African Journal of Biotechnology Vol. 8 (16), pp. 3798-3805, 18 August, 2009
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2009 Academic Journals

Full Length Research Paper

Effects of leaf area of downy oak (*Quercus pubescens* Willd.), common ash (*Fraxinus excelsior* L.) and boxelder (*Acer negundo* L.) seedling plants on diameter, height, volume and weight increments

Nuri Oner[1]* and Meriç Çakır[2]

[1]Cankiri Karatekin University, Faculty of Forestry, 18200, Cankiri-Turkey.
[2]Istanbul University, Faculty of Forestry, 34473, Istanbul-Turkey.

Accepted 13 July, 2009

In this study, the effects of the leaf area (l.a) and leaf area index (l.a.i) values on diameter, height and weight increments for various forest tree seedlings in Cankiri Kenbag forest nursery was investigated. 30 seedlings of 3 tree species which are downy oak (DO) (2+0) (*Quercus pubescens* Willd.), common ash (CA) (2+0) (*Fraxinus excelsior* L.) and boxelder (B) (2+0) (*Acer negundo* L.) were examined. The volume parameters of the seedlings [diameter (mm), height (cm), leaf area (mm²), stem and leaf weights (g)] were measured. ANOVA and Tukey's multiple comparison tests were used in order to determine the different groups with regard to volume and volume parameters. According to the results, there were significant differences between B and CA with regard to lead area index and diameter and height increment, between CA and DO with regard to leaf area index and height increment. A significant difference has been found between B and DO and between CA and DO with regard to volume increment in individual leaf area. Also, another significant difference between semi-shade tolerant and light demanding tree species with regard to the volume increment effect of the leaf area (1 m²).

Key words: Boxelder, common ash, downy oak, leaf area, leaf area index.

INTRODUCTION

Plants produce their own food. Green plants produce organic substances by combining CO_2 from air and the water that it brings to its leaves by transpiration with the help of chlorophyll of the leaves and using the energy supplied from sun light. This event is called as photosynthesis (assimilation). Produced food is transferred from leaves to the other parts of the plant which need nourishment. Plant uses this product as energy in order to perform growth and increment (Assman, 1961; Bozcuk, 1997; Kadioglu, 2004).

Light is a vital physical factor that the plants required to ensure reproducing and growing. The most important ecological function of the light is providing photosynthesis for the green plants. The increase of photosynthesis with light intensity continues proportionally to a certain light intensity; after that point, photosynthesis does not increase, but remains constant even though the light intensity increases (Irmak, 1970). This limit value of the light intensity that produces the maximum energy possible varies depending on plant species, especially on whether they are light demanding or shade tolerant plants (Firat, 1972). The light amount necessary for photosynthesis of the green plants varies depending on the time and plant species. The light amount that enables the plant making a maximum growth is called "the light optimum" or "optimum light intensity" (Kalipsiz, 1998; Saracoglu, 2002; Carus and Catal, 2005).

The intensity of the photosynthesis is calculated according to a unit area of leaf or n unit weight of leaf. At opti-

*Corresponding author. E-mail: nurioner@gmail.com. Tel.: +90376 212 2757. Fax: +90 376 213 6983.

Abbreviations: DO, Downy oak (*Quercus pubescens* Willd.); **CA,** common ash (*Fraxinus excelsior* L.); **B,** boxelder (*Acer negundo* L.)

mal light conditions, photosynthesis intensity of the shade leaves is significantly lower than the light leaves. The photosynthetic activity of the coniferous plants is low with respect to other leaved plants and the photosynthesis amount of these is low like the shade tolerant plants (Irmak, 1970; Kalipsiz, 1998; Carus and Catal, 2005).

On the other hand, the light energy that is held by a leaf depends on the size of the leaf area (leaf surface). The measure of the leaf surface area (l.a.) is total leaf surface area of the plant (m^2). The ratio between the total surface leaf area of a plant and the land area it covers (m^2/ha or m^2/m^2) at a certain area is called leaf area index (l.a.i.) (Oliver and Larson, 1996; Smith et al., 1997).

