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Full Length Research Paper

The effect of snow weight on trees bending at the edge of the Hyrcanian forest roads

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This study was conducted to investigate the relation among the bending of trees caused by snow weight in coniferous and broadleaved species using the Height of tree: Diameter of breast height (H: D) ratio and crown projection area (CPA). For this purpose, the diameter, height and the bending angle of trees as well as the CPA in plots were respectively measured using caliper, clinometer and laser rangefinder. Results in broadleaved species showed that the CPA had more effects than that of H: D ratio, but in coniferous species the H: D ratio had more effects on bending of trees. We found significant linear relationship with equation of $Y=1.827x^{0.66}$ among CPA and the rate of trees bending (R^2= 0.6). Also there was significant difference between trees bending in different classes of H: D ratio (P<0.05, for broadleaved species), and we found significant linear relationship with equation of $Y = 191.4x^2 – 122.9x + 30.44$ among H:D ratio and the rate of trees bending (R^2 = 0.7). There was significant difference between trees bending in different classes of CPA (P<0.05, coniferous species). The branches angle in most of the broadleaved species is irregular, so this status causes collection of uneven snow on crown of trees. It is most important especially at the edge of forest roads, because the trees bending and breaking is dangerous financially and health-wise. So, a deciduous species with deep root system must be selected for planting at the edge of forest roads.

Key words: Bending of trunks, broadleaved species, crown projection area (CPA), coniferous species, breast height (H: D) ratio, snow.

INTRODUCTION

Maintaining roadsides for safety and aesthetics is an important issue for all levels of government throughout Iran. A well-constructed and maintained forest road enables owners' access to their properties for harvesting operations, reforestation projects, timber-stand improvement activities, fire protection and suppression, recreation opportunities, search and rescue (Demir et al., 2009; Gumus, 2009; Ozturk et al., 2009; Hosseini et al., 2011). Vegetation is one important element of roadside maintenance. Roadway safety cannot be achieved without a good maintenance program. Trees close to the road can present a hazard (Wolshon, 2004; Wolf and Bratton, 2006). A healthy roadside environment reduces maintenance needs and costs, provides safety for vehicles and travelers, limits liability for the governing agency, maintains good public relations, improves the overall driving experience and provides habitat for wildlife populations (Ronald et al., 2008).

Heavy snow, freezing rain and ice can mean bowed and broken tree limbs and trunks. Some trees break under the recent heavy snow-loads, but for some only bending or bowing is common on young deciduous trees, as well as on certain types of evergreens trees and shrubs. The wood in these plants is more elastic, with wood bending instead of breaking. In these cases, it was merely a factor of the snow and ice and the branches yielding to the weight. In some instances the tops of trees bent and touched the ground (Parish et al., 2008). It appears that this causes most disruption to traffic rather than either parts of trees actually fracturing and shedding material, or trees toppling. This bending of trees therefore causes transport problems (Ronald et al., 2008).

Lang et al. (2010) reported that ground slope and soil type have significant effect on bend rate of trees. Phototropism and geotropism are the most important

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factors influencing on bend of trees crown on forest slopes. Moreover, Zhu et al. (2006) in north east of China investigated the effects of site on damage rate of snow and wind to trees and then described that topography, slope and soil depth have significant effects on damage rate to trees. A measure of slenderness is the height of tree: Diameter of breast height (H: D) ratio. An H: D ratio is the quotient quantifying a unit of height per unit of diameter. These ratios have been used to determine when trees are susceptible to snow and wind damage (Ferguson et al., 2011). Wonn and O'Hara (2001) found that four northern Rocky Mountain conifer species (including ponderosa pine) were more prone to stem bending and breakage when H/D ratios were 80:1 (ft: ft) or higher.

