

SOIL HEALTH AND ENVIRONMENTAL SAFETY CRITERIA FOR ORGANIC FERTILIZERS

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Abstract: This review highlights the importance of continuous monitoring of soil and organic fertilizer quality to prevent contamination by toxic chemicals, heavy metals, and radionuclides. Key indicators of soil health, including chemical, biological, and functional parameters, are discussed. Proper management ensures safe agricultural production, urban land use, and recreation areas. The study emphasizes evidence-based criteria for maintaining soil integrity, environmental safety, and sustainable land use in the face of modern ecological challenges, while supporting long-term soil fertility, ecosystem resilience, and compliance with environmental regulations.

Keywords: soil health, organic fertilizers, contamination, monitoring, environmental safety.

Introduction

The assessment and management of soil quality have become increasingly important for sustainable agriculture, urban planning, and environmental protection. National legislation provides the framework for soil monitoring and management. In Serbia, the Law on Agricultural Land (Sl. glasnik RS, br. 62/2006, 65/2008 – amended, 41/2009, 80/2017 and 95/2018 – amended) defines the legal basis for land use, conservation, and improvement. Complementing this, the Regulation on Systematic Monitoring of Soil Status and Quality (Sl. glasnik RS, br. 88/2020) establishes procedures for regular assessment of soil

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health and pollutant levels. Together, these normative documents emphasize the need for evidence-based evaluation of soil to ensure its sustainable use in agriculture, urban development, and recreational areas.

Historically, standardized, scientifically grounded indicators for evaluating soil quality were largely absent, limiting the ability to effectively diagnose soil health. Contemporary soil assessment incorporates multiple diagnostic parameters, including chemical composition, biological activity, and functional characteristics (Abshiba et al., 2025). Chemical indicators focus on pollutants, heavy metals, radionuclides, and toxic compounds that may accumulate in soils due to anthropogenic or natural processes. Biological parameters address the presence of pathogens and other harmful organisms, while functional indicators evaluate nutrient cycling, soil structure, and the natural self-purification capacity (Cardoso et al., 2013). These integrated criteria are essential for determining soil ecological status and potential risks to human health, agriculture, and ecosystems (Benício, 2025).

Regular monitoring of soil is crucial for agricultural productivity, urban planning, and recreational land management. Data derived from monitoring guide decisions regarding crop production, soil improvement, urban development, and land rehabilitation. Soil health assessments also inform the management of organic fertilizers, ensuring that their application does not degrade soil quality or introduce additional risks (Futa et al., 2024).

The interaction between soil properties and environmental factors such as pH, organic matter content, and cation exchange capacity significantly influences the mobility and bioavailability of contaminants. Understanding these processes enables accurate risk assessments and supports the establishment of threshold limits for toxic metals and other pollutants (Campillo-Cora et al., 2025). Evidence-based criteria derived from systematic monitoring provide a scientific foundation for preserving soil integrity, ensuring environmental safety, and promoting sustainable land use in the context of contemporary ecological challenges, including climate change, urbanization, and global pollution (Mensah and Amoakwah, 2024).

A comprehensive overview of the main indicators of soil health, the regulatory framework for soil and organic fertilizer quality, and methodologies for assessing contamination risks is presented. This approach provides a contemporary perspective on maintaining soil integrity, safeguarding environmental and public health, and supporting sustainable management practices in both agricultural and urban contexts.

Standards for Contaminants in Soils and Organic Fertilizers

Agricultural soils, urban soils, recreational areas, and organic fertilizers (hereafter referred to as fertilizers) must comply with the requirements established by current regulatory documents (Ministry of Health of Russia (1999); Hygienic Safety Requirements for Agrochemicals (2003)). The evaluation of potential hazards associated with contamination of organic fertilizers—such as compost, biohumus, and dry granular manure – during direct handling by personnel is determined based on their epidemiological significance and their role as potential sources of pollutants for soils and surrounding environments. Furthermore, this assessment considers the cumulative impact of repeated fertilizer application, possible interactions with existing soil contaminants, and the potential for transfer of hazardous substances into crop plants or water systems (Shah et al., 2023). Compliance with these standards ensures the maintenance of soil quality, protection of human health, and the sustainable use of land for agricultural, urban, and recreational purposes.

