THE ANNALS OF “VALAHIA” UNIVERSITY OF TARGOVISTE
2011

EFFECTS OF PARTICULATE MATTER CONTAMINATION ON APPLE, PEACH AND OLIVE TREE LEAF CHARACTERISTICS AND OLIVE LEAF INORGANIC ELEMENT COMPOSITION

P.A. Maletsika and G.D. Nanos
Lab. of Pomology, School of Agricultural Sciences, University of Thessaly, Fitoko Str, 38446 Volos, Greece
E-mail: pmalets@yahoo.gr

Abstract

In the Mediterranean region, summer is characterized by semi-arid conditions with rare rain events. At the same time, many sources of particulate matter emissions result in foliar dust accumulation. We investigated the effect of unpaved road dust, quarry dust and cement kiln dust foliar accumulation on leaf characteristics of apple, peach and olive trees and the effect of cement kiln dust foliar accumulation on the inorganic element composition of olive tree leaves. Dust deposition on leaf surfaces increased chlorophyll content, mainly chlorophyll b and decreased chla/chlb ratio, changes associated with shading. But dust deposition also altered leaf morphology, increasing specific leaf matter and percent dry mass, in a way clearly showing that dusts affect more leaf mechanisms besides shading. The alkaline nature and chemical composition of cement kiln dust seemed to alter olive leaf nutrition by decreasing useful trace element and increasing Cd concentrations around the cement industry.

Keywords: *Malus x domestica, Prunus persica*, *Olea europaea,* unpaved road dust, quarry dust, cement kiln dust, chlorophyll, inorganic analysis

1. INTRODUCTION

Apple, peach and olive trees are extensively cultivated in Greece, where during the summer period rain events are rare. These conditions promote the dispersion of particulate matter in the atmosphere emitted by several sources as unpaved roads, limestone quarries, loose building materials, cement industries, mines or other contamination sources.

Particulate matter can be transferred on the soil and the growing plants, leaves and fruits and exert physical or chemical effects or both. Physically dust can shade the leaves and negatively affect their physiological functions, but the chemical effect of dusts on soil or directly on the plant surface may be more important. Limestone quarry dust, cement dust and that from many roads is highly alkaline and may contain a number of metals which could have a direct toxic effect themselves to the plant surfaces and, over the years, change the soil properties and health [2].

The effect of particulate matter accumulation on vegetation depends on the dust quantity, the duration of its presence, the dust’s chemical composition and the plant species. Alkaline dust contamination of leaves is known to affect several physiological processes of plants linked to photosynthesis, carbohydrate metabolism, chlorophyll and carotenoid contents and mineral nutrition [2, 10, 11]. In addition, cement kiln dust commonly forms surface crusts on plant material after hydration. This may cause blocking of stomata and shading of photosynthetic tissue, and, as a result, reduction of leaf (and other tissues) photosynthetic and transpiration capacity [2]. These effects are common for various types of dusts, as research in forest species showed that increased particulate matter dust deposition on vegetation may negatively affect carbon assimilation, due to shading and reduced stomatal conductivity [4].

The aim of this study was to investigate the effect of unpaved road dust, quarry dust and cement kiln dust foliar accumulation on leaf characteristics of apple, peach and olive trees and the effect of cement kiln dust foliar accumulation on the inorganic element composition of olive leaves.

2. MATERIAL AND METHODS

2.1 Experimental set up

The effect of unpaved road dust was investigated in apple and olive trees. The effect of quarry dust was investigated in apple and peach trees and the effect of cement kiln dust was investigated in olive trees. The experimental fields were randomly selected.

Ten-year-old apple trees (*Malus*domestica* cv. Red Delicious) were grown at mountain Pelion (400 m elevation), central Greece. The trees were next to unpaved road with farm slope >35^{o}. The effect of unpaved road dust was also studied in mature olive trees (*Olea europaea* L. cv. Konservolea) grown near the seaside on flat terrain at mountain Pelion.