Crown size and canopy cover has an important effect on the rate of trees bending. The crown projection area can be estimated from stem dimensions (Dubrasich et al., 1997), but has to be thoroughly parameterized for specific stand conditions (Gilmore, 2001), which in most cases involves again a large number of direct measurements. Finally, canopy cover cannot be assumed to be the sum of tree crown projection areas, because overlapping is a common phenomenon particularly in dense, uneven-aged, and mixed stands. Akio and Nakatani (2000) in Japan indicated the relationships among bending angle of trees trunk, crow area variation and H: D coefficient. The resistance of tree to the snow damage tended to increase with increasing stem diameter and age and decreasing tree height. The resistance of a single tree to snow damage increased immediately after heavier pruning and increased with the rise in tree height or age for similar removal ratio of foliage. Teste and Lieffers (2011) in Canada examined the bending and breakage of trees in relation to thinning and fertilization and used a multimodel information-theoretic approach to model stand and tree level predictors of snow damage. Fertilized stands suffered the greatest amount of snow damage, and this was most noteworthy when stands were also thinned; here 22% (17% broken stems) of trees were damaged compared to 8% (4% broken stems) in the thinned and unfertilized stands. It was also stated that snow damage is an important agent for self-thinning in unthinned stands and fertilization tends to exacerbate damage because of increase in foliage size.

This study was conducted to investigate the relation among the bending of trees caused by snow weight in coniferous and broadleaved species using H: D ratio and crown projection area.

MATERIALS AND METHODS

Description of the study area

Hyrcanian vegetation zone is a green belt stretching over the northern slopes of Alborz mountain ranges andcovers the southern coasts of the Caspian Sea. The average annual rainfall ranges between 530 mm in the east and 1350 mm in the west reaching up to an occasional record of 2000 mm in the west. Based on the climatic data from meteorological stations, the maximum annual rainfall is experienced during spring and late fall and winter. The warmest month temperature ranges between 28 to 35°C while that of the coldest month is between 1.5 to 4°C. In general, large areas of these forests are located on steep to very steep slopes with an average altitude greater than 1000 m above sea level, with snow cover in the winter.

The study was conducted in Sonbolrood forest (Figure 1). The site is located in southeastern edge of the city of Savadkooh in Mazandaran province. In order to provide beautiful landscape at the edge of the studied forest roads, the stands of *Cupressus sempervirens* var. horizontalis and Alder was separately planted at the edge of the forest roads. In this region the snows usually starts from the end of the autumn and continue to the end of the winter. Tree species in this region are often deciduous and do not have leaves in winter. Sometimes the early frost in autumn and snow causes sever damage to stands at the edge of road. So, this research was conducted in a period of early cold in autumn (October 2011) when the deciduous trees have canopy cover.

Data collection

The coniferous and broadleaved forest stands were selected separately to investigate the effects of the weight of snow on bending rate of trunk. The first inventory was conducted in late summer season and before the snow falling. The eight plots were selected for coniferous forests (C sempervirens var. horizontalis) and eight plots for broadleaved forests (Alder). The Alder and C sempervirens var. horizontalis species are of important species which are usually found as natural or planted stands along forest roads in Iran. The plots are in shape of rectangular (20 × 50) with distances of 250 m from each other (for two kilometers parallel to forest road). The diameter, height and the bending angle of tree as well as the crown projection area in plots were respectively measured using caliper, clinometer and laser rangefinder.

According to Figure 2, the bending angle of trees was calculated and then the maximum and minimum radius of crown was measured by laser rangefinder to achieve the canopy cover area. The crown projection area was estimated using mathematical formula. In second inventory (after 20 cm snow falling in autumn) the bending angle of tree was calculated for marked trees using laser rangefinder. The data was inserted into Excel software and then the H: D, crown area and bending angle of tree was calculated.

For inventory, in average 11 trees were selected in each plot (Totally 176 trees). Trees selection was carried out on slopes less than 15% to reduce the effects of slope direction and slope gradient. The region is mountainous but the plots of road margin are located in gentle slopes (2 km selected). In addition, it was attempted to calculate the correct coefficient of H:D using the formula of the slope correction of trees height (the first inventory in summer). The soil depth was equal, because all selected plots were located near to each other. Besides, the applied method in this study to measure the rate of bend is based on variation in measured angles for marked trees in two seasons. Therefore, the variation in trees crown expansion (because of the similarity in produced angles), trees height (because of applying H:D coefficient), soil depth and slope of region (because of marking and the selection type of trees) was not significant on average of values in achieved results.