The primary requirement regulating the use of organic fertilizers is to prevent any deterioration of the quality of cultivated soils. This includes:

1. Exceeding hygienic thresholds for contaminants in soils, associated environments, and harvested products, including toxic and hazardous substances (Table 1) (Hygienic Assessment of Soil Quality in Settlements, 1999; Orientational Permissible Concentrations, 2006), technogenic and natural radionuclides, toxic heavy metals and metalloids, persistent organic pollutants, stable organochlorines, and other pollutants;
2. Disruption of the structure and functioning of the geobiota;
3. Presence of pathogenic microorganisms and other harmful biological agents in the soil (Sokolov et al., 2003).

Compliance with these standards ensures that organic fertilizer use does not compromise soil health, environmental safety, or agricultural productivity, supporting sustainable land management practices.

Table 1. Limiting chemical indicators characteristic of organic fertilizers and healthy (clean) soils

Substance (mg/kg)	Radiation Source (Bk/kg)	Hazard Class	MAC / ODC*	Limiting Toxicity Factor
Benzo(a)pyrene	1	0.02	GS†	Solid
Vanadium	3	150	GS	Solid
Vanadium + Manganese	3	100+1000	GS	Solid

HCH (sum of isomers)	2	0.1	T	Solid
DDT, DDE, DDD (total)	2	0.1	T	Solid
Cadmium	1	0.5	T‡	Mobile
Cadmium	1	0.2–2	T	Soluble in acid
KSE (as K ₂ O)	?	360	WM§	–
Cobalt	2	5	GS	Mobile
Manganese	3	1500	GS	Solid
Manganese	3	60–700	GS	Mobile
Copper	2	33–132	GS	Solid
Copper	2	3	GS	Mobile
Arsenic	1	2–10	T	Solid
Nickel	2	4	GS	Mobile
Nickel	2	40–80	GS	Solid
Nitrate ion (NO ₃ ⁻)	2	130	WM	Solid
Polychlorinated biphenyls	2	0.06	GS, T, AM¶	Solid
Pentachlorobiphenyls	2	0.1	GS, T, AM	Solid
Mercury	1	2.1	T	Solid
Mercury	1	1	T	Mobile
Mercury + Lead	1	1+20	T	Solid
Lead	1	32–130	GS	Solid
Lead	1	6	GS	Mobile
Superphosphate (P ₂ O ₅)	?	200	T	Mobile
Antimony	2	4.5	WM	Solid
Trichlorobiphenyls	2	0.1	GS, AM, T	Solid
Fluorine	1	2.8	T	Mobile
Fluorine	1	10	T	Water-soluble
Chromium (III)	2	6	GS	Mobile
Chromium (VI)	2	0.05	T, WB, AM	Mobile
Zinc	1	55–220	GS	Solid
Zinc	1	23	T	Mobile
Natural radionuclides (Σ activity)	–	300	T, WB	Solid
Technogenic radionuclides (specific activity)	–	N/A	T, WB	Solid

GS – General Sanitary; MAC / ODC – Maximum Allowable Concentration / Orientational Permissible Concentration; T – Translocation; ‡ Corrected for different soil types; WM – Water Migration; AM – Atmospheric Migration; WB – Waterborne Migration.

Specifics of Standardizing Toxic Chemical Compounds

Orientational permissible concentrations (ODC) for heavy metals (HMs) – naturally occurring chemical elements ubiquitously present in soils – have been established for three lithogeochemical soil groups (Table 2). Heavy metals include more than 40 chemical elements with atomic masses greater than 50 atomic units.

Among chemical elements, heavy metals are among the most toxic, second only to pesticides in terms of hazard. The toxic elements include Co, Ni, Cu, Zn, Sn, As, Se, Te, Rb, Ag, Cd, Au, Hg, Pb, Sb, Bi, and Pt. According to soil regulations (Table 2), the most hazardous contaminants – classified as Hazard Class 1 (Hg, Pb, Cd, As) – have defined limits not only for their total content in soil but also for their mobile forms (soluble in acid or water). Unlike most heavy metals, these four elements are not essential micronutrients for plants, animals, or humans. At the same time, for many micronutrients, the range between the essential and toxic concentration is narrow. This limitation is even more pronounced for standard macroelements (N, P, K).

Table 2. Standards and baseline content of chemical elements in soils (mg/kg)

Element	Hazard Class	MAC	ODC by Soil Group	Baseline Content
			Solid Content	Extracted AAP* (pH 4.8)
Pb	1	32	6	32
Zn	1	-	23	55
Cd	1	-	-	0.5
Cu	2	-	3	33
Ni	2	-	4	20

*AAP – Ammonium-acetate buffer

The mobility of a micronutrient in soil and groundwater is largely determined by soil acidity (Table 3) and the dominant anions in the soil solution. In acidic soils, Cu, Pb, and Zn are strongly adