Caspian J. Env. Sci. 2013, Vol. 11 No.1, pp 141~150

CJES
Caspian Journal of Environmental Sciences

[Research]

Lead and Cadmium Concentrations in Throughfall of *Pinus eldarica* and *Cupressus arizonica* Plantations in a Semi-Arid Polluted Area

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(Received: Aug. 17. 2012. Accepted: Jan. 15. 2013)

ABSTRACT
This research was carried out in order to quantify throughfall (TF) and interception loss (I) and to compare the chemical composition of TF, i.e. lead (Pb) and cadmium (Cd) as well as electrical conductivity (EC) and pH beneath *Pinus eldarica* and *Cupressus arizonica* plantations and the open field rainfall. The research was accomplished in the Chitgar Forest Park, a semi-arid polluted urban area, around Tehran, Iran. Gross rainfall (GR) was measured using ten collectors located in an open field. TF was quantified by randomly manual TF collectors placed beneath each plantation. Measurements were recorded on an event basis from 15 April 2010 to 15 February 2011. During the measurement, eighteen rainfall events with cumulative GR value of 114.8 mm were recorded. Interception loss was 35.3 mm by *P. eldarica* plantation and 30.4 mm by *C. arizonica*. There were strong correlations between I:GR and GR (($r^2_{Pinus} = 0.686$, $r^2_{Cupressus} = 0.766$, p value ≤ 0.01). Pb and Cd concentrations as well as EC of TF were significantly different among *P. eldarica* and *C. arizonica* and the open field. The results demonstrated that interception represents a considerable portion of GR in *P.eldarica* and *C. arizonica* plantations and, therefore, it should be considered while choosing trees for plantations in semiarid climate zones of Iran. Our results showed that *P.eldarica* and *C. arizonica* plantations have good potentials for filtering the polluted air with Pb and Cd.

Keywords: *Throughfall, Cupressus arizonica, Pinus eldarica, Lead, Cadmium*

INTRODUCTION
Partitioning of rainfall into: I. throughfall (TF) which may or may not contact the canopy and which falls to the ground between the various components of the vegetation, II. stemflow (SF): the amount of water flowing to the ground via trunks or stems and III. interception loss that remains on the vegetation and evaporates during or subsequent to a rainfall, after it reaches canopies, constitute the first interaction between water cycle and forest (Crockford & Richardson, 2000). TF, I, and SF are highly influenced by rainfall characteristics, climatic factors, and forest structure characteristics (Staelens et al., 2008; Muzylo et al., 2009). The rainfall characteristics are the size, intensity, and duration of rainfall (Crockford & Richardson, 2000; Xiao et al., 2000; Huber & Iroumé, 2001; Iroumé & Huber, 2002). The most important climatic factors influencing interception loss are wind speed and direction, air temperature and humidity (Crockford & Richardson, 2000), as well as evaporation rate during and after rainfall events (Gash & Morton, 1978; Viville et al., 1993). The forest structure characteristics include species composition (Pypker et al., 2005), stand age, basal area, stand density (Stogsdill et al., 1989), and the canopy characteristics such as leaf area, leaf angle distribution, leaf surface features (Xiao et al., 2000), and branch angle (Huber & Iroumé, 2001). Evaporation of intercepted water has the main role in the water balance, especially during long periods of gentle rain (Gash, 1980).

Before rainfall reaches to the forest floor, its chemical composition may be altered by the surrounding condition and the forest canopy. Therefore, atmosphere plays a key role in global chemical composition cycles and leads to metal dispersion at earth scale (Rauch & Pacyna 2009). Interactions between canopy and rainfall include accumulation of dry deposition, release of elements and direct assimilation by canopy (Lovett & Lindberg, 1984; Balestrini et al., 2007). These chemical inputs interact with the canopy and are then released to the forest floor via the major pathway of TF and a much smaller flux of SF (Douglas et al., 1988). TF is influenced by the type and chemistry of precipitation and by the structure and physiology of trees (Aussenac, 1970; Miller et al., 1976; Kellman, 1979).

