Chapter 2

Contamination of Soils and Substrates in Horticulture

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Abstract

Contamination of the soil environment mostly is identified with industry, especially mining and road transport. Unfortunately, also in the commercial horticulture, there are numerous problems concerning the contamination of soils and substrates. Sources of contamination can be fertilizers and waste materials polluted by heavy metals, particularly by cadmium. In the greenhouses where traditional methods of cultivation are used, the soil pollution due to the application of excessively high doses of fertilizers constitutes an environmental hazard. Much faster similar effect occurs in greenhouses where an open system of fertigation is used. In addition to mineral impurities, organic compounds emitted by the plant or that are formed during decomposition of organic matter are the problem. This phenomenon is called allelopathy. In practice, it concerns the monoculture and perennial crops and especially is observed in nurseries, orchards, plantations of berries and asparagus. For this reason, in the later section, the soil sickness, replantation problem and toxicity of mulches in green areas are also discussed.

Keywords: overfertilization, heavy metals, allelochemicals, soil sickness, replantation

1. Introduction

Soil pollution is commonly associated with industry, mines and road transport. In the case of water contamination, the significant role of agriculture is primarily indicated. Horticulture can also adversely affect the soil environment. In this case, the basic problem is the use of very high doses of fertilizers and the heavy metals contained in some fertilizers. Contaminants can also occur in waste materials used to improve the properties of soil and horticultural substrates. Besides mineral impurities, toxic organic substances, which are metabolites of plants and micro-organisms or substances of anthropogenic origin used for the control of pests, pathogens and weeds can be released into soil and substrates. The ability to suppress other plants through the release of toxic substances from living parts or dead plant tissues during their decomposition is called allelopathy. Understanding of the causes and consequences of risks outlined above determines for rational decision-making in horticulture.

2. Heavy metals in fertilizers and waste materials

Horticulture is the branch of agriculture dealing mainly with the cultivation of vegetables, medicinal plants, ornamental plants and fruit trees and bushes. Horticultural plants are an important part of the human diet. For this reason, attention is paid to factors affecting the quantity and quality of yield.

Crop yield depends on many factors including variety, control of diseases and insects, and weather conditions. However, the essential role is played by the physical and chemical properties of the soil or growing medium. To improve soil quality, farmers use organic and mineral fertilizers. Unfortunately, fertilizers can be contaminated by substances that can potentially pose a risk to human and animal health and the environment. In the case of mineral fertilizers, this problem concerns mainly cadmium compounds.

The presence of cadmium in topsoil is a consequence of the use of phosphate fertilizers contaminated with this element [1–4]. Cadmium uptake by plants depends on pH of soil or growing medium. Under acidic conditions, cadmium solubility increases. In these conditions, the adsorption of cadmium by soil colloids, hydrous oxides, and organic matter is very low. However, zinc can reduce cadmium's availability to plants, by inhibiting calcium uptake and preventing it from moving from the roots to the shoots of the plants [5]. Lime fertilizers, as well as waste materials rich in calcium and/or magnesium, can also be contaminated by heavy metals [6–8]. Moreover, in this case, the list of potentially toxic elements is much longer: Cd, Cr, Co, Cu, Pb, Mo, Ni, Zn, As and Hg [8–11]. Essential and beneficial elements can become toxic only at high concentrations. In many countries, the use of fertilizers or waste materials contaminated with heavy metals is limited by the introduction of a maximum permissible content of these elements. However, the rules of individual countries are not unified [4]. For example, in Poland, the maximum permissible concentrations of heavy metals in fertilizers are as follows:

- in organic and organic mineral fertilizer (in 1 kg of dry weight of the fertilizer): Cr—100 mg, Cd—5 mg, Ni—60 mg, Pb—140 mg, Hg—2 mg,
- in agricultural lime (expressed per 1 kg CaO): Cd—8 mg, Pb—200 mg,
- in agricultural lime containing magnesium (calculated per 1 kg of the sum CaO + MgO): Cd—15 mg, Pb—600 mg, and
- in other mineral fertilizers (in 1 kg of dry weight of the fertilizer): As—50 mg, Cd—50 mg, Pb—140 mg, Hg—2 mg [12].

