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A review of the performance of woody and herbaceous ornamental plants for phytoremediation in urban areas

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Urban and periurban areas are often contaminated by several pollutants. Phytoremediation is considered to be an effective and eco-friendly strategy for the restoration of these contaminated lands. For this purpose, the exploitation of ornamental plants could be an additional option, due to their positive impact on the landscape. In this paper, we reviewed a selection of species which have been proposed for utilization in phytoremediation. Several tree species have been introduced in the past into urban environments for parks, gardens and avenues, with a selection studied for their capacity to absorb, tolerate, and translocate contaminants. Shrubby and herbaceous species are also commonly exploited for their ornamental features and are now studied for phytoremediation purposes. The responses of several effective species to the presence of heavy metals or dangerous organic compounds in the growth substrate are examined in this paper.

Keywords: Environment, Heavy Metals, Landscape, Organics, Pollution

Introduction

Environmental pollution is an increasing global problem. Contaminants vary depending upon their source and the type of ecosystem involved. Urban areas can be affected by several organic and inorganic contaminants, which negatively impact soils, water and the atmosphere (Biasioli et al. 2006). The study of the effect of contamination by pollutants on these urban environments and potential solutions to the problems associated with soil contamination and rehabilitation dates to the last few decades (Tiller 1992).

Urban and periurban soils are often polluted as consequence of human activities. Brownfield sites, mainly located in periurban sites, reflect industrial heritage and are probably the most common scenarios where urban and periurban contaminated soils are found (Sleegers 2010). In general, heavy metals are the major contaminants: lead is commonly found near roads and associated with zinc and cadmium (Garcia & Millan 1998); excessive copper is frequently detected in soils used for a long period as agricultural land, especially vineyards (Bretzel & Calderisi 2006), and chromium is a residual of some industrial activities (Zayad & Terry 2003). Organic pollutants can also injure urban soils by direct contamination, or after initial emission into the atmosphere followed by transport in both gaseous and particulate forms, and subsequent accumulation in soils after dry and wet atmospheric deposition (Cachada et al. 2012). Urban soils may also be very different to more natural soils, due to lower organic fraction, water drainage and aeration, different pH value, microorganism content and the presence of anthropic material. These features can change the performance of these soils with respect to pollutants (Tiller 1992, Schleu et al. 1998). As stated by Cunningham & Berti (1993) "new technologies are needed to address numerous contaminants, especially those that are neither volatile nor mobile in soil solution". Plants have been proposed to mitigate the dangerous effects of pollutants, with phytoremediation recognized as a promising technology for the recovery of contaminated environments (Salt et al. 1995). Phytoremediation could be successfully exploited in urban territories; in these contexts, many herbaceous and some woody species (including forest species) are suitable for planting because of their ornamental features and adaptability to inhabited areas. Furthermore, plants are useful sensors to identify environmental contamination and potential exposures to pollutants (Henry et al. 2013). In fact, some of these species show the capacity to absorb, hold or translocate specific contaminants; moreover, these ornamentals pose little threat to food chain contamination, and can be appreciated by the resident populations for their positive impact on landscape.

In the more circumscribed field of flowerbeds and urban green plantations, special mixtures of topsoil are commonly used and rules have to be followed with regards to the presence of contaminants (Huinink 1998). Risks are higher in allotments, since contaminants could be transferred to the food chain (Scheyer 2000, Khalid et al. 2017). Attention has to be paid to parks, playgrounds, kindergartens and urban areas where people come into close contact with soil (Abrahams 2002, Chiesura 2004, De Miguel et al. 2006, Lee et al. 2006, Ljung et al. 2006a, Ljung et al. 2006b). In these areas, selected ornamental plants may play an important role in reducing the presence of pollutants, while at the same time giving a pleasant temporary decoration. Botanists have elaborated several definitions of ornamental plants; these can be defined as plants that have highly ornamental features such as ornamental flowers, fruits or foliage (Li & Zhou 2005). Nevertheless, we must also consider that the ornamental value of a plant may vary according to the different tastes and traditions of each country.

The focus of our attention is the "original" soils, and the present article is aimed primarily at suburban areas, which can be even heavily contaminated, due to their past uses. If the plants chosen to be used in remediation are tree species, several selection criteria have to be taken into account (Conway & Vander Vecht 2015), including problems linked to climate change

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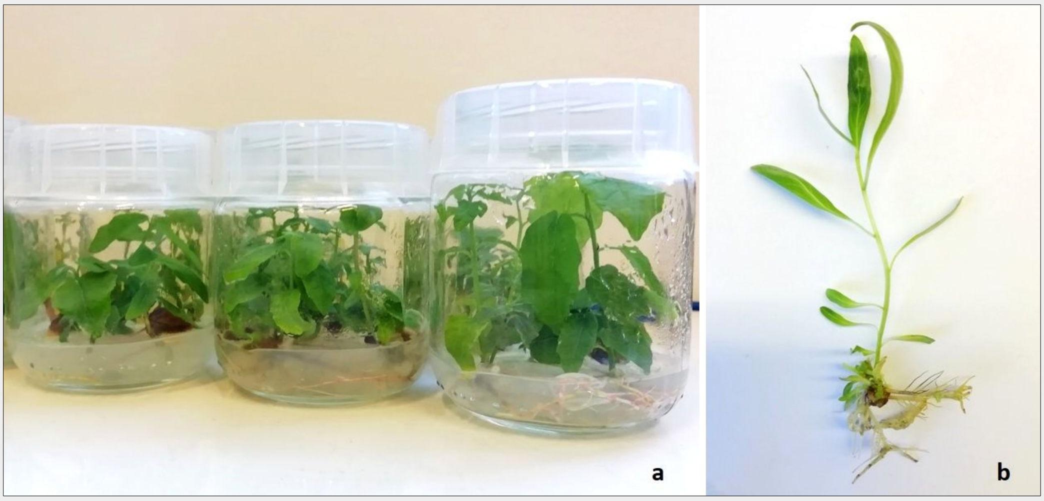

Fig. 1 - *In vitro* culture for the rapid mass propagation of plants to be exploited in phytoremediation: (a) multiclonal culture of *Populus alba*; (b) *in vitro*-rooted plantlet of *Salix alba.*

(Roloff et al. 2009, Killi et al. 2018) and the preferences expressed by the resident populations (these inclinations are generally for plantations with high level of biodiversity – Carrus et al. 2015). Also, it is always advisable to consider all of the actions related to the sustainability of plantations (Ferrini & Fini 2011) and the analysis of costs for their periodic removal and disposal (Berndes et al. 2004, Lewandowski et al. 2006, Compernolle et al. 2012, Saxena et al. 2019, Wan et al. 2016).