The three processes that change TF chemistry are (Parker, 1983): (i) washing, by precipitation, of accumulated deposits on the canopy between events; (ii) leaching of material from internal plant tissues; and (iii) uptake of solute, gases or particles by foliage. Atmospheric deposition depends on several factors, for instance distance to the emission sources, meteorological conditions, e.g. prevailing wind direction, frequency and the amount of precipitation, and structure of forest canopy (Avila & Rodrigo, 2004). Lead (Pb) and cadmium (Cd) spreading in the atmosphere is induced by natural processes (Nriago, 1989) and anthropogenic activity (Pacyna & Pacyna, 2001).

The important source for Cd may be waste incineration and for Pb can be gasoline (Pacyna, 2001). They can be transported to long distances from producing sources (Steinnes & Friedland, 2005) and impact remote ecosystems (Shotyk et al., 1996). Chiwa et al. (2004) showed that TF chemistry in Sitka spruce (*Picea sitchensis*) plantation, in south-central Scotland at Deepske, was changed compared to the open field area. Acidification and chemical enrichment were observed to be extremely significant for stemflow, but only slightly for TF in a Chinese fir (*Cunninghamia lanceolata*) plantation in Fujian, China (Hou Bao et al., 1999). Gandois et al. (2010) showed that Pb concentration increased, but Cd concentration either slightly increased or even decreased in the TF of six plantations (*Picea abies*, *Abies alba*, *Fagus sylvatica*) in France. Plantations can increase the carbon sequestration capacity and combat desertification (Grünzweig et al., 2003), reduce runoff generation and flood hazard (Gholami et al., 2010) and also alleviate air pollution (Zhou et al., 2002). The concentrations of many trace metals in the atmosphere have risen dramatically in and around the industrial cities and may pose a threat to the human health (Cole, 1990).

Elder pine (*Pinus eldarica* Medw.) and Arizona cypress *(Cupressus arizonica* Greene) are major species extensively planted around the polluted cities in Iran. To our knowledge, no research has been reported for the effects of *P. eldarica* and *C. arizonica* plantations on rainfall interception loss and also on the chemical composition of TF in polluted areas of Iran, despite the widespread use of these species in plantation efforts.

The main goals of this study were to measure interception loss of *P. eldarica* and *C. arizonica* plantations in a semi-arid climate zone of Iran, and to compare the chemical composition of the open field rainfall or gross rainfall (GR) and TF, analysing the electrical conductivity (EC), pH, Pb, and Cd concentrations.

MATERIALS AND METHODS

Site description

The study carried out in the almost closed canopies, forty-year-old pure and even-aged *P. eldarica* and *C.arizonica* plantations located in the Chitgar Forest Park of Tehran, Iran (Fig. 1). The species cover 386 ha of the Park and represent 48% of the Park total area. Measurements were made in two sites, circular shapes with 250 m^2 area, of *P. eldarica* and *C. arizonica* plantations (35˚10´ N, 51˚10´ E, and 1269 m asl.). The shapes and density of the trees in the sites were typical of the plantations in the Forest Park. Tree densities of *P. eldarica* and *C. arizonica* were 1185 and 955 trees ha^{-1} and their total basal areas were 63.5 and 58.5 m^2 ha^{-1}, respectively. Mean tree height and diameter at breast height (DBH) were 11 m and 23.5 cm for *P. eldarica* and 9 m and 18 cm for *C. arizonica*, respectively.