Heavy metals may be introduced into the soil and substrates also with soil improvers or mulches. 'Soil improver' is defined as a material added to soil in situ whose main function is to maintain or improve its physical and/or chemical and/or biological properties, with the exception of liming materials. 'Mulch' means a type of soil improver used as protective covering placed around plants on the topsoil whose specific functions are to prevent the loss of moisture, control weed growth and reduce soil erosion. According to a regulation of the European Union, the maximum content of heavy metals in the final product or constituent may not exceed the values shown in **Table 1**.

Element	Maximum content in the product (mg kg dw)
Cadmium (Cd)	1
Chromium total (Cr)	100
Copper (Cu)	100
Mercury (Hg)	1
Nickel (Ni)	50
Lead (Pb)	100
Zinc (Zn)	300

Table 1. Heavy metals limits for soil improvers, mulch and organic constituents of growing media [13].

In organic and mineral growing media, the content of heavy metals in the final product may not exceed the values shown in **Table 2**.

Element	Maximum content in the product (mg kg dw)
Cadmium (Cd)	3
Chromium total (Cr)	150
Copper (Cu)	100
Mercury (Hg)	1
Nickel (Ni)	90
Lead (Pb)	150
Zinc (Zn)	300

Table 2. Heavy metal limits for growing media, including mineral growing media [13].

The source of heavy metals may also be sewage sludge from municipal sewage treatment plants used to fertilize soil or compost from sewage sludge. The use of these materials in the EU is subject to a number of strict requirements. The most important are the Water Framework Directive 2000/60/EC on water protection, Directive 91/271/EEC on urban waste water treatment, Directive 96/61/EC concerning integrated pollution prevention and control, Directive 99/31/EC on the landfill of waste and Directive 86/278/EEC on the use of sludge in agriculture [13–17]. The limit values for heavy metals in sludge or in composts are defined in national regulations. The regulatory framework prevents harmful effects on soil, vegetation, animals and humans [18–20].

3. Effect of intensive fertilization on chemical composition of soil in greenhouse

3.1. Effect of long-term traditional fertilization

Traditional cultivation of plants in greenhouses or plastic tunnels is based on intensive organic and mineral fertilization of soil. Manure and compost are commonly used organic fertilizers. In temperate climate of central Europe, the cultivation of plants in greenhouses and tunnels is uneconomic due to short days and low light intensity as well as high heating costs from November to March. The gardening season begins in early spring and ends in late autumn. In this relatively short period, intensive fertilization is carried out. The doses of fertilizers used in greenhouses and plastic tunnels are much higher than the doses used in field crops. For example, for wheat, 230–360 kg NPK/ha is recommended, while for early varieties of cauliflower grown in the greenhouse, 450–580 kg NPK/ha is recommended. Moreover, due to the greenhouse effect, the average day and night temperatures in greenhouses and tunnels are significantly higher than the temperatures in the field. Plants grow faster and produce greater biomass. For this reason, the watering of plants is more intense, and therefore, the elution of components into the soil is stronger. A detailed documentation of this problem was presented by Breś and Roszyk [21, 22]. The authors selected five horticultural farms near Poznan (Poland) in which the plants were grown for 20–40 years. In the middle of the growing season, the authors took soil samples from the layers 0–20, 20–40, 40–60, 60–80, 80–100 and 100–120 cm. For the sake of comparison, the studies also included samples taken near the greenhouse from occasionally fertilized lawn. To evaluate the effect of long-term fertilization on the distribution of nutrients in the profile of soils, chemical analysis of samples was performed. For nutrient extraction, 0.03 M CH_3COOH was used. This method allows one to assess the amount of components readily available for plants. As an example, the content of N-NO_3, P, K, Ca, Mg, Cl and S–SO_4 in soil samples collected in two of the five test farms is given below. In **Table 3**, data refer to a greenhouse where vegetables and ornamental plants were grown for 40 years, while **Table 4** presents the results of analyses of soil samples from a greenhouse in which for 40 years only vegetables were cultivated. Most of the nitrogen, phosphorus, calcium, magnesium, chlorides and sulphates were found in a layer 0–40 cm deep. In extreme cases, the greenhouse in soil nitrogen content was 60 times, phosphorus 3 times and potassium 15 times higher compared to the soil next to the greenhouse. Greenhouse soils were very rich, even at a depth of 80 cm. The significant amount of sulphates in the soil in greenhouses is a result of more frequent use of potassium sulphate than potassium chloride. This practice is very common in horticulture. Based on the scale of pollution, it can be assumed that in these farms, the evaluation of fertilization requirements based on the chemical analysis of soil or substrate was conducted infrequently or not at all. The authors found that the range of changes in the chemical properties of the investigated soils depended most on the length of greenhouse utilization. Moreover, the soil of the farms where ornamental plants were grown exclusively contains more nutrients than the soil from farms specializing in the cultivation of vegetables. Soil texture had the least impact on the chemical composition of soils. Similar trends were observed by examining the content of micronutrients. The results of these studies clearly indicated strong leaching of nutrients and the threat of groundwater contamination. The soil contamination in the greenhouse reported in this study was so high that it became necessary to rapidly introduce new technologies friendly for the environment. As a method to reduce leaching of nutrients, wider use of slow-release, controlled-release and inhibitor-stabilized fertilizers was proposed. Another solution to the problem was soilless cultures and fertigation.

