink for CO_2 on a global scale, they probably will never fully compensate the increase in atmospheric CO_2 concentration. Nevertheless, it is important to understand the C sequestration capacity of forests in order to potentially increase their C sequestration capacity under future atmospheric CO_2 scenarios.

Poplars and their hybrids have displayed the capacity for rapid biomass accretion [1-22], Populous species are grown in short-rotation forests because of their rapid growth, easy vegetative propagation, high potential for trait manipulation through breeding, hemisphere wide distribution and economically valuable wood and fiber [23]. Poplar species are also used in remediation of contaminated sites [14-33], effluent disposal and restoration or establishment of riparian buffers [25]. Aboveground biomass and carbon in poplar plantations and agroforestry systems has been studied around the world [8-35].

The direct (destructive) method of investigating the biomass and carbon sequestration that used in this study consists of harvesting the tree to determine biomass through the actual weight of each of its components for example, roots, stem, branches, and foliage [36]. Biomass estimates derived from allomeric equations are also an integral component of nutrient budgets [18], because the biomass of individual tree components (stem wood, branches, stem bark, foliage, roots, etc.) are multiplied by average tissue nutrient concentrations to estimate nutrient content.

The term 'allocation' has been used to describe everything from fine-scale carbon dynamics within a plant to coarse-scale carbon dynamics within an ecosystem [6-19]. Measuring and defining it in a meaningful way has therefore become one of the greatest challenges in plant science. In a review of carbon allocation in forests, Litton [19] defined three constituents of allocation for use in the context of forest ecosystems: biomass (the amount of material present); lux (carbon low to a component per unit time); and partitioning (the fraction of gross primary productivity used by a component).

Plant spacing and different managements in poplar plantations can affect on amounts of carbon sequestration among plant organs and plant growth [8-34] and net productivity [11]. Fang investigated biomass and carbon sequestration of poplars in different plantations density in China. The result showed the ranking of the plantation biomass production by planting density was 1111 >833>625>500 stems per ha, and by components was stem>root>branch>leaf for all plantations. At 10 years, the highest total biomass in the plantation of 1111 stems per ha reached about 146 t per ha, which was 5.3%, 11.6% and 24.2% higher than the plantations of 833, 625 and 500 stems per ha, respectively.

Although there is more than 7000 hectare of poplar plantations in Chaharmahal and Bakhtiari province- Iran [28], mostly from *Populus alba* L. poplar species there is a lack of proper and comprehensive studies that researched about the biomass and carbon sequestration capacities of these lands. This plantation has also been done in a thick density's and local people are insisting on traditional poplar plantation patterns. The aim of this study is to investigate the biomass and carbon allocation of *Populus alba* L. species in short rotation period in four planting spaces to obtain the distribution of carbon sequestration inside the tree organs and the effect of planting space factor on the product of this species.

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Materials and Methods

Study area

The study area was located at Chaharmahal and Bakhtiari Province (East longitude of 50° 51′ 17″and North latitude of 32° 19′ 39″) poplar plantations in the west of Iran as in Figure 1. The mean annual rainfall of the province is 560 mm and shahrekord (the center of province) station average temperature is 11°C. There is about 7000-hectare poplar plantation in this province.

Figure 1: Study area location on the map.

Plantation design and establishment

Four areas with different planting densities were selected from among 10-year-old *Populus alba* L . plantations. The surface of the whole area was 1-hectare. Planting densities were 20000, 10000, 2500 and 625 stems per hectare included four plants spacing (0.5 × 0.5, 1 × 1, 2 × 2 and 4 × 4 meter) respectively which consisted of 20000, 10000, 2500 and 625 trees respectively.

Sample trees selection

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

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 [26].

Calculation of the wet weight and biomass

The wet mass of each tree component was measured in the field. The leaf and twig samples were dried at 75°C for 24 hours. The trunk and branch samples were dried at 80°C for 48 hours. Then all components were weighted in order to estimate the amount of their moisture.

Equation (1) was used to determine the components dry weight [2-26].

$$WDC = \frac{WFc + WDs}{WFs} (1)$$

Where:

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.

Calculation of the carbon stock

Carbon percent (Cc%) of the samples was obtained by burning via electrical method and the carbon stock of the trees organs was investigated by using equation (2).

$$Wc = \frac{Wdc \times Cc\%}{100} (2)$$

Finally, the result of biomass and carbon stock of the staccato trees were expanded to all of the trees of four planting densities by having the inventory results. And the biomass and carbon percent of each organ were calculated.