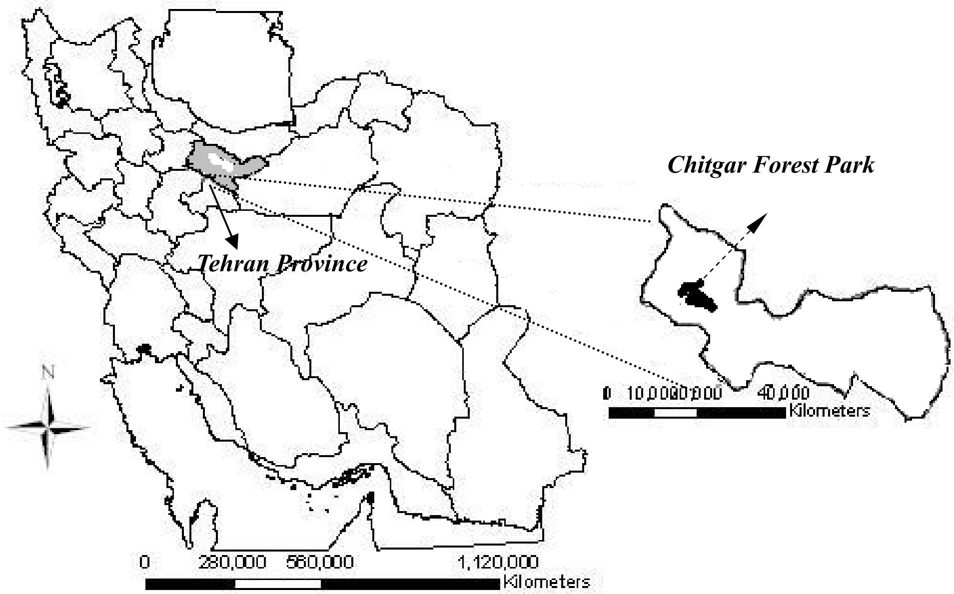

Fig. 1. Location of the Chitgar Forest Park inside Tehran, Iran (The sample sites inside the Park were not shown).

The fifteen years records of meteorological data (1996-2010) recorded at the meteorological station nearest to the Forest Park, Chitgar Meteorological Station (35° 42´ N, 51° 08´ E, and 1269 m a. s. l.), indicate that the mean annual precipitation is 267.6 mm (SE: ± 20.4 mm). The wettest and driest months are March (45.4 mm; SE: ± 10.7 mm) and August (0.9 mm; SE: ± 0.4 mm), respectively. The dry period begins in May and ends in October. The wet period extends from November to April and historically accounts for 86% of the total annual precipitation. The mean annual temperature is 17.2 °C (SE: ± 0.1 °C). August is the warmest month with an average temperature of 29.4 °C (SE: ± 0.3 °C), and January is the coldest month (3.8 °C; SE: ± 0.8 °C).

Field sampling

From 15 April 2010 to 15 February 2011, eighteen rainfall events were recorded. The open field rainfall was collected using 10 manual cylindrical plastic collectors, 9 cm in diameter and 20 cm in height, placed in a neighboring open area, about 20 m away from the *P. eldarica* and *C. arizonica* plantations. The quantity of water collected was manually measured using a graded cylinder with an accuracy of 1 ml. The average content of the 10 collectors was used to estimate GR.

TF was sampled using 30 manual collectors of the same design as the collectors used to quantify GR for each plantation. TF collectors were randomly placed beneath the forest plantation canopy within the study sites. TF volume was measured when measuring GR, using the same method. The mean TF depth of each event was calculated through the collected TF from all 30 manual collectors in each plantation.

The difference between GR and TF allowed the estimation of I. In the present study, SF was not directly measured as it is a very small fraction for both *P. eldarica* and *C. arizonica.* The literature also showed that rough-barked species typically have low stemflow values (Helvey & Patric, 1965; Geiger, 1965).

Chemical analysis

Three rainfall events occurring in spring, fall, and winter were used for the chemical analysis. Four samples from each plantation were collected for TF chemical analysis in every rainfall event. The samples were immediately sent to the laboratory to record pH and EC by pH meter (made by HANNA company, Italy) and EC meter (made by Corring Company, England), respectively. All samples were filtered through 0.22 µm nitrocellulose filter and then acidified (pH < 2) with HNO_3. The samples were stored in the refrigerator (4 °C) before being analyzed. The samples were analyzed by ICP (OES ICP made by GBC Company, Australia). GR samples were also collected using the same method. Four samples from every GR were collected for the chemical analysis of the open field rainfall. Three rainfall events were analyzed separately and finally were averaged to obtain the pH, EC, Pb, and Cd of TF and those of the open field. Analysis of variance (ANOVA) was accomplished by the factorial design using SAS 9.1

RESULTS

Gross rainfall (GR) and throughfall (TF)

During the measurement, eighteen rainfall events were recorded. Cumulative GR was 114.8 mm and mean GR depth per event was 6.4 mm, ranging from 0.9 mm to 18 mm. Of the 18 rainfall events recorded during the measurement period, 79.5 mm (69.2%) and 84.4 mm (73.5%) of the cumulative GR reached the forest floor as TF for *P. eldarica* and *C. arizonica*, respectively. Mean TF per event was 4.4 mm (60.6%) of GR, ranging from 0.9 mm to 9.5 mm (22.2% to 81.1%) of GR for *P. eldarica* and 4.7 mm (65.9%) of GR, ranging from 0.9 mm to 8.7 mm (33.3% to 87.4%) of GR for *C. arizonica,* respectively (Table 1). The rainfall events were grouped into three classes in order to allow a better understanding of the relationship between GR and I (Table 1). The three classes were: GR ≤ 3.5 mm, 3.5 mm ≤ GR ≤ 7 mm, and GR ≥ 7 mm. Thus, 5, 7, and 6 rainfall events, correspondingly, were allocated to each of the above mentioned classes. The mean TF:GR values per each class were 37%, 66.3%, and 73.4% for *P. eldarica* and 47.8%, 67.9%, and 78.5% for *C. arizonica*, respectively (Table1).