In this context, we might also consider the possible use of tree planting for short-rotation coppicing, by which a profitable recovery of the used plants can be performed. For instance, willows may be exploited for this purpose, since these species display high ornamental value and are suitable for bioenergy production combined with potential for phytoremediation (Guidi et al. 2013, Guidi Nissim et al. 2014b). Therefore, the choice of species to be used for phytoremediation includes consideration of criteria such as respect for biodiversity, easy harvesting management, by-product utilisation and possible economic returns.

After their use for soil remediation, all plants (woody and herbaceous) must be harvested and treated, since the content of pollutants is an important concern. Several solutions are available for this purpose, including compacting, composting, biogas production and pyrolysis (Blaylock & Huang 2000, Nanda Kumar et al. 1995, Garbisu & Alkorta 2001). The easiest procedure is incineration of biomass, with recovery of residual heavy metals. When ornamental flowers are used, cut flowers with limited contaminants content can be eventually sold.

An overview is provided of the most effective woody and herbaceous plants (tree species, shrubs and herbaceous flowers) for the remediation of urban and suburban areas, through analysis of recent literature illustrating how these species react when facing either inorganic (heavy metals) or organic contaminants. This review is specifically addressed to a selection of species suitable for exploitation in urban environments, due to their adaptability, ornamental characteristics and appreciation by resident populations; the proposed selection, albeit large, is mainly focused on the species best suited to European and American environments.

Several tree species have been successfully used in urban parks, gardens and avenues; for instance, in Europe pines, cypresses, poplars, willows, birches, sycamores and lindens are widely planted (Miller et al. 2015). Numerous recent studies demonstrated that some tree species have a good attitude to tolerate, absorb and remove specific contaminants from the soil (reviewed by Mahar et al. 2016, Pajević et al. 2016). Trees can enhance the aesthetic quality of urban landscape (Chen et al. 2009), simultaneously providing other functions, such as improved air quality (Mukherjee & Agrawal 2018), reduction of noise pollution (Pathak et al. 2011), mitigation of waterlogging (Livesley et al. 2016) and reducing heat island effects (Scholz et al. 2018 – Fig. 1, Fig. 2).

A great variety of herbaceous and shrubby species have been analysed for phytoremediation purposes (reviewed by Liu et al. 2018 – Fig. 3), but many still remain to be studied. Furthermore, plants' association, with its huge possibilities of combinations, offers interesting perspectives and is therefore discussed.

The choice of ornamental woody and herbaceous plants for urban (and periur-

Fig. 2 - Woody species for phytoremediation: (a) a poplar plantation in an urban site (outskirts of Florence); (b) *Betula pendula.*

Fig. 3 - Two widespread ornamental species studied and proposed for phytoremediation purposes: (a) *Chrysanthemum*; (b) *Nerium oleander.*

ban) environments should also take into account some factors. In these sites (often smaller areas compared to the countryside), the problem of the scattering of leaves could be more relevant; especially when using trees, and for species that translocate pollutants to the leaves, leaves should be periodically collected and treated. Moreover, due to the greater anthropic presence in urban site and transport constraints, it is probably opportune to choose species that have less maintenance needs and leaves which are easier to collect at the end of the leaf life-cycle.

Heavy metals

Pollution from industrial emissions, effluents and solid discharges are the main source of an abnormal high presence of heavy metals in soils. In general, numerous human activities result in the emission of these harmful pollutants that enter into the biosphere through wastes (emission, waste-water and waste solid), including municipal wastes in agriculture and excessive use of fertilizers. Several plant species have the capacity to absorb and translocate specific metals; a selection of woody and herbaceous species, which could be identified as "multipurpose species", are reviewed below, for their possible utilisation in metal remediation coupled to considerable ornamental features (Tab. 1, Tab. 2).

Woody species

Among tree species traditionally used in urban and periurban plantations, a limited number showed suitability for phytoremediation purposes. Analysis of the recent literature indicates that the most promising are some species of the Salicaceae family (*Salix* spp., *Populus* spp.), but some others also show significant pollution resistance traits, such as *Ailanthus altissima, Robinia pseudoacacia, Betula pendula, Carpinus betulus, Ginkgo biloba* and *Platanus hispanica* (Dadea et al. 2017). Several tree species (mainly willows and poplars) are not hyperaccumulators, but do exhibit traits of high interest, such as fast growth and high production of biomass, easy propagation, a deep root system and the capacity to uptake and translocate a significant amount of metal contaminants in the soil to the shoots (Vassilev et al. 2004, Guerra et al. 2011). Poplars in particular, display a number of different characteristics useful towards environmental protection, which include phytoremediation, especially in combination with short rotation forestry and landscape restoration (Facciotto et al. 2014). Woody species may also be utilised for the plantation of green belts around contaminated lands. Eucalypts, willows and poplars are all fast-growing trees with short rotation coppice systems that could be successfully utilised for this purpose (Pulford & Watson 2003). This phytoremediation would have to be undertaken in consideration of the need to harmonize these choices with the landscape character, as generally requested by the resident populations (Boll et al. 2014).

The effect of lead (Pb) has been assessed in one-year-old potted seedlings of Cappadocian maple (*Acer cappadocicum*), European ash (*Fraxinus excelsior*) and Oriental aborvitae (*Platycladus orientalis*). Increasing Pb application in the soil (from 100 to 500 mg kg^{-1}) did not affect the dry weight of roots of all species, while a gradual decrease was detected in leaves and shoots, with the highest inhibition in *P. orientalis.* This species, however, showed the highest translocation factor values, tolerance index and bioconcentration factor, indicating a possible use of this conifer species for remediation of Pb-polluted soils (Abbasi et al. 2017). The bioconcentration factor (BF) is defined as the ratio of metal(loid) concentration in aerial biomass to that in soil, and the translocation factor (TF) the ratio of metal(loid) concentration in shoots to that in roots, both factors taking values >1 in accumulators and <1 in excluders; the tolerance index (TI) is the percent of the organ's growth of the treated plant compared to the growth of the control plant (McGrath & Zhao 2003, Turner et al. 1991). Three leguminous woody species, *Mimosa caesalpiniaefolia, Erythrina speciosa* and *Schizolobium parahyba*, were tested in a lead-contaminated area. While *M. caesalpiniaefolia* did not show symptoms of Pb toxicity, the other two species exhibited reduced shoot biomass yield, leaf area and height. The increase of Pb concentrations in soil led to augmented Pb concentration in shoots and roots, but most of the Pb accumulated in the roots, and only a small fraction was translocated to the aboveground parts of the plant. *Mimosa* showed the highest Pb tolerance and phytostabilisation potential in lead-contaminated soils (Ribeiro De Souza et al. 2012).

In a study to identify candidate species among fast-growing trees for remediating Pb-contaminated soils (Yongpisanphop et al. 2017), hydroponic cultures of cuttings from *Acacia mangium*, *Azadirachta indica*, *Eucalyptus camaldulensis*, and *Senna siamea*, were tested in increasing Pb concentrations. All species showed high Pb tolerance (over 78%) but low TF (<1) for all treatments (10, 30, and 50 mg L^{-1}). Based on these indices, *A. mangium* and *E. camaldulensis* were found to be good candidate species for Pb remediation (Yongpisanphop et al. 2017).