All leaves on the plant are measured in order to determine the wet or dry substance weight per m^2, total leaf area or leaf area index. As a result of the various researches made in order to determine the relationship between leaf amount of unit area and production, It has been found that the organic substance amount produced by photosynthesis depends on external factors (light amount, CO_2 intensity, wind, water amount that can be taken from the land, minerals), genetic characteristics of the plant (specific photosynthesis power of the species, the minimum, maximum and optimum points of required light, water, minerals), conditions of the plant (the land of the plant and neighborhood relations, age, leaf area, leaf area index, health conditions, leaf age, etc. of the plants) (Smith et al., 1997; Kalipsiz, 1998). Each of these factors is an independent variable. But most of them are related to each other and their effects vary depending on each other. The photosynthesis product emerges as a common result of all these factors.

MATERIALS AND METHODS

The seedling material used at the research is taken from Cankiri Kenbag forest nursery. The elevation of the region from the sea level is 710 m and the slope in east-west direction is 2%. The Tatli creek passes through the nursery area. According to data from the Cankiri meteorological station at 731 m altitude, average temperature is 11.1°C, highest temperature is 39.2°C at August and lowest temperature is -23.9°C at February in the region. When 10ºC is taken as a limit, as described Rubner (1949) as forest vegetation period, the vegetation period of the region is to be 7 months, between April and October. The average annual rainfall is 417.7 mm, while the rain fall in vegetation period is 245.0 mm and average annual relative humidity is 67%, while it is 62% in vegetation period. The fastest wind direction is 21.1 m/s (SSW) at April (Anonymous, 2008). According to Thornthwaite method, Cankiri has a climate type of “arid-semiarid, mezothermal, no extra water, or very little extra water, close to the oceanic climate effect” which is shown by $DB'_1db'_3$ symbol (Imal et al., 2007).

The nursery area consists of base lands and little slope lands as geomorphologic structure. Base lands are alluvium of quaternary period. This alluvium is a mixture of gravel, sand, silt and clay. Soil depth varies. The Cankiri series of the nursery area is either flat or nearly flat terrain, with small amount of stone and deep soil. Permeability is decreasing because of the increase of the clay amount in the lower layer. Although there is no saltiness on the surface, it increases through deeper layers. Texture is loamy on surface soil, while it becomes clay loamy soil at deeper layers. The Cankiri series belong to Argid sub-ordo and belong to Haplargid big soil group and to Typic haplargid sub-ordo. Most of the lands of the nursery are on alluvial flats. One of the most important characteristics is the changes in the texture at very short distances. The soil depth in the experiment area varies between 120 and 150 cm (Yuksel et al., 2001).

Seedling characteristics

The Cankiri origin 2+0 year-old seedling materials (Boxelder, common ash and downy oak) used in the study is supplied from Cankiri Kenbag forest nursery as 30 pieces from each species.

Determining diameter, height, volume and weight increments of the seedlings

The leaf and body weights are measured by a Prescia 1620C gravity meter with sensitivity of 0.01 g and by means of formula 1. The 1st and 2nd age volumes of the seedlings were calculated by surface middle formula (Formula 2). The volume increment of the 2nd age is calculated by subtracting 1st age volume from the total volume. The volume amount per m^2 is calculated by multiplying the seedling number (per m^2) with average individual volume. Weight increment is calculated by subtracting 1st age body weight from body weight of 2nd.

