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Tree species effects on canopy albedo in temperate forest plantations: comparing conifers and broadleaf trees

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A B S T R A C T

Albedo is the fraction of solar energy reflected from a surface back to the atmosphere; it is controlled by the characteristics of the surface, specially land cover type. Here, we examined the effects of five types of tree species (maple, poplar, chestnut-leaved oak, cypress and alder) in the mono-cultured plantations at Hyrcanian temprature forests (in the north of Iran). The field data were collected during the summer and the winter. Albedo was estimated by an albedometer set-up that was installed on a movable mast in each stand. In this study, two analytical methods were used to estimate the reaction of forest trees to the summer and winter albedo. ANOVA was used to determine the significance difference between tree species considering the summer and winter albedo. TOPSIS technique that is one of the famous classical Multi-Criteria Decision Making (MCDM) methods was employed to prioritize tree species considering the combination of both factors (summer and winter albedo).The analysis of variance indicated that, there was a significant difference among tree species albedo in two seasons ($p< 0.01$). In the summer alder and cypress had the highest and lowest albedo (0.34 and 0.16 respectively) and in the winter chestnut-leaved oak and alder had the highest albedo (0.19) and cypress had the lowest one (0.10). The results of TOPSIS ranking indicated that, the preferred tree species are alder, poplar, chestnut-leaved oak, maple and cypress, respectively. Our findings suggest considering the combination of these factors (summer and winter albedo), plantation with broadleaved trees is the best selection for forest regeneration in the temperate Iranian forests.

1. Introduction

Forests significantly influence local climate by variety factors (Scheidel 2016; Ellison et al. 2017; Naudts et al. 2016) such as evaporation and transpiration (Hesslerová et al. 2013; Maes et al. 2011), carbon sequestration (Bonan 2008), changes in albedo (Amiro et al. 2006; Ellison et al. 2017) , impact on emission of aerosols (Unger et al. 2014) and greenhouse gases emission (Haren et al. 2013). One of the most important climatic factors, is albedo (Lutz and Howarth 2014).

Albedo is the ratio of Earth reflected radiation to incoming solar radiation, and is one of the most important biophysical factors affecting both local and global climates (Bright et al., 2014). It plays an important role in climate by reflection or absorbtion and subsequently it is reradiated as a long-wave radiation by a surface (Burakowski et al. 2015).

More albedo cools the earth surface and the magnitude of cooling depends on a variety of factors including snow depth, cloud cover, solar zenith angle, land cover type, growth conditions and air humidity (Mote 2008; Atlaskina et al. 2015). Land cover albedo is a critical component of the Earth climate system (Hollinger 2010) that changes, considering the characteristics of the vegetation (Lutz and Howarth 2014). Of the main vegetated land surface types is forest that changes the surface albedo (Amiro et al., 2006; Betts and Ball, 1997).

Surface albedo of a forest describes the ratio of reflections from the soil or forest floor to the incident solar radiation (Kuusinen 2014). Considering this factor, forests have an important role in controlling the temperature of the Earth's surface (Hovi et al. 2016). In tropical and temperate regions, albedo is one of the critical variable affecting local climate (Rautiainen et al., 2011; Ellison et al. 2017) and is directly affected by forest management activities such as tree harvesting, plantation, reforestation and natural disturbances (Halim et al., 2019).

Nowadays, forest managers have established large-scale forest systems (Streck 2012; Angelsen and Kanounnikoff 2008) in order to change the local climatic conditions by altering the forest structure and tree species composition (Kuusinen et al. 2016).

Forest structure, tree species composition (Stephens et al. 2015; Kuusinen 2016), canopy structure (Bonan 2008), arrangement, type and size of the trees, the foliage structure of trees (Roberts et al. 2004; Rautiainen and Stenberg 2005; Smolander and Stenberg 2005), seasonal changes (Kuusinen et al. 2014; Nilson et al. 2008; Niemi et al. 2012) and understory vegetation (Kimes et al. 1986) influence forest albedo. These factors should be considered by forest in the reforestation and plantation (Bright et al. 2014; Alkama and Cescatti 2016; Naudts et al. 2016; Hovi et al. 2016).

