Soil and its properties in the urban environment

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Abstract

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Soils in the urban environment have a character antrosoils, technosoils, at best case cultisoils. They are formed most often by reclamation of areas devastated by construction activities (antrosoils). They therefore have a wide range of properties, often unfavorable for the growth of plants. The work states optimal, permissible and undesirable texture, structure, moisture, biotic and some pedochemical features (pH, humus content, Na^+, Mg^{2+}). The following are criteria for evaluating the nutrient content of the soil (N, P, K, Ca, Mg, $CaCO_3$, C_{tot}) and their optimal ratios and limits for 23 other risk elements including heavy metals in the soil. The importance, functions and deficiency of physiologically important trace elements in plants and their contents in the soil are also discussed.

Keywords

greenery of housing estate urban soils, heavy metals, macronutrients, micronutrients

Introduction

Trees in the urban environment perform multiple public benefit functions and are an important component of residential green, serve as edificator and are crucial for improving the human environment. Form an integral organic part of the internal structure of housing estate (Noskovič et al., 2011). Particular attention must be paid to soils of parks, estate and streets, green land of school, medical, military and recreational sports facilities, soils with greenery in enterprises and institutions, greenery of internal housing estate, accompanying greenery and soils along roads (roads, railways), soils with green insulation in manufacturing and technological equipment (industrial green). However, its growth, especially the growth of trees is usually limited by a wide range of negative factors. These primarily include unfavorable soil properties (Nádašský et al., 2003).

Material and methods

Soils in the urban environment have character of antrosoils, technosoils, i.e. man-made soils, at best in situ reformulation soils, thus of cultisoils. The most often they are formed by reclamation of land devastated by construction activities (antrosoils). The field and laboratory investigation of soil properties enable to get a picture of the state of the soil in terms of trees (Szombathová et al., 2007). In the following, the results of our previous research and generalized knowledge of literature are evaluated (Supuka et al., 1991; Macko et al., 2012). Soil characteristics are evaluated from the point of optimal, permissible and undesirable characteristics in relation to the growth of trees in the urban environment.

Results and discussion

The basic soil properties are mainly granularity which is greatly influenced by humidity conditions, the structure, the amount of nutrients bound in the soil and after the plant growth (Craul, 1982; Kuhns, 1987). Optimal soil should be loamy, i.e. the coarse clay, i.e. fraction < 0.01 mm should be between 20 and 45% (Table 1). Admixture of dust fractions (0.01 to 0.05 mm) in the soil is beneficial. Transitions of particle soil composition between planting hole and its surroundings should be gradual or texture would be identical, otherwise problems arise in the supply of water in plant root growth (significant at replanting risen trees). Skeleton content, i.e. fragmentary rock > 2 mm should not be the more than 50% (preferably below 25%). This applies to the rock skelet weathering of which may release nutrients, but not for a variety of quartz gravel and construction residues (fragments of concrete, bricks, etc.). The share of these contaminants should be no more than 30% of the soil (preferably below 10%).

Form and size of aggregates influence the porosity and pore size distribution in soils (Harris, 1992). Crumbing structure with the size of aggregates 1–5 mm is considered for optimum soil structure. The lower limit is more appropriate to drier, upper to humid areas. The proportion of aggregates from 1 to 10 mm should be above 75% in optimal soils and their water stability greater than 50% (Table 1). Most favourable ratio between solid, liquid and gaseous components is 50%: 30 %: 20 % of the soil volume.