Willow (*Salix nigra*) showed a moderate tolerance to silver (Ag) in a hydroponic experiment with increasing $AgNO_3$ concentrations, observing a significant reduction of biomass production with $AgNO_3$ 0.027 µM, but also adaptation signals over a longer timeline (Guidi Nissim et al. 2014a).

Eastern cottonwood (*Populus deltoides*) was evaluated for arsenic (As) tolerance and phytostabilization potential, by exposure to various As levels in soil (control, 5, 10, 15, and 20 mg kg^{-1}) in a 9-month pot experiment. Plant height stress tolerance index (TI) significantly decreased with increasing As levels, while indices related to root length and dry matter were not affected. TF and BF were less than 1.0, but root and shoot As content significantly increased with increasing As concentrations (Hussain et al. 2017). The effect of high copper (Cu) concentrations was investigated on poplar woody cuttings (*Populus × euramericana*, clone "Adda"), finding that in-

Tab. 1 - Ornamental plants for the phytoremediation of heavy metal: trees and shrubs. (A): accumulation; (T): translocation.

Group	Species	Pollutants	A / T	References
Trees	*Acacia mangium*	Pb	A	Yongpisanphop et al. 2017
	Acer cappadocicum	Pb	A	Abbasi et al. 2017
	Azadirachta indica	Pb	A	Yongpisanphop et al. 2017
	Betula pendula	Zn	A,T (partial)	Rosselli et al. 2003
	Cinnamomum camphora	Zn	A,T	Zeng et al. 2018
	Eucalyptus camaldulensis	Pb	A	Yongpisanphop et al. 2017, Motesharezadeh et al. 2017
		Cd	T	
	Fraxinus excelsior	Pb	A	Abbasi et al. 2017
	Mimosa cesalpiniaefolia	Pb	A	Abbasi et al. 2017
	Platycladus orientalis	Pb	T	Abbasi et al. 2017
	Populus alba	Cd,Pb	A	Houda et al. 2016, Zacchini et al. 2009
	Populus deltoides	As	A	Hussain et al. 2017
		Cd	A	Zacchini et al. 2009
	Populus nigra	Cd	A	Zacchini et al. 2009
	Populus trichocarpa	Cd	A	Zacchini et al. 2009
	Populus × canadensis	Cd	A	Zacchini et al. 2009
	Populus × euramericana	Cu	A	Borghi et al. 2007
		Zn	T (partial)	Di Baccio et al. 2003
		Cr, Fe	T (partial)	Giachetti & Sebastiani 2006
	Populus × generosa	Cd	A	Zacchini et al. 2009
	Salix dasyclados	Cd	A	Landberg & Greger 1994
		Zn	T	Vyslouzilová et al. 2003
	Salix fragilis	Cd, Zn	T	Meers et al. 2007
	Salix miyabeana	Zn	T	Desjardins et al. 2016
	Salix nigra	Ag	A	Guidi Nissim et al. 2014b
	Salix schwerinii	Cd, Zn	T	Meers et al. 2007
	Salix viminalis	Cd	A	Landberg & Greger 1994
		Zn	T	Vyslouzilová et al. 2003
	Senna siamea	Pb	A	Yongpisanphop et al. 2017
Shrubs	*Buddleja asiatica*	Pb	T	Waranusantigul et al. 2008
	Buddleja paniculata	Pb	T	Waranusantigul et al. 2008
	Catharanthus roseus	Ni, Pb	A	Subhashini & Swamy 2013
	Euonimus japonicus	Cd	A	Zeng et al. 2018
	Euphorbia milii	Cr	T	Ramana et al. 2015
	Ligustrum vicaryi	Cd	A	Zeng et al. 2018
	Lonicera japonica	Cd	T	Liu et al. 2009
	Loropetalum chinense	Cd	A	Zeng et al. 2018
	Osmanthus fragrans	Cd	A, T	Zeng et al. 2018, Wu et al. 2011
		Pb	T	Wu et al. 2011
	Rhapis excelsa	Cd	A	Zhang et al. 2010
	Ricinus communis	Ni	A	Adhikari & Kumar 2012

creasing levels of Cu up to 100 µM resulted in a general reduction of plant growth and that the metal was mainly accumulated in the root system at all Cu levels (Borghi et al. 2007). Several poplar species (*Populus alba, P. deltoides, P. nigra, P. trichocarpa, P. × generosa, P × canadensis*) showed the capacity to accumulate cadmium (Cd), albeit with different effectiveness (Zacchini et al. 2009). Poplars also demonstrated phytoextraction capacity for zinc (Zn – Di Baccio et al. 2003).

Cadmium accumulation was also demonstrated in *Cinnamomum camphora,* that showed the maximum Cd content in stems and leaves (Zeng et al. 2018).

In a greenhouse experiment on ornamental plants, four shrubs (*Osmanthus fragrans, Ligustrum vicaryi, Loropetalum chinense* var. *rubrum*, and *Euonymus japonicus* cv. Aureo-mar) were tested in the presence of Cd. The results showed that these species can grow normally at Cd soil concentrations lower than 24.6 mg kg^{-1}. The metal accumulated principally in the roots, with the highest amount detected in *Euomymus* (Zeng et al. 2018).

Rhapis excelsa, Camellia polyodonta and *C. gigantocarpa* were tested for soil Cd absorption in a pot experiment with different Cd treatments (10, 25 and 50 mg kg^{-1}). The three species never showed any toxic symptom and grew well at all Cd concentrations. Cadmium contents was higher in the roots than in the stems and leaves. At 50 mg kg^{-1} Cd concentration, the Cd content in the roots of *Rhapis excelsa* was the highest amongst all the tested species and 7.05 times higher than that at 10 mg kg^{-1} Cd concentration (Zhang et al. 2010). *Lonicera japonica* plants exposed to Cd concentrations up to 50 mg L^{-1} did not show significant differences (compared to control) in height and dry biomass of leaves and roots. TIs were all above 0.8 and the high BF and TF justified the proposal to include the species in the list of potential Cd accumulators (Liu et al. 2009).

The ornamental shrub *Euphorbia milii* tolerated up to 75 mg of applied Cr per Kg soil, and was efficient in translocating Cr from roots to shoots. Plant death occurred when higher metal concentrations were used (Ramana et al. 2015).