Previous studies indicated forest albedo was influenced by tree species type, broad-leaved tree species have presented higher albedo than the coniferous trees (Lukeš et al. 2013; Kuusinen et al. 2014; Hollinger et al.

Seasonal variations in vegetation influence the albedo and forest reflectance properties (Kuusinen et al. 2014; Betts and Ball 1997; Nilson et al. 2008; Niemi et al. 2012; Kuusinen et al. 2012). The study of albedo in boreal forests showed different patterns in the winter and the summer. Albedo in the needleleaf trees, with lower seasonal variation was lower than broadleaf trees (Kuusinen et al. 2014). Most of the solar radiation is received during summer, when the coniferous forest albedo is very low because about 90% of the incident solar radiation is absorbed (Lukeš et al. 2013; Hollinger et al. 2010).

Hyrcanian forests in the North of Iran, are the last remnants of natural deciduous forests in the world (Parsapour et al. 2018), with unique richness of biological diversity, endemic species and natural beauty creative genius in the form of this ancient forests (Poorzady and Bakhtiari 2009; Akhani et al. 2010).

Nowadays, natural forest areas have been decreased due to intensive logging and regarding the other part, the necessity for woods had growing trend due to increase within population, consequently plantation with local species for rehabilitating degraded forests is fundamental (Yousefi et al., 2010).

In general, albedo has two distinct effects on the local climate: warming or cooling (Bernier et al. 2011; Schwaiger and Bird 2010), and investigating the interactions between sunlight and the forest canopy albedo is an urgent requirement to monitor the effects of climate change in forest.

Hence, in this study we examined seasonal variation of albedo in two types of forest tree species: broadleaved and needleleaved. It's hypothesized that stands with higher dominance of deciduous broadleaf species would show higher albedo than conifer-dominated stands in the temperate broadleaf forests.

The specific aims of this study are: (i) estimating the albedo in two types of tree species (broadleaf and needleleaf), (ii) determining the effect of seasonal variation (summer and winter) on forest albedo.

2.Materials and methods

A. Site description

This research carried out in Mahdasht and Pahnekola district of Mazandaran Province, northern Iran (36°,30′,00″N, 53°,00′,00″E (Mahdasht); 36°,07′,20″ N, 53°,02′,25″ E (PahneKola) Fig. 1). Previously, these areas were dominated by natural forests and native tree species such as chestnut-leaved oak (Quercus castaneifolia C.A.Mey), hornbeam (Carpinus betulus L.), and ironwood tree (Parrotia persica (DC)C.A.Mey). In the 1990s, these forests were partially destroyed because of extensive exploitation carried out by local residents. Consequently, in 1993 these parcels were clear-cut, stumps eradicated, and then afforested in 1994.

The dominant forest types which were planted at a spacing of 3×3m, included maple (Acer velutinum Bioss), poplar (Populus deltoids Barter.ex Marsh), cypress (Cupressus sempervirens var. Horizeotalis), chestnut-leaved oak (Quercus castaneifolia C.A.Mey) and alder (Alnus glutinosa (L.) Gaertn)(Fig. 1).

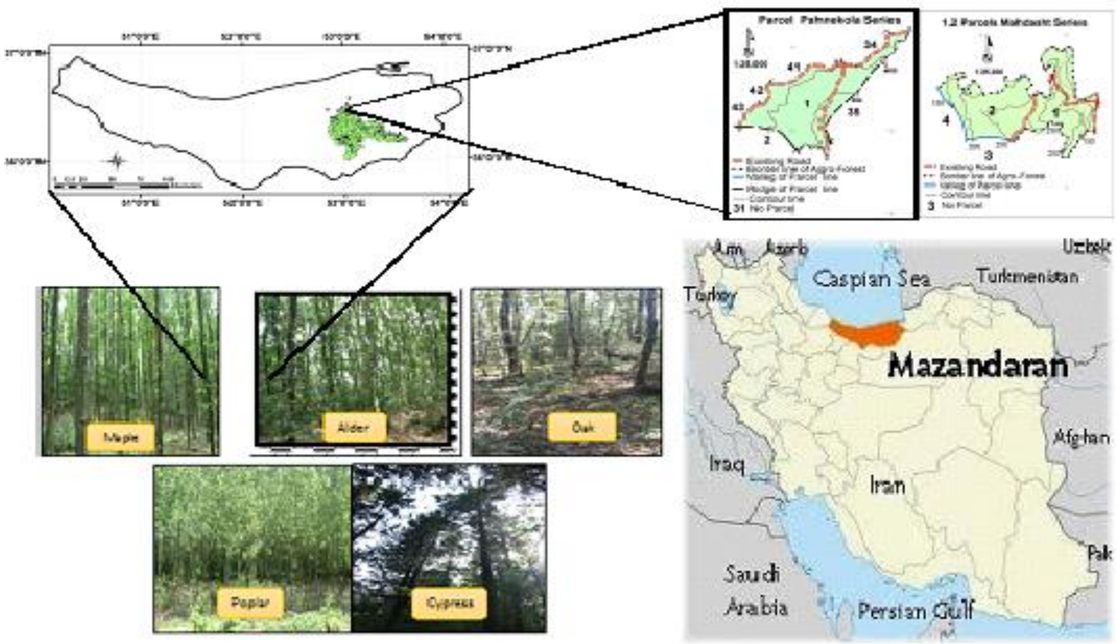

Fig. 1. Location of the study area in the Mazandaran Province, northern Iran (left). Treatments including plantations with maple (*Acer velutinum* Bioss), poplar (*Populus deltoids* Barter.ex Marsh), cypress (*Cupressus sempervirens* var. Horizontalis), chestnut-leaved oak (*Quercus castaneifolia* C.A.Mey) and alder (*Alnus glutinosa* (L.) Gaertn) (Right).

The study area, located between 230 to 250 m a.s.l., shows very similar physiographic, climatic conditions and management practices. Annual mean rainfall is 923 mm, average daily temperatures vary from 6.4 °C in January to 31 °C in August and mean annual temperature is 16.9 °C (Mahdasht meteorological station) (Fig. 2).

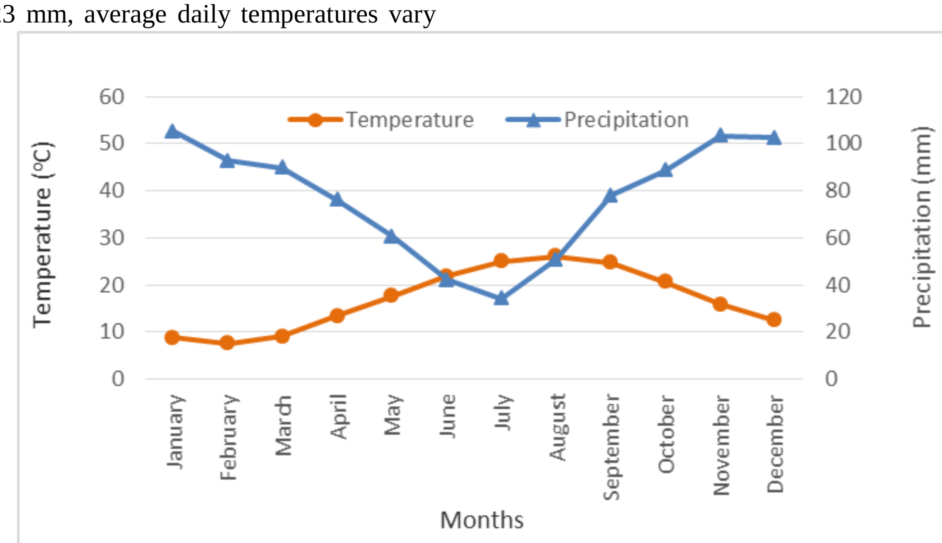

Fig. 2 Mean monthly temperature and precipitation in the study area based on Mahdasht meteorological station

All of the sample plots in each site were on similar slope, elevation and aspect (Northern). Measurements were performed between July and August (In the summer) and December to January (In the winter) (2017-2018). Total tree height, DBH (diameter at breast height), stand density (number of live tree per hectare), crown length and diameter, percentage of living crown and slope & elevation of study sites were measured in each plot (Table.1). These data were taken at 8 plots (20×20 m) per each planted stand.