$$FYSw = \frac{SYSwxFYv}{SYSv} \quad (1)$$

FYSw and SYSw: First and second year’s stem weight, FYv: First year’s volume, SYSv; Second year’s stem volume

$$V = \frac{\pi}{4} D_{\frac{1}{2}}^{2} L \quad (2)$$

V: Volume; $D_{1/2}$ = Diameter in the middle, L = Length

The heights and height increments of 1st and 2nd ages are measured by a ruler with mm precision. The basal diameters of the 2nd ages of the seedlings were determined by a digital caliper with sensitivity of 0.001 mm (Mitutoyo absolute digimatic caliper). The diameter increment of the seedling is calculated by the means of relations between diameter increment of 2nd age, height increment of 1st and 2nd ages and by the means of formulas 3 and 4 (Carus and Catal, 2005; Oner ve Cakir, 2006).

$$FYBd = \frac{SYBd.FYh}{ih} \quad (3)$$

$$id = \text{SYBd} - \text{FYBd} \quad (4)$$

FYBd and SYBd = First and second year’s basal diameter, FYh = First year’s height, *ih* = Increment in height, *id* = Increment in diameter.

Determining leaf area and leaf area index

Since there was no possibility to use expensive systems like WinNEEDLE (Kenefic and Seymour, 1999) which is a light mechanism with microscope support etc., the following procedure is applied respectively:

Table 1. Effects of leaf (1 g) on volume parameters.

Species	Volume (cm^3)	Volume increment (cm^3)	Stem Weight (g)	Weight increment (g)	Diameter increment (mm)	Height increment (cm)
Boxelder	1.37	0.99	1.29	0.93	4.68	2.66
Common ash	3.02	2.62	2.97	2.56	4.39	9.15
Downy oak	0.99	0.87	1.34	1.17	0.89	4.59

1. The leaves are detached from stems and shoots and separated into 3 class according to their length (< 1 cm, 1-2 cm, ≥ 2 cm) and then, leaf number with in each class is determined.
2. 30 leaves from each length class are chosen in order to be used in measurements.
3. In each species, the leaf width (w, mm) and length (l, mm) are measured by digital caliper at sensitivity of 0.01 mm and by multiplying these values the area of a leaf (l.a, mm^2) is calculated.
4. The arithmetic average of area value of chosen leaves from each length class is calculated. Leaf area is calculated by multiplying arithmetic average of leaf area with the frequency of the length class. This process is repeated for each length class and total leaf area of the seedling is calculated by summing up all calculated average values (Formulas 5 and 6).

$$LCAa = ALALC.f_i \tag{5}$$

$$TLA = \sum^{k} LCAa.l \tag{6}$$

LCAa = Length class average area (mm^2), ALALC = Average leaf area of the length class (mm^2), fi = frequency count in length classs, TLA = Total leaf area in a nursery (mm^2), k = number of length classes, l = length of leaf (mm).

Total leaf area in per m^2, in other words, leaf area index of individual species is calculated by multiplying a sample seedling's leaf area by seedling count in per m^2 (Carus and Catal, 2005; Oner and Cakir, 2006).

Determining the production power of a leaf

Diameter and length increments of seedlings are associated to leaf area of seedlings which is used to determine the production power of a seedling and leaf unit. Diameter and length increments of unit leaf (1 mm^2) are calculated by dividing diameter and length increment value of every seedling by leaf surface measurement value. The same process is repeated for seedling weight and the production power of leaf per unit weight (1 g). Then, diameter, length, volume and weight increment power of per mm^2 and per gram is compared to each other (Carus and Catal, 2005; Oner and Cakir, 2006).

Statistical evaluations

The statistical evaluation of relationships between the leaf area, leaf area index of seedling and volume, volume parameters are carried out after processing the measurement values as data files in the computer. SPSS for windows Ver. 10.0 is used as statistics software. ANOVA is used as a statistical test in order to determine whether the arithmetic means of diameter and length increments of seedling species were statistically equal. In the same time, significantly different groups were determined by Tukey's multiple comparison tests.

RESULTS AND DISCUSSION

The effect of (1 g) leaf on volume and volume parameters

When considering volume and volume increment, common ash (CA) has the best values among all species. This species is followed by boxelder (B) and downy oak (DO). When we consider stem weight and weight increment the order is like CA, DO and B. The highest diameter increment is made by B with 4.68 mm and the others are following as CA (4.39 mm) and DO (0.89 mm). When considering the length increment, CA has the best value as 9.15 cm. It is followed by DO (4.59 cm) and B (2.66 cm) (Table 1).