Buddleja asiatica is known to display a high accumulation capacity and tolerance for lead. This species, and the related ornamental *B. paniculata,* were therefore investigated in a hydroponic culture, in the presence of 10 or 20 mg L^{-1} Pb. Both species showed increased biomass and Pb concentrations in the roots of 12.1 and 21.7 mg kg^{-1}, respectively. In a 3-month pot experiment, using three different soils with various Pb levels (10.6, 31.3, and 89.1 mg kg^{-1}) the two species of *Buddleja* had a slight decrease in survival rates at the highest Pb concentration, but a general regular growth. In a 6-month field trial experiment conducted in Pb-contaminated sites (Pb content: 95-101 mg kg^{-1}), both *Buddleja* species showed 100% survival, increased biomass production and phytoextraction capacity (TF) from 1.1 to 2.3 (Waranusantigul et al. 2008). *Ricinus communis*, as well, showed the capacity to uptake nichel (Ni) from contaminated soils, and was therefore classified as an accumulator (Adhikari & Kumar 2012); this species also demonstrated a great potential for Cd removal, due to its features of fast growth, high biomass and considerable absorption and accumulation (Huang et al. 2011).

It is more common for a soil to be affected by the pollution of a mix of heavy metals; some case studies are therefore reported below concerning woody plants.

In a pot experiment with seven willow clones, significant differences between clones were found in cadmium and zinc accumulation. Cd and Zn were transferred from roots to aboveground tissues (mainly leaves), leading to the conclusion that willows are suitable phytoextractors of moderately contaminated soils (Vyslouzilová et al. 2003). Another study tested the ability of five woody species to extract heavy metals (copper, zinc or cadmium) from a polluted soil. *Salix viminalis* and *Betula pendula* had already demonstrated phytoextraction ability for Zn and Cd, while the phytoextraction capabilities of *Alnus incana, Fraxinus excelsior* and *Sorbus mougeotii* were unknown. The results suggest that none of these species transferred Cu to the shoots. *Salix* and *Betula* were able to transfer Zn and Cd to leaves and twigs, while *Al-*

nus, *Fraxinus* and *Sorbus* excluded them from their above-ground tissues (Rosselli et al. 2003). A pot experiment involving *Salix miyabeana* grown in brownfield soils differentially contaminated with Ag, Cu and Zn (up to 113.60, 47.50, and 117.00 mg kg^{-1} respectively), demonstrated a potential capability for phytoremediation, since a high concentration of Zn (119.96 ± 20.04 mg kg^{-1}) was detected in above-ground plant tissues at the end of the treatment (Desjardins et al. 2016).

Five species of *Salix* were tested in a pot experiment to compare their capacity to extract and accumulate Cd, Zn, Cu, Ni, Pb, and chromium (Cr). *Salix schwerinii* "Christina", *S. dasyclados* "Loden" and *S. fragilis* "Belgisch Rood" showed the highest Cd and Zn accumulation and were therefore considered good candidates for remediation (Meers et al. 2007). In an experiment on a strongly polluted soil (up to 18 mg Cd kg^{-1}, 1400 mg Cu kg^{-1}, 500 mg Pb kg^{-1} and 3300 mg Zn kg^{-1}), *Salix viminalis* demonstrated a high translocation of Cd (≥80 mg kg^{-1}) and zinc (≥3000 mg kg^{-1}) to the leaves alongside reduced growth. In contrast, when grown in a moderately polluted soil (2.5 mg Cd kg^{-1} and 400 mg Zn kg^{-1}), *S. viminalis* extracted 0.13% of total Cd and 0.29% of total Zn per year and exhibited vigorous growth (Jensen et al. 2009). In another study on eight *Salix viminalis* clones and one *S. alba* clone, differences emerged between clones in biomass production and accumulation efficiency, with two *S. viminalis* clones demonstrating a superior capacity to accumulate five heavy metals (Cd, Cu, Hg, Pb, Zn – Mleczek et al. 2010).

Poplars also showed some potential for phytoextraction of chromium and iron (Giachetti & Sebastiani 2006), cadmium and lead (Houda et al. 2016).

The accumulation of heavy metals has been assessed in leaves of some ornamental trees and shrubs used in districts of Turkey affected by high heavy metal pollution, finding significant differences among the tested species. The highest concentrations (mg kg^{-1}) of Zn, Cu, Cd and iron (Fe) were observed in *Cedrus libani* (618.0), *Betula alba* (106.3), *Salix alba* (24.5) and *Eleagnus angustifolia* (0.3), while the highest Ni (6.4) and Pb (3.8) contents were found in *Pyracantha coccinea* (Gülser et al. 2011).

A pot experiment was carried out on osmanthus (*Osmanthus fragrans* var. *thunbergii*), cultured in substrate supplemented with different concentrations of Cd, Pb, Zn, and Cu. The species showed high Cd and Pb transfer efficiencies and a limited transfer of Zn and Cu in the presence of Cd, suggesting the possible utilization of osmanthus in phytoremediation applications (Wu et al. 2011).

Tab. 2 - Ornamental plants for the phytoremediation of heavy metals: herbaceous species. (A): accumulation; (T): translocation.

Group	Species	Pollutants	A / T	References
Herbaceous	*Althaea rosea*	Cd	T	Liu et al. 2008
		Pb	A	Liu et al. 2008
	Alternanthera bettzickiana	Cd, Pb	T	Tauqeer et al. 2016
	Alyssum maritima	Cr	T	Budak et al. 2011
	Amaranthus caudatus	Ni	T	Bosiacki & Wojciechowska 2012
		Cd	T	Cay 2016
	Aptenia cordifolia	Cr	T (partial)	Budak et al. 2011
	Calendula officinalis	Cd	A	Liu et al. 2008
		Cr	T (partial)	Ramana et al. 2013
		Cu	T	Goswami & Das 2016
	Canna indica	Pb, Zn Cr, Ni, Cd	T	Subhashini & Swamy 2014
			A	Subhashini & Swamy 2014
	Chlorophytum comosum	Cd	T	Wang et al. 2012
		Zn	T	Tao et al. 2011
	Gomphrena globosa	As	A	Signes-Pastor et al. 2015
	Helianthus annuus	Cu	T	Forte & Mutiti 2017
		Cd	T	Bosiacki 2008
		Ni	T	Mohammadzadeh et al. 2014
		As	T	Reed et al. 2013
	Hydrangea paniculata	Cu	T	Forte & Mutiti 2017
	Impatiens balsamina	Cr	T (partial)	Miao & Yan 2013
	Iris lactea	Cd	A	Han et al. 2007
	Iris pseudacorus	Cr, Zn	A	Caldelas et al. 2012
	Mesembryanthemum crystallinum	Ni	T (partial)	Amari et al. 2016
	Mirabilis jalapa	Cr	T	Miao & Yan 2013
	Salvia splendens	Cd	T	Bosiacki 2008
	Polianthe tuberosa	Cd	T	Ramana et al. 2012
	Pteris vittata	As	T	Zeng et al. 2019
	Sedum alfredii	Zn	A	Cheng & Zhou 2014
	Syngonium sp.	As	A	Huq et al. 2005
	Tagetes erecta	Cd	A	Bosiacki 2008
		Ni	T	Bosiacki & Wojciechowska 2012
		As	T	Reed et al. 2013
	Tagetes patula	As	A	Huq et al. 2005
	Tagetes erecta × patula	As	T	Chintakovid et al. 2008
	Vinca rosea	Cr	T	Ehsan et al. 2016a
	Zinnia elegans	Pb, Cr	T	Ehsan et al. 2016b
		As	A	Signes-Pastor et al. 2015