Loamy soil should have an optimum moisture content from 20 to 30%, depending on the course of the weather. The wetter the soil, the resilient the foliage to toxicity of easy soluble salts. Water storage capacity should be at least 12% (found in sand), optimum around 20 to 25% (loamy soil) of the volume. To obtain such capacity, porosity should be between 35–50% for the corresponding bulk density of not more than 1.33 for the lower and 1.7 g cm^{-3} for the upper limit (Craul, 1982). The depth of 130–200 cm can be considered as groundwater optimum for tree plants. If it is higher, the trees may suffer from water logging and a lack of air. It is also important to know the capillary uplift which is in the sand and loamy sand 30 cm, in loamy and silty sands from 30 to 80 cm, in sandy loams 80 to 150 cm, in loams 150 to 300 cm, in clay loam 300 to 400 cm and in clays from 400 to 600 cm. In the last two cases, however, capillary lift is so little, that despite its height is less significant to plant due to its slowness. Physiological soil depth should be at least 60 cm for successful growth of trees. Humus content is crucial to soil fertility. It is a source of nitrogen and its high sorption capacity binds other nutrients and microorganisms. In the root zone it should be at least 5%, C:N ratio in the organic-mineral horizon is appropriate below 20. Ratio of bacteria, fungi and actinomycetes should be about 20:1:2. Even azotobacter presence is the indicator of favourable soil (pH above 6).

Table 1. Optimal, permissable and undesirable values of physical and some other soil properties up to 30 cm soil depth

Characteristics	Optimal	Permissable	Undesirable
Carbonate content [%]	1.0–3.0	0.3–5.0	>5.0
Humus content [%]	35– 0	2.0–10.0	<2.0 or >10.0
Skelet content [%]	<25	25–50	>50
Extranous inert skelet	<10	10–30	>30
Skelet size [cm]	<05	0.5–15	>15
Bulk density [g cm^{-3}]	0.8–1.2	1.2–1.5	<0.8 or >1.7
Minimal airiness [%]	15–25	10–15	<10 or >25
Clay content < 0.01 mm [%]	20–45	10–60	<10 or >60
Aggregates share 1–10 cm [%]	>75	50–75	<50
Agregates watersteadyness [%]	>50	20–50	<20
Water table [cm]	130–200	60–130 (200)	<60
Water content in loamy soil [%]	20–30	15–35	<15 or >35
Soil depth [cm]	>60	30–60	<30
B* : H* : A* share	20 : 1 : 25	(10–20) : 1 : (1–2)	<10 : 1 : 1
pH	5–6.5	3.5– 8.5	< 3.5 or >8.5
Water leachate evaporite [%]	<0.3	0.3–0.5	0.5
Na^+ of value T [%]	<5	5–15	>15
Mg^{2+} of value T [%]	<15	15–40	>40

B*, bacteria; H*, mushrooms; A*, actinomycetes.

Soil reaction (pH soils) is summary measures of physical and biological condition of soil. pH in a range of 5–7 may be considered as optimal value for the growth of green vegetation. Unlike agricultural crops, most plants grow well in the acidic region. Coniferous species prefer soil reaction in a range of pH (H_2O) = 5–6, broadleaves pH (H_2O) = 5.5–6.5. For all plants pH below 3.5 or above 8.5 is harmful (indicates presence of mineral acid or increased sodium in the soil sorption complex). If the weight of the water leachate evaporite exceeds 0.5%, the soil is saline, over 1.0% is the heavily salted. If the soil contains more than 0.5% of soluble salts is not suitable for the growth of plants without amelioration. Soils intact by salting contain less than 100 mg dm^{-3} Na^+ (Horký and Soukup, 1975). Soils with withering trees damaged very heavily by winter salting of roads contain over 1,000 mg dm^{-3}. Soda Na_2CO_3, bicarbonates and chlorides are the most dangerous for plants. Over the year, the soil in not totally desalinated (Noskovič and Rakovská, 1986). During the year, Cl^- ion content does not fall more than 10–50% of its initial state (Suchara, 1983). Na^+ in the soil increased chemically lead to alkalization of soil pH and with the carbonates easily creates the mentioned soda. Next Na^+ ion causes peptization of mineral and organic colloids, eroding soil structure, rapid changes in soil moisture and volume, creating drought, muddy, eventually excessive compation (Supuka et al., 1983). Chlorides have the highest proportion of anions (after HCO_3^- which is understandable). Soils with higher salt content should be meliorated by ground gypsum. Acid precipitation and mainly high content of suphates worsen soil properties and damage vegetation (Babošová et al., 2006).

