

Evaluation of different shrub species for carbon uptake and pollution removal

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Abstract

The aim of this work was to evaluate the ability of seven shrub species (*Arbutus unedo*, *Elaeagnus x ebbingei*, *Laurus nobilis*, *Ligustrum japonicum*, *Photinia x fraseri*, *Viburnum lucidum*, *Viburnum tinus*) to assimilate CO₂ and to remove some pollutants. Plants were grown in 5-L containers. CO₂ uptake and carbon allocation were determined in 2010 and 2011. Carbon assimilation was measured in either well watered or water stressing conditions. Removal of heavy metals and particulate matter were measured in 2011. Results may provide useful information for sustainable planning of urban areas and roadside greening.

Presenter biography: **Alessio Fini**

Alessio Fini is a researcher at the Department of Agri-Food Production and Environmental Sciences at Florence University. Since 2005, he has been working on projects regarding sustainable cultivation techniques for nursery production and urban forestry and on stress tolerance of urban trees. Research topics include: reduction in use of herbicides, irrigation and chemical fertilizers; effects of shading on leaf gas exchange and leaf anatomy; alternative techniques to tillage and their effects on plant physiology; effects of mulching on plant physiology and soil chemical, physical and biological properties; development of native and species-specific mycorrhiza to improve health and growth of urban trees; development of nursery pre-conditioning techniques to improve success at transplant; roles of phenolic compounds in plant response to stress and plant responses to climate change. His PhD thesis dealt with the mechanisms of drought tolerance of shade trees and the selection of drought tolerant species. He is author of about 65 publications in international peer-reviewed journals and conference proceedings.

INTRODUCTION

Rising atmospheric CO₂ concentration is driving a whole set of environmental modifications, known as climate change (Christensen et al., 2007). Urban Forestry and urban greening has been reported to contribute effectively to CO₂ uptake (Pugh et al., 2012) because: 1) trees and shrubs are planted inside or nearby the urban environment, where the concentration of CO₂ and pollutants is higher (Niinemets and Peñuelas, 2007); 2) they offer benefits *in situ*, where they can be appreciated by over half of World population (McCarthy et al., 2010).

CO₂ is absorbed through the stomata, then is it assimilated in the photosynthetic process and stored as woody and non-woody biomass. In parallel to CO₂ assimilation and carbon storage, urban greening removes significant quantities of trace metals produced by vehicular traffic and human activities (i.e. Cd, Cu, Zn, Pb, Ni) (Imperato et al., 2003; Lorenzini et al., 2006; Nowak et al., 2006; Saebo et al., 2012). However, growing

conditions of urban trees are different than those experienced in their natural environment, and several stressors can harm tree health and cause premature plant death; thereby reducing benefits of urban plants up to 90%. To maximize the benefits of green areas, care must be taken in the selection of species. The impact of different tree species on carbon sequestration and air quality has been extensively studied in the last 15 years (Beckett et al., 2000; Nowak et al., 2002; Nowak and Crane, 2002; Pugh et al., 2012), while shrubs have been little considered. However, the effect of shrubs in carbon uptake and pollutant sequestration is significant (Jo and McPherson, 1995; Bombelli and Gratani, 2003). Studies aimed at identifying the shrubby species with the highest assimilation rate and with the capacity to withstand the stressful condition of cities are required to increase sustainability of urban areas.

The aim of this work was: 1) to evaluate the ability of seven shrub species (*Arbutus unedo*, *Elaeagnus x ebbingei*, *Laurus nobilis*, *Ligustrum japonicum*, *Photinia x fraseri*, *Viburnum lucidum*, *Viburnum tinus*) to sequester and store CO₂ in conditions of optimal substrate moisture (experiment 1); 2) to compare the tolerance of the different species to water stress, and to evaluate how carbon assimilation is constrained by drought (experiment 2); 3) to evaluate the ability of the six shrub species to remove pollutants from the air (experiment 3).

