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Growth and biomass production of lowland forest plantations in north of Iran

Niloufar Haghdoost, Moslem Akbarinia*, Seyed Mohsen Hosseini

Department of Forestry, Faculty of Natural Resources, Tarbiat Modares University, Noor, Mazandaran, Iran

ABSTRACT

Plantations may play an effective role in balancing the CO_2 levels in atmosphere by capturing and storing the carbon in biomass and soil. There are few studies in north of Iran whit focusing on carbon sequestration in forested lands. Acer velutinum .Boiss, Alnus subcordata .L and Cupressus sempervirens. var. horizontalis are the most used species in lowland plantations in this region. We quantified survival rate, growth characteristics and above- and belowground biomass after 18 years of these species establishment in Chamestan region of Mazandaran province. Results showed that C. sempervirens had the lowest survival rate and growth compared to other studied species. Based on higher survival rate and rapid growth, A. subcordata may be the best option for lowland plantations in this region. Also our results indicated that biomass production and carbon storage was significantly higher in A. subcordata and A. velutinum plantations compared to C. sempervirens. The rate of biomass carbon storage was calculated around: 23.41, 21.47 and 11.27 (t/h/yr) for A. subcordata, A. velutinum and C. sempervirens respectively. These results showed that lowland plantations in this area can be very effective on reducing the negative consequences of global warming.

Keywords: Aboveground biomass, belowground biomass, CO_2 mitigation, carbon storage, global warming.

INTRODUCTION

Land use changes from forestry to other uses, as well as greenhouse gas emissions associated with exploitation of fossil fuels have disrupted the planet's fragile carbon (C) balance and caused global climate change [38]. Problems caused by global warming which associated with the increase in Greenhouse Gases (GHG) are the most important global environmental issue in current century [14]. Even in the most optimistic scenarios, climate change can be detrimental to several production chains, with a strong impact on developing economies which depend largely on agriculture [11].

Terrestrial and marine ecosystems are estimated to absorb about half of the CO_2 emissions from fossil fuel combustion [33]. In terrestrial ecosystems, C which absorbed via photosynthesis is stored in the biomass of living vegetation (leaves, branches, trunks and roots), litter and soil [25, 37]. Among terrestrial ecosystems, forests may help contribute toward C sequestration by capturing and storing atmospheric CO_2 where it is not immediately re-emitted to the atmosphere [14]. Forest lands are the primary source of terrestrial C uptake, storing approximately two-thirds of Earth's terrestrial C [3]. Such knowledge has created increased interests in managing forests for more C sequestration. There are numerous carbon-based stores that recognize a wide variety of terrestrial C sequestration activities as potentially viable means for reducing atmospheric CO_2 concentrations [23]. Forest management practices offer a unique means of offsetting greenhouse gas emissions [20]. Among forest management options for C sequestration, forest plantations have been known as a cost-effective and environmentally beneficial strategy for C sequestration [23, 14]. Therefore, forest plantations have been established all over the world as C stocks [4, 13, 31, 35] to slow down the increase of atmospheric CO_2 concentrations. A potential expansion is possible of 345 million ha as trees are planted in disturbed forest, pastures or abandoned agriculture areas [4]. Changes in silvicultural management can alter C stocking and enable stored C valuation. In the case of plantations, increases in stored C are brought about by regimes that enhance long-lived wood product volume. In the case of existing forests, C sink enhancing is related to lower deforestation rates [11].

Establishment of large-scale short-rotation woody crop plantations has been advocated as an effective method for sequestering CO_2 and mitigating increased atmospheric CO_2 levels [34], through increasing long-term C storage in woody biomass [33] and in the soil [10, 36], and by providing an alternative source of biomass for bioenergy [2, 36]. So estimating the production and biomass C storage of plantation stands can play an important role in management approaches for reducing CO_2 levels in atmosphere.