Herbaceous species

Cadmium is one of the most widespread contaminating metals in soils. Its action was investigated on three ornamental plants, *Tagetes erecta, Salvia splendens*, and *Abelmoschus manihot*, finding a little effect on seed germination of the three species and on shoot elongation of *S. splendens*, but a significant inhibitory effect on root elongation of all the tested plants and on shoot elongation of *T. erecta*. The calculated Cd-tolerance indices led to the conclusion that *A. manihot* was the most tolerant plant to Cd while *S. splendens* the most sensitive (Wang & Zhou 2005). Conversely, Bosiacki (2008) found high Cd accumulation in leaves and shoots of *Salvia splendens,* as well as in inflorescences of *Helianthus annuus,* which is one of the most studied ornamental species for remediation purposes, while *Tagetes erecta* proved a moderate capacity to extract and accumulate Cd, with the greatest amount found in roots, then in leaves and shoots, and the lowest in inflorescences (Bosiacki 2008). Five concentrations of Cd (0, 25, 50, 75 and 100 mg kg^{-1} soil) were tested with three varieties of tuberose, finding that this metal did not produce any toxic macroscopic symptoms in all the three varieties. Having shown Cd accumulation in the shoots higher than 100 µg g^{-1} dry weight and a ratio of Cd >1 in the shoots to bulbs, this species has to be considered as a potential effective Cd accumulator (Ramana et al. 2012). *Chlorophytum comosum* is a potential Cd accumulator; in a pot experiment it showed a TI above 100 in soil Cd concentration of 100 mg kg^{-1}, and at Cd concentration up to 200 mg kg^{-1}, the Cd content in roots and aboveground tissues reached 1522 and 865 mg kg^{-1}, respectively (Wang et al. 2012). A detailed work on the relation between *Canna indica* and Cd, demonstrated its considerable potential in cadmium accumulation, but the root concentration factor was higher than the BF, indicating a limited translocation (Solanki et al. 2018). *Calendula officinalis* was found to grow normally in soils containing 100 mg kg^{-1} Cd, with high metal accumulation in roots and shoots. In a hydroponic culture, for *Althaea rosea* the highest Cd accumulation was detected in shoots, and for both *Calendula officinalis* and *Althaea rosea,* a good accumulation capacity and tolerance to Pb were also observed (Liu et al. 2008). *Iris lactea* var. *chinensis* was found to accumulate Cd in leaves and roots after treatment with a hydroponic culture with 0 to 160 mg L^{-1} Cd treatment, showing a TI higher than the value detected in the other species tested, *I. tectorum* (Han et al. 2007).

The effects of increasing doses of Ni (up to 300 mg dm^{-3} substrate) were investigated in three selected ornamental plants: *Tagetes erecta, Helianthus annuus*, and *Amaranthus caudatus*, finding that the highest amounts of Ni were accumulated in leaves of tagetes and amaranth, and in inflorescences of sunflower. Globally, tagetes showed the highest Ni uptake at concentrations of 25 and 50 mg dm^{-3}, while for the substrates with an addition of 75, 150 or 300 mg Ni dm^{-3}, the greatest accumulation was recorded in amaranth (Bosiacki & Wojciechowska 2012). An interesting ornamental halophyte, *Mesembryanthemum crystallinum,* was compared to the model species *Brassica juncea*, growing the plants for 3 months on a soil containing 0, 25, 50, and 100 mg kg^{-1} $NiCl_2$. Ni reduced the growth activity of both species, but to a lower extent in *M. crystallinum*. Ni accumulated mainly in roots and the fraction translocated to shoots was higher in *M. crystallinum* than in *B. juncea* (Amari et al. 2016). *Catharanthus roseus* irrigated for 60 days with aqueous solutions of nickel and lead showed high accumulation of the two metals by roots, and to a lesser extent in stems and leaves (Subhashini & Swamy 2013).

Chlorophytum comosum seedlings treated with Zn showed inhibition of root length and fresh and dried plant weight at all the tested Zn concentrations (from 200 to 2000 mg kg^{-1}), while the length of aboveground tissues and the volume of roots declined with the Zn dose. TI was above 50 at Zn concentrations lower than 600 mg kg^{-1} (Tao et al. 2011).

Aptenia cordifolia, Brassica juncea, Brassica oleracea, and *Alyssum maritima* were studied for their capacity to uptake and translocate hexavalent chromium (VI) supplied by irrigation. Increases in the Cr concentration significantly enhanced both accumulation and translocation of the metal in the roots and shoots of the tested species, with highest values recorded in the shoots of *Alyssum maritima* and in the roots of *Brassica juncea* (Budak et al. 2011). In a study on exposure to Cr of four ornamental plants, calendula, chrysanthemum, aster and dahlia, the metal caused a drastic reduction of plant growth at 10 mg kg^{-1}, and at 25 mg kg^{-1} was responsible of a diffuse mortality in chrysanthemum. Overall, only calendula could be considered a possible candidate for phytoremediation of soils contaminated with low level of Cr (Ramana et al. 2013). In another experiment on three ornamental species cultured in pots containing substrate with four Cr concentrations, *Impatiens balsamina* showed a decline in the biomass as the dose of Cr increased, while in *Mirabilis jalapa* and *Tagetes erecta* the four treatments did not impact growth; TF and BF of *M. jalapa* were greater than 1, indicating this species is a good candidate for the remediation of Cr-polluted soils (Miao & Yan 2013). In *Vinca rosea* grown in pots containing soil with levels of chromium from 10 to 60 mg kg^{-1}, plant height, fresh and dry weight decreased with high contamination levels of chromium. TFs were found to be lower than 1 for low metal concentrations and higher than 1 with Cr concentrations from 30 to 60 mg kg^{-1} (Ehsan et al. 2016a).

In the presence of Pb, the remediation potential of *Vinca rosea* was higher than 1 at Pb concentrations from 20 to 40 mg kg^{-1} and lower with 50 to 90 mg kg^{-1} (Ehsan et al. 2016b). Similar results were obtained with zinnia (*Zinnia elegans*) grown in pots containing soils with different levels of lead and chromium. Plants grown in the presence of lead were healthier compared to plants grown in Cr-contaminated soils. TF was also higher in Pb-contaminated soils (Ehsan et al. 2016c).

For copper remediation, *Calendula officinalis* showed a high tolerance (up to 400 mg kg^{-1}) to copper contamination, with the maximum Cu accumulation (4.67 and 3.99 mg g^{-1} in leaves and roots, respectively) in soil treated with 300 mg Kg^{-1}, a level considerably higher than the amount of 1 mg g^{-1} which defines Cu hyperaccumulators (even the TF was >1 at all Cu doses – Goswami & Das 2016).