The effect of quarry dust was investigated in 25-year-old ‘Red Delicious’ apple trees growing at the same region as the apple trees above. The field was at the southeast side of a quarry material distribution center. Finally, the effect of quarry dust was investigated in 10-year-old ‘Everts’ peach trees (*Prunus persica*) growing near

Tyrnavos, central Greece. The field was next to an unpaved road covered with quarry sand.
Two treatments were defined at each above case. The one included trees next to the dust source, while the second included trees at a distance from the dust source and used as control.
The effect of cement kiln dust was investigated in olive trees (*Olea europaea* L. cv. Konservolea). The study was carried out near the cement industry of Volos area, Central Greece. The industry lies at the foot of the mountain Pelion next to the sea. Thus, the topography around the cement factory is inclined and the emitted particulate matter of the cement industry depending on wind direction can accumulate at the area around and at the city of Volos. The climate of the region is semi-arid, with rare precipitation events at summer with the first rains at mid-September. Around the cement industry there are olive orchards and four study locations located at different distances from the cement industry were chosen for our investigation (Lat: 39^o 35΄, Lon: 22^o 98΄) (Picture 1).

Picture 1. Cement Industry.

At each of the four locations, two orchards with 'Konservolea' olives with different characteristics were studied (Table 1).

Table 1. Olive orchards' characteristics around the cement industry.

Location	Distance from cement industry (m)	Orchard characteristics
Loc 1	500	Non-irrigated with standard locally-applied horticultural practices (SLHAP)
Loc 1	500	Non-irrigated abandoned
Loc 2	700	Irrigated with SLHAP (two farms)
Loc 3	1100	Irrigated with SLHAP (two farms)
Loc 4	1300	Non-irrigated with SLHAP
Loc 4	1300	Non-irrigated abandoned

2.2 Leaf analyses

From all the above fruit tree categories, six leaf replicates and six leaves per replicate were collected from the middle of shoots around each tree, placed in plastic bags and transported to the Laboratory of Pomology for analysis. Leaf characteristics were analyzed to all leaf samples. The inorganic element composition of the olive leaves of trees growing close to the cement industry was also studied. All samples were collected late August or early September 2010 before the first rain events.

To quantify particulate matter contamination, the dust was carefully removed from the leaves and weighed. The leaf surface was measured using a scanner and the dust presence was expressed as μg per cm^2 leaf surface. Then, the leaves were washed with deionized water and excess water was removed carefully. Leaf discs were removed with 9 mm diameter corer, their fresh mass and surface were measured, dried at 80 ^{o}C and their dry mass was measured. Leaf % dry mass (DM) and specific leaf mass (SLM, g dry mass per m^2 of leaf surface) were then calculated. Similar leaf discs were extracted in 95% ethanol and chlorophyll was measured spectrophotometrically [18]. Chlorophyll a and b contents (expressed as mg per m^2 of leaf surface) and the ratio chlorophyll a / chlorophyll b (chla/chlb) were calculated.

For the measurement of olive leaf inorganic element composition, the leaves were initially washed thoroughly with deionized water. After washing, the leaves were dried in a force-air drying chamber at 70 ^{o}C until constant mass. The dried samples were finely ground and 1 g was placed in crucible porcelain and ashed in a Carbolite muffle furnace at 480 ^{o}C for 4 h. For the determination of the inorganic element concentrations, the ashed samples were digested with concentrated HNO_3 [14]. The concentrations of Mg, Mn, Fe, Cu, Zn, Ni, Pb, Cd, Cr, Co were measured using an Atomic Absorption Spectrometer with flame atomization (Analyst 700, Perkin Elmer). The concentrations of K, Na and Ca were determined by flame photometer (Flame photometer 410, Sherwood Scientific Ltd). P concentration was determined spectrophotometrically with the ammonium vanadate-ammonium molybdate method. Inorganic elements were expressed on leaf dry mass basis.