MATERIALS AND METHODS

Experiment 1

In autumn 2010, 84 two-year-old plants (12 per species) of *Arbutus unedo*, *Elaeagnus x ebbingei*, *Laurus nobilis*, *Ligustrum japonicum*, *Photinia x fraseri*, *Viburnum lucidum* e *Viburnum tinus* were potted into 3-L containers in a peat:pumice substrate (4/1, v/v) fertilized with 3 kg/m³ of a controlled release fertilizer (Osmocote Exact, 18-2,5-7, 8-9 mesi, Everris, Intl. B.B, Geldermalsen, NL). Plants were grown outside under full sunlight, and irrigated daily to container capacity to avoid any water stress until the end of the experiment. Plants were arranged in a randomized block design with 6 blocks and 2 plants per species in each block. Daily trend of net photosynthesis, transpiration, water use efficiency was measured between 09.00 and 18.30 on twelve different days during summer 2011 with an infrared gas analyzer (Ciras 2, PP-system, Amesbury, MA) as described elsewhere (Ferrini et al., 2008). Daily carbon gain was calculated by integrating the daily assimilation curve (Fini et al., 2012). Fresh and dry weight of stems, leaves and roots were measured in April 2011 and November 2011. Relative growth rate and leaf area were calculated as described in previous works (Fini et al., 2010). Finally, whole-plant carbon uptake was calculated from net photosynthesis per unit leaf area and total leaf area per plant using Wimovac software (University of Illinois).

Experiment 2

In March 2012, 144 three-year-old plants of the same species used in exp. 1 (24 plants per species; *Laurus nobilis* was not used in exp. 2) were potted in 5-L container. Substrate and fertilization were done as in exp. 1. All plants were daily watered at container capacity until August, then exposed to water stress according to the following treatments: 1) WW: plants were watered at container capacity throughout the experiment; 2) WS: water was withheld for 5 days (withholding 1); then substrate moisture was maintained at 30% of container capacity for 14 days (partial relief); finally water was withheld for 5 days (withholding 2) (Fig. 1). Substrate moisture was determined using a gravimetric method (Sammons and Struve, 2008; Fini et al., 2011). Significant physiological parameters were measured 6 times during the 24 days of the water stress

experiment. These included: 1) leaf gas exchange, measured at T-0 (before the onset of drought), T-1 (1 day after the imposition of drought), T-2 (3 days after the imposition of drought), T-3 (5 days after the imposition of drought), T-4 (end of partial relief), T-5 (end of the experiment), as in exp. 1; 2) pre-dawn water potential, measured at T-3 using a Scholander type pressure bomb (PMS Instruments, Albany, OR) between 03.00 and 05.00; 3) the maximum quantum yield of PSII photochemistry (Fv/Fm) and the chlorophyll *a* fluorescence induction (OJIP) curve were measured simultaneously as leaf gas exchange as described in previous works (Fini et al., 2011; 2013); 5) drought-induced changes in growth rate were measured as RGR as described in exp. 1.

Experiment 3

In March 2010, 25 two-year-old plants of *Arbutus unedo*, *Elaeagnus x ebbingei*, *Laurus nobilis*, *Ligustrum japonicum*, *Photinia x fraseri*, *Viburnum lucidum* (150 plants in total), were planted in the field (in a loam soil) next to a 4-lanes principal road located in Pescia (Pistoia, Italy). At planting, plants were similar in size and leaf area. The different species were planted to form a row (or barrier) parallel to the road. The barrier was 1.5 m far from the road and made up of 5 randomized blocks (each block was made of 5 plant per species and was approximately long 21 m). The species were allowed to establish undisturbed for one year. Plants were irrigated as needed with a sprinkler system.