Data analysis

Completely randomized block (CRB) design was used as for the

Figure 1. Bending of trees at the edge of the Sonbolrood forest roads of Iran.

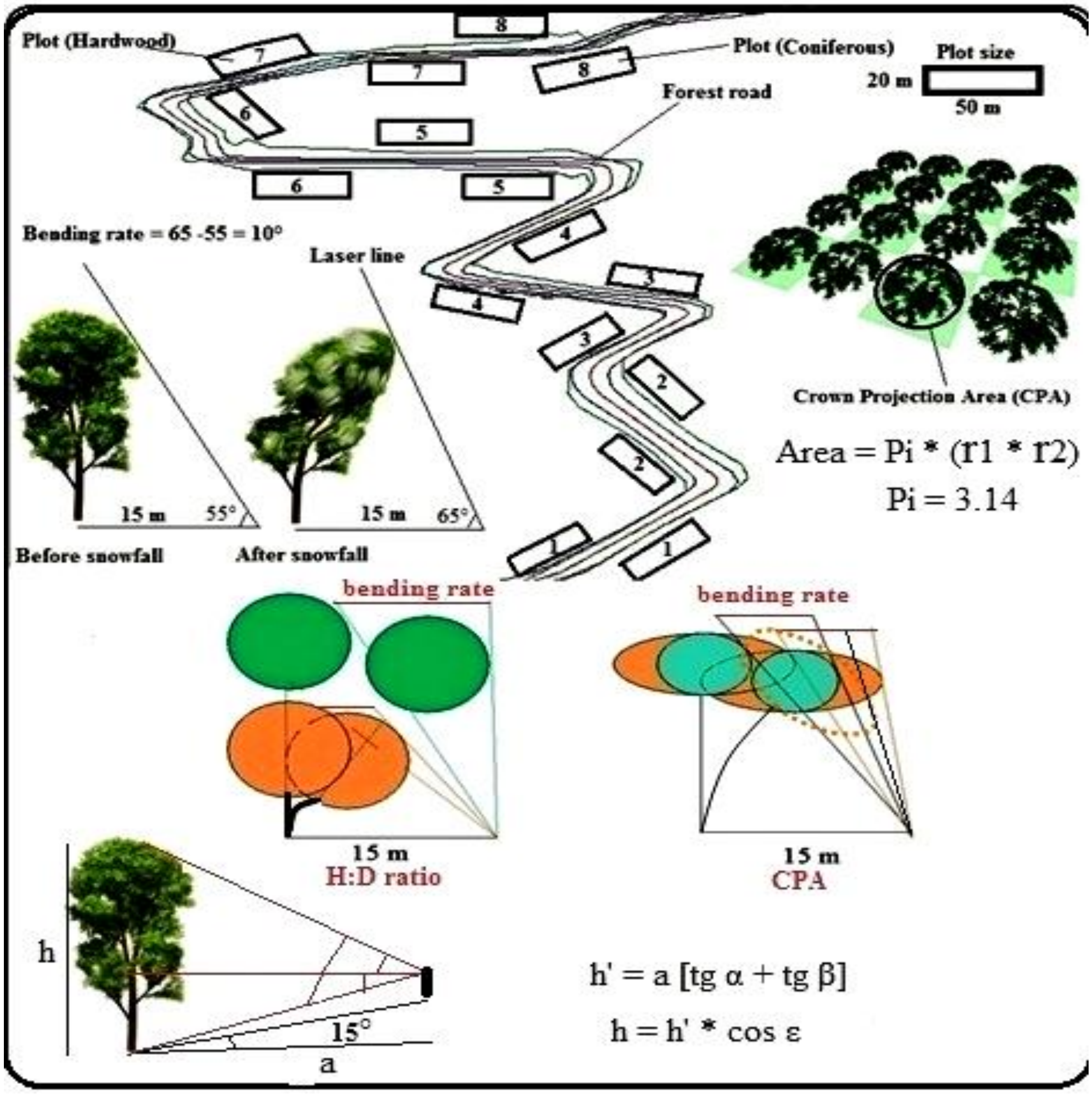

Figure 2. Measurement method of bending of trees at the edge of forest road.