Forest production can be evaluated in terms of resource supplies, rates of use, and growth [35]. Estimates of C pools in the vegetation component of forest ecosystems can be obtained by using allometric functions [22, 25]. Such functions allow the estimation of plant biomass from variables that are easily and non-destructively measured, such as plant height and trunk diameter at breast height [25].

In north of Iran, Caspian forests have been under continuous degradation over the last few decades and there is an urgent need to maintain the functions of this unique forest ecosystem [12]. Therefore, different forms of management approaches are planned for implementation, such as documenting the forest disturbance and management of the remaining natural forest ecosystems in this region [27]. Also forest plantations were introduced to supply fuel-wood, charcoal, fodder, sticks and building materials. They were also planted to restore degraded lands, to control soil erosion or to serve as buffer zones around roads and areas of natural forests [12]. There were many plantations with endemic and exotic species in north of Iran. But, unfortunately, there is little published information on tree growth and biomass in this region. Also results of such researches are not consistent and generalizations are not possible and most of these researches are not published in English language. The aims of this study were to compare growth, biomass production and biomass C storage of three prevalent species plantations: (I) *Acer velutinum* .Boiss, (II) *Alnus subcordata* .L and (III) *Cupressus sempervirens.* var. horizontalis. As amounts of C storage and biomass accumulation for studied species are unknown in this area. Also we introduced the most suitable species in terms of maximum biomass C storage.

MATERIALS AND METHODS

2.1. Study area

This study was conducted in Chamestan region at Noor County in Mazandaran province, in the north of Iran. Study sites located at district 12 of watershed 51 of northern forests of Iran (36^o 29' N, 52^o 7' E) with an altitude of 90 m above sea level and low slope (<5%) (Fig1). Annual rainfall averages 803 mm, with wetter months occurring between September and February, and a dry season from April to August. Monthly rainfall usually occurs <40 mm for 4 months. Average daily temperatures ranges from 11.7 ^{o}C in February to 29.5 ^{o}C in August. The soils have the textures of loam and clay loam with an acidic pH in top layers and in deep layers soil textures were clay and silt clay and soil pH was less acidic. 18 years ago plantations have been established (with 2m × 2m spaces) in this area with three species including: *A. subcordata*, *A. velutinum* and *C. sempervirens* [1]. These species are the most used in lowland plantation programs in north of Iran. We selected three sites each with an area of 10 ha to compare growth and biomass production.