Statically analysis and used software's

The collected data was examined by Kolmogorov-Smirnov test. Regarding data normality one-way ANOVA test was used to compare the biomass and carbon stock means between the treatments. And Duncan test was used to test significance differences between the means. All data was analyzed using the SPSS software-version 19 and Minitab software-version 16. Graphs were plotted in Sigma plots-version-12.

Results

The results of comparing the biomass of the staccato trees in four planting spaces showed that the most product (495.8 Kg in summation) is related to 0.5 × 0.5 m treatment. then 1 × 1 m, 2 × 2 m and 4 × 4 m planting spaces had the most biomass. Also, it was a significant different between the biomass of the components of 0.5 × 0.5 and 1 × 1 planting spaces with the means of biomass in two other treatments (Table 1). Most biomass between the components was related to bole wood (197.6 Kg) and branches, twigs, bole bark and leaf were after that (77.5, 53.1, 28.6, 22.5 Kg respectively).

Mean of the staccato trees components biomass (Kg)					
Components	4 × 4 m	2 × 2 m	1 × 1 m	0.5 × 0.5 m	Mean
Bole wood	194a	240b	176.5a	179.9a	197.6a
Branch	44.9b	39.5b	111.1a	114.5a	77.5b
Twig	32c	48.5b	64.5a	67.9a	53.1c
Bole bark	27a	28a	28.1a	31.5a	28.6d
Leaf	24b	16.09b	23.3a	26.7a	22.5e
Summation	321	372	403	495.8	

Table 1: Dry weight of staccato tree. *Different letters are the indication of significant difference between the means.

The results of biomass allocation of the staccato trees were summarized in Figure 2 the results showed that the most percent of bole wood biomass in four planting spaces is related to 2 × 2 m and 4 ×

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4 m planting spaces (more than 60%). Biomass percent of other components of 0.5 × 0.5 m and 4 × 4 m planting spaces are more than two other treatments except leaf biomass in 4 × 4 planting space.

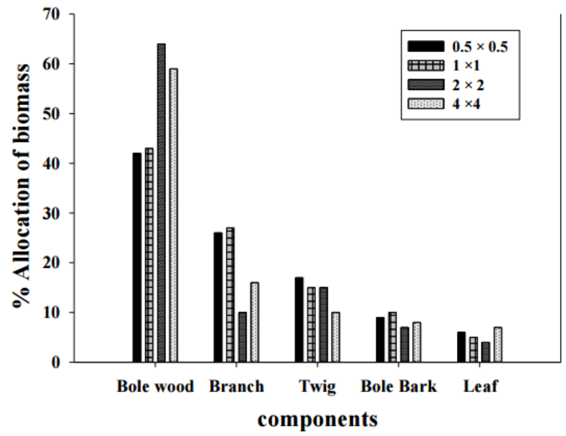

Figure 2: Biomass allocation of staccato trees.

The amount of carbon factor in the structure of different components was obtained and showed that the bole wood with 52%, bole bark with 50%, branches with 47%, twigs with 44% and leaf with 38% had been the most percent of carbon factor in their structures (Figure 3).

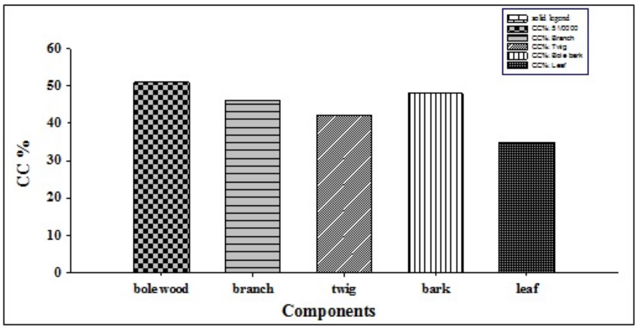

Figure 3: Amounts of carbon factor in trees organs.

The results of the carbon stock of the staccato trees structures in four planting space are summarized in Table 2. The results showed that the most carbon sequestration between the components is related to the bole wood, branches, twig and leaf with the means 100.7, 37.9, 23.9, 3.7 and 9 kg respectively. Most carbon sequestration was related to the 0.5 × 0.5 m planting space with 204 Kg and the least amount was related to 4 × 4 m planting space with 157.9 kg.