analysis of the experiments in this study and the data were analyzed using SPSS (Sciences Statistical Package for the Social)computer program. The block was selected based on distribution of H:D ratio. The effects of H:D ratio and CPA on the rate of bending of trees were investigated using univariate linear regression along with Tukey`s HSD mean comparison test. In order to statistical analysis, the collected data were classified as blocks. The reason of difference in classifying blocks for broadleaved and coniferous species are the high variation in crown expansion and coefficient of H:D.

RESULTS

Effect of H: D ratio and CPA on the rate of trees bending

A significant linear relationship was found between H:D ratio and the rate of trees bending ($R^2 = 0.45$) (Figure 3). Also, there was a significant difference between trees bending in different classes of H:D ratio (P<0.05). The rate of trees bending increased with increasing CPA. We found significant linear relationship with equation of $Y = 1.827x^{0.66}$ among CPA and the rate of trees bending ($R^2=0.6$) (Figure 3). According to Tables 1 and 2 of means comparison in broadleaved species, the CPA had more effects than that of H: D ratio.

The rate of trees bending increased with increasing CPA (Figure 3). We found significant linear relationship with equation of $Y = 191.4x^2 – 122.9x + 30.44$ among H:D ratio and the rate of trees bending ($R^2 = 0.7$) (Figure 3). There was significant difference between trees bending in different classes of CPA (P< 0.05) (Table 4).