Table 1. Stand variables average (*Acer velutinum* Bioss, *Populus deltoids* Barter.ex Marsh, *Cupressus sempervirens* var. Horizontalis, *Quercus castaneifolia* C.A.Mey and *Alnus glutinosa* (L.) Gaertn.

Planted forest	Stand density (trees ha^{-1})	Height (m)	DBH (cm)	Crown diameter (m)	Crown length (m)	Canopy cover %	Elevation (m)	Slope (%)	Age (years)
Alder	1465	20	20	5	6.5	85	235	5%	22
Chestnut-leaved oak	1585	17.5	17.7	3.8	5	92	240	5%	22
Maple	1480	20.9	24.2	4.7	6.4	94	235	4%	22
Poplar	1525	21.8	25.6	5	7	82	250	4%	22
Cypress	1470	17.8	19.2	3.8	5.5	70	240	5%	22

DBH = diameter at height (1.3 meter height)

B. In-situ albedo measurements

Field data were collected in each site during early and late summer of 2017,as well as the winter of 2018. Forest albedo was measured from the ground level measurements that measured the direct normal radiation and the Earth reflection using portable albedo-meter. It was the CM-7B, manufactured and calibrated by Kipp & Zonen and measures the albedo in the wavelengths ranging from 300 to 3000 nm (Hollinger et al., 2010; Thiel et al., 2008). The albedo-meter is positioned approximately 2 m above the canopy on the fixed tower in each site. The set-up was installed at 17-22m height into a horizontal area (Fig.3). In this study, in-situ masurement was used to estimate tree species albedo separately by albedometer set-up, because, in situ measurements are accurate and can be directly linked with field-measured forest structure. On the other hand, they are extremely tedious and cannot cover large variations in forest structure. Satellite data provide ample coverage of varying forest structures and wide spatial extent but may compromise spatial resolution and detail in the characterization of forest structure (Hovi et al., 2016).

Fig. 3 Albedometer CM-7B by Kipp & Zonen

Nearly all of the measurement data were taken during full sunny days. The daily albedos were measured 24 hours a day (Eight days in each site). Albedo was

(1)

$$Albedo = \frac{reflected\ light\ (Wm^{-2})}{incident\ light\ (Wm^{-2})}$$

C. Statistical analysis

The normality of the variables was checked by the 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 albedo among the different sites. Duncan test was further employed for grouping of tree species considering one of these factors (Summer or winter albedo) at the P=0.05 level. Two way ANOVA test was used to compare albedo in two seasons of summer and winter. All statistical analyses

calculated from the ratio of daily total reflected (W m-2) to incident solar radiation (W m-2) (Equation. 1) (Kuusinen 2014).

were conducted using the SPSS 24 statistical software package.

In order to prioritize the most appropriate tree species under global warming condition, TOPSIS technique was used (Using the Excel software). The TOPSIS technique (A technique for order performance by similarity to ideal solution) was used to integrate all the research data into a final ranking by considering the results of all factors (Summer and winter albedo). TOPSIS is one of the famous classical Multi-Criteria Decision Making (MCDM) methods, which was initiated for the first time by Hwang and Yoon (1981). The basic concept of this method is that the best selected alternative should simultaneously minimize the distance from an ideal point and maximize the space from a nadir point in a geometrical sense (Olson, 2004). TOPSIS algorithm determines the most preferable choice among all possible choices. The best alternative is the one with the shortest distance to the fuzzy positive ideal solution and with the longest distance to the fuzzy negative ideal solution. There have been some studies in the literature using TOPSIS for the solution of MCDM problems (Olson, 2004; Uzun and Yıldırım, 2016). The TOPSIS procedure is shown in Figure 4 in five main steps (Shyur et al., 2006):