The effect of 1 mm² leaf area on volume and volume parameters for different species

B has the highest leaf weight values followed by CA and DO, respectively. When considering volume increment (cm^3), 1st age height (cm) and body weight CA has the highest values and followed by B and DO, respectively. For 1st age diameter and diameter increment (mm), weight increment (g), height increment (cm) the highest values belong to CA, DO and B, respectively (Table 2).

Diameter, height, volume and weight relationships with respect to an individual leaf area

The relationship between leaf area and diameter increment, height increment, volume increment and weight increment of the seedlings used in the study is given at Figure 1. The figure shows that the relationship between leaf area and diameter, height, volume and weight increment has a polynomial structure. This is because dry substance production proportionally increases with leaf amount per unit area (Kalipsiz, 1998; Nabuya and Toshihiro, 2003; Carus and Catal, 2005; Oner and Cakir, 2006).

Table 2. Effect of leaf area (1 mm^2) on volume parameters.

Species	Leaf weight (g)	Volume increment (cm^3)	First year's height (cm)	Stem weight (g)	First year's diameter (mm)	Diameter increment (mm)	Weight increment (g)	Height increment (cm)
Boxelder	0.000088	0.00009	0.0006	0.00010	0.00002	0.00002	0.000081	0.0002
Common ash	0.000086	0.00020	0.0009	0.00020	0.00005	0.00008	0.000200	0.0007
Downy oak	0.000075	0.00006	0.0003	0.00009	0.00004	0.00006	0.000084	0.0003