Layer of soil (cm)	$N–NO_3$	P	K	Ca	Mg	Cl	$S–SO_4$
	Content in the soil (mg/dm^3)						
Farm Ogrody—greenhouse							
0–20	314	248	491	4013	256	306	497
20–40	297	244	484	4600	230	346	342
40–60	77	261	376	1123	106	224	94
60–80	76	231	517	1322	12	215	69
80–100	65	152	676	752	136	93	55
100–120	89	138	586	556	108	151	93
Farm Ogrody—lawn							
0–20	5	77	29	2408	99	22	0
20–40	4	78	16	2624	111	21	0
40–60	5	89	12	2949	102	23	1
60–80	4	80	12	2793	94	20	0
80–100	4	71	16	2255	91	22	0
100–120	3	70	14	2140	80	20	0

Table 3. Effect of long-term fertilization on the distribution of nutrients in profile of greenhouse soil—farm Ogrody [21].

3.2. Soilless culture and fertigation

Soilless culture is the cultivation of plants in systems other than soil in situ, including hydroponics and another growing media or substrates. The main advantage of soilless culture is a pathogen-free root environment at the beginning of the crop cycle. Thanks to that fact, one can avoid costly and time-consuming soil replacement or sterilization [23]. An essential element of this technology is fertigation, that is the process in which fertilizers are applied with the irrigation. Fertigation can be carried out in an open or closed system. In the open system, an excess of the applied nutrient solution leaks into the soil. In the closed system, the

Layer of soil (cm)	$N–NO_3$	P	K	Ca	Mg	Cl	$S–SO_4$
	Content in the soil (mg/dm^3)						
Farm Marcelin—greenhouse							
0–20	159	255	309	2445	229	151	891
20–40	111	238	326	1379	160	126	779
40–60	90	160	431	728	95	56	284
60–80	69	99	541	1463	125	45	441
80–100	79	97	420	1491	91	33	296
100–120	49	66	476	2599	78	54	149
Farm Marcelin—lawn							
0–20	13	54	155	3101	77	124	84
20–40	9	71	103	1493	87	105	141
40–60	13	54	125	2340	72	80	43
60–80	14	50	110	1538	61	57	7
80–100	12	34	102	1103	49	49	40
100–120	11	28	119	1062	57	47	38

Table 4. Effect of long-term fertilization on the distribution of nutrients in profile of greenhouse soil—farm Marcelin [21].

excess of nutrient solution after disinfection returns to the fertigation system (recirculation of nutrient solution). In this system, drainage water does not contaminate the environment [24]. Fertigation would also provide less water and fertilizer utilization. In soilless cultures as a growing medium expanded clay aggregates, growstones, perlite, pumice, sand and wood fibre are used. However, the most commonly used substrates in soilless cultures are rockwool and coconut fibres. The described cultivation technology requires high-quality water and very good water-soluble fertilizers [25, 26]. According to the recommendations, in order to stabilize the concentration and the pH value of the solution in the root zone and in order to adjust the substrate moisture, the volume of nutrient solution must be higher than the nutritional requirements of plants [27]. For most soilless cultures, 30–50% overflow is recommended [28]. As an effect of open systems, the excess nutrient solution leaks from the growing medium and pollutes the soil. This process was documented by Breś [25]. The author measured the volume of leaking solution and analysed the chemical composition of leakage during the growth of cherry tomato in coconut fibre, as well as gerbera, rose, tomato and cucumber growing in rockwool. Concentrations of nutrients found in the drainage from soilless cultures were many times higher than the mean concentrations of components in the nutrient solution supplied to plants. This suggests that the basic cause of the increase in ion concentrations is a predominance of transpiration over nutrient uptake by plants [29]. The monthly deposition of elements transferred with drainage waters to the soil was also calculated. Some details from the publications of Breś [25] are given in **Table 5**. Notable is deposition of K (up to 413 kg/month/ha), $N–NO_3$ (up to 230 kg/month/ha), Ca (up to 220 kg/month/ha) and $S–SO_4$ (up to 101 kg/month/ha). Leaching of Na (up to 62 kg/month/ha) and Cl (up to 34 kg/month/