The CPA by the crown of coniferous species was less

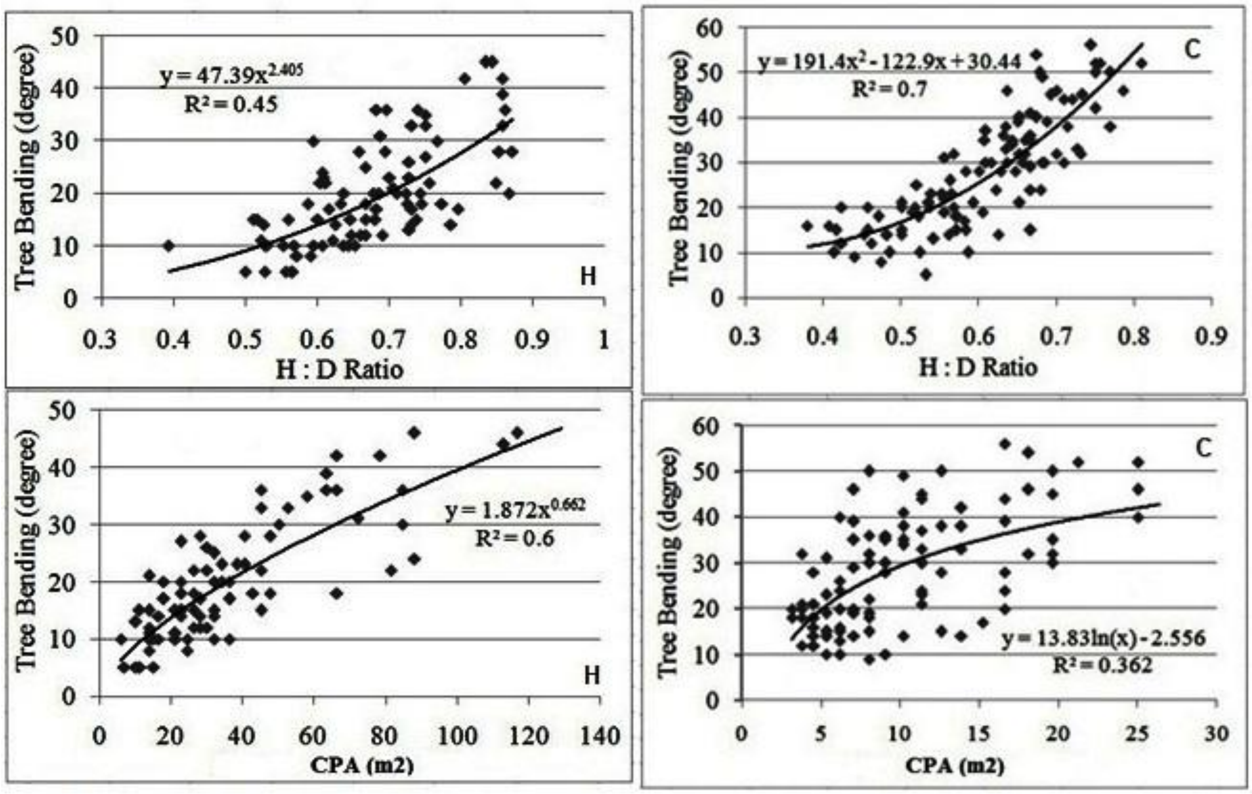

Figure 3. Relationship between H:D ratio, CPA and the rate of tree bending; (H) = Hardwood species (C) = coniferous species.

Table 1. Statistical test for H:D ratio impact on the rate of tree bending (Hardwood species).

Treatment	4 - 6	6 - 8	X > 8
Trunks bending	12.7^{c}	21.6^{b}	32.4^{a}*

*Significantly different at 0.05 probability level.

Table 2. Statistical test for CPA impact on the rate of tree bending (Hardwood species).

Treatment	0 - 30	30 - 60	X > 60
Trunks bending	14.4^{c}	22.7^{b}	35^{a}*

*Significantly different at 0.05 probability level.

Table 3. Statistical test for H:D Ratio impact on the rate of tree bending (coniferous species).

Treatment	3 - 5	5 - 7	X > 7
Trees bending	13.5^{c}	28^{b}	43^{a}*

*Significantly different at 0.05 probability level.

than that of the crown of broadleaved species. In these species, the H: D ratio had more effects on bending of trees (Tables 3 and 4).

DISCUSSION

The shape of tree stem is dependent to species type and

Table 4. Statistical test for CPA impact on the rate of tree bending (coniferous species).

Treatment	0 - 10	10 - 20	20 - 30
Trees bending	21.5 [c]	34.2 [b]	40.9 [a]*

*Significantly different at 0.05 probability level.