Mean of the staccato trees components Carbon stock (Kg)					
Components	4 × 4 m	2 × 2 m	1 × 1 m	0.5 × 0.5 m	Mean
Bole wood	98.9a	122.4b	90.0a	91.7a	100.7a
Branch	22.0b	19.4b	54.4a	56.1a	37.9b
Twig	14.4c	21.8b	29.0a	30.6a	23.9c
Bole bark	13.0a	13.4a	13.5a	15.1a	13.7d
Leaf	9.6a	6.4b	9.3a	10.7a	9e
Summation	157.9	183.4	196.2	204.2	

Table 2: Carbon stock of staccato trees.

Carbon allocations of the staccato trees are summarized in Figure 4. Most percent are related to the bole wood of the trees in four treatments (42 to 66%). Also, the branches in the 0.5 × 0.5 m and 1 × 1 m planting spaces has more amount of carbon percent in comparing with two other planting spaces. After that the most carbon sequestration is related to the twigs, bole bark and leaf respectively.

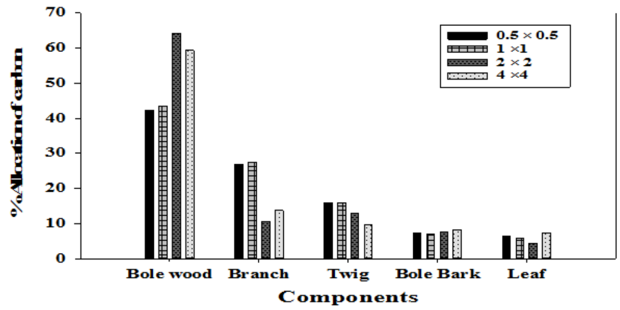

Figure 4: Carbon allocation of staccato trees.

There is a significant difference between the trees components biomass, between four treatments. Most biomass is related to the 0.5 × 0.5 m planting space (823.8 per hectare totally) after that 1 × 1 m planting space with 663-ton biomass per hectare is second. After that 2 × 2 m and 4 × 4 m planting spaces are in the next ranks with 199.4 and 258.6-ton biomass per hectare. There are not significant differences between the biomass amounts of 2 × 2 m and 4 × 4 m meter spaces. Also, there are not signi icant difference between the biomass product of twigs and bole bark of the 0.5 × 0.5 m and 1 × 1 m spaces (Table 3).

Biomass of trees components of four treatments (Ton per hectare)					
Components	4 × 4 m	2 × 2 m	1 × 1 m	0.5 × 0.5 m	Mean
Bole wood	87.8c	63.5c	383.5b	456.2a	247.7a
Branch	63.2c	47.4c	79.8b	121.0a	77.8b
Twig	45.6b	35.9b	93.4a	91.9a	66.7c
Bole bark	31.9b	26.9b	62.4a	80.7a	50.4d
Leaf	30.1c	25.7c	44.4b	74.0a	43.5e
Summation	258.6	199.4	663	823.8	

Table 3: Dry weight of trees components per hectare.

The result of biomass allocation of the trees components per hectare showed that 0.5 × 0.5 m and 1 × 1 m spaces have the most percent of biomass between all four treatments. Most percent are related to the

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bole wood (59%) and the least percent are related to the leaf (5%)(Figure 5).

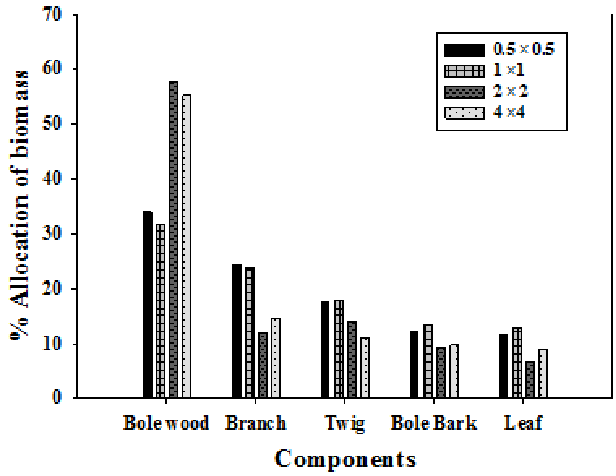

Figure 5: Biomass allocation of trees components per hectare.

The results of carbon sequestration amount of four regions are summarized in Table 4. Most carbon stock is related to 0.5 × 0.5 m planting space (401.7 ton per hectare) and the least carbon stock is related to 2 × 2 m planting space (95 tons per hectare). There is a significant difference between the carbon amounts of the different components per hectare.