In 2011, leaf trace metal deposition was measured three times (June, August e October). Samplings were conducted after at least 10 rain-free days. For metal deposition determination, 10 leaves were harvested at different heights from the central of the 5 plants of the same species (50 leaves per species in total). Harvested leaves were carried to the laboratory for the quantification of trace metal deposition. Metals measured were Zn, Cd, Pb, Ni, Cu. In the laboratory leaves were washed in 50 ml of solution composed by bi-distilled water and HCl 0,01M (pH 2.0), per 30 minutes taking samples on an orbital shaker. The solutions of the different samples were analyzed by Inductively Coupled Plasma – Optical Emission Spectrometer – Dual Vision (Optima 2000, Perkin Elmer). Total leaf area per plant was determined by fully defoliating one plant species and block (30 plants in total) and by scanning the leaf as reported in Fini et al., 2010. Leaf area measurement was performed in October 2011, after the last sampling of trace metal deposition. Trace metal deposition on the whole plant was then calculated by multiplying average deposition per unit leaf area and whole plant leaf area.

RESULTS AND DISCUSSION

Experiment 1: carbon uptake and storage under optimal water availability

Elaeagnus x ebbingei had the highest carbon gain (both expressed on leaf area basis and of the whole plant) when grown under optimal water availability (Fig. 2), mainly because of higher water use efficiency than the other species (data not shown). *Laurus nobilis* ranked second for CO₂ uptake, while photinia performed good on leaf area basis, but whole plant uptake was limited by lower leaf area if compared to other species. *V. lucidum* and *V. tinus* showed lower capacity of CO₂ assimilation because of limited photosynthetic potential, while lower leaf area resulted in limited carbon gain in *L. vulgare* and *A. unedo* (Fig. 2).

High carbon uptake does not necessarily translate in high long-term carbon storage, as not all assimilated carbon is used for growth. Conversely, some carbon is allocated to the secondary metabolism, or for reserve production, or for reproduction (Herms and Mattson, 1992). However, in our experiment conducted under optimal conditions, we found a good correlation between carbon uptake and growth rate

(Fig. 3) which confirms *E. x ebbingei* and *L. nobilis* as the best species for carbon sequestration among those investigated if resources are not limiting.

Finally, it must be considered that, for a given increase in plant biomass, species which invest more in leaves than in woody biomass, store carbon for a shorter period of time, particularly in the urban environment where shedded leaves are artificially removed (Nowak et al., 2002). Carbon allocation to leaves was higher in *V. lucidum* than in the other species, while *V. tinus*, *E. x ebbingei* and *L. japonicum* displayed to lowest C-allocation to leaves.

In conclusion, under optimal water availability, *Elaeagnus x ebbingei* was the species showing the highest daily carbon uptake, the highest growth rate, and the highest allocation to woody biomass, which make this species a very promising shrub for carbon sequestration in well watered urban areas.

Experiment 2: carbon uptake during drought stress

On average substrate moisture of WS plants declined to 15% at the end of the “withholding 1” phase (T-3), then was maintained around 30% until T-4, finally declined to 12% at the end of the “withholding 2” phase (T-5) (Fig. 5).

Drought differentially reduced the maximum quantum yield of PSII photochemistry (Fv/Fm) during the “withholding water 1” phase (Fig. 6). *Ligustrum japonicum*, *Elaeagnus x ebbingei* and *Viburnum lucidum* showed the larger decline in Fv/Fm, whereas *Photinia x fraseri* displayed the lowest variation. In particular, Fv/Fm decreased below 0.70 in *Ligustrum japonicum* and *Viburnum lucidum*, indicating severe photoinhibition in these species (Percival et al., 2005; Kalaji et al., 2012; Fini et al., 2013).

Carbon assimilation of WW plants was similar to values observed in exp. 1. Consistently, under optimal water availability, *E. x ebbingei* was the species showing the higher net photosynthesis (data not shown). However, as drought progressed photosynthesis of *E. x ebbingei* was strongly reduced (Fig. 7). Similarly, *V. lucidum* displayed very low CO₂ assimilation during drought. These findings are consistent with “mesic” species showing high values of carbon assimilation under optimal conditions, but photosynthesis is largely decreased in stressful conditions. Among “mesic” species, *Photinia x fraseri* was the species more capable of maintaining carbon assimilation during drought and to promptly recover during partial relief (T-4). On the other hand, more xeric, Mediterranean shrubs as *Arbutus unedo* and *Viburnum tinus*, which showed relatively low assimilation rates under optimal conditions, were less affected by drought (Fig. 7).