Nutrient	Tomato in rockwool	Cherry tomato in coconut fibres	Rose in rockwool
$N–NO_3$	30–230	23–177	13–83
P	7–54	2–18	3–16
K	53–413	36–282	17–106
Ca	23–178	28–220	9–54
Mg	7–57	5–38	3–21
Na	4–33	8–62	1–6
Cl	1–10	4–30	0.1–0.3
$S–SO_4$	13–101	12–90	4–24

Table 5. Ranges (kg/ha) of monthly losses of nutrients during plant cultivation in soilless culture with the application of open fertigation systems [25].

ha) was lower. A similar trend was found for *Anthurium* grown in expanded clay aggregates [29]. Some authors believe that the ratio of the uptake rates of NO_3, K and P, in comparison with the transpiration rate, decreased from May to September because the substrate temperature had a greater effect on nutrient uptake than on water absorption [30].

In research conducted by Uronen [31] during the cultivation of cucumbers grown in rockwool, phosphorus leakage was 35–47% while nitrate leakage amounted to 33–43% of the applied nutrients. Cultivation in organic substrates is characterized by a smaller run-off than in rockwool [25, 31]. Thus environmental pollution is reduced. The amount of nutrients leaking from 1 ha of agricultural field crops is distinctly smaller. For example, nitrogen seldom exceeds 140 kg N/ha/year [32, 33].

Besides the amount of fertilizers leaking from open fertigation systems, the vertical distribution of nutrients accumulating in the soil profile (mean content in subsequent soil layer), in relation to the duration of greenhouse operation, is also important. Such investigations were conducted in the years 2004–2011 in horticultural farms specializing in soilless plant cultivation [34]. The greenhouses were located in the Wielkopolska province (Poland). Every year, from February to November tomatoes were grown in rockwool. Before the first crop culture, soil samples were collected for chemical analyses at every 20 cm layer to the depth of 1 m. Successive samples were taken in autumn after the completion of 1, 2, 3 and 7 growing cycles. For nutrient extraction from soil, 0.03 M CH_3COOH was used. The amount of components readily available for plants was determined. Significant changes in the chemical properties of soils were detectable already after the first growth cycle of plants. **Figure 1** shows the dynamics of changes in electrical conductivity measured in soil layers. The degradation rate of the soil environment as a result of application of an open fertigation system depended primarily on the duration of greenhouse operation. The increase of nutrient contents in the soil profile during seven years of monitoring was very high: Ca 283%, Mg 325%, $N–NO_3$ 326%, K 666%, P 684% and $S–SO_4$ 2164%. Once again, it proved that the previously reported benefits of fertigation apply only for recirculating systems. Only in closed systems, it is possible to reduce water consumption by 15–35% and to limit losses of nutrient solution by 15–67% [35, 36].

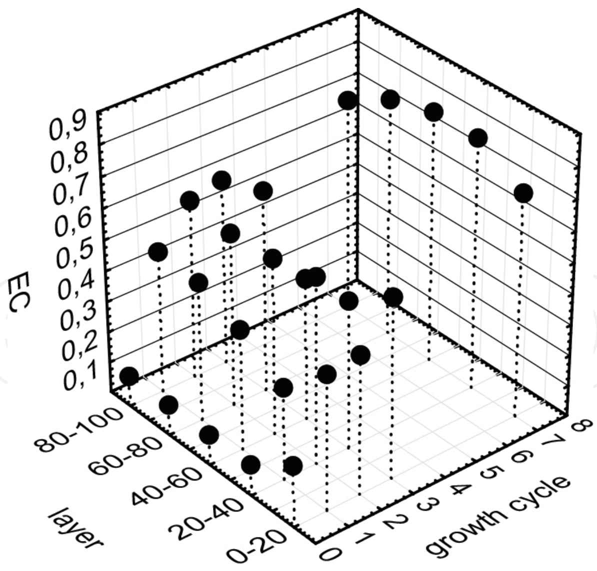

Figure 1. Relationship between duration of greenhouse operation (0—before first growth season and after 1, 2, 3…7 growth cycles), depth of soil sampling (cm) and electrical conductivity (EC mS/cm).