Step 1: Construct normalized decision matrix

$$r_{ij} = x_{ij}/ \sqrt{(x^2_{ij})} \quad \text{for} \quad i = 1, \ldots, m;\ j = 1, \ldots, n \quad (1)$$

where x_{ij} and r_{ij} are original and normalized score of decision matrix , respectively

Step 2: Construct the weighted normalized decision matrix

$$v_{ij} = w_j\, r_{ij} \qquad (2)$$

where w_j is the weight for j criterion

Step 3: Determine the positive ideal and negative ideal solutions.

$$A^* = \{ v_1^*, \ldots, v_n^* \}, \quad (3) \quad \text{Positive ideal solution}$$

where $v_j^* = \{ \max (v_{ij}) \text{ if } j \in J ;\ \min (v_{ij}) \text{ if } j \in J' \}$

$$A' = \{ v_1', \ldots, v_n' \}, \quad (4) \quad \text{Negative ideal solution}$$

where $v' = \{ \min (v_{ij}) \text{ if } j \in J ;\ \max (v_{ij}) \text{ if } j \in J' \}$

Step 4: Calculate the separation measures for each alternative.

The separation from positive ideal alternative is:

$$S_i^* = [\ (v_j^* - v_{ij})^2]^{½} \quad i = 1, \ldots, m (5)$$

Similarly, the separation from the negative ideal alternative is:

$$S'_i = [\ (v_j' - v_{ij})^2]^{½} \quad i = 1, \ldots, m\ (6)$$

Step 5: Calculate the relative closeness to the ideal solution C_i^*

$$C_i^* = S'_i / (S_i^* + S'_i) , \quad (7) \quad 0 \quad Ci^* \quad 1$$

Select the Alternative with C_i^* closest to 1.

Fig. 4. Procedure of TOPSIS method

3.Results

A. Summer albedo

Our data showed that there were significant differences in albedo among different tree species and albedo was affected by various tree species. Daily albedo varied between 0.157 (Cypress) and 0.338 (Alder). Mean albedo was found in ranked order of alder > poplar > maple > chestnut-leaved oak > cypress. Albedo in the alder was higher ($p< 0.01$) than in the other stands. Cypress had the lowest summer albedo (Fig.5). Broadleaved trees had significantly higher albedo than needleleaved tree species. In this study, the amount of albedo in the broadleaved trees was 62–76% higher than that in the coniferous trees.

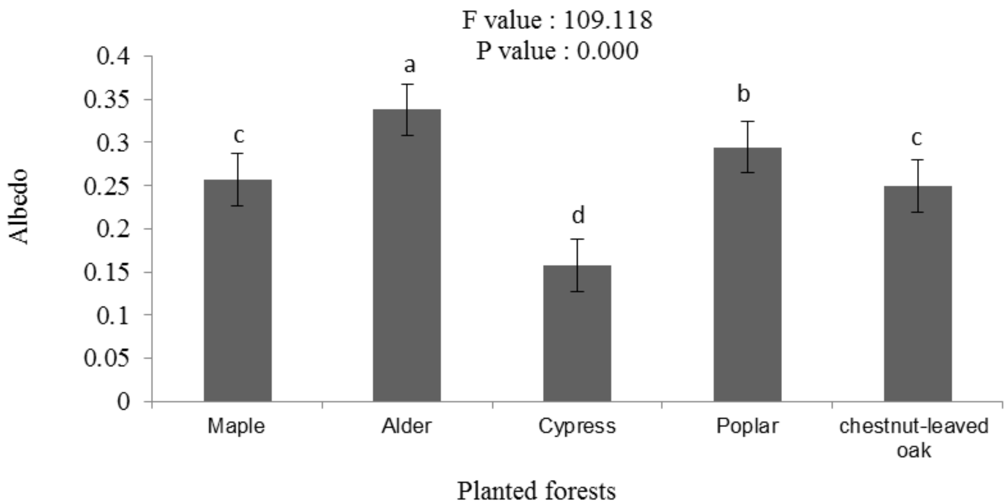

Fig. 5 Mean (±SE; n = 8) of summer albedo in different tree species.The studied trees species were maple (*Acer velutinum* Bioss), poplar (*Populus deltoids* Barter.ex Marsh), cypress (*Cupressus sempervirens* var. Horizontalis), chestnut-leaved oak (*Quercus castaneifolia* C.A.Mey) and alder (*Alnus glutinosa* (L.) Gaertn)