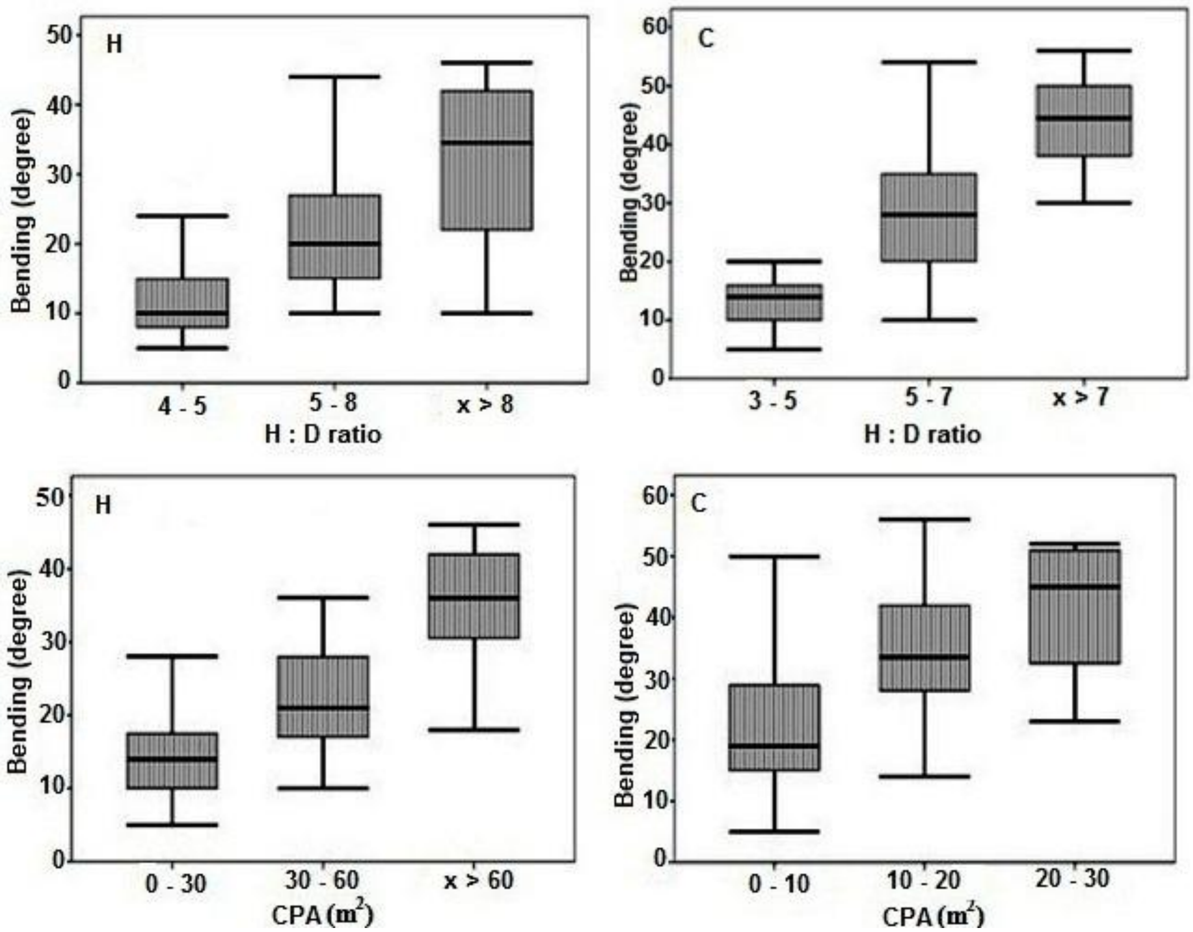

Figure 4. Comparision of bending of trees in different classes of H:D ratio and CPA; (H) = Hardwood; (C) = Coniferous.

environmental factors. The stem in the crown of broadleaved species do not have a specific shape and it lost its shape (Mohajer, 2007). The shape of stem in coniferous species is often incomplete cone (Zobeiry, 2006). When snow or ice bend branches and entire trees out of shape, the offending snow or ice should be removed immediately and an attempt made to straighten the bent branch or trunk. If the plant part is not straightened very soon after the snow has stopped, the plant may remain bent permanently. Birch (*Betula pendula*), for example, is considered vulnerable to snow and wind damage. Similarly, the Hornbeam (*Carpinus betolus* L.), a tree notorious for splitting during wind storms is also vulnerable. Other trees that may bend or break during winter include *Chinese elms*, *Picea abies*, *poplars* and *Alders*. *Alnus subcordata*, *Caucasian alder*, is a species in the family Betulaceae, native to temperate areas of Iran and the Caucasus. It is a deciduous tree growing to 15 to 25 m tall, closely related to the Italian Alder (*A. cordata*), with similar glossy green cordate leaves 5 to 15 cm long. Alder tree is a stabilizer of nitrogen and often appear in the edge of the Hyrcanian forest road after construction (Parsakhoo et al., 2009; Jalilvand et al., 2010). Smaller trees, such as *Juniperus communis* and *Juniperus sabina* are considered resistant to winter damage. The *C. sempervirens* var. *horizontalis* is also a good example of a tree with a weak structure due to branch angles (Zare, 2001). *C. sempervirens* var.

horizontalis is one of the coniferous species which is planted at the margin of Iranian forest roads. It is a resistant species. The roots of this species are deep and powerful, so it can increase the stability of tree in boulders and steep slopes. In moist soils with deep layers of humus, the roots expand in surface layers. Thus, the dense crown of tree is limbered and then fallen under the snowy days (Zare, 2001). In 2009, a large number of Cupressus trees in herbarium of the faculty of natural resources (Sari) were fallen under a severe wind blow (approximately 80 km per hour).