4. Organic contaminants released from plant residues

4.1. Post-harvest residues

There are many plant species that possess the ability to suppress other plants through the release of toxic substances from living parts or dead plant tissues. This phenomenon is called allelopathy. Allelopathy is a chemical interaction between plants defined as any direct or indirect, beneficial or harmful effects of one plant (donor plant) on another (recipient plant) through the production of chemical compounds that are released into the environment through root exudation, leaching, volatilization and decomposition of plant residues. A wide variety of phytotoxic substances exists in plant residues. Microbial decay of plant residues releases the toxic metabolites into the soil where they may adversely affect the growth and development of plants. In agro-ecosystems, decaying post-harvest residues are the main source of phytotoxic compounds, and they can provide a serious problem [37].

Allelopathic chemicals are generally secondary metabolites, and most of them have been identified as volatile terpenes and phenolic compounds [38]. Allelochemicals can be synthesized in every part of the plant. They can be found in seeds, flowers, fruits, pollen, leaves, stems and roots. Their content depends on the developmental stage of the plant or plant part. It was found that significantly larger amounts of them occur in young plants [39]. Different stress factors can enhance the production and release of allelochemicals by plants [40].

Some plant species with a high allelopathic potential release into the environment particularly high amounts of allelopathic compounds. These include crop plants from the families Fabaceae and Brassicaceae. Perennial crops and monocultures of these families are common in many parts of the world, and they cause a number of problems due to soil sickness, regeneration failure and replant problems. Allelochemicals from legumes are mainly polyphenols and propanoids [41]. Crops from the family Brassicaceae contain compounds called glucosinolates, which break down during the decomposition of post-harvest residues into powerful volatile allelochemicals—isothiocyanates, which can affect plant growth and microbial activity [42–44]. Also, plants belonging to the group of the world's worst weeds displaying great expansion and invasiveness properties such as quackgrass (*Agropyron repens*), Canada thistle (*Cirsium arvense*), field bindweed (*Convolvulus arvensis*), white pigweed (*Chenopodium album*) and Johnson grass (*Sorghum halepense*) exhibit high allelopathic potential [45, 46]. On the other hand, the weed suppressive ability of crop plants with allelopathic properties may also be considered as plant weed control in agricultural systems [47]. The use of allelopathic cover crops, inclusion of allelopathic plants in crop rotation and the use of their residues as mulches can be an economical and environmentally friendly form of weed control [48].

Allelopathic chemicals act in many ways. Some retard plant growth or inhibit seed germination by disrupting cell division. Some interfere with respiration and other physiological process. Many affect plant nutrition by reducing the water and nutrient uptake. Biological activity of phytotoxic substances depends on their chemical nature and concentration—at lower concentrations, they may exert stimulatory effects, whereas at higher concentrations, they may exert inhibitory effects [49].

The decomposition of crop residues is the result of complex microbial processes controlled by numerous environmental factors influencing the activity of microflora such as temperature, moisture, aeration, inorganic ions and pH [50, 51]. Allelochemicals released into the soil are also continuously removed from the soil solution by plant uptake, immobilized due to adsorption to soil particles and degraded by micro-organisms [52–55]. Moreover, allelopathic compounds are subjected to degradation by oxidation and photolysis as well as processes of removal by volatilization or leaching [53]. The type of soil is important in the accumulation of allelochemicals, for example, in poorly drained, clay soils, the allelochemicals are not leached easily. By contrast, in well-drained sandy soils, the allelochemicals have a tendency to leach. The difference between the speed of allelochemicals' release into the environment and the speed of their degradation will decide whether they will accumulate in the soil to a toxic level [49]. A low concentration of allelochemicals at a given point in time is not an argument against their allelopathic role or evidence of their activity at low concentrations, because the allelopathic effects depend on many factors interacting with them in the soil and may not be directly related to the actual concentrations. Soil factors and their interactions with microflora need to be considered in assessing the factors that determine the presence and stability of allelochemicals [56–58].