B.Winter albedo

The results indicated that there was significant difference in albedo among different tree species. Mean albedo was found in ranked order of alder≈ chestnut-leaved oak> poplar> maple> cypress. Albedo in the alder and chestnut-leaved oak was significantly higher ($p<0.01$) than other trees. While cypress had the lowest canopy albedo among all tree species in the winter (Fig. 6).In the winter albedo in the broadleaved trees was 42–74% higher than that in the coniferous trees.

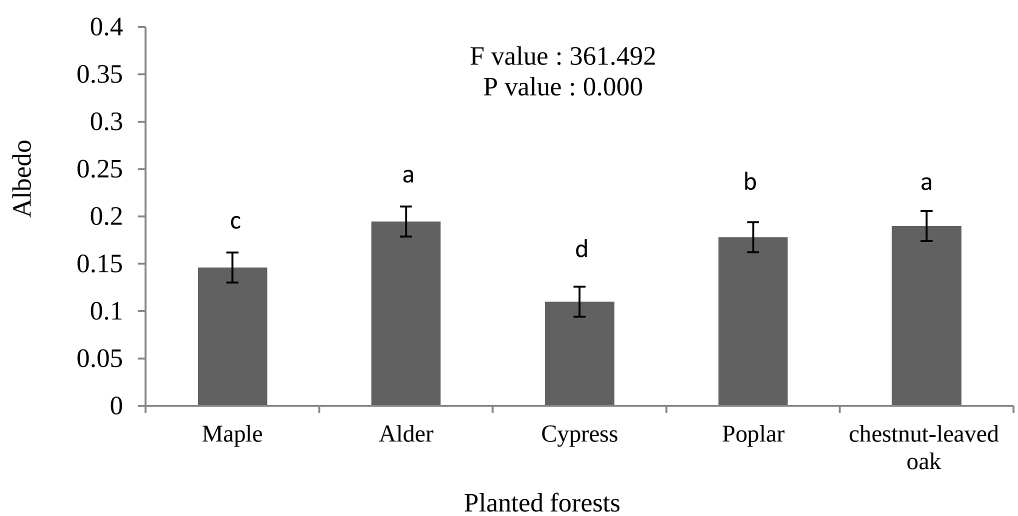

Fig. 6 Mean (±SE; n = 8) of summer albedo in different tree species.The studied trees species were maple (*Acer velutinum* Bioss), poplar (*Populus deltoids* Barter.ex Marsh), cypress (*Cupressus sempervirens* var. Horizontalis), chestnut-leaved oak (*Quercus castaneifolia* C.A.Mey) and alder (*Alnus glutinosa* (L.) Gaertn)

C.Summer and winter albedo

Seasonal variations of albedo indicated that winter albedo in all planted forests was lower than summer albedo (P≤0.05). In the summer and winter, alder in the summer had the highest albedo, and cypress in the winter had the lowest albedo (Fig. 7).