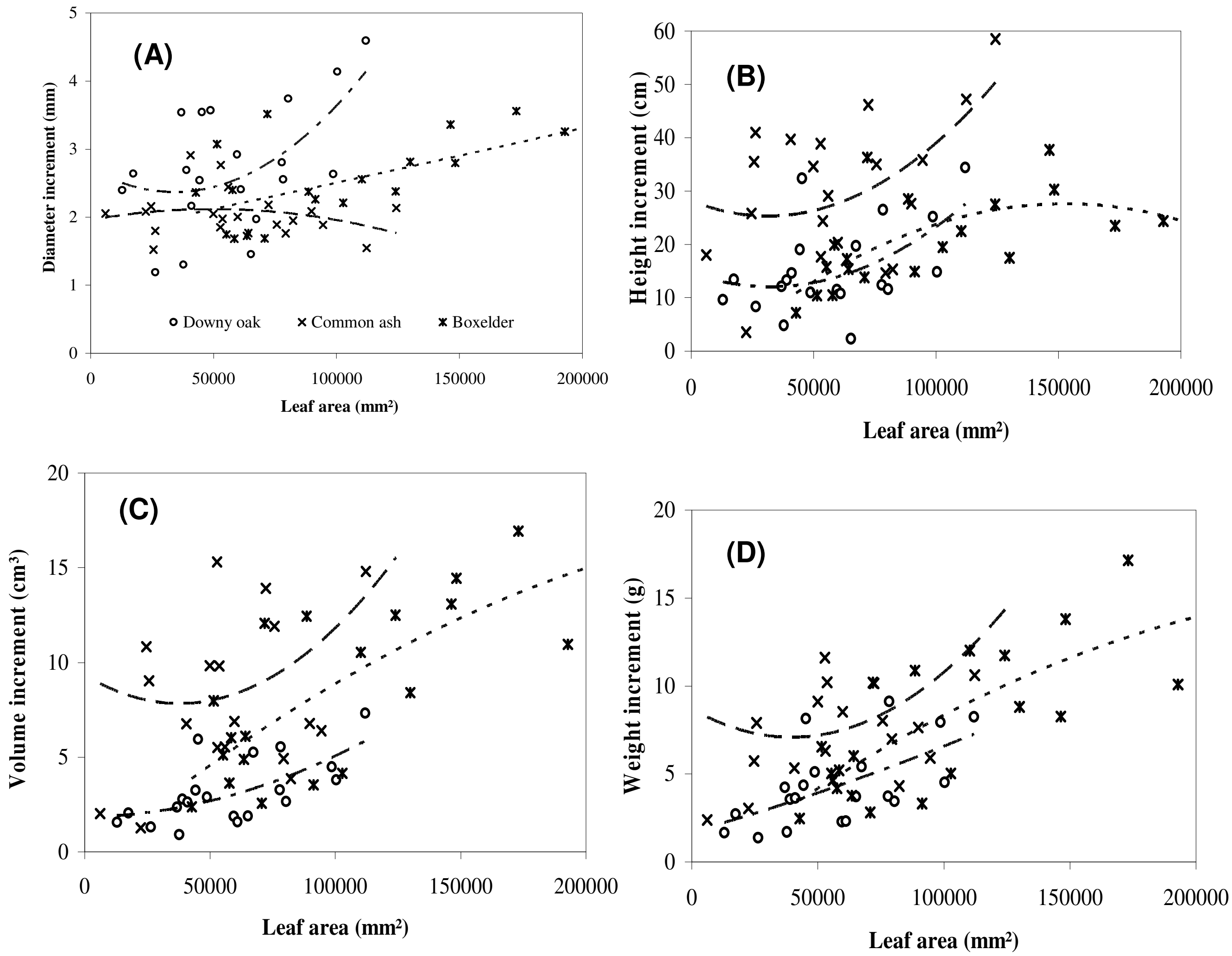

Figure 1. Leaf area versus diameter increment (A), height increment (B), volume increment (C) and weight increment (D) relationships.

The relationship between leaf area per m² and diameter increment, height increment, volume increment and weight increment

The relationship between leaf surface area (leaf area per m^2) and diameter increment, height increment, volume increment and weight increment is given at Figure 2. The results of ANOVA and Tukey's test, which are realized in order to examine the statistical importance of the aforementioned visual relationship, are shown at Table 3.

If Table 3 and Figures 1-2 are considered together, it is bserved that there is no significant statistical difference at diameter increment between B and DO, and between DO and CA but there is a significant difference (p <