3. RESULTS AND DISCUSSION

3.1 Leaf dust contamination and leaf characteristics

Leaf dust content (μg cm^{-2} leaf area) decreased with the distance from the source of dust in all studied tree species. Actually, dust deposition on leaves varied among the tree species and this depended on the kind of dust, the dust particle size, the dust emission rate, the leaf epidermal and cuticular features, the leaf structure, geometry and phyllotaxy, the height and canopy of trees the local climate, the soil slope, the wind direction and the human activities (Tables 2-6) [2, 15].

Apple unpaved road dusted leaves had increased SLM (by 11.5%) and DM (by 7.4%) compared to control leaves. In addition, chlorophyll a, b and total contents increased in apple unpaved road dusted leaves (by 16.5%, 20.6% and 18%, respectively) compared to control leaves, while in dusted leaves the chla/chlb ratio slightly decreased (by 3.5%) compared to control leaves (Table 2).

Table 2. Apple leaf unpaved road dust content and leaf characteristics of apple leaves.

Apple tree	Control	Unpaved road dust
	20 m	2 m
Dust content (μg cm^{-2})	5±1.2	10±1.6
SLM (g m^{-2})	91±5	102±4
DM (%)	48±0.7	50±2.4
Chl a (mg m^{-2})	440±18	512±20
Chl b (mg m^{-2})	254±17	307±26
Tot Chl (mg m^{-2})	694±34	819±45
Chla/Chlb	1.73±0.05	1.67±0.04

In olive trees grown beside the unpaved road, SLM was not affected by leaf dust content, while in dusted leaves DM increased (by 10.5%) compared to control leaves. In addition, chlorophyll a, b and total contents of unpaved road dusted leaves increased (by 1.3%, 9.7% and 4.2%, respectively) compared to control leaves, while in dusted leaves the chla/chlb ratio slightly decreased (by 7.6%) compared to control leaves (Table 3).

Table 3. Olive leaf unpaved road dust content and leaf characteristics of olive leaves.

Olive tree	Control	Unpaved road dust
	50 m	2 m
Dust content (μg cm^{-2})	8±4	81±38
SLM (g m^{-2})	195±3	193±0
DM (%)	53±1.0	59±0.8
Chl a (mg m^{-2})	502±1	508±3
Chl b (mg m^{-2})	273±13	299±4
Tot Chl (mg m^{-2})	774±13	807±6
Chla/Chlb	1.84±0.05	1.70±0.03

Apple quarry dusted leaves had increased SLM (by 6.5%) and DM (by 10.2%) compared to control leaves. In addition, apple quarry dusted leaves had increased chlorophyll a, b and total contents (by 18.9%, 29.5% and 22.8%, respectively) compared to control leaves. Finally, the chla/chlb ratio decreased (by 9%) in dusted leaves compared to control leaves (Table 4).

SLM and DM increased (by 28.7% and 6.2%, respectively) in peach quarry dusted leaves compared to control leaves. In addition, in peach quarry dusted leaves chlorophyll a, b and total contents increased (by 14.4%, 12% and 13.5%, respectively) compared to control leaves, but the chla/chlb ratio was not affected by dust content on leaf surface (Table 5).

Table 4. Apple leaf quarry dust content and leaf characteristics of apple leaves.

Apple tree	Control	Quarry dust
	50 m	10 m
Dust content (μg cm^{-2})	14±3	24±13
SLM (g m^{-2})	97±2	104±4
DM (%)	51±1.5	56±2.5
Chl a (mg m^{-2})	280±20	333±16
Chl b (mg m^{-2})	165±16	214±22
Tot Chl (mg m^{-2})	445±33	546±37
Chla/Chlb	1.70±0.08	1.55±0.06

According to the above presented data, regardless of the tree species or the kind of dust accumulated on leaf surfaces, dusted leaves had increased SLM (except olive leaves), DM, and chlorophyll a, b and total contents expressed as mg m^{-2} compared to control leaves. In addition, in dusted leaves chla/chlb ratio decreased (except peach leaves) compared to control leaves.