Plants for their growth and development need large amounts of mineral elements that largely derive from the soil. Out of the total number of elements found in the earth's crust only a small portion is needed for plant and animal life. It relates to so-called essential elements. The life cycle of plants without them will not be completed, can not be replaced by another element, and the element is directly involved in the metabolism of plants. They can be divided according to different criteria, and in some respects. The most appropriate classification is according to their content in plants. According to this criterion 14 essential elements are to be essential to higher plants, classified as macronutrients – N, P, K, Ca, Mg, S occurring in higher concentrations (typically over 1% = 10,000 ppm) and micronutrients – Fe, Mn, Cu, Zn, Mo, B, Se and Cl occuring in trace amount.

Macronutrients in organisms are usually involved in the construction of tissues, microelements fulfill specific functions in them. For animals is essential even Ni and Cr. Other elements which are able to compensate the toxic effects of other elements or needed for less specific functions (such as maintenance of osmotic pressure) are classified as useful. Among them belong Na, Si, Co, I and V. Finally, there are the elements harmful, toxic to plants and operating at a minimum rate. These include in particular Cd, Pb, As, Hg (for plants too Cr and Ni).

From the viewpoint of successful plant growth is still interesting, how much nutrients soil contains (Table 2). Out of these, nitrogen is the element which acts most intensively on the growth of plants (Gábriš et al., 1995; Noskovič et al., 2000). Nitrogen supplies are assessed by its total or accessible form, eventually according to the ecological quality of humus (C/N ratio). The content of other nutrients is too important (Table 2).

Table 2. Criteria for evaluating the nutrient content of the soil

Parmeters		Method	Supply			
			Insuficient	Medium	Good	Surplus
C_{Org}	[%]	Tjurin	< 2	2–4	>4	>6
N_{tot}	[%]	Kjeldahl	<0.1	0.1–0.4	>0.4	>1.2
$N_{Available}$	[mg kg^{-1}]	Pazler	<40	40–80	>80	>450
Ratio C/N			>20	10–20	<10	<5
$P_{Available}$	[mg kg^{-1}]	Mehlich III	<55	101–170	171–245	>245
		Mehlich II	<35	75–125	126–160	>160
		Egner-Riehm	<13	13–35	>35	>350
		1% Lemon Acid	<45	45–90	>90	>450
$K_{Available}$	[mg kg^{-1}]	Mehlich III	<130	131–260	261–400	>540
		Mehlich II	<80	131–200	201–300	>300
		Schaschsabel	<50	50–90	>90	>415
		1% Lemon Acid	<60	60–115	>115	>460
$Mg_{Exchangeable}$	[$cmol^+$ kg^{-1}]	NH_4Cl extract	<0.08	0.08– 0.12	>0.12	>2.47
$Ca_{Exchangeable}$	[$cmol^+$ kg^{-1}]	NH_4Cl extract	<1	1–3	>3	>10

Respective supply levels of exchangeable Mg are as follows (insufficient, medium, good in mg kg^{-1}) <20, 20–30 and >30 mg kg^{-1}. Ca content in exchangeable form should be at least 3 $cmol^{+}$ kg^{-1}. The content of carbonate ($CaCO_3$) should not exceed 5%.

In the residential and productive country in which pollution or overload by some element is assumed, the soil should be checked for relative proportions of nutrients or their ratio to carbon. The violation of the natural balance of nutrients leads to their mutual antagonism, despite their sufficient amounts in the soil (Bublinec, 1976; Supuka, 1983). Optimal ratios of elements are as follows in Table 3 (Ratios of oxides were transformed to ratios of element, because current methods provide element concentrations).

Table 3. The optimum ratio of elements in the soil (Weight ratio)

Oxides (Elements)		Ratio	Elements		Ratio
MgO:	CaO	(3–6) : 10	Mg:	Ca	1.5 : 3
	K_2O	3–6		K	4.5–8.5
	P_2O_5	1–5		P	3–14
	N_{Av}	<3		N_{Av}	<2
CaO:	K_2O	5–15	Ca:	K	2–25
	P_2O_5	7–11		P	23–36
	N_{Av}	<10		N_{Av}	<7
C:	N	<20	N:	S	>(4– 5)
	S	>50			

$N_{Av} = N_{Available}$.