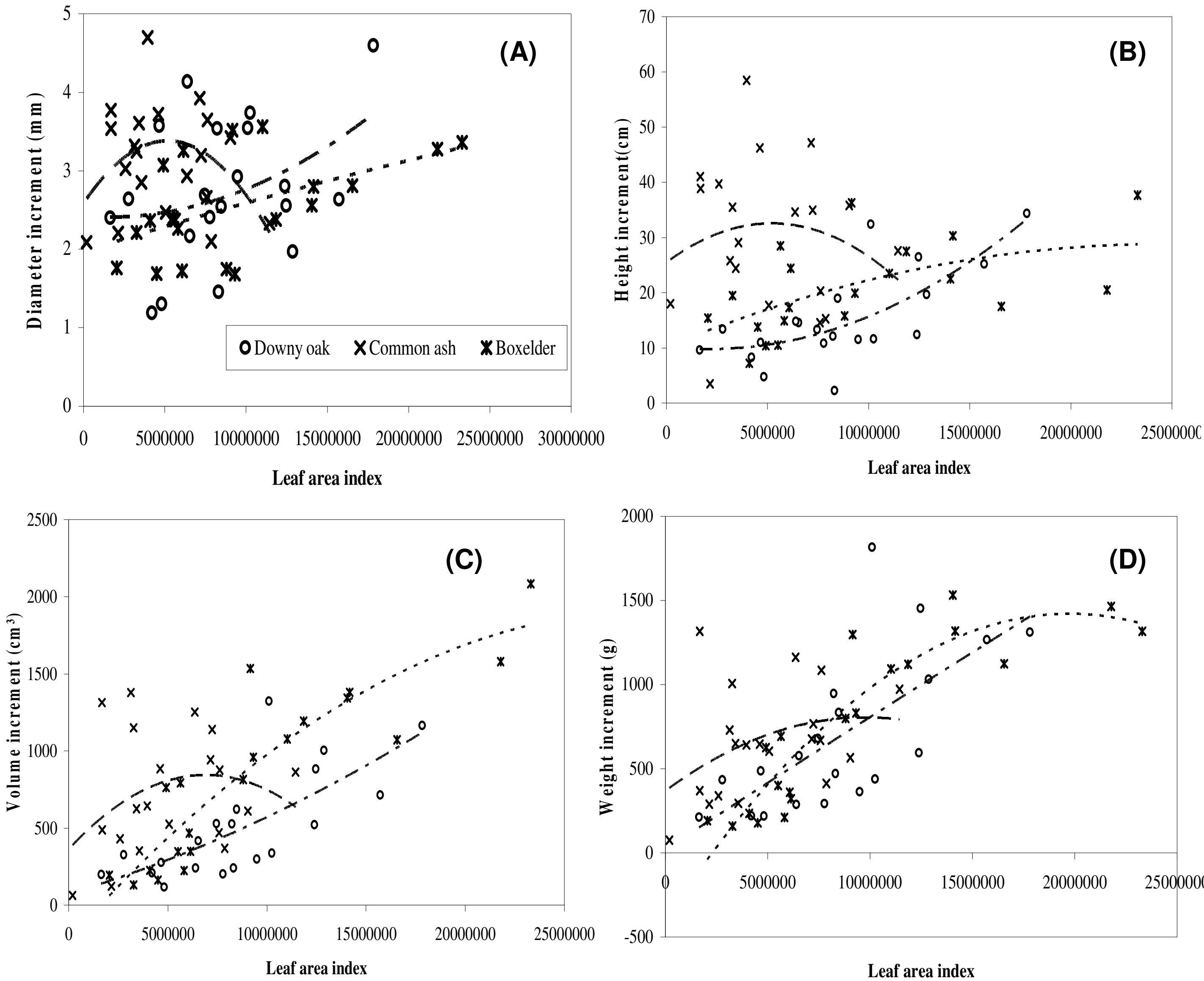

Figure 2. Leaf area index versus diameter increment (A), height increment (B), volume increment (C) and weight increment (D) relationships.

Table 3. ANOVA and Tukey's test result for volume parameters of individual seedling and seedlings in per unit area (m^2) according to species.

Species	Light demanding	Leaf area (m^2)	Leaf area index (m^2/m^2)	Diameter increment (mm)	Height increment (cm)	Volume increment (cm^3)		Weight increment (g)	
						Individual	1m²	Individual	1m²
Boxelder	Semi shade	0.104	9.40	2.54(ab)	20.67(b)	8.71(b)	835(d)	8.13(c)	764(c)
Common ash	Semi light	0.060	4.98	3.14(c)	30.44(c)	9.31(b)	725(cd)	8.46(c)	664(bc)
Downy oak	Light	0.058	8.62	2.74(bc)	15.39(b)	3.17(a)	508(bc)	4.36(b)	697(c)
F- Ratio				9.004***	36.206***	35.111***	15.129**	31.715***	8.367*

* p<0.1; ** p<0.01; and *** p<0.001.

Table 4. Variation in volume and volume parameters in individual seedling and seedlings in per unit area (m^2) according to species, leaf area and leaf area index.