In conclusion, photosynthesis of some species (*V. lucidum*, *L. japonicum*, *E. x ebbingei*) was very sensitive to substrate moisture, therefore the use of these species in drought-prone environments is not recommended. On the other hand, more xeric species (*Arbutus unedo*, *Viburnum tinus*) or drought tolerant “mesic” species (*Photinia x fraseri*) should be planted to maximize carbon uptake in areas where water is a limiting resource.

Experiment 3: leaf deposition of some pollutants

The relative ability to adsorb trace metal on leaf surface depended on both plant species and type of metal. Despite of some species with very hairy leaves (i.e. *E. x ebbingei*, *L. nobilis*) showing a larger overall content of pollutants adsorbed on the unit of leaf surface area than other species, species effectiveness in trace metal adsorption varied largely depending on the pollutant considered (Table 1). Deposition per unit leaf area of cadmium, nickel and zinc was not influenced by plant species. Deposition of copper per unit leaf area was greater in *L. nobilis* than in *L. japonicum*, *P. x fraseri* and *V. lucidum*, while *E. x ebbingei* and *A.*

unedo showed an intermediate behavior. Deposition of lead per unit leaf area was higher in *E. x ebbingei* than *P. x fraseri*, *L. nobilis*, *A. unedo*, while *V. lucidum* and *L. japonicum* performing intermediately.

The amount of pollutants adsorbed by the whole canopy was significantly greater in *E. x ebbingei* than in the other species (Table 1). In accordance with previous works (Freer-Smith et al., 2005;), the larger leaf area of *E. x ebbingei* if compared to the other species probably determined this finding (Table 2). In conclusion, growth rate and whole plant leaf area were more important than leaf anatomical characteristics in setting differences in leaf pollutants deposition across six shrub species. Therefore, species capable of a fast growth rate and of sustaining large leaf areas are better suited for trace metal removal from the air. In this experiment, *E. x ebbingei* outperformed the other species investigated.

CONCLUSION

The present experiment was aimed at evaluating the potential of some shrub species to sequester air pollutants and to absorb and store CO₂ from the atmosphere. *Elaeagnus x ebbingei* was the best-performing species under optimal water availability, but the species was shown to be unable to thrive in drought-prone environments. If water availability is limiting, other species, such as *Photinia x fraseri*, *Arbutus unedo* and *Viburnum tinus* should be preferred.

Similarly, *E. x ebbingei* was the most suitable species for removal of trace metal from the air near a heavily polluted road, because of faster growth rate, higher leaf area and high metal deposition per unit leaf area because of very hairy leaves.

We are aware that only a limited number of species was tested here, therefore this experiment is unlikely to be a conclusive evaluation of CO₂ uptake potential of shrubs. Therefore, this study is not willing to stimulate extensive planting of *E. x ebbingei* or *P. x fraseri* monoculture, but it may offer for the first time a useful insight of CO₂ assimilation potential of widely used shrubs for urban green areas.

Acknowledgments

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Figure 1: Irrigation scheduling for WS plants in experiment 2. T indicate when physiological measurements were carried out.