If the factor of trees height is used to measure bend rate, the results would not be correct. So, the best criterion to measure the bend of trees with different heights is H:D coefficient. With consideration of this coefficient, the high level of bend angle variations was observed for trees with lower diameter and more height and the low level of bend angle variations was observed for trees with more diameter and lower height. Thus, height of tree (without considering diameter) cannot only be applied as independent factor to measure the bend rate of trees caused by snow heaviness, but the area of trees crown (measuring of similar trees in snowy and non-snowy conditions) can be used as criteria to compare trees resistance against bend. Trees crown in also influenced by trees physiology and environmental factors (phototropism and geotropism). Trees with a lower center of gravity are less likely to break than those with a higher center of gravity (Rottmann, 1985). Reducing the length of certain branches helps create a lower center of gravity on those branches and might help contribute to their survival in windstorms. In addition, reducing the entire crown size would also theoretically reduce damage potential, at least temporarily. The box-and-whisker plot shows a graphic presentation of information on the distribution of data that are examined. The values of inferior and superior percentile (25th and 75th percentile) determine the beginning and the end of the box-and-whisker, which contains the intermediate 50% of prices of data. The horizontal line that cuts the box-and-whisker depicts the median. According to Figure 4, it can be found that the bending rate of trees increased with increasing the H:D ratio. The branches angle in most of the broadleaved species is irregular, and this status results in the collection of uneven snow on crown of trees and uneven distribution of snow on branches bending trunk. In Mazandaran province (Iran), the most snow damage occurs during the cold in early autumn season. At this time, most of the deciduous species have leaves and leaves cause to sit snow on crown. Under this situation the trees may be grubbed. It is most important especially at the edge of forest roads, because the trunk bending and breaking is dangerous financially and health-wise. So, a deciduous species with deep root system must be a selector for planting at the edge of forest roads. According to Figure 4C, the mean of the bending of *Cupressus* species is more than that of alder species. This status has been proved in several countries. It was also proved that there was significant relationship between the wood freezing (caused by cold) and bending rate of trees. Schmidt et al. (2010) in Germany assessed the effects of snow on breaking branches, and their results showed that the resistant of trees decreased with increasing their height.

Moreover, deciduous trees which are without leaves in winter have more resistant. Ice crystals in cells of frozen wood increase the wood's modulus of elasticity so that branches become more rigid at colder temperatures. As temperature increases after a snowstorm, melting of crystals within the cells allows increased bending of branches under intercepted snow loads (Schmidt and Pomeroy, 1990). Sometimes, the collected snow on trees crown is estimated to be 300 to 800 tons per hectare. This pressure is too large that can break the trees branches. Of course the wind blow can also be effective in snow falling from the branches. Most of the young trees are limbered by snow with increasing snow on trees crown. The coniferous species (evergreen species) in winter is severity under danger. The old trees are broken rapidly because of low flexibility and heavy crown. The shape and form of trees crown have significant effects on trees resistant. Usually the crown area in broadleaved species is more than that of crown area in coniferous species because of expansion. Therefore, the weight of snow on canopy cover of coniferous species is less than that of broadleaved species because of small canopy covers in coniferous species. Figure 4 shows that mean coefficient of variation in C. *sempervirens* var. *horizontalis* is more than that of alder species. Moreover, the area of canopy cover has less effect on bending rate as compared to H:D ratio. In alder species the coefficient of variation is low and this species is affected by canopy cover. Most of the broadleaved species in Iran is deciduous and are without leaves in winter season. This increases the Alder trees resistant because of the lack of canopy cover. Thus, Alder can be used at the edge of forest roads without early frost in autumn.

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