4.2. Soil sickness and replantation problem

The phenomenon of soil sickness is defined as a decrease in soil fertility as a result of the prolonged growth of the same plant species, in spite of its intensive cultivation and fertilization. Delayed development of plants and a significant reduction in yield are symptoms of soil sickness. It is widely assumed that soil sickness is a phenomenon caused by a complex combination of biotic and abiotic factors disturbing the biological balance in soil, that is deficiencies or imbalance of plant nutrients, degradation of soil properties, disproportionate development of various groups of micro-organisms in soil, increased infestation of pathogens, pests and weeds and accumulation of phytotoxic compounds [59]. The intensive modern agriculture with mechanization, indiscriminate use of fertilizers and pesticides and with an emphasis on reduced crop diversity has led to serious changes in the physical, chemical and biological properties of soil, which have adversely influenced plant development and crop yields. Soil sickness in modern agriculture is mainly due to specialized single crop based limited rotations. These systems do not follow the scientific principles of crop rotations. In horticulture, soil sickness concerns mainly monoculture and perennial crops with limited rotation, such as nurseries, orchards, plantations of berries and asparagus, lawns as well as greenhouse cultivations, where the same substrate is used many times [54, 60–62]. One of the main causes of soil sickness is the accumulation of phytotoxic compounds, that is plant and microbial phytotoxins, as well as remains of pesticides [59].

As a result of long-term growth of the same plant species, there occurs in the soil accumulation of homogeneous compounds secreted from plants and the products of microbial decomposition of plant post-harvest residues. The living plants can secrete allelochemicals and the decaying plant residues can release toxic metabolites into the soil. In soil sickness, the release of toxic substances from the dead plant tissues during their decomposition plays a greater role than their active secretion from the living plants. A specific kind of soil sickness is autotoxicity, which manifests when a plant species releases chemical substances that inhibit or delay the germination and growth of the same plant species. Many crop plants exhibit autotoxicity, i.e. self-destruction of a plant species through the production of metabolites that escape into the environment and directly inhibit the growth of that species [63]. Autotoxicity is a cause of soil sickness in the cropping of such vegetables as asparagus, carrot, cucumber, eggplant, pea and tomato [64–66]. This phenomenon is also observed in orchards and then is called the replantation problem. Cutting down an old, non-productive orchard and establishing a new one in the same place is associated with the replantation problem. It occurs most frequently in apple, peach, sour cherry and sweet cherry orchards. When an old orchard is removed, large amounts of root residues remain in the soil. They are a rich source of phytotoxic substances. For example, peach root bark contains two glycosides—amygdalin and prunasin—that under enzymatic hydrolysis in soil produce hydrogen cyanide, a powerful inhibitor of respiration [67]. The main cause of soil sickness in apple orchards is accumulation of the toxic dihydrochalcone—phlorizin, large amounts of which occur in the bark of apple roots. The release into the soil of these compounds from the decaying residues of tree roots after the liquidation of old trees prevents the normal growth of young trees in the replanted orchard [68].

Monoculture and perennial crops with limited rotation favour the proliferation of pathogenic fungi, which produce mycotoxins. *Aspergillus*, *Penicillium* and *Fusarium* are the major fungal genera producing secondary metabolites toxic not only to humans and animals but also to plants [54, 69]. The phytotoxic activity of mycotoxins manifests in their inhibitory effects on growth parameters and differs from their effects in plant diseases [69].

Pesticides are toxic chemicals used to control weeds, pests and pathogens in crops. It is normal practice to apply several different pesticides to a single crop in any given growing season. In intensive agriculture, the application of pesticides is frequently inappropriate or excessive. Although each pesticide is meant to kill a certain pest, pathogen or weed, a very large percentage of pesticides reach other destinations than their target. Instead, they enter the air, water and soil [70]. Some of these pesticides or their remains can act as toxins to plants when found in soil at sufficient concentrations. Accumulation refers to the build-up of pesticides resulting from repeated use. Excessive use of pesticides is one of the main factors causing soil pollution and can lead to several unintended, harmful effects on the environment, adversely affecting the soil micro-organisms and generally causing a decrease of soil fertility. The toxicity level of a pesticide depends on the kind of chemical, the dose, the length of exposure and the route of entry or absorption by the plant. The accumulation of pesticides in the soil can kill or reduce the populations of essential soil macro- and micro-organisms, including earthworms, insects, spiders, mites, fungi and bacteria, thus reducing or stopping important nutrient cycles [71, 72]. The fate of pesticides in soils varies greatly depending on their chemical nature, the type of soil, the climate conditions and the agricultural practices. In the soil, they are decomposed by soil micro-organisms, leached from the root zone, or they are adsorbed and accumulated by soil particles [73]. The amount of pesticide adsorbed to the soil varies with the type of pesticide, soil moisture, pH and texture. Pesticides are strongly adsorbed to soils that are rich in clay or organic matter, whereas they are not as strongly adsorbed to sandy soils. Pesticide degradation in soil generally results in a reduction in toxicity; however, breakdown products of some pesticides are sometimes more toxic than the substrate. Plant injury can be a problem resulting from adsorption of pesticides to soil particles. Injury can result when a pesticide used for one crop is later released from the soil particles in amounts great enough to cause injury to a sensitive rotational crop. It is also hard to predict the long-term effects of such changes in the soil microbial communities, which may lead to the occurrence of soil-borne pathogens [73].