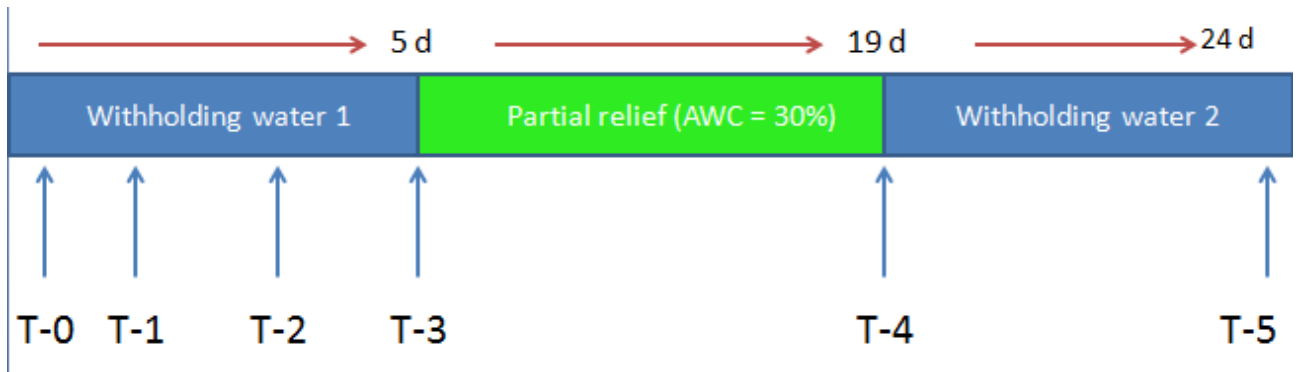


Figure 2: daily CO₂ uptake per unit leaf area (A) or of the whole plant (B) by seven different shrubs. Data are the average of 12 daily measurement of net photosynthesis. Different letters indicate significant differences among species at P<0.01 using Duncan's MRT.

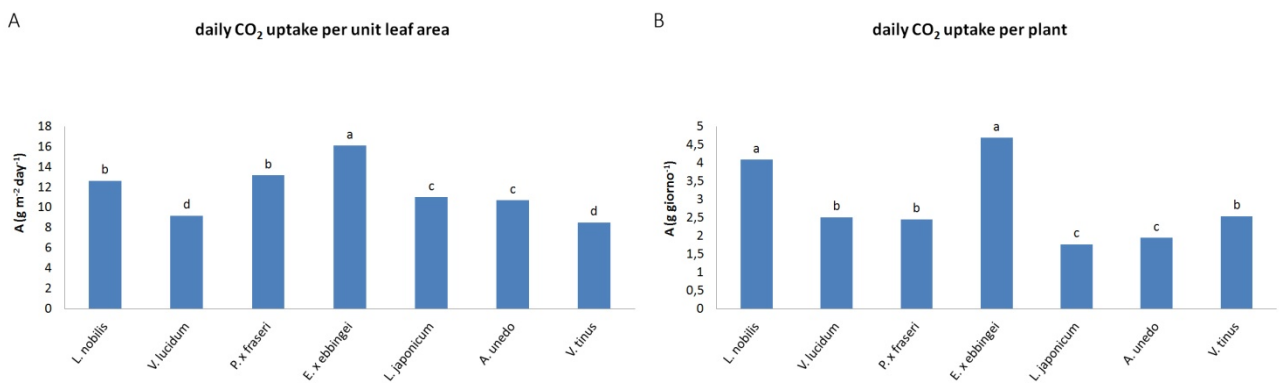


Figure 3: relative growth rate (A) and relationship between RGR and whole plant daily CO₂ assimilation (B) in seven shrub species. Different letters indicate significant differences in RGR among species at P<0.01 using Duncan's MRT.

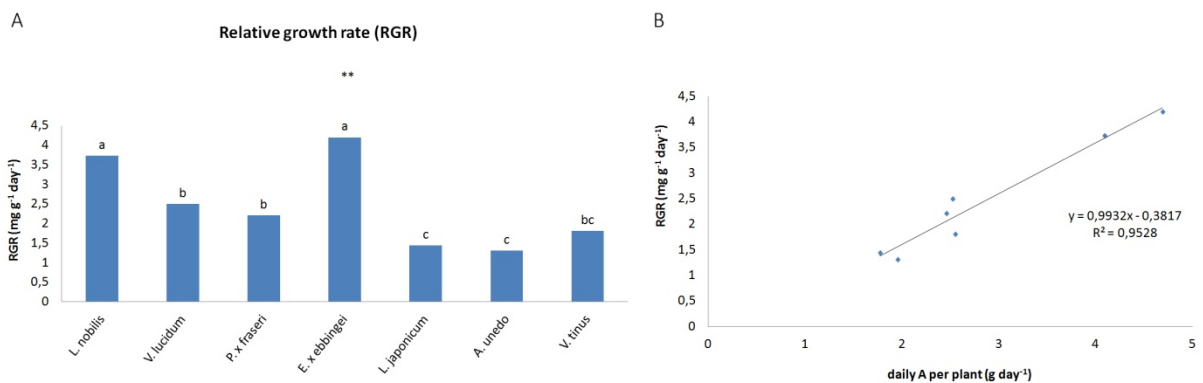


Figure 4: carbon allocation to different plant organs in seven shrub species. Different letters within an organ (i.e. leaves, stem and roots) indicate significant differences among species at $P < 0.01$ using Duncan's MRT.