Table 1. Cumulative gross rainfall (GR) depth, the percent of average relative throughfall (TF:GR) and standard error (SE), divided into 3 GR classes for *P. eldarica* and *C. arizonica*

		P. eldarica					*C. arizonica*			
	GR class (mm)	Frequency	GR (mm)	I:GR* (%)	TF:GR* (%)	SE* (%)	Frequency	I:GR* (%)	TF:GR* (%)	SE* (%)
	< 3.5	5	9.7	63	37	6	5	52.2	47.8	4.4
	3.5-7	7	32.5	33.7	66.3	4.4	7	32.1	67.9	3
	>7	6	72.6	26.6	73.4	3.4	6	21.5	78.5	2.7
Cumulative		18	114.8				18			

*Event based for each class

Rainfall interception loss (I)

Out of the total GR, 35.3 mm (30.8%) by *P. eldarica* plantation and 30.4 mm (26.5%) for *C. arizonica* were intercepted and subsequently returned to the atmosphere through evaporation process.

When I was expressed as percentage of GR for each event, I:GR varied from 18.9% for larger rainfall events (corresponding to GR = 9.5 mm) to 78% for smaller rainfall events (GR = 0.9 mm) for *P. eldarica*. For *C. arizonica,* I:GR ranged from 12.6% of GR for larger rainfall events (GR = 8.7 mm) to 67% of GR for smaller rainfall events (GR = 0.9 mm).

It was found that the contribution of I to GR (relative I or I:GR) was correlated with GR size both in *P. eldarica* and *C. arizonica* plantations (Fig. 2). The mean values of I:GR showed decreasing trends when GR increased.

Negative significant relationships (r^2_{Pinus} = 0.686, $r^2_{Cupressus}$ = 0.766, $P \leq 0.01$) were found between I:GR and GR in both plantations.