Table 5. Peach leaf quarry dust content and leaf characteristics of peach leaves.

Peach tree	Control	Quarry dust
	100 m	2 m
Dust content (μg cm^{-2})	ND	30±9
SLM (g m^{-2})	61±5	78±5
DM (%)	44±2.3	48±1.7
Chl a (mg m^{-2})	371±34	424±26
Chl b (mg m^{-2})	215±8	241±15
Tot Chl (mg m^{-2})	586±41	665±40
Chla/Chlb	1.72±0.07	1.76±0.06

Apple quarry dusted leaves had increased dust deposition and accordingly increased chlorophyll content compared to apple unpaved road dusted leaves. In addition, the change in chlorophyll b content due to dust deposition was more intense compared to chlorophyll a content change in both cases. In olive trees, even though large amounts of dust were deposited, the changes in chlorophyll contents were smaller than in apple trees, but still the increase in chlorophyll b content due to dust deposition was more intense compared to chlorophyll a content increase. All the above agree with the decreased chla/chlb ratio due to dust deposition in apple and olive trees. On the other hand, peach trees were more sensitive to SLM changes in leaves due to dust deposition compared to apple and olive trees. In addition, leaf chlorophyll a and b contents in peach trees increased in a similar degree due to dust deposition without affecting chla/chlb ratio. In addition, DM changes caused by dust deposition had the lowest value in peach dusted leaves and the highest in olive dusted leaves. SLM and DM are indexes of sclerophylly and comparing the three studied species, olive tree leaves had the highest values [1], while peach tree leaves had the lowest one. The individual species leaf structure seemed to affect their reaction to dust accumulation besides the origin and characteristics of the dust itself with the more sclerophyllus species being more resistant to changes due to dust deposition.

The increased chlorophyll a, b and total contents in dusted leaves are probably associated with the shading effect. In a previous study, shade increased chlorophyll a+b content per unit fresh mass, which was not affected when expressed per unit leaf area, increased chlorophyll b, and decreased chla/chlb ratio in olive leaves [5]. In addition, shading decreased leaf thickness and SLM in olive leaves [5]. On the contrary, we found that dusted leaves had increased SLM and DM, which means that dust deposition increased leaf thickness. It is clear that dusts can affect many more leaf functions than shading leaf surfaces such as changing the microclimate on leaf surface, blocking the stomata and reducing stomatal conductivity [2], and affecting leaf tissue inorganic composition. Nanos and Ilias [13] found increased SLM and DM in cement kiln dusted olive leaves compared to control leaves, while olive cement dusted leaves had lower chlorophyll a content and higher chlorophyll b content (expressed per g DM) than control leaves. On the other hand, high amounts of cement dust in spruce needles resulted in reduced chlorophyll a expressed per g fresh mass content, while chlorophyll b was only slightly affected [10]. This reduction in chlorophyll content from cement dust covering the vegetative organs may be only partially due to shading effect, but must also be associated with changes in the temperature and water regimes of the plant tissues, or damage to the photosynthetic apparatus due to cement’s alkaline nature and possibly unbalanced nutrition and toxicity [9, 10, 13]. Similar decreases in total chlorophyll content in exposed leaves of several plant species to unpaved road dust have been attributed to the alkaline nature and the solubility of metals present in the dust negatively affecting leaf physiology [2]. Finally, the presence of cement dust on olive leaves and one-year-old spruce needles decreased chla/chlb ratio supporting the shading effect explanation [10, 13].