4.3. Toxicity of mulches in green areas

Mulching is a popular form of soil care, especially in green areas. A mulch is a layer of material applied to the surface of soil. It limits weeding, improves soil moisture, stabilizes soil temperature, reduces soil compaction and increases soil nutrition, which indirectly contribute to better plant growth. For the preparation of mulches, various organic and inorganic materials are used. Natural materials such as bark, sawdust, straw, shredded or chipped wood, leaves, coniferous needles or dried grass clippings are used as organic mulches. Plant residues from a crop may also be used to form a mulch [43, 47]. However, most of these materials are not suitable in green belts because of poor aesthetic appeal [74].

Although mulches are multifunctional and in green areas, they are applied mainly for aesthetic purposes, mulching is one of the most effective methods for non-herbicide weed control [75]. Mulches can act only as a physical barrier that limits access of light to germinated weeds and reduces their ability to photosynthesis. Certain organic materials, especially shredded and chipped bark or wood, may control weeds chemically through the leaching of allelopathic compounds. Bark and wood mulches are often used for weed suppression in urban landscapes and gardens where herbicides are prohibited or unwanted [74]. Biological activity of phytotoxic substances depends on their chemical nature and the tree species from which they are derived. The results obtained by Rathinasabapathi and co-workers [76] showed the phytotoxic activity of wood chips from deciduous trees and conifers (*Acer rubrum*, *Quercus michauxii*, *Juniperus silicicola*, *Azadirachta indica* and *Magnolia grandiflora*).

Most commonly, the branches of various tree species are used as mulch material, fresh and without composting, because composting is a time- and cost-consuming process. Thus, the use of these wood wastes for the preparation of mulches is a simple way of recycling them. However, although the wood chips are easy to obtain and one of the cheapest organic materials for mulching, especially in green areas, their application may be associated with the release into the soil of phytotoxic substances. The use of wood chips for mulching the soil contributed to an increase in the content of phenolic compounds [77]. It was found that the strongly lignified wood wastes decomposed in the soil by micro-organisms are a rich source of phenolic compounds, even small amounts of which may adversely affect the growth and development of plants [77, 78]. According to Krasutsky [79], the bark of *Betula pendula* contains large amounts of polar triterpenes—betulin, betulinic acid and lupeol. Phytotoxicity of these compounds has been shown in numerous biological assays [80].

In recent years, interest has grown in mulches from a variety of wood wastes, which are crushed and coloured. Wood chips are durable and easy to use as an organic material for mulching. Their sources are sawmill wastes and wastes arising from logging or cutting trees and shrubs [81]. Sometimes processed wood is also used, for example manufactured product debris, discarded pallets and wood reclaimed from constructions and demolitions [82]. Depending on the source of the wood chips, they may contain toxic chemicals, which pollute soil and ground water. It has been found that some of the recycled waste wood used for making landscape mulch products is contaminated with various chemicals, such as creosote, chromium copper arsenate or lead-based paints used for wood preservation against fungi and insects [83–85].

Some problems can develop when hardwood bark is stored in overlarge or waterlogged piles, which creates anaerobic conditions. Then, anaerobic micro-organisms carry out fermentation and in the pile such products as acetic acid, methanol, ammonia and hydrogen sulphide accumulate. Application of such bark as mulch can cause direct plant injury. Damage symptoms including leaf scorch, bleached leaves and defoliation occur very quickly, and in the case of sensitive herbaceous plants, even plant death may occur [86].

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