For arsenic remediation, *Tagetes patula* and *Syngonium* sp. were tested in pots with soil containing As up to 10 mg kg^{-1}. The plants showed significant As accumulation, particularly in roots, with an average TF of 0.91 for marigold and 0.75 for arum (Huq et al. 2005). A further experiment on a triploid hybrid *Tagetes erecta × patula* showed that arsenic was found mostly in leaves (46.2%) with the lowest As content (5.8%) in flowers. The hybrid plants continued to grow vigorously in the As-contaminated substrate (Chintakovid et al. 2008). Several ornamental plant species were tested for their potential for As remediation in a hydroponic system: iris (*Iris savannarum*), switchgrass (*Panicum virgatum*), *Tithonia rotundiflora, Coreopsis lanceolata*, sunflower (*Helianthus annuus*), and marigold (*Tagetes erecta*). *Tithonia* and *Coreopsis* showed respectively 85% and 65% reductions in dry weight at 0.75 mg L^{-1} As concentration. At the highest As rate, marigold and sunflower had uptake ratios of 7.4 and 16.6, respectively, and TF near one, allowing consideration of these species as interesting candidates for As phytoremediation (Reed et al. 2013).

The effects of As were tested under hydroponic conditions on two other flowering species, *Gomphrena globosa* and *Zinnia elegans*. Arsenic principally accumulated in the roots, followed by leaves, stems and flowers, indicating that these species were arsenic tolerant plants but not potentially As-remediating (Signes-Pastor et al. 2015).

For the phytoremediation of mixed heavy metals, a study on *Alternanthera bettzickiana*, a species commonly used as an ornamental edging plant, showed a good accumulation of Cd and Pb at concentrations up to 1.0 mM, with total uptake of both metals higher in shoots than roots (Tauqeer et al. 2016). Based on BF and TF, also *Canna indica* was indicated to be a good accumulator of Cd, Pb, Ni, Zn, and Cr, with high TF for Ni and Cr (Subhashini & Swamy 2014). The macrophyte *Iris pseudacorus* is considered to be a candidate for Cr rhizofiltration and Zn phytoextraction, having shown a good tolerance and accumulation capacity towards these two metals. Plants grown in a nutrient solution containing $ZnCl_2$ or $CrCl_3$ from 0 to 200 µg ml^{-1} survived and accumulated Cr and Zn in all tissues (Caldelas et al. 2012). In a greenhouse experiment, *Hydrangea paniculata* and *Helianthus annuus* accumulated significant amounts of Cu and Pb. *Helianthus* showed high accumulation of heavy metals in the shoots and efficacious translocation to the leaves, while Pb was not as easily taken up and translocated as Cu. *Hydrangea* stored more metals in stems than in leaves, showing a lower translocation ability than *Helianthus* (Forte & Mutiti 2017). *Tanacetum vulgare* showed environmental adaptability on high industrial pollution and an interesting capacity of mercure and lead uptake (Stević et al. 2010).

Organics

Phytoremediation of organic contaminants generally involves few classes of compounds, which are principally chlorinated solvents, petroleum hydrocarbons (PHCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and explosives. Contamination of soils with such products can have several causes, the main ones being uncontrolled industrial activity, intensive farmland exploitation and percolation of polluted waters of various origins. The most common contaminated soils are probably former industrial sites, which may display residual pollutants at different soil depths.

Over recent years, positive results have emerged regarding the capacities of several plant species to degrade specific organic compounds. According to Shimp et al. (1993) it is fundamental to understand the physical, biological, and chemical relationships that determine the fate of each organic contaminant in the rhizosphere.

In this section some case examples concerning ornamental woody and herbaceous species are illustrated (Tab. 3).

Tab. 3 - Ornamental plants for the phytoremediation of organic compounds. (B[a]P): benzo[a]pyrene; (DDT): dichlorodiphenyltrichloroethane; (HCH): hexachlorocyclohexane; (PCB): polychlorinated biphenyls; (PAH): polycyclic aromatic hydrocarbons; (TCE): trichloroethylene; (TPH): total petroleum hydrocarbons.

Group	Species	Pollutants	References
Trees	*Itea virginica*	Oryzalin	Baz & Fernandez 2002
	Populus deltoides × nigra	TCE	Doty et al. 2017
		Dioxane	Aitchison et al. 2000
		PCB	Liu & Schnoor 2008
		Atrazine	Burken & Schnoor 1997
	Populus hybrids	HCH	Bianconi et al. 2011
	Salix alba	Oryzalin	Baz & Fernandez 2002
	Salix miyabeana	PAH, PCB	Guidi et al. 2012
	Salix sachalinensis	PAH, PCB	Guidi et al. 2012
Shrubs	*Cytisus striatus*	HCH	Becerra-Castro et al. 2013
	Nerium oleander	Fluoride	Khandare et al. 2017
	Ricinus communis	DDT	Huang et al. 2011
Herbaceous	*Aloe vera*	Formaldehyde	Liu et al. 2007
	Aster amellus	Dyes	Khandare et al. 2011
	Canna indica	Triazophos	Cheng et al. 2007
	Chrisanthemum morifolium	Benzene, Formaldehyde	Liu et al. 2007
	Crassula portulacea	Benzene	Liu et al. 2007
	Dianthus chinensis	Sulfur dioxide	Liu et al. 2007
	Echinacea purpurea	TPH	Liu et al. 2012
	Festuca arundinacea	TPH	Liu et al. 2012
	Gaillardia aristata	TPH	Liu et al. 2012
	Gaillardia grandiflora	Dyes	Chandanshive et al. 2018
	Impatiens balsamina	TPH	Cai et al. 2010
	Iris lactea	TPH	Cheng et al. 2017
	Medicago sativa	TPH	Liu et al. 2012
	Mirabilis jalapa	B[a]P	Sun & Zhou 2016
	Portulaca grandiflora	Dyes	Chandanshive et al. 2018
	Portulaca oleracea	Fluoride	Khandare et al. 2017
	Tagetes patula	Dyes	Chandanshive et al. 2018
		B[a]P	Sun & Zhou 2016

Woody species

In a soil contaminated with a mix of PAHs, PCBs and heavy metals, two clones of different willow species (*Salix sachalinensis* SX61 and *S. miyabeana* SX64) gave encouraging growth and survival results after a single growing season planted in soils with high concentrations of both organic and heavy metal contaminants (Guidi et al. 2012). *Salix alba, S. gracilistyla* var. *melanostachys* and *Itea virginica* were treated for 9 days with a 4 mg L^{-1} suspension of two herbicides (isoxaben and oryzalin). Isoxaben reduced the growth rate of white willow and *I. virginica*, while both herbicides reduced the growth index for *S. gracilistyla*. The final dry weight was lower for all taxa when exposed to both herbicides, but the set of data suggest that *S. alba* and *I. virginica* display some attitude in the remediation of oryzalin (Baz & Fernandez 2002).