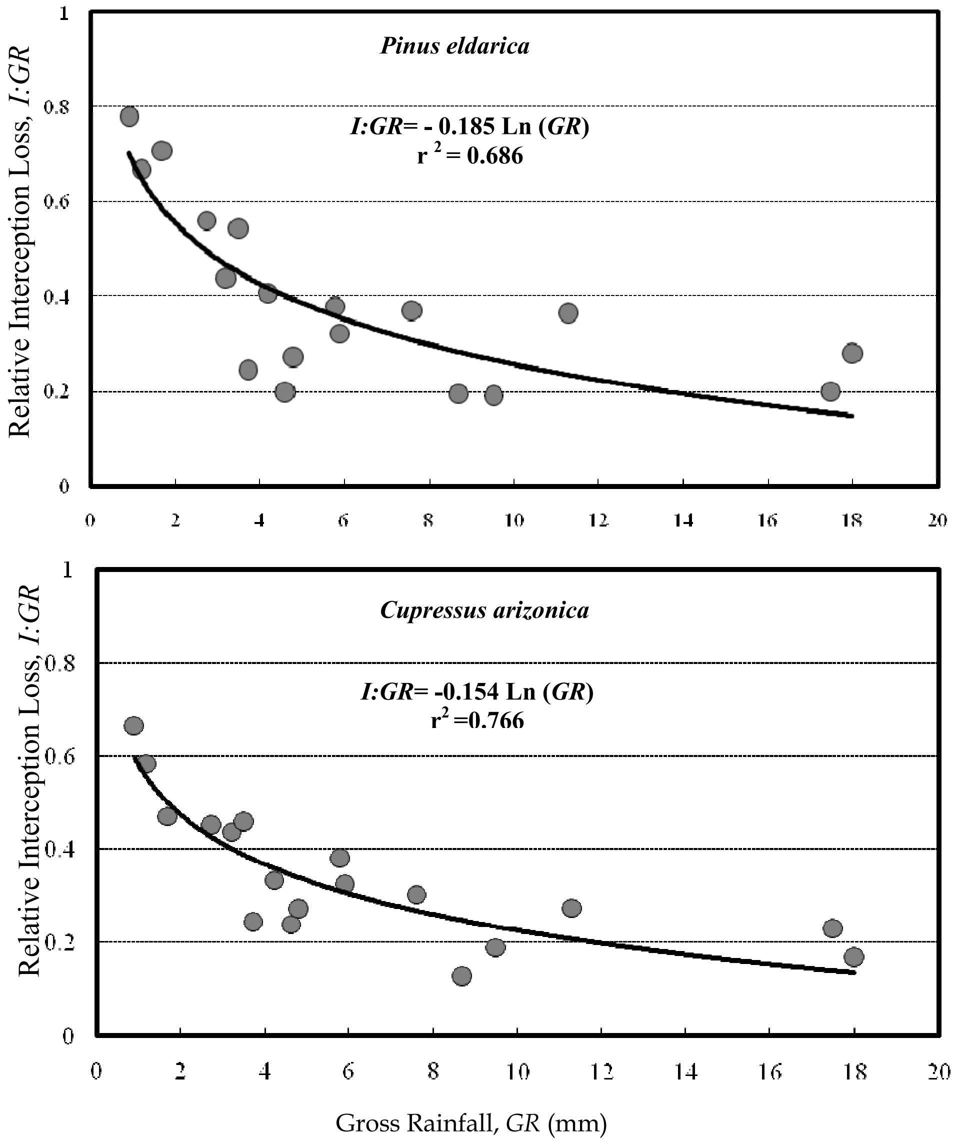

Fig.2. The relations between relative interception loss (I:GR) and gross rainfall (GR) for *P. Edarica* and *Cupressus arizonica* plantations. Every filled circle refers to a rainfall event.

pH and EC in open field rainfall and TF

The maximum and minimum EC were observed in TF of *P. eldarica* (298 µS cm^{-1}) and the open field rainfall (90.5 µS cm^{-1}). However, the maximum and minimum values of pH were observed in the open field (6.2) and in TF of *P. eldarica* (5.5) (Fig. 3). Duncan test showed significant differences among EC of TF in *P. eldarica*, *C. arizonica* and the open field rainfall, however, pH of TF in *C. arizonica* and the open field rainfall showed no significant differences (Fig.3). Analysis of variance indicated that pH and EC of TF were significantly different between *P. eldarica*, *C. arizonica* and the open field rainfall (Table 2).

Pb and Cd concentrations of the open field rainfall and TF

The maximum concentrations of Pb (74.07 ppb) and Cd (13.25 ppb) were found in TF of *P. eldarica* and the minimum concentrations of Pb (30 ppb) and Cd (8.55 ppb) were observed in the open field rainfall (Fig. 3). Duncan test showed significant difference among Pb and Cd of TF in *P. eldarica*, *C. arizonica* and the open field rainfall (Fig. 3). Analysis of variance showed that Pb and Cd of TF were significantly different between *P. eldarica*, *C. arizonica* and the open field rainfall (Table 2). The three rainfall events showed no significant differences for the pH, EC, Pb and Cd values (not shown).