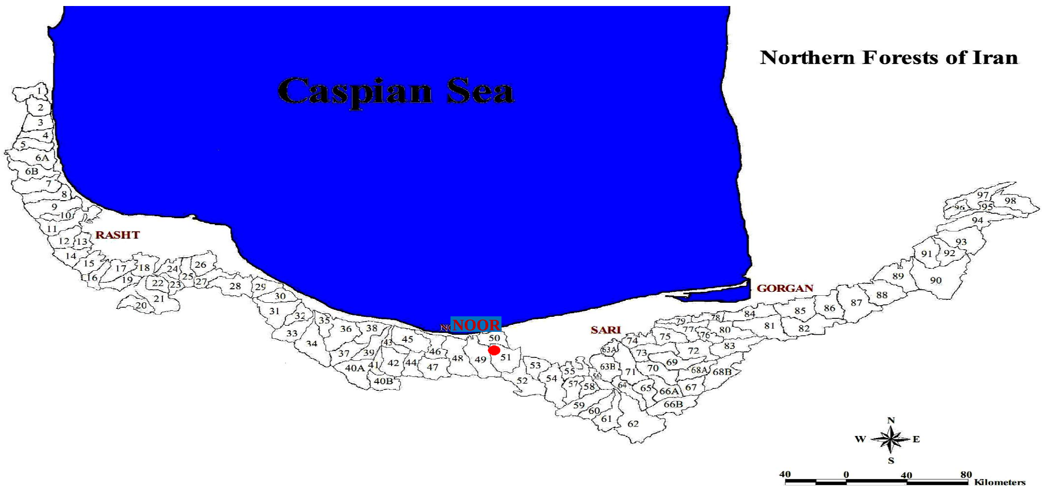

Fig 1- Study area location in northern forests of Iran

2.2. Field measurements

Measurements were performed to compare growth and biomass production of above-mentioned plantations, in November of 2010, after finishing the growing season. In each sites four 10 m × 10 m plots were established. Then tree height (H), diameter at breast height (DBH), diameter of canopy or crown in two perpendicular directions, termed here for convenience "length" (L) and "width" (W), stem height to the base of the crown (Hc) and percentage of foliage cover in the crown or canopy (Fc) were measured for all of the trees in each plot [26]. Also survival rate (%) and basal area were calculated for each plot.

2.3. Biomass and carbon accumulations

First, tree's biomass estimated in two separate part of aboveground and belowground, then, the total biomass was estimated for each site. To estimate the aboveground tree biomass we used an allometric method suggested by Ponce-Hernandez et al., [26]:

For methodological convenience, the calculations of trees are divided in two sections according to tree morphology: (I) calculation of biomass for stem (II) calculation of biomass for crown. To calculation of stem biomass, first the basal area estimated by equation 1:

(1)

Where A_b is tree basal area, π = 3.145927, and r is the radius of the tree at breast height (0.5 DBH). Then the stem volume (V) of each tree calculated from equation 2:

$$V = A_b \times H \times K_c \qquad (2)$$

Where A_b is tree basal area, H is the total tree height and K_c is a site-dependent constant in standard cubing practice used in forest inventory. To calculation of crown volume (V) we used following equations:

$$V = \pi \times \frac{Db^2 \times Hc}{12} \qquad \text{(3) For coniferous species}$$

$$V = \frac{\pi \times Db^2}{12} \qquad \text{(4) For broadleaf species}$$

Where: π = 3.141592, Db = diameter of the crown (L+W/2) and Hc = height from the ground to the base of the crown. The volume of the crown estimated by these equations is the gross total volume. In reality, much of this volume is empty space. The actual proportion of the volume occupied by branches and foliage is estimated by standing beneath the canopy or crown, beside the trunk, and obtaining a careful visual appreciation of the canopy structure. This proportion is then used to discount the air space in the crown volume:

Solid volume = V × proportion of branches and foliage in crown volume

Biomass (stem and crown) in kilograms calculated by multiplying by the wood density (WD) corresponding to each tree species measured through equation 5:

$$Biomass = V \times WD \times 1000 \qquad (5)$$

Total aboveground biomass estimated as:

Total Aboveground Biomass = Stem Biomass + Crown Biomass

Because of the high cost of root sampling and measurement, non-destructive methods (such as allometric equations) preferred to assess the belowground biomass. On the other hand, it is recommended that in situations where no empirical equation exists, the root volume and biomass should be estimated as a fraction of the aboveground biomass, as an interim measure, in order to estimate total biomass [26]. So following relationships suggested by Ponce-Hernandez et al., [26] were used to estimate belowground biomass:

For coniferous species: Belowground biomass = 0.25 Aboveground biomass

For broadleaf species: Belowground biomass = 0.30 Aboveground biomass

These values converted to tons per hectare and then calculation of C stock as biomass consists of multiplying the total biomass by a conversion factor that represents the average C storage in biomass. It is not practically possible to separate the different biomass components in order to account for variations in C storage as a function of the biomass component. Therefore, we assumed C to equal 50% of a tree's biomass [5, 9, 19, 28, 29]:

C = 0.5 × Biomass (total)

2.4. Statistical analyses

The growth, biomass and C storage of biomass among experimental sites were analyzed using the randomized block design. Normality of the variables was checked by Kolmogorov-Smirnov test and Levene's test was used to examine the equality of the variances. One-way analysis of variance (ANOVA) was used to compare tree growth, biomass, and C storage of biomass data among experimental sites. Duncan test were used to separate the averages of the dependent variables which were significantly different between studied sites.