Concerning the studied olive trees around the cement industry, the leaf cement kiln dust content decreased with the distance from the cement industry (Table 6). More specifically, olive leaves collected from 700 m (Loc. 2), 1100 m (Loc. 3) and 1300 m (Loc. 4) away from the cement industry had 3-fold, 5-fold and 11-fold, respectively, lower cement kiln dust compared to leaves collected 500 m away from the cement industry (Loc. 1) (Table 6). But, even at 1300 m away from the cement industry, olive leaves still had increased levels of cement kiln dust. As a result, the differences among the locations in leaf characteristics were not clear. Furthermore, the sampled olive orchards around the cement industry (Table 1) varied in the applied horticultural practices, irrigation regime and soil slope. Nevertheless, olive leaves from Loc. 1 had increased SLM and decreased chlorophyll a and total contents and chla/chlb ratio compared to the other three locations (Table 6). These changes may reflect the long term effects of cement kiln dust in soils and trees around the cement kiln factory and are of particular interest as they seem related to the leaf productivity, but the changes are partially masked from the differences in orchard management and soil and climatic conditions.

Table 6. Olive leaf cement kiln dust content and leaf characteristics of olive leaves according to the distance from the cement industry.

	Loc. 1 500 m	Loc. 2 700 m	Loc. 3 1100 m	Loc. 4 1300 m
Dust content ($\mu g\ cm^{-2}$)	232±9	70±7	45±23	21±13
SLM ($g\ m^{-2}$)	281±2	261±2	247±9	270±8
DM (%)	66±14	65±1	59±1	67±3
Chla ($mg\ m^{-2}$)	319±8	402±8	387±7	403±7
Chlb ($mg\ m^{-2}$)	184±7	188±7	182±4	207±3
TotChl ($mg\ m^{-2}$)	503±6	590±9	569±7	610±6
Chla/Chlb	1.7±0.0	2.1±0.1	2.1±0.2	2.0±0.1

3.2 Inorganic element content in olive leaves

Olive trees grown around the cement industry and the soil around accept over the dry season significant quantities of cement kiln dust as shown by the accumulation of dust on the leaves (Table 6). Olive leaf samples were collected on September 1st, 2010 before the first rain events to pinpoint the maximum cement kiln dust accumulation even though this type of dust due to crust development will not be substantially removed with rain (Table 6). Thus, the leaf inorganic element analysis could show the possible alteration of nutrition regime and olive leaf contamination by metals present in cement kiln dust.

Cement kiln dust of different forms comes from all the stages of cement manufacturing, including limestone-quarry, a deposit site, a storage site for raw materials, the cement mill, storage of bulk or packaged cement and the unpaved roads, where the trucks transport the raw materials and the final product [6] (Picture 1). As a guide, the raw materials used to manufacture Portland cement are rich in Ca, Al, Si, Fe, Mg, but also contain Mn, Cu, Zn, Ni, Pb, Co, Cr, Cd and other trace elements [16].

K concentration in olive leaves from the 4 locations around the cement industry ranged from 0.43% to 0.6% to the 4 locations (Table 7). According to Therios [17], olive leaves with K concentration below 0.5% are relatively deficient. Only leaves collected from Loc. 1 had K concentration below this threshold level, but low K values are common in leaves of dry-cultivated olive trees [3] and the olive orchards in Loc. 1 were not irrigated. Ca concentration in olive leaves of all studied locations were above 1%, which is the sufficiency threshold level. On the contrary, P concentration was below the sufficiency threshold level of 0.1% to all locations. Mg concentration in olive leaves from locations 1 and 2 were below the sufficiency threshold level of 0.1% compared to olive leaves from locations 3 and 4. Mn concentration in olive leaves from locations 1, 2 and 4 was below the sufficiency threshold level of 20 mg kg^{-1} and only Mn concentration of leaves from Loc. 3 was slightly above this level [3]. Fe concentration in olive leaves was always sufficient (above 50 mg kg^{-1}) [17]. Na concentration of leaves highly increased in Loc. 1 compared to the other locations. In guava trees grown around a cement factory, dusted leaves also had increased Na concentration compared to control leaves [8]. Zn concentration in olive leaves was also almost always deficient (sufficiency threshold level at 10 mg kg^{-1}). In addition, Cu concentration was also deficient in the three locations (sufficiency threshold level at 5 mg kg^{-1}), except of the leaves from Loc. 3, where Cu fungicides were used regularly [3, 17]. In conclusion for the main necessary nutrients in our experimental olive farms, K, Ca and partly Mg were sufficient in olive leaves and P, Mn, Fe, Zn and Cu were usually deficient.