In the urban soil, especially the ratio of calcium and magnesium to potassium is disrupted. These ratios and the value of available nutrients must be optimized not only for new plantations, but also at a later stage of development, in the maintenance of greenery. In intoxicated urban soils and along the roads, it is recommended to plant deep rooting tree species. Excessive (toxic) values of other elements in the soil (mg kg^{-1}) in 1 M HCl extract are shown in Table 4. Readings indicate really high element concentrations in the soil. Eight elements (Fe, Mn, Cu, Zn, Mo, B, Cl, Se) stated in the Table 4 form physiologically essential microelements. The values above are a sign of toxic, harmful effects.

Table 4. Above limit levels of other elements [mg kg^{-1}] in the soil releasable in 1 M HCl

Chemical element [mg kg^{-1}]	Above limit value in soil [mg kg^{-1}]
Iron (Fe)	>10,000
Manganese (Mn)	> ,000
Aluminium (Al) – by Sokolov	>800
Chlorine (Cl) – a total content	>460
Zinc (Zn)	>200
Copper (Cu)	>100
Lead (Pb)	>100
Vanadium (V)	>100
Sulphur (S)	>100
Nickel (Ni)	>40
Cobalt (Co)	>40
Arsenic (As)	>30
Chromium (Cr)	>30
Antimony (Sb)	>30
Florine (F)	>20
Selenium (Se)	>20
Molybdenum (Mo) – leachate $(COOH)_2 + (COONH_4)_2$	>10
Boron (B)	>10
Tin (Sn)	>10
Mercury (Hg)	>4
Cadmium (Cd)	>2
Beryllium (Be)	>2
Sodium (Na)	> 30% of T value (from maximum sorption capacity)

Iron in the soil is mostly found in the form of insoluble polymeric compounds (FeOOH), therefore to ensure its required amount the plants must increase secretion of H^{+} leading to lower pH values in the immediate vicinity around the roots. Because remobilization of Fe in the plant is very low, its deficiency is primarily reflected in the young leaves. The manganese content in plants is given by its presence in the soil. Its deficiency in the plant is manifested as chlorosis and necrosis of the leaf veins and tip sheets. According to the type of plant the young as well as older leaves may be affected.

Copper is mainly bound up in various low molecular organic compounds. The function of Cu is given by the ability of Cu^{2+} cation to be reduced even in the presence of very weak reducing agents. Plants take Cu^{2+} from the soil by several types of membrane transporters. Lack of Cu is at first seen as a dark necrotic spots on young leaves. Later there is the onset of a total necrosis and leaf fall, accompanied by racking leaves. Plants take zinc from the soil in the form of Zn^{2+} cation and its content in them is mainly given by the availability of soil Zn. Deficiency is manifested by changing plant habit. The leaves are small with a wavy blade. The initial chlorosis passes to white necrotic spots.

Unlike other micronutrients, the availability of Mo increases with increasing pH. While the soil fertilization by phosphorus increases Mo intake by plants, sulfur fertilization reduces this intake. Its deficiency is commonly manifested by assimilation organs yellowing and dwarfed plants. Actually it is a nitrogen deficiency caused by its reduced income. In the soil with a pH < 7, boron occurs in the form of boric acid H_3BO_3, in a alkaline range creates the borate anion $B(OH)_4^-$ which is easily absorbed by the soil particles and passes to an inaccessible form to plants. Reduced B availability to plants leads to disturbances in their nutrition. Boron deficiency symptoms depend on the age and the plant type. It especially relates to the dark necrosis occurring on young leaves bases and on apical buds, creates fruit distortions and produce growth inhibition.