RESULTS

3.1. Tree survival and growth

Measurements in the experimental plantation sites (at the age of 18 years) indicated that *A. subcordata* had the higher survival rate (44%) compared to other studied species. Also *C. sempervirens* had the lowest survival rate (29%) among plantation sites (Fig 1a). DBH was significantly higher in *A. subcordata* in comparison to *C. sempervirens* but there were no significant differences between *A. velutinum* and other plantation sites (Fig 2b).

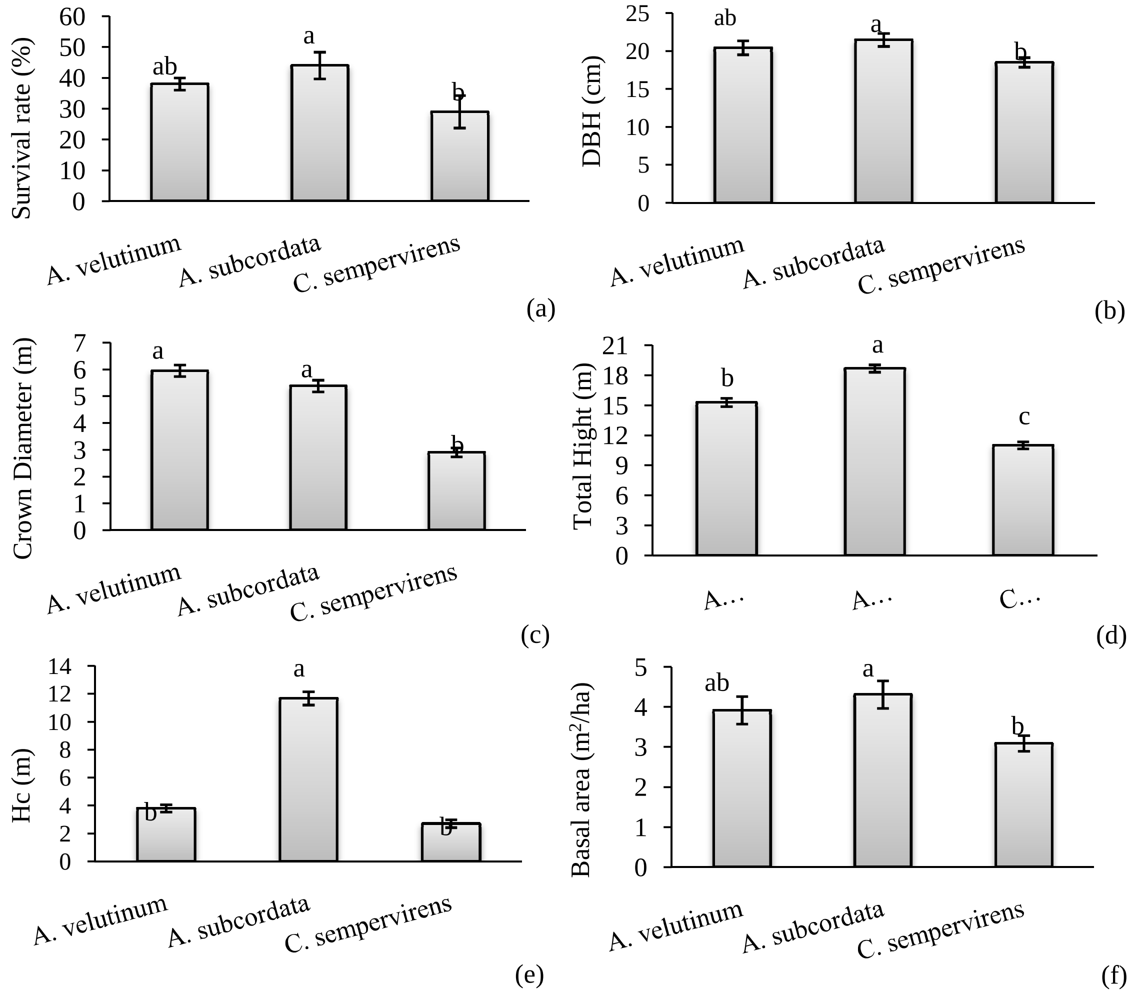

Fig 2- Comparison of survival rate (a), DBH (b), crown diameter (c), total height (d), Hc, stem height to the base of the crown (e) and basal area (f) of three plantation sites