Table 7. Inorganic elements concentrations of olive leaves cement kiln dusted.

	Loc. 1 500 m	Loc. 2 700 m	Loc. 3 1100 m	Loc. 4 1300 m
	In % DM			
K	0.43±0	0.60±0.15	0.50±0.15	0.50±0.13
Ca	1.16±0	1.03±0.14	1.52±0.15	1.19±0.04
P	0.02±0	0.03±0.00	0.03±0.00	0.03±0.00
Mg	0.06±0	0.09±0.01	0.12±0.01	0.10±0.01
	In mg kg^{-1} DM			
Mn	17.4±0	15.9±5.7	24.1±2.1	14.5±1.7
Fe	21.0±0	15.4±6.4	23.6±3.4	26.1±0.4
Na	112.7±0	68.8±7.1	71.3±10.6	73.8±7.1
Zn	10.24±0	9.76±0.62	9.91±2.06	8.79±1.64
Cu	1.49±0	1.88±0.48	12.4±13.9	1.26±0.06
Ni	2.36±0	1.90±0.30	2.14±0.07	1.03±0.04
Cd	0.43±0	0.43±0.06	0.48±0.00	0.39±0.01
Pb	2.15±0	1.81±0.16	2.66±0.27	1.78±0.14
Co	ND[a]	ND	ND	ND
Cr	ND	ND	ND	ND

[a] ND: Not Detected

Concerning the heavy metals Ni, Cd and Pb, according to Kabata-Pendias [7], concentrations of Ni, Cd and Pb considered tolerable in mature leaf tissue of agronomic crops are: Ni: 1-10, Cd: 0.05-0.5 and Pb: 0.5-10 mg kg^{-1} DW, while normal concentrations are: Ni: 0.1-5, Cd: 0.05-0.2 and Pb: 5-10 mg kg^{-1} DW. According to the above, in our study Ni concentration was at normal levels, Pb concentration was low, while Cd concentration was especially high in the olive leaves studied around the cement industry (Table 7). Cd is an extremely significant air, land and water pollutant due to thermal processes such as cement manufacturing, and, as it is a relatively mobile metal in soils, many crops accumulate Cd [6].

Many researchers have reported the alkaline nature of cement kiln dust. In a conifer forest near a cement kiln factory, cement dust caused alkalization of soil and together with the alkaline dust deposited on trees the availability of several nutrients was altered, causing serious deviations in the mineral composition of trees. In particular, the content of N, P, Mg and Mn in the spruce needles from the heavily polluted area was lower, while that of K, Ca, S and B was higher compared to control trees in an unpolluted control area [11, 12]. This latter alkalization is due to calcium hydroxide; which, after hydration, may raise leaf surface pH up to 12 [4]. In guava trees grown around a cement factory dusted leaves had increased K, Ca, P and Na concentrations in relation to control leaves [8].

Besides the direct effects of cement dust on leaf surfaces, the changes in the root ambient solution pH may play a significant role in the availability of certain trace elements [7]. It was reported that pH and Ca concentration affect Cd, Cu, Pb and Zn mobility in soils by competition at the adsorbing clay sites. In addition, interactions of chemical elements are important to deficiency and toxicity in the physiology of plants. Interactions between chemical elements may be both antagonistic and synergistic and their imbalances may cause chemical stress in plants. It has been shown that Ca, P and Mg are the main antagonistic elements against the absorption and metabolism of several trace elements [7]. Aerial contamination was found as an important source of trace elements for plants and the absorbance of trace elements by the leaves and translocation to other plant tissues including roots, where the excesses of some metals seem to be stored, has been proposed as major mechanism for trace element nutrition [7].