Biomass of trees components of four treatments (Ton per hectare)					
Components	4 × 4 m	2 × 2 m	1 × 1 m	0.5 × 0.5 m	Mean
Bole wood	44.8c	32.4c	195.6b	232.7a	126.3a
Branch	30.9c	23.2c	39.1b	59.3a	38.1b
Twig	20.5b	16.2b	42.1a	41.4a	30.0b
Bole bark	15.3b	12.9b	30.0a	38.7a	24.2b
Leaf	12.0c	10.3c	17.7b	29.6a	17.4d
Summation	123.5d	95c	324.5b	401.7a	

Table 4: Carbon sequestration in trees components per hectare.

The results showed that the most carbon allocation of components between all treatments is related to the bole wood (30 to 47%) as in Figure 6 and the least amount is related to the bark and leaves (10% in average).

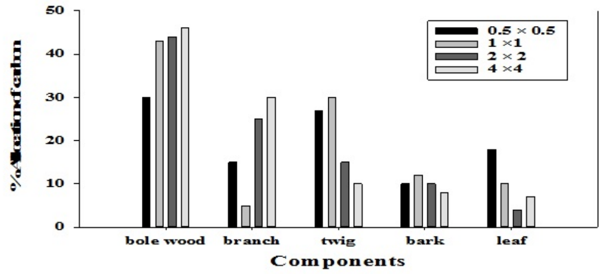

Figure 6: Carbon allocation of trees components per hectare.

Discussion

Forest loss often results in a decline of ecosystem functionality and goods and services for local and regional communities and fast growth species are one of the options to help the earth to keep its carbon cycle stability and to prepare the raw materials for the wood producer industrials [4-29].

Poplar has many advantages both as a model organism and as a crop for carbon sequestration [30]. Focus on trees has some advantages over non-woody plants due to the large fraction of the total global terrestrial biomass in forests, rapid growth, high value wood products that could help the economics of carbon sequestration, and widespread distribution.

More than 81% of above- ground carbon stored in the trees structures of forest ecosystems [15] and global bioenergy market based on forest biomass is growing rapidly (like poplar species [20]. Overall, wood has an elemental composition of about 50% carbon, 6% hydrogen, 44% oxygen [5-36]. Also in this study, the plant organs carbon percentage calculated about 50%.

The most biomass and carbon sequestration of staccato trees was calculated for the densest stand (20000 stem per ha) with 495.8 and 204.2 ton per hectare respectively. So, the high density is more effective factor on the trees biomass and carbon sequestration because in the low spaces the trees diameter is less than the trees with high spacing (because of the competition) but in these occasions the trees height will be more than the open stands. The results of Fang [8] study about the biomass production of poplar species in four different densities' (1111, 833, 625, 500 stems per ha) showed that the most biomass product was related to the highest density (1111 stem per hectare that have conformity with this study.

The result showed that the most biomass and carbon allocation between the trees organs are related to bole wood, branch, twig, bole bark and leaf respectively (with little exceptions that have conformity with the other studies [8].

The results showed that the most biomass between the components per hectare is related to the bole wood and 2 × 2 m and 4 × 4 m planting spaces have the most quantity of the bole wood biomass between the four planting spaces (456.2 and 383.5 ton per hectare) and 0.5 × 0.5 m and 1 × 1 m planting spaces are after them (63.5 and 78.8 ton per hectare). But the other components biomass quantities are different and the most amounts are related to the 0.5 × 0.5 m and 1 × 1 m planting spaces. It can be because those in open treatments all the trees have the more diameter and the trees trunk biomass will be more but in dense plantation all the trees try to absorb sun light, so they are taller and they have excessive crown biomass.

Similar to biomass amount of the trees, the result of calculating the carbon stock and carbon allocation of the trees in four planting spaces showed that the most carbon reserve of the woody components (bole wood and branches) is related to the 2 × 2 m and 4 × 4 m planting spaces but the most amounts of the twigs and bole bark and leaves carbon allocation is related to the 0.5 × 0.5 m and 1 × 1 m planting spaces. However, there are differences between the carbon allocations of the trees when calculated in percent. But generally, the most carbon sequestration is related to the 0.5 × 0.5 m planting space with 401.7-ton sequestered carbon per hectare and the lowest amount is related to 4 × 4 m planting space with 123.5-ton sequestered carbon per hectare.

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