Crown diameter was significantly lower in *C. sempervirens* compared to other plantations and the highest amount of crown diameter was observed in *A. velutinum* plantation (Fig 1c). As can be observed in the results that shown in fig 1d, the total tree heights was significantly different between studied plantation sites and took the order: *A. subcordata* > *A. velutinum* > *C. sempervirens*.

The highest amount of stem height to the base of the crown (Hc) was observed in *A. subcordata* plantation site (Fig 1e). The stand basal area, as shown in fig 1f, was higher in *A. subcordata* (4.3 m^2/ha) and *C. sempervirens* site had the lowest amount of basal area (3.08 m^2/ha) in compared to other plantation sites.

3.2. Biomass production

The results of Duncan test of above- and belowground biomass between studied plantation sites are shown in fig 3. These results indicated that biomass production of studied species was significantly different after 18 years of plantation. Estimated aboveground biomass was significantly higher in *A. subcordata* and *A. velutinum* plantation sites than *C. sempervirens* site. The results of comparison of belowground biomass were similar to that of aboveground biomass and took the order: *A. subcordata* > *A. velutinum* > *C. sempervirens* (Fig 3). Total amount of biomass production (at the age of 18 years) in *A. velutinum*, *A. subcordata* and *C. sempervirens* plantations were estimated around 773.13, 843.2 and 405.83 tons per hectare respectively.

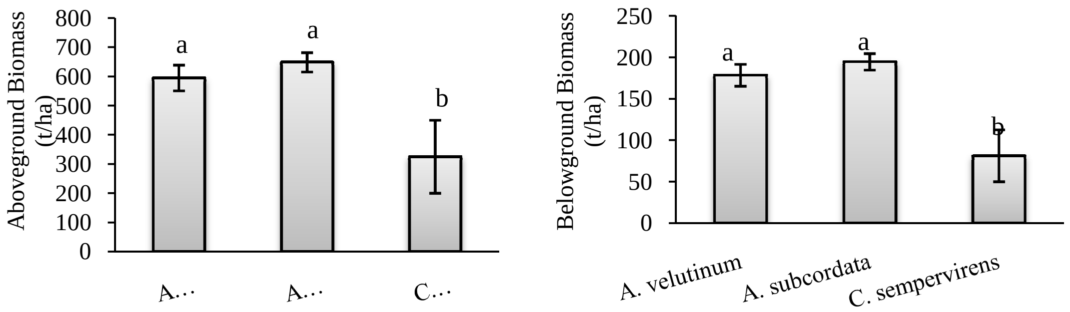

Fig 3- Comparison of above- and belowground biomass of three plantation sites

3.3. Biomass C storage

In fig 4 significant differences can be observe between biomass C storage that we estimated in our studied plantation sites. Biomass C storage in *C. sempervirens* plantation site was significantly lower than other plantation sites and they took order: *A. subcordata* (421.55 t/ha) > *A. velutinum* (386.56 t/ha) > *C. sempervirens* (202.91 t/ha). The yearly rate of C storage calculated around: 23.41, 21.47 and 11.27 (t/h/yr) for *A. subcordata*, *A. velutinum* and *C. sempervirens* respectively.