Species	Wet Leaf Weight (g)		Leaf Area (m^2)	Leaf Area Index (m^2/m)	Diameter Increment (mm)	Height Increment (cm)	Volume Increment (cm^3)		Weight Increment (g)		Ratios of volume and weight increment according to leaf area		Ratios of volume and weight increment according to leaf area index	
	Individual	m^2					Individual	$1m^2$	Individual	$1m^2$	cm^3/mm^2	g/mm^2	cm^3/m	g/m^2
Boxelder	9.0	832	0.104	9.40	2.54	20.67	8.71	835	8.13	764	83.8	78.2	88.8	81.3
Common ash	4.7	390	0.060	4.98	3.14	30.44	9.31	725	8.46	664	155.2	141.0	145.6	133.3
Downy oak	4.3	654	0.058	8.62	2.74	15.39	3.17	508	4.36	697	54.7	75.2	58.9	80.9

0.001) between species. The highest diameter increment is done by CA and DO.

There is also a significant statistical difference ($p < 0.001$) with regard to height increment. The highest height increment is done by CA. Even though there is not a significant difference between B and DO with regard to height increment, there are significant differences between B and CA and CA and DO. In the aspect of individual and volume increment on a 1 m^2 leaf surface, there are significant statistical differences ($p < 0.001$ and $p < 0.01$) between species. With regard to volume increment on an individual leaf surface, although there is no significant difference between B and CA, there are significant differences between B and DO and between CA and DO. There are no significant statistical differences between B and CA and between CA and DO with regard to volume increment per m^2 leaf surface. On the other hand, there is a difference between B and DO, where the former is a semi-shade tolerant tree and latter is a light demanding tree. B and CA have the highest volume increment per m^2 leaf surface as an individual, respectively.

Although there are statistical differences ($p < 0.001$) in point of weight increment on an individual's leaf surface, there is no significant difference with regard to weight increment on 1 m^2 leaf surface between the species. With regard to weight increment on leaf surface, although there is no significant difference between B and CA, there are significant differences between B and DO and between CA and DO. CA and B have the highest weight increment.

When seedling species are ordered according to their light requirements, the differences of volume and volume parameters of an individual and per m^2 with respect to leaf area and leaf area index is given at Table 4.

According to Saatcioglu (1969), when tree species are evaluated depending on their light requirements, B which is a semi-shade tolerant tree, has the highest wet leaf weight for an individual seedling. This species is followed by CA, a semi-light demanding tree and DO, a light demanding tree, respectively. Same characteristic per m^2 is maximum level at B which requires semi-shade tolerant. This species is followed by DO, a light demanding tree and CA, a semi-light demanding tree, respectively. Leaf surface area and leaf area index is higher for semi-shade tolerant tree, B, than light and semi-light demanding trees (DO, CA).

Diameter increment at light and semi-light demanding trees (DO, CA) is more than semi-shade tolerant (B). With regard to height increment, the semi-light demanding tree CA has the highest value, while it is followed by semi-shade tolerant tree B and light demanding tree DO has the minimum value. Semi-light demanding tree CA has the maximum values for volume and weight increment at an individual; where semi-shade tolerant tree CA has the maximum values for volume and weight increment per m^2. In points of volume and weight increment with respect to leaf area and leaf area index, semi-light demanding tree CA has the maximum values and it is followed by semi-shade tolerant tree B and light demanding tree DO (Table 4). The leaves of shade tolerant trees are darker, larger and thinner; number of stomas is less. On the other hand, the chlorophyll amount and concentration of minerals are higher. Thus, it can realize photosynthesis with less light, but the production amount is less (Daniel et al., 1979; Kelty et al., 1992; Kent and Coker, 1992).

There are many studies on ability of shade resistance of trees with respect to their leaf area index (Givinish, 1988; Parker and Long, 1989; Ashton and Berlyn, 1992, 1994). According to these studies, the leaf area index of light and semi-light demanding trees, which have low resistance ability against shade is high; while leaf area index of semi-shade tolerant trees, which have more resistance ability against shade, is low (Mueller-Dombois and Ellenberg, 1974). According to this study, leaf area indexes of light and semi-light demanding trees (DO, CA) are 8.62 and 4.98, respectively; while the leaf area index of B, which is a semi-shade tolerant tree is measured higher (9.40) than the aforementioned species.