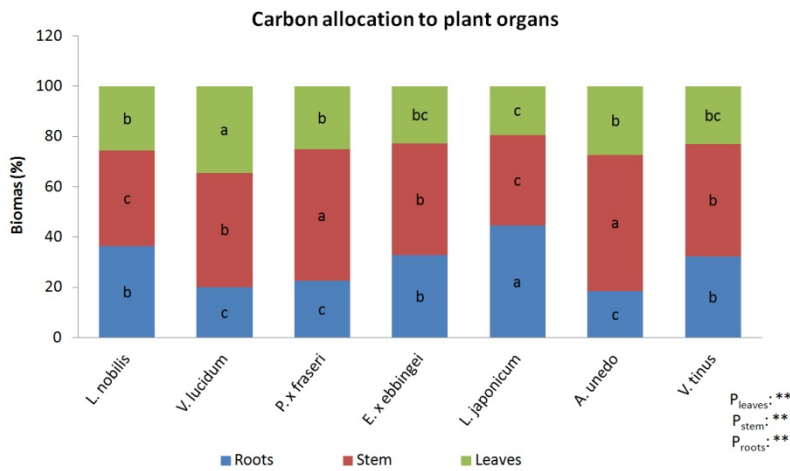


Figure 5: Substrate moisture of WS plants (expressed as percentile of the water holding capacity of the container) during the drought experiment. Data are the average of 6 species and 12 plants per species.

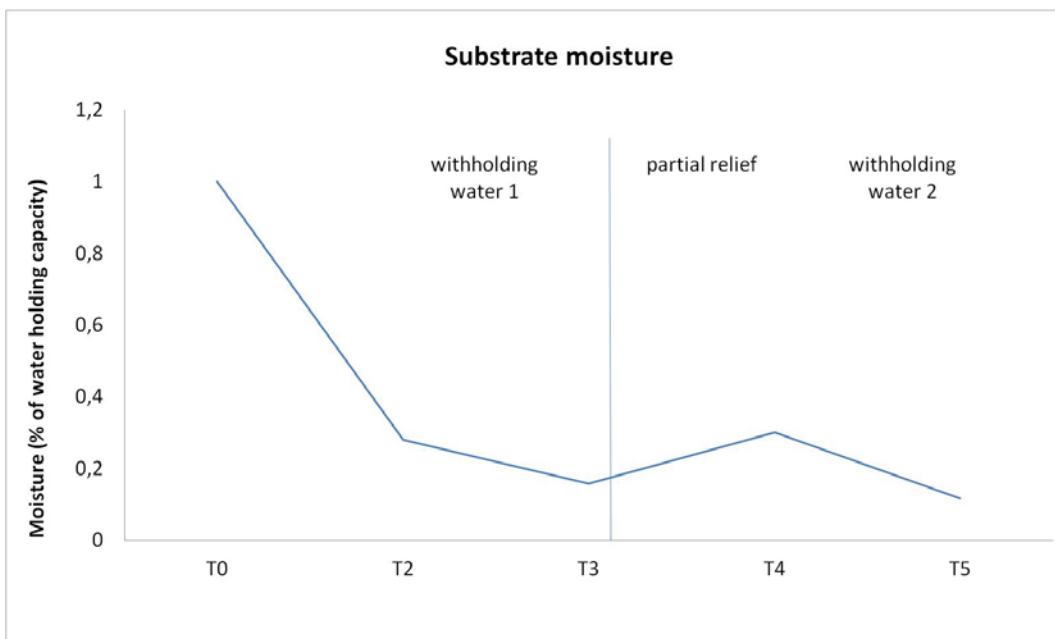


Figure 6: Maximum quantum yield of PSII photochemistry during the “withholding water 1” phase in 6 shrubs grown in either well watered (WW) or water stress (WS) conditions. ** indicate significant differences between WW and WS plants of a species. The normalized index of variation (NIV) was calculated as: $[(Fv/Fm)_{ws} - (Fv/Fm)_{ww}] / [(Fv/Fm)_{ws} + (Fv/Fm)_{ww}]$ (Tattini et al., 2006)