In hydroponic studies, hybrid poplar cuttings (*Populus deltoides × nigra*) removed 54.0% of dioxane (1,4-Dioxane), a persistent environmental pollutant, indicating the potential of this species in the phytoremediation of sites contaminated by dioxane and other hydrophilic pollutants (Aitchison et al. 2000). *P. deltoides × nigra* showed also the capacity to accumulate PCBs, observing that mono- and di-chlorinated congeners were primarily translocated from the roots to the secondary stems, tri-chlorinated to the main stem but not farther, and tetra-chlorinated were bound strongly to root tissues (Liu & Schnoor 2008). With the same hybrid, the capacity to uptake, hydrolyze and dealkylate atrazine to less toxic metabolites was detected by Burken & Schnoor (1997).

Nerium oleander (Fig. 3b) resulted able to remove 92% of fluoride from a 10 mg L^{-1} NaF solution, within 15 days (Khandare et al. 2017). *Ricinus communis* showed a great potential for removing dichlorodiphenyltrichloroethane (DDT) from contaminated soils, with different effectiveness depending on the genotype (Huang et al. 2011).

Herbaceous species

In a study on *Aster amellus*, the capacity was observed to decolorize the sulfonated azo dye Remazol Red. After the cultivation period, four non-toxic metabolites were identified; this indicated that the plant can be used for cleaning textile effluents (Khandare et al. 2011). In another study on phytoremediation of dyes from textile wastewater, *Tagetes patula, Aster amellus, Portulaca grandiflora* and *Gaillardia grandiflora* were tested separately, finding that within 30 days they reduced the color value by 59, 50, 46 and 73%, respectively. Only a minor decrease in plant growth was observed, suggesting that these ornamental species could be an interesting solution for use on the ridges of constructed wetland for the treatment of dyes (Chandanshive et al. 2018).

Tagetes patula and *Mirabilis jalapa* were tested in a pot experiments to evaluate their remediation capacity towards benzo[a]pyrene (B[a]P). The dry biomass of the two species increased at low B[a]P doses and then reduced with increasing concentrations. It also emerged that the tolerance to this pollutant was greater at the plant's flowering and mature stages compared with the seedling stage. Significantly positive correlations were found between the B[a]P content of roots, stems, leaves and shoots to soil B[a]P concentrations (Sun & Zhou 2016).

For the treatment of PHCs-contaminated soil, *Iris dichotoma* and *I. lactea* were investigated in a pot culture experiment. These species were found to promote degradation of fractions of PHCs. *I. lactea* tolerated high concentration of PHCs (40,000 mg kg^{-1}) and showed a good degradation rate of petroleum hydrocarbons. In contrast, *I. dichotoma* tolerated lower PHC concentrations, with a lower rate of total petroleum hydrocarbons (TPHs) degradation (Cheng et al. 2017). *Impatiens balsamina* was also tested for petroleum remediation, finding that after a 4-month culture period in pot, the average TPHs degradation rate was up to 18.13-65.03%, greater than that (10.20-35.61%) of natural degradation in the control treatment (Cai et al. 2010).

In a pot-culture experiment to assess the TPHs-phytoremediation potential of 14 ornamental plants in petroleum-contaminated soil, it emerged that *Gaillardia aristata, Echinacea purpurea, Festuca arundinacea* and *Medicago sativa* were effective in reducing TPHs (and related compounds) in 10 mg kg^{-1} TPH-contaminated soil. Removal rates after 30 days were between 37.2 and 49.4%, (control only 12.9%). Removal rates of TPH composition were also significantly higher than controls, and Fourier transform infrared spectroscopy confirmed the presence of oil in the plant tissues (Liu et al. 2012).

Plants of *Portulaca oleracea* were able to remove fluoride from a 10 mg L^{-1} NaF solution, within 15 days by 73%; the higher fluoride concentrations showed lower removal rates (Khandare et al. 2017). *Canna indica* was studied in a hydroponic system for testing its ability to remediate triazophos contamination, a harmful pesticide. After 21 days of exposure, a significant percentage of the substance was removed from the substrate (Cheng et al. 2007). Among numerous other cases, *Chrysanthemum morifolium* can simultaneously absorb and purify benzene and formaldehyde to a large extent, while *Aloe vera* var. *chinensis* can absorb formaldehyde; *Crassula portulacea* is active towards benzene, and *Dianthus chinensis* towards sulfur dioxide (Liu et al. 2007).

Wild ornamentals with high ornamental value, fast growth and extensive root systems are, in general, a suitable solution, when deemed capable of degrading contaminants, due to their broad adaptability, widespread distribution and ease of cultivation (Cheng & Zhou 2014).

Consociations

Soils are often polluted by different metals or organic compounds, so phytoremediation may require multiple plant species and ecotypes since most of the plants suited to this purpose show an aptitude to accumulate only one or a few pollutants.

A pot experiment was carried out with the aim of determining the phytoextraction potential of the hyperaccumulator *Pteris vittata* when co-planted with a woody tree (*Morus alba* or *Broussonetia papyrifera*) in soil contaminated with Cd, Pb, Zn, or As. The uptake of As was significantly increased when co-planted with *Morus* or *Broussonetia* (by 80.0% and 64.2% respectively). However, co-plantation did not have a promoting effect on the metal accumulation of both *M. alba* L. and *B. papyrifera* (Zeng et al. 2019).

In the case a huge expanse of land, a consociation of grasses could be a good solution. Work by Maila et al. (2005) demonstrated the potential of the grass species *Brachiaria serrata* and *Eleusine corocana* in decontaminating PAHs-contaminated soil. It was found that after a ten-week treatment the naphthalene concentration was undetectable in the "multispecies" vegetated soil compared to 96% removal efficiency in the monoplanted treatment and 63% in the control. For the same contaminants, ryegrass (*Lolium perenne*), white clover (*Trifolium repens*) and celery (*Apium graveolens*) were tested, finding that the remaining percentage of PAHs in mixtures was significantly lower than those in monocultures and non-planted soils (Meng et al. 2011). Another work proved that *Brassica campestris* showed low removal of PAHs, while *Medicago sativa* had the highest potential for remediation of phenanthrene and *Trifolium repens* for pyrene; but mixed cropping (rape with white clover or alfalfa, *Medicago sativa*) showed far better results than single cropping for the remediation of PAHs (Wei & Pan 2010).

Concerning polychlorinated biphenyls (PCB), Terzaghi et al. (2019) demonstrated that *Festuca arundinacea* cultivated by adding compost or in consociation with *Cucurbita pepo* ssp. *pepo* and *Medicago sativa* cultivated with *Rhizobium* spp. and mycorrhizal fungi reduced total PCB concentrations by about 20%, with a significant depletion in a high number of PCB congeners. In an *in vitro* experiment, *Petunia grandiflora* and *Gaillardia grandiflora*, when cultured together, showed a great effectiveness in degrading and removing a dye mixture from the substrate in 36 h, with results significantly higher than those detected from the cultivars in isolation (Watharkar & Jadhav 2014).