Although chlorine is classified as a micro-nutrient, plants receive it in amounts comparable to those of macronutrients. It comes from many sources and therefore its deficiency in plants occurs sporadically. Plants take it in the form of Cl^- anion, in which it is also distributed. Chlorides have long been considered nonessential element for plants, but recent results of their application have shown the increased plant production and higher resistance of plants to disease. In the natural cycle Cl^- do not release chlorine and do not act harmfully to soil organisms. In the soil Cl is distributed in a relatively wide concentration range of 20 to 900 mg kg^{-1} with an average value of 100 mg kg^{-1}. Selenium is essential to some plants – has antioxidant properties, affects the course of some enzymatic reactions. In the case of plants, Se occurs mainly in organic form and at higher concentrations of 2 mg kg^{-1} begins to be toxic.

What relates to other elements, it should be noted that the contents of sodium, aluminum and silicon, i.e. elements with a concentration of above 100 ppm, but also of elements that occur in assimilation organs in minimal amounts (below 1 ppm) are very fluctuating and exhibit high variability. Since they are ballast elements, from the viewpoint of nutrition they can be tolerated.

Availability of elements to plants is influenced by several factors, forefront of which is their contents in the soil and soil properties. Elevated concentrations of monitored elements are assessed according to the limit values with new knowledge continuously regulated. Limits used are imposed by the Act no. 220/2004 of Laws "The conservation and use of agricultural land" (Table 5). Limits represent the values of maximum levels of hazardous substances in agricultural soil and contamination level (in mg kg^{-1} dry mater, decomposition by aqua regia, at Hg a total contain). They are divided according to soil type, i.e. grain size, into three groups. The lighter the soil, thus more sandy, the less the soil buffering. Thus in light soils, risk element limits are lower, and vice versa in heavy soils higher.

Previously, the rate of soil contamination with heavy metals was assessed by the highest available levels of harmful substances in accordance with the decisions of the Ministry of Agriculture no. 531/1994-540. These two criteria declare very similar limits, but the former standard takes into account the presence of humus, content of which is particularly important for forest soil.

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Table 5. The limit values of risk substance in agricultural soil

Soil type	As	Cd	Co	Cr	Cu	Hg	Ni	Pb	Se	Zn	F
	[mg kg^{-1}]										
Sandy, loamy-sand	10	0.4	15	50	30	0.15	40	25	0.25	100	400
Sandy-loam, loamy, clay-oam	25	0.7	15	70	60	0.5	50	70	0.40	150	550
Loamy-clay, clayey, clay	30	1.0	20	90	70	0.75	60	115	0.60	200	600

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Pôda a jej vlastnosti v urbánnom prostredí

Súhrn

Optimálne pôdy pre rast drevín sú hlinité s obsahom hrubého ílu (frakcia menšia ako 0,01 mm) 20 – 40 %, s obsahom skeletu pod 25 %, odrobinkovitej štruktúry o hrúbke 1 – 5 mm. Takéto pôdy by mali mať vlhkosť 20 – 30 %, s kapilárnou kapacitou 20 – 25 %, s objemovou hmotnosťou v rozpätí 1,33 – 1,70 g cm^{-3}. Optimálna hĺbka podzemnej vody pre stromovú vegetáciu sa odporúča 130 – 200 cm, hĺbka pôdy by mala byť aspoň 60 cm, s obsahom humusu v koreňovej zóne okolo 5 % a pomerom C/N pod hodnotou 20. Hodnotu pH považujeme za optimálnu pre rast stromovej zelene v rozpätí 5 – 7. Pre ihličnaté dreviny sú vhodné hodnoty okolo spodnej hranice rozpätia, pre listnaté horná hranica. Pre všetky dreviny je škodlivé pH pod 3,5 a nad 8,5. Ak hmotnosť odparku vodného výluhu prevyšuje 0,5 %, pôda je zasolená a nie je vhodná bez meliorácie pre rast drevín. Kriteriálne hodnoty obsahu C, N, P, K, Mg a Ca sú v tab. 2, nadlimitné obsahy 23 ďalších prvkov v tab. 3 a limitné hodnoty rizikových prvkov (As, Cd, Co, Cr, Cu, Hg, Ni, Pb, Se, Zn, F) sú v tabuľke 4.

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