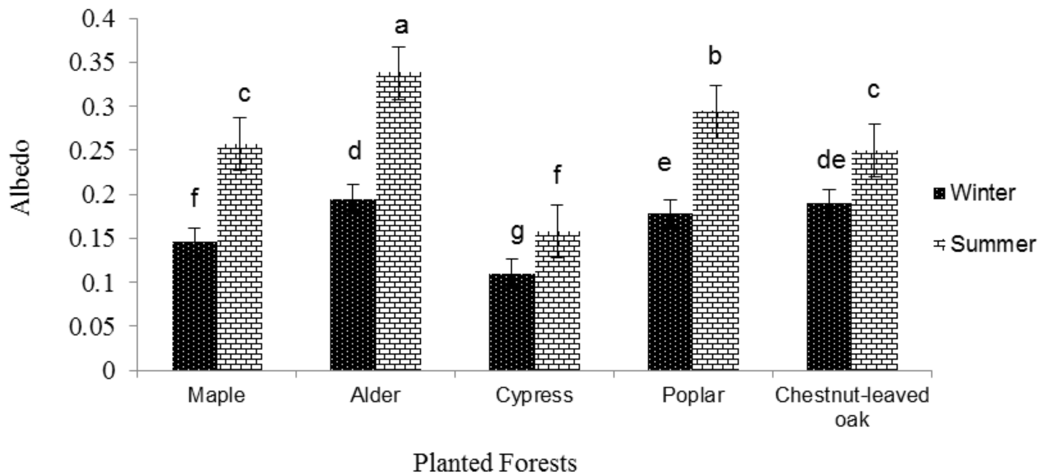

Fig. 7 Mean value of summer and winter albedo in plantation forests. The studied trees species were maple (*Acer velutinum* Bioss), poplar (*Populus deltoids* Barter.ex Marsh), cypress (*Cupressus sempervirens* var. Horizontalis), chestnut-leaved oak (*Quercus castaneifolia* C.A.Mey) and alder (*Alnus glutinosa* (L.) Gaertn)

D. Ranking tree species based on TOPSIS technique

The results of TOPSIS technique are presented in table 2. Alder with the maximum number in TOPSIS ranking, is the first tree species for forest development in this region. Based on the TOPSIS analysis, overall ranking for the preference of species to develop the forested areas are alder, poplar, chestnut-leaved oak, maple and cypress respectively.

Table 2 Ranking of the optimum forest tree species considering the summer and winter albedo in plantation forests (Chestnut-leaved oak, poplar, cypress, maple and alder)

Tree species	Sum of the ideal and nadir alternatives	Ideal alternative (Si+)	Nadir alternative (Si-)	The distances measured using each criterion for both ideal (*Si**) and nadir (*Si-*)	Priority
Alder	0.381106	0.000	0.381106425	1	1
Poplar	0.38157	0.087077448	0.294492515	0.771	2
Chestnut-leaved oak	0.415729	0.150429146	0.2653	0.638	3
Maple	0.383292	0.189116925	0.194175	0.506	4
Cypress	0.381106	0.381106425	0.000	0.000	5

4. Discussion

Forest tree albedo is one of the most factors that influences local climate by exchanging the energy between forest and atmosphere, therefore for helping the environment to face climate change impacts, forest areas should be extended via plantation, afforestation and reforestation in large scale by means the most suitable tree species. These results were presented in the studies such as Ellison et al. 2017; Kuusinen et al. 2016; Scheidel 2016. In our study site, also, to extend forested areas, plantation and reforestation are performed by forest managers.

Albedo mainly changes according to land cover type, tree species composition and canopy structure (Mote 2008; Atlaskina et al. 2015; Bonan 2008; Kuusinen et al. 2014; Lutz and Howarth 2014; Atlaskina et al. 2015; Kuusinen et al. 2016), these results are in agreement with our results that demonstrated tree species type can change the forest albedo.

Differences in reflectance properties among tree species are attributed to different tree species, for example, coniferous needles are often marked by a lower albedo than the leaves of broadleaved trees (Gates 1965; Williams 1991; Roberts et al. 2004; Lukeš et al. 2013). In our study albedo in the cypress was lower than albedo in broadleaved trees, that is reported in previous studies.

Deciduous broadleaved trees may be more effective in decreasing the surface temperature and cooling the the deciduous leaves of these tree species, this result supported the earlier research by Kuusinen et al. (2016). In addition, , the smaller change in summer albedo of broadleaved trees could be explained by the known difference between broadleaved and coniferous foliage: The foliage clumping in broadleaved trees is smaller than in needleleaved trees, where the needles are packed into shoots (Rautiainen and Stenberg 2005).