This contradiction is thought to have arisen from the little ages of the seedlings. At the same studies, leaf area is stated to be little for light and semi-light demanding trees, while is to be high for shade and semi-shade tolerant trees (Jackson, 1967; Carpenter and Smith, 1975; Boardman, 1977). Data obtained from this study supports this situa-tion.

Conclusions

Considering obtained data from this study of effects of leaf area and leaf area index on diameter, height, volume and weight increments of seedlings for boxelder (B), common ash (CA) and downy oak (DO), which have different light requirements, we reached the following conclusions:

i) Considering the effects of (1 g) leaf area on volume parameters, the semi-light demanding tree CA has the maximum volume, volume increment, stem weight, weight and height increment values. A semi-shade tolerant tree, B has the maximum diameter increment value.
ii) Considering the effects of (1 mm^2) leaf area on volume parameters for aforementioned species, being a semi-shade tolerant tree, B has the maximum leaf weight; while being a semi-light demanding tree, CA has the maximum values of 1^{st} age height and diameter, body weight, diameter, weight and height increments.
iii) Considering statistically the relationship between leaf area indexes and diameter increment of the species, although there is no significant difference between semi-shade tolerant tree B and light demanding tree DO, and between DO and semi-light demanding tree CA, there is a significant difference between CA and B.
iv) Considering the relationship between leaf area indexes and height increment of the species, there are significant statistical differences between semi-shade tolerant tree B and semi-light demanding tree CA and between CA and light demanding tree DO.

There is no significant difference between B and CA with regard to volume increment on an individual seedling's leaf area. On the other hand, there are significant differences between B and DO and between CA and DO. The considered parameter is higher for semi-shade tolerant trees when semi-shade tolerant and light demanding trees are compared and it is higher for semi-light demanding trees when semi-light and light demanding trees are compared with each other.

Leaf area (1 m^2) is most effective on volume increment for B. When the species compared, the significant differences are determined between semi-shade tolerant (B) and light demanding (DO) trees.

Even though there is no significant statistical difference with regard to weight increment on an individual's leaf area between semi-shade tolerant (B) and semi-light demanding (CA) trees, there is a significant difference in favor of B between semi-shade tolerant and light demanding trees. Although 1 m^2 leaf area is most effective on volume increment for B, no significant difference between the species is realized.

The volume efficiency of trees proportionally increases with the leaf amount they have. But this increase does not continue forever. After a certain amount of leaf, there is no increase as the light increases. This is because the leaves cover each other with increasing number. The age of the tree affects the relationship between leaf area and wood efficiency (Firat, 1972; Mueller-Dombois and Ellenberg, 1974; Smith et al., 1997). At young ages, the increment amount of the tree is directly proportional with leaf area. At later ages, this relationship survives more strongly for shade tolerant trees than light demanding trees, that is, the positive relationship between leaf area and increment amount is more continuous for shade tolerant trees. This relationship gets weaker with more obvious light demanding tree characteristics. It is known that this situation emerges because the aging tree produces a larger canopy, thus the leaves cover each other and shade trees make better use of weak light (Jackson, 1967; Kalipsiz, 1998; Saracoglu, 2002). Moreover, leaf area and wood efficiency relations differ for dominant trees and overtopped trees (Oliver and Larson, 1996). It will be possible to calculate the tree number per m^2 by the means of relations between leaf area and leaf area index and production power, which are obtained by this study, in order to gain the highest efficiency in afforestation with B, DO and CA trees in this region.

As a result, the efficiency of a forest stand varies with the growing and increment capacity of tree species, the conditions and relations of the habitat, growing and tending methods that are applied. For obtaining the highest efficiency, the situation of leaves, which provides the real growth in the trees, should be examined through the smallest details. It is aimed to contribute to forestry of Turkey by determining the effects of leaf area and leaf area index on volume parameters of boxelder, common ash and downy oak, which are used widely in afforestation studies.

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