Enhanced phytoremediation

It is worth noting that, for several tree species, the plant-fungi-bacterium system represents an important interactive balance for the implementation of the phytoremediation activity, as recently observed in hybrid poplar (*Populus deltoides* × *P. nigra*) and willow (*Salix purpurea* subsp. *lambertiana* – Guarino et al. 2018). *Eucalyptus camaldulensis* also demonstrated increased effectiveness in extraction, uptake, and translocation of Cd when inoculated with arbuscular mycorrhiza fungi or plant growth promoting rhizobacteria (Motesharezadeh et al. 2017). As an example for herbaceous species, *Helianthus annuus* inoculated with *Bacillus safensis* and/or *Kocuria rosea* was tested in soil with four levels of Ni concentrations (0, 150, 300, and 450 mg kg^{-1}), finding that the highest Ni uptake was observed at Ni 300, when the sunflower seed was co-inoculated by *B. safensis* + *K. rosea* (Mohammadzadeh et al. 2014).

With regard to organic pollutants, endophyte-assisted phytoremediation of a site contaminated with Trichloroethylene (TCE) was studied using *Populus deltoides* × *nigra* inoculated with a strain of *Enterobacter*. The inoculated trees showed an increased growth and a reduced toxic effect compared to control, excreting 50% more chloride ions into the rhizosphere, a good signal of an increased TCE metabolism *in planta*. A significant decrease in the concentration of TCE and its derivatives from the tree-associated groundwater plume was also detected (Doty et al. 2017). With hybrid poplar clones associated to *Arthrobacter* strains, the possibility to rhizoremediate soils contaminated with the insecticide exachlorocyclohexane (HCH) isomers was demonstrated, stressing the importance of *in situ* pre-selection of the best candidate plants and bacteria strains (Bianconi et al. 2011). The shrub *Cytisus striatus*, also in association with microbial inoculants (*Rhodococcus erythropolis* and *Sphingomonas* sp.) showed an interesting activity on the dissipation of the HCH. HCH concentration in soil was reduced after plant growth and, more significantly, with inoculated plants (Becerra-Castro et al. 2013).

Many studies assess the remediation of metal-polluted soil with the help of several agents, mainly synthetic organic chelates, but also natural organic compounds and inorganic products, that overcome limitations to phytoremediation due to low metal solubility and availability (Leštan et al. 2008). Nevertheless, the high cost of these products and the possible toxic outflow into the environment have to be taken into account. Below, a few cases are mentioned as examples.

The application to soil of sodium dodecyl sulfate (SDS), ethylenediaminetriacetic acid (EDTA) and ethylenegluatarotriacetic acid (EGTA) to enhance Cd remediation was studied with *Calendula officinalis*. EDTA was observed to be toxic to the plants, while the addition of SDS and/or EGTA resulted in significantly increased plant biomass ($p < 0.05$). Almost all of the treatments containing SDS or/and EGTA led to an increase in the total Cd content in the plants (Liu et al. 2010). For enhancing the uptake and translocation of Cd, Cr, and Ni, two cultivars of *Helianthus annuus* were used in conjunction with EDTA and citric acid (CA) as chelators. EDTA at a concentration of 0.1 g kg^{-1} produced the best results for both cultivars, while the highest CA concentrations had a phytotoxic effect (Turgut et al. 2004). In *Althaea rosea,* EDTA and tannic acid led to higher heavy metal removal of Cd, Ni, Pb and Cu from an artificially contaminated soil, with significant heavy metal accumulation in stems and leaves (Cay et al. 2015).

In view of a more environmentally friendly choice, less harmful products can be used. *Amaranthus caudatus* showed an increased capacity to uptake cadmium when solutions of tea saponin (extracted from camellia seeds) or EDTA were supplied to the soil, detecting TF >1, with better values for saponin (Cay 2016). In a pot experiment with *Helianthus annuus*, the effects of culture in a soil contaminated with Cd and Zn and amended with swine manure, salicylic acid (SA), or potassium chloride (KCl) were assessed. The three amendments increased sunflower biomass, height, and flower diameter. Manure significantly decreased the bioaccumulation coefficient (BCF) of Cd and Zn, while KCl increased the BCF of Cd. Either swine manure and KCl increased Cd and Zn translocation from roots to aboveground parts, while swine manure and SA reduced the Cd/Zn ratios in flowers (Hao et al. 2012).

Within this wide frame, the development of transgenic plants with enhanced phytoremediation capacity is also a possible approach (Shah & Pathak 2019), but the general opposition of public opinion to the introduction of genetically modified plant species has to be carefully considered.

Conclusions

The use of ornamental (woody and flowering) plants for the phytoremediation of urban and periurban environments shows many positive aspects that have been highlighted in this work. The "multipurpose" function of these plants plays an important role in the environmental restoration and aesthetic enhancement, but the success of the phytoremediation strategy lies in the careful choice of species and/or genotypes matching the specific environments and pollutants.

From the review of the available literature it emerged that, trees in general, even if not classifiable as hyperaccumulators, display a greater potential for exploitation in phytoremediation compared to herbaceous species. This is simply due to the greater biomass growth potential and rooting system depth of woody species. On the other hand, herbaceous species are characterised by higher variability and plasticity, and offer the possibility of frequent replacements.

Among trees, Salicaceae are probably the most investigated species for phytoremediation purposes (Marmiroli et al. 2011). Great interest is addressed to *Salix* spp., while poplars are now considered to be model species, comparable to *Arabidopsis* among herbaceous plants. Due to their adaptability to different environments, fast growth, ease of propagation and good performances when exposed to some pollutants, these species might possess some useful practical applications in phytoremediation, particularly in peri-urban areas. For urban environments, several other woody species are probably more suitable, being characterised by a higher ornamental value. Among flowering herbaceous plants, the possibility of choice is significantly wider; for instance, the Asteraceae family shows a wide range of interesting species (Nikolić & Stevović 2015) with sunflowers having been studied in depth and demonstrating a high capacity to remediate specific pollutants.

Several interesting species are yet to be explored, and special attention should be paid to the huge possibilities offered by plant consociation, including aspects related to modifications in the structure of the rhizosphera. Within this topic, possible associations between herbaceous plants, trees or between herbaceous and woody plants are practically infinite, allowing a perfect adhesion to the needs of each specific environment, and making phytoremediation an "aesthetic experience", as proposed by Sleegers (2010).

Finally, efforts are required to overcome problems related to the disposal of contaminated materials and how to limit the costs related to the exploitation of this technique.

In synthesis, phytoremediation could now be seen as part of a multifunctional process that creates a green infrastructure network defining evolving landscapes, not only in the countryside but also in urban environments.

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