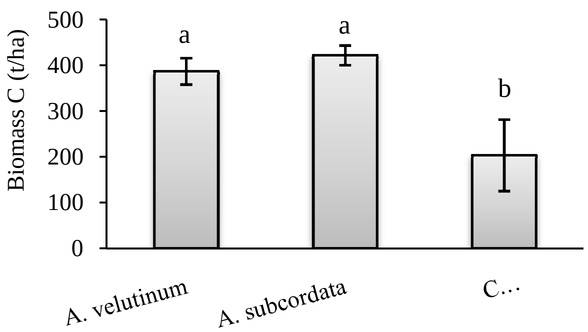

Fig 4- Comparison of biomass C storage of three plantation sites

DISCUSSION

4.1. The most productive species in studied area

In north of Iran, forest plantations are established to provide industrial wood requirements. Other general goals of these forest plantations are to eliminate or alleviate soil erosion and water loss in watersheds, to restore degraded lands and some other environmental purposes. Therefore, identification of suitable species for such purposes in each specific area is very essential. In our studied area *C. sempervirens* had the lowest and *A. subcordata* had the highest survival rate. The results of comparison of DBH between studied species were the same and *A. subcordata* and *C. sempervirens* had the highest and lowest amount of DBH respectively. Sayyad et al. [32], in Chamestan region, reported that survival rate of *A. subcordata* after 7 years of plantation was 70% which was lower than *Populus deltoides*. Also they reported that the DBH of *A. subcordata* was reduced when this species was grown in combination with *P. deltoides* as compared with monocultures but the relative proportion of *P. deltoides* did not further affect that result. Jacobs and Severeid [15], in southwestern Wisconsin, reported that American chestnut had more rapid height (47-77%) and diameter (50-140%) growth compared to black walnut and northern red oak.

The highest amount of crown diameter was observed in *A. velutinum* plantation and it was significantly lower in *C. sempervirens*. Sayyad et al. [32] observed higher crown diameter in *A. subcordata* compared to *P. deltoides*. Our results showed that total height growth was significantly different between studied plantation sites and took the order: *A. subcordata* > *A. velutinum* > *C. sempervirens*. While, total height growth of *A. subcordata* was lower than *P. deltoides* in the study that obtained by Sayyad et al. [32] in this region.

The amount of stem height to the base of the crown was significantly higher in *A. subcordata* in comparison to other plantation species. Also *A. subcordata* plantation site had the highest amount of stand basal area and the results took order: *A. subcordata* > *A. velutinum* > *C. sempervirens*. While, higher amount of basal area in *P. deltoides* compared to *A. subcordata* plantation was reported by Sayyad et al. [32] in this region.

Our results showed significant differences in biomass production of studied species. Aboveground and belowground biomass production of *A. subcordata* and *A. velutinum* were almost twice the biomass production of *C. sempervirens* plantation. Different estimates are available on biomass production of common plantation species. For example, in a 10 years old *P. tremuloides* stand (12670 stems/ha), total aboveground biomass was reported at 25.4 (t/ha) by Ruark and Bockheim [30]. Also Jacobs et al. [14] reported that American chestnut had significantly greater biomass than northern red oak and black walnut on 8 years old sites.

Our results indicate that in studied region *A. subcordata* may be the best option for plantation programs and *A. velutinum* can be the second priority in terms of wood production. Previous study in this region indicated that these species also have great influences on soil fertility and nutrients and their establishment restored degraded soils [12]. Due to the low survival rate, growth characteristics and low biomass production, we do not recommend planting of *C. sempervirens* in this region and further researches will be helpful to find the best area for establishment of this species.

4.2. The role of lowland plantations in carbon mitigation

Today, programs are developing all over the world that provide financial incentives to individuals conducting forest management practices that increase the amount of C sequestered by their forest plantations [14]. Regarding the observed increase in the atmospheric concentration of CO_2 and the global climate question, forests offer two main options. First, the volume of atmospheric CO_2 may be reduced by increasing forest biomass. This may be achieved through an expansion of forests-either by planting currently unforested land, or by allowing the existing forests to accumulate higher biomass. The second main approach is to utilize forest directly as a source of raw materials for energy production, usually referred to as bioenergy, which is considered a carbon-neutral energy source [6]. Duo to the large scale of forest plantations and natural forests, north of Iran has a great potential for CO_2 mitigation activities and projects in the forestry sector. Soil C sequestration and C stocks were estimated in few researches [12] in this area, but biomass C storage among different plantation species, regions and management measures has not been carried out yet.