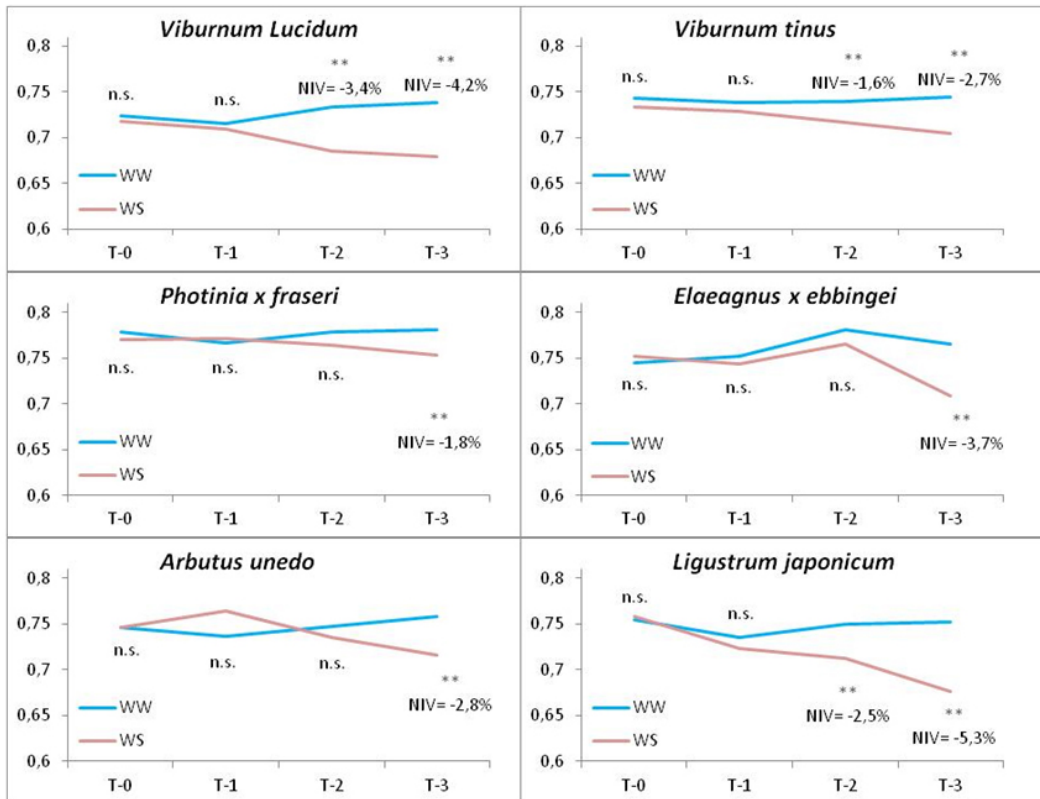


Figure 7: whole plant carbon uptake in 6 shrubs grown under water stress. Arrows indicate the end of the withholding 1 phase (arrow down) and the end of partial relief (arrow up). Different letters within the same sampling date indicate significant differences among species at $P > 0.01$ using Duncan's MRT.