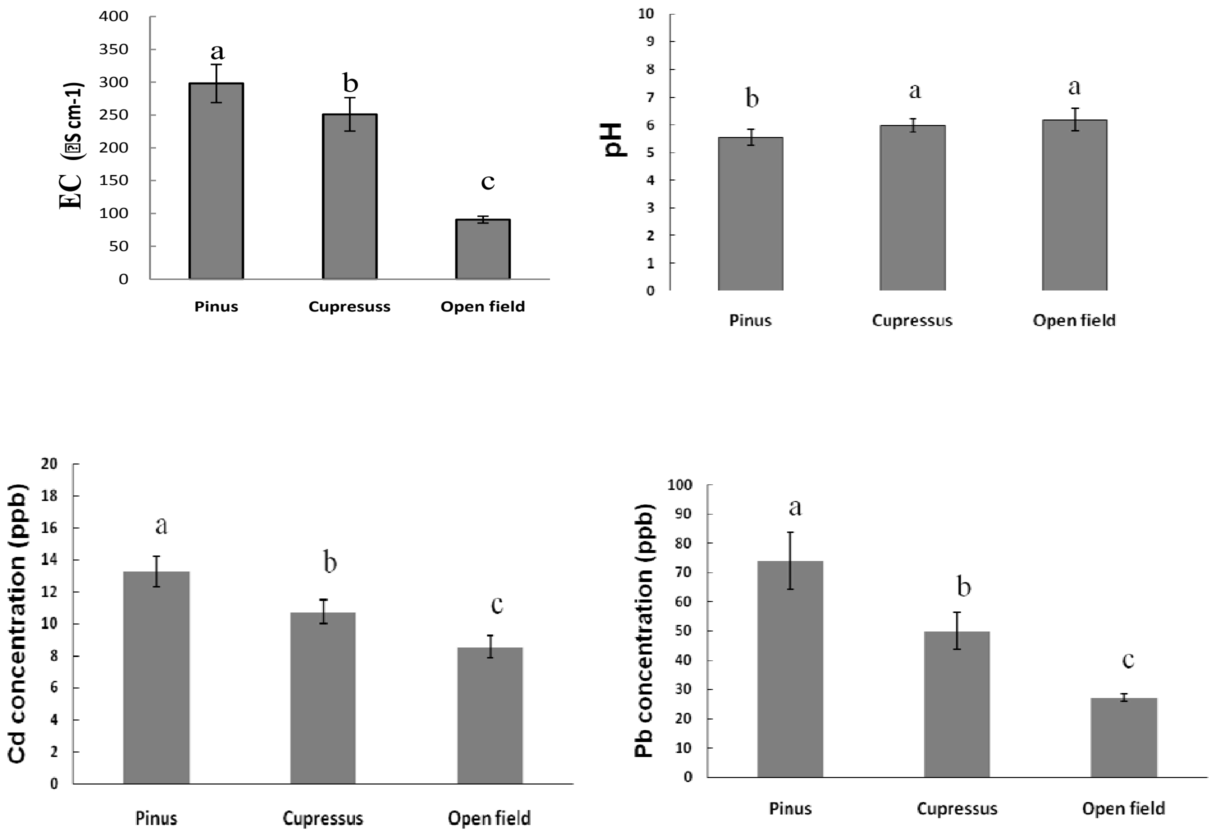

Fig. 3. Chemical compositions of throughfall (TF) in *P. edarica*and *C. arizonica* plantations compared with those of the open field rainfall. Bars refer to the standard error of mean compared with Duncan test. The dissimilar letters show significant difference at 5% level of significance.

* and ** are significant at 5 and 1 percent levels of significance, respectively.

Table 2. Analysis of variance of EC, pH, lead (Pb) and cadmium (Cd) of the open field rainfall and throughfalls of *P. eldarica* and *C. arizonica* plantations.

Sources of Variation (SOV)	Degree of Freedom (df)	Mean square (Ms)			
		EC (Electro Conductivity)	pH	Pb (Lead)	Cd (Cadmium)
Treatments	2	116960.59**	1.17**	5098.60**	57.58**
Error	33	6597.85	0.09	599.18	7.62
Coefficient of variation (CV)		36.24	5.33	45.93	24.96

DISCUSSION

In the period of measurements, 18 events were recorded in the study site. Interception loss was 30.8% for *P. eldarica* and 26.5% for *C. arizonica*. The values were on the higher end of the 20% to 40% of I measured in other needle-leaved evergreen forests (Hibbert, 1967; Zinke, 1967). The differences of TF and I among *P. eldarica* and *C. arizonica* is attributed to species composition, stand age, basal area, stand density and canopy morphology and architecture (Forgeard et al., 1980; Xiao et al., 2000; Iroumé & Huber, 2002; Carlyle-Moses, 2004; Fleischbein et al., 2005; Deguchi et al., 2006; Staelens et al., 2008; Muzylo et al., 2009). In the present study, the size of GR had a major effect on rainfall partitioning into TF and I in the *P. eldarica* and *C. arizonica* plantations by increasing GR , intercepted GR by the canopies of the two species (I:GR) and loss through evaporation process decreased. For example, for rainfall events <3.5 mm, the means I:GR were 63% and 52.2% for *P. eldarica* and *C. arizonica*, respectively, but for rainfall events >7 mm, the means I:GR were 26.6% and 21.6% for *P. eldarica* and *C. arizonica*, respectively (Table 1).

The rainfall interception from afforestations in Iran is significant and, therefore, rainfall interception loss needs to be considered in future water balance studies and in the selection of tree species for afforestations. In addition, future research is needed to quantify the full hydrological effect including transpiration of afforestation projects.

The chemical composition of TF was changed by canopy of the *P. eldarica* and *C. arizonica* plantations significantly compared to the open field rainfall. Literature also showed that the change in TF of chemical composition is due to wash off of dry deposition, uptake and release of elements by the canopy and associated micro-flora (Lovet & Lindberg, 1984). A canopy acts as a sink of dust, elements and other materials relating to species. No significant differences were observed among the pH, EC, Pb and Cd values of the three rainfall events in the spring, fall, and winter showing that the chemical composition of throughfall and rainfall would not possibly be affected by the season. More research, however, should be accomplished in different seasons with larger number of samples to confirm these findings.

EC, Pb and Cd concentrations of TF of *P. eldarica* and *C. arizonica* were higher than those recorded in the open field rainfall, showing the potential of collecting elements by the plantation canopies and ensuing the leaching and dry deposition as well as canopy uptake by the two plantations. The rainfall events cause decreasing air pollution and increasing soil pollution. Increasing soil pollution affects macro and micro-organisms of soil. Although the concentrations of Pb and Cd were higher in TF of the two species against those of the open fields showing the potential of the species for filtering the polluted air, the higher values obtained from TF of *P. eldarica* emphasized the priority of this species for plantations in polluted areas with lead and cadmium.

pH values in the TF of both plantations were less than that of the open field rainfall, though the difference was not significant between TF of *C. arizonica* and the open field rainfall. The values are comparable to the results obtained from a Chinese fir plantation in Fujian, China (Hou Bao et al., 1999). The results of the present study showed that both plantations were differently affected by pollutants. The effect of canopy plantations on the quality of rainfall, therefore, should be considered when selecting species for plantation projects in the urban polluted areas in the semi-arid climate regions.

Trace metal including Pb and Cd in the open field rainfall and its interaction with plantation cover and change in the concentration of TF provide new avenues to reduce trace metals.

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اندازه گیری سرب و کادمیم تاج بارش جنگل‌کاری‌های کاج تهران و سرو نقره‌ای در منطقه‌ای آلوده با اقلیم نیمه خشک

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(تاریخ دریافت:91/5/27 - تاریخ پذیرش: 91/10/26)

چکیده

این تحقیق به منظور اندازه‌گیری تاج‌بارش(TF) و باران ربایی (I) و مقایسه‌ی عناصر سرب و کادمیم و همچنین هدایت الکتریکی (EC) و pH تاج‌بارش جنگلکاری‌های کاج تهران و سرو نقره‌ای در پارک جنگلی چیتگر انجام گرفت. باران در فضای باز با استفاده از 10 جمع‌اوری کننده و تاج بارش با استفاده از 30 جع‌آوری کننده در هر توده که به صورت تصادفی در زیر تاج پوشش درختان قرار داده شدند، اندازه‌گیری شد. اندازه‌گیری‌ها از 15 آوریل تا 15 فوریه 2010 انجام گرفت. در طول دوره اندازه گیری، 18 مورد باران با عمق 114/8 میلی‌متر اندازه‌گیری شد که از این مقدار، سهم باران ربایی توده کاج تهران 35/3 میلی‌متر و توده سرو نقره ای 30/4 میلی‌متر بود. بین مقادیر I:GR و GR در هر دو توده همبستگی بالایی مشاهده شد ($r^2_{Pinus} = 0.686$, $r^2_{Cupressus} = 0.766$, p value ≤ 0.01). سرب، کادمیم و EC تاج بارش کاج تهران و سرو نقره‌ای اختلاف معنی‌داری را با مقادیر باران اندازه گیری شده در فضای باز نشان دادند. باران‌ربایی کاج تهران و سرو نقره‌ای در مناطق نیمه‌خشک ایران سهم قابل ملاحظه‌ای از باران را شامل می‌شود و بنابراین لازم است در تراز آبی این جنگل‌کاری‌ها، اندازه‌گیری باران ربایی لحاظ گردد. به علاوه نتایج نشان می‌دهند که کاج تهران و سرو نقره‌ای پتانسیل خوبی برای جذب آلودگی های سرب و کادمیم هوا از طریق تاج بارش دارند.

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