Niu and Duiker [23] found that aboveground tree biomass accounts for about two thirds of the total C sequestration potential of afforestation plantations in the Midwestern U.S. The other one third of C capacity was approximately equally distributed over C in roots, forest floor, and soil organic C pools. Our results indicated that *C. sempervirens* had lower biomass C storage than other plantation species. Kraenzel et al. [17] estimated tree C storage in Panamanian teak plantation to be 126 t/ha (after 20 years of plantation) which is very lower than biomass C storage that we estimated for our studied species (after 18 years of plantation). Afforestation and reforestation produce large potential for C sequestration. Niu and Duiker [23] estimated that about 52 (t C/ha) could be sequestered in aboveground tree biomass 20 years after afforestation in the Midwestern U.S.

The rate of biomass C sequestration for *A. subcordata*, *A. velutinum* and *C. sempervirens* was 23.41, 21.47 and 11.27 (t/h/yr) respectively. Thus, *C. sempervirens* plantations make a lower contribution to the C sequestration and mitigation of greenhouse gas emissions in this area than other studied species. Different rates of biomass C storage have been reported for different species in world. For example, Fang et al. [6] estimated a rate of 6.234 (t/h/yr) for poplar plantations in China. For American chestnut this rate was 3.1 (t/h/yr) estimated by Jacobs et al. [14] while Lamlom and Savidge [18] estimated biomass C rate of 3.58 and 3.3 (t/h/yr) for red and white pine, respectively. Biomass storage rate was estimated 3.489 (t/h/yr) for Chinese fir plantation [7] and 4.823 (t/h/yr) for Masson pine plantation [8] in China. Compared to these results, our results showed that there is a great potential of biomass C storage in forest plantations in north of Iran which can have a significant influence on CO_2 mitigation.

Many environmental conditions can affect C storage potential even within a relatively small geographic area [6]. Management practices (such as species selection, fertilization, irrigation methods,…) can easily affect C storage of forest plantations [16, 21]. Paul et al. [24] suggested that rate of accumulation of C was dependent on annual rainfall, they reported that with average annual rate of sequestration of C in tree biomass and litter during the first rotation of *E. cladocalyx* (or C. maculata) increasing from 3.68 to 4.72 (t/h/yr) as annual rainfall increased from about 500 to 750 mm. As with any other attempt to evaluate rates of terrestrial C sequestration between tree species or regions, variation in both planting density and site quality make direct comparisons regarding C uptake and storage difficult [14]. This type of extrapolation often occurs, however, due to the logistical challenge and cost of collecting biomass information [39]. So based on the lack of information about C storage potential of different species and the role of management options and varied environmental conditions on this potential in north of Iran, more researches will be helpful to increase our knowledge.

CONCLUSION

Our results showed that lowland plantations in north of Iran can be very effective on reducing the atmospheric CO_2 concentrations besides the role that they play in wood production for industries. Based on survival rate, growth characteristic and biomass production, we introduce *A. subcordata* as the best species for plantation in this area. *A. velutinum* can be the second priority due to the low significant differences that it showed in comparison to *A. subcordata*. But we do not suggest planting of *C. sempervirens* in studied area and more researches will be helpful to find the best area for establishment of this species. On the other hand, compared to results of other researches for commonplace species in the world, all three studied species had a huge potential for C sequestration in their biomass. Therefore, establishment of such plantations in north of Iran will play a fundamental role in CO_2 mitigation, environmental protection and increasing the ecosystem productivity.

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