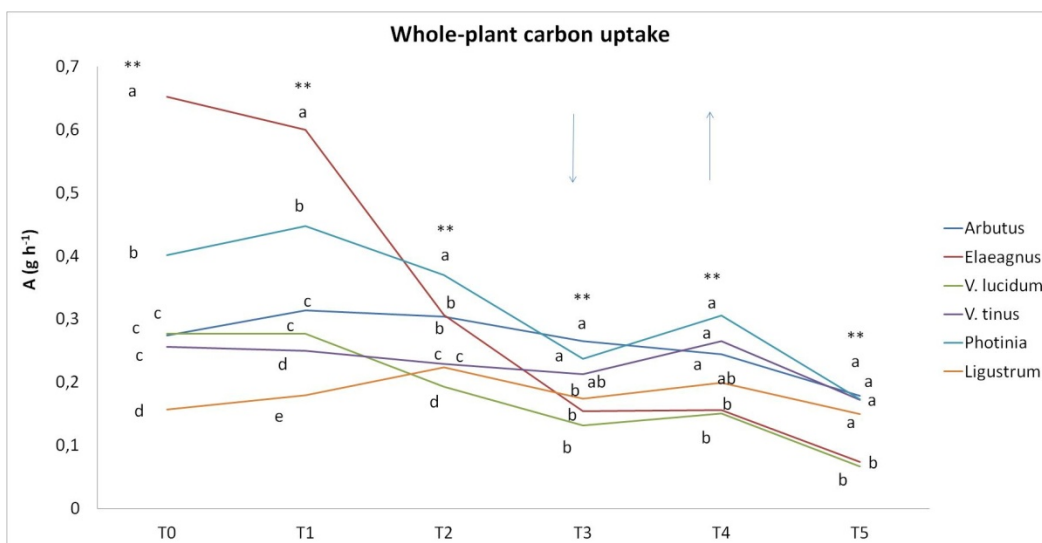


Table 1: Foliar deposition per unit leaf area or on the whole canopy of six shrub species of some trace metals (cadmium, copper, nickel, lead, zinc). Data are the average of three samplings performed in June, August and October. Different letters within the same column indicate significant differences among species at P<0.05 (*) or P<0.01 ()** using Duncan's MRT.

Species	Cd	Cu	Ni	Pb	Zn
Deposition per unit leaf area ($\mu\text{g}/\text{m}^2$)					
<i>V. lucidum</i>	0.40	768.62 b	144.71	23.94 ab	856.02
<i>A. unedo</i>	0.35	882.72 ab	157.78	15.88 bc	1296.81
<i>P. x fraseri</i>	0.23	680.17 b	114.42	18.88 bc	1043.58
<i>E. x ebbingei</i>	0.35	969.32 ab	211.73	28.25 a	1511.02
<i>L. nobilis</i>	0.43	1529.49 a	251.00	11.14 c	1657.30
<i>L. japonicum</i>	0.28	708.43 b	167.51	24.84 ab	1797.04
P	n.s.	*	n.s.	*	n.s.
Deposition on the whole plant (μg)					
<i>V. lucidum</i>	0.0023	4.08 b	0.76 b	0.14 b	4.49 b
<i>A. unedo</i>	0.0015	3.78 b	0.66 b	0.065 bc	5.39 b
<i>P. x fraseri</i>	0.0015	3.77 b	0.62 b	0.11 bc	6.00 b
<i>E. x ebbingei</i>	0.0038	9.67 a	2.15 a	0.28 a	14.64 a
<i>L. nobilis</i>	0.0013	4.28 b	0.70 b	0.035 c	4.99 b
<i>L. japonicum</i>	0.0012	2.37 b	0.54 b	0.097 bc	7.24 b
P	n.s.	**	**	**	**

Table 2: Leaf area of the whole plant, number of leaves per plant and average lamina size in six shrub species planted in the field near a heavily polluted road. Different letters within the same column indicate significant differences among species at P<0.01 ()** using Duncan's MRT.

	Whole plant leaf area (m^2)	Leaf number	Average leaf size (cm^2)
<i>V. lucidum</i>	5.00 bc	1632 d	30.63 a
<i>A. unedo</i>	3.99 cd	3786 b	10.54 c
<i>P. x fraseri</i>	5.58 b	2905 bc	19.21 b
<i>E. x ebbingei</i>	9.70 a	7804 a	12.43 c
<i>L. nobilis</i>	2.90 d	1457 d	19.90 b
<i>L. japonicum</i>	3.80 cd	2226 c	17.07 b
P	**	**	**