Many studies indicated that change in forest albedo was larger in winter with snow covering than during the snow-free season (Ni and Woodcock 2000; Amiro et al. 2006; Bright et al. 2012; Lukeš et al. 2013; Kuusinen et al. 2014), but this result was not accordance to our study, because in our study site there was not enough snow cover in the winter, and therefore winter albedo was lower than summer albedo. Considering the importance of forests in modifying the effects of climate change, it is necessary to take systematic steps towards preserving forests. Unfortunately, the area of forests in the world is declining and would be replaced by plantation, local climate than the evergreen conifers (Anderson 2010; Eugster et al. 2000; Breuer et al. 2003; Jackson et al. 2008). Deciduous forests have a higher albedo than coniferous forest depending on the region. In this study, albedo in deciduous plantations was clearly higher than that in the evergreen needleleaved plantation in two seasons. This result is in agreement with Anderson (2010), Eugster et al. (2000), Breuer et al. (2003) and Jackson et al. (2008).

Some authors (e.g. Roberts et al. 2004; Lukeš et al. 2013; Hollinger et al. 2010) reported that the leaves of broadleaved deciduous tree species often have a higher single scattering albedo than the needles of coniferous species, therefor, higher albedo in broadleaved is attributed to higher single scattering.

Albedo varies diurnally and seasonally due to the changing sun angle (Mathews,1984; Kotoda, 1986; Betts and Ball, 1997; Nilson et al. 2008; Niemi et al. 2012; Kuusinen et al. 2012; Kuusinen et al. 2014), seasonal variation in vegetation has been observed to affect forest reflectance or albedo. Our results indicated that winter albedo in all sites was lower than summer albedo. Of course, winter measurements were limited by short periods of sunlight.

Broadleaved trees have shown a smaller change in summer albedo, but they have shown differences between summer and winter albedo. In broadleaved stands, the decline in winter albedo also depended on reforestation and afforestation. Plantation is performed with native tree species which lead to regeneration of the forests. Tree species that are used in plantation can cause a warmer or cooler environment, depending on a number of factors that should be considered under global warming conditions.

The most impotrtant silviculture operations that could have impacts on forest albedo, is improvement of tree species composition by selecting the best tree species for forest development. Forest structure and species composition influence albedo, managing forests to increase albedo is a potential means of maximizing the climate cooling effects of forests (Bright et al., 2014; Alkama and Cescatti, 2016; Naudts et al., 2016). There is an urgent need to understand how forest management practices change forest albedo, and how forest albedo and local climate are interconnected.

Nowadays, under global warming conditions, the strategy of tree species selection, have changed to mitigate the climate change impacts. Our results

demonstrated that considering the albedo, deciduous tree species may offer additional biophysical cooling effects compared to coniferous tree species and inter-species difference in climatic impacts is an important consideration for forest management decisions.
TOPSIS ranking proffers that in this region, coniferous such as cypress should not be used in plantation forests and broadleaf tree species such as alder, poplar, maple and chestnut-leaved oak could be used for developing the forest areas. Significant differences in the albedo among tree stands support the general hypothesis that albedo in broadleaf trees was lower than in the coniferous trees at temperature broadleaf forests.

5. Conclusions

This study demonstrated that forest albedo under similar climate conditions is significantly influenced by tree species, in temperature broadleaf forests. On the other hand, a large part of the albedo variation in the forested landscape can be explained by tree species (conifers or broadleaf trees). Based on the results presented here, the most obvious way in which forest albedo can be controlled by silvicultural options is the choice of the optimal tree species. These findings can help to improve forest management activities, such as selection of tree species in plantation systems. This study is a demonstration of concept in showing that it is possible to estimate forest surface albedo from the ground level measurements. In this study we have measured the vertical albedo profiles of plantation forests canopy. The advantages of in-situ albedometer measurements are the spatially explicit and temporally comprehensive albedo estimates. The findings of this study, suggest that reforestation with suitable native broadleaved trees such as alder have been proposed to rehabilitate degraded natural forests in the North Iran. Our results have important implications for climate-friendly forest management practices. Since the proportion of deciduous broadleaf trees is a strong predictor of albedo, stand-level albedo can be increased by enhancing proportion of deciduous broadleaf species in a stand. It is clear that the influence of tree species on canopy reflectance should be studied further, and forests with variable species compositions at different climatic conditions should be taken into consideration for mitigating the climate change consequences.

Confilict of interest statement

The authors declare no conflict of interest.

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