4. CONCLUSIONS

In this study, the effect of foliar dust accumulation from various sources on leaf characteristics of apple, peach and olive trees and the effect of cement kiln dust accumulation on the inorganic elements composition of olive tree leaves were investigated. Dust deposition on leaf surfaces resulted in changes of chlorophyll content related to shading. But dust deposition altered leaf morphology by increasing SLM and DM, showing that other mechanisms besides shading are involved. The alkaline nature and chemical composition of cement kiln dust, possibly through the leaves and the soil, negatively altered the nutrition of olive trees growing around the cement industry by reducing the leaf concentrations of useful trace elements and increasing Cd accumulation.

5. REFERENCES

[1] Bacelar EA, Correia CM, Moutinho-Pereira JM, Gonçalves BC, Lopes JI, Torres-Pereira JMG. Sclerophylly and leaf anatomical traits of five field-grown olive cultivars growing under drought conditions. Tree Physiol. 2004; 24: 233-239.

[2] Farmer AM. The effects of dust on vegetation - a review. Environ. Pollut. 1993; 79: 63-75.

[3] Fernández-Escobar R, Moreno R, García-Creus M. Seasonal changes of mineral nutrients in olive leaves during the alternate-bearing cycle Sci. Hort. 1999; 82: 25-45.

[4] Grantz DA, Garner JHB, Johnson DW. Ecological effects of particulate matter. Environ. Intern. 2003; 29: 213-239.

[5] Gregoriou K, Pontikis K, Vemmos S. Effects of reduced irradiance on leaf morphology, photosynthetic capacity, and fruit yield in olive (*Olea europaea* L.). Photosynthetica 2007; 45(2): 172-181.

[6] Işikli B, Demir TA, Akar T, Berber A, Ürer SM, Kalyoncu C, Canbek M. Cadmium exposure from the cement dust emissions: A field study in a rural residence. Chemosphere 2006; 63: 1546-1552.

[7] Kabata-Pendias A. Trace Elements in Soils and Plants. Boca Raton, Florida: CRC Press, 2000.

[8] Lal B, Ambasht RS. Impact of cement dust on the mineral and energy concentration of *Psidium guayava*. Environ. Pollut. 1982; 29(A): 241-247.

[9] Lepeduš H, Cesar V, Suver M. The annual changes of chloroplast pigments content in current- and previous-year needles of Norway spruce (*Picea abies* L. Karst.) exposed to cement dust pollution. Acta Bot. Croat. 2003; 62: 27-35.

[10] Mandre M, Tuulmets L. Pigment changes in Norway spruce induced by dust pollution. Water Air Soil Pollut. 1997; 94: 247-258.

[11] Mandre M, Klõŝeiko J, Ots K, Tuulmets L. Changes in phytomass and nutrient partitioning in young conifers in extreme alkaline growth conditions. Environ. Pollut. 1999; 105: 209-220.

[12] Mandre M. Relationships between lignin and nutrients in *Picea abies* L. under alkaline air pollution. Water Air Soil Poll. 2002; 133: 361-377.

[13] Nanos GD, Ilias IF. Effects of inert dust on olive (*Olea europaea* L.) leaf physiological parameters. Environ. Sci. Pollut. Res. 2007; 14: 212-214.

[14] Papafilippaki A, Stavroulakis G. Assessment of lead and cadmium contamination in roadside soils and plants from Chania city (Greece). In: Proceedings 11th International Conference Environmental Science and Technology, Chania, Greece, 2009.

[15] Prusty BAK, Mishra PC, Azeez PA. Dust accumulation and leaf pigment content in vegetation near the national highway at Sambalpur, Orissa, India. Ecotoxicol. Environ. Saf. 2005; 60: 228-235.

[16] Taylor HFW. Cement chemistry. London: Academic Press, 1997.

[17] Therios I. Olive production. Thessaloniki, Greece: Gartaganis Publications, 2005 (in Greek).

[18] Wintermans JF, de Mots A. Spectrophotometric characteristics of chlorophyll and their pheophytins in ethanol. Biochim. Biophys. Acta 1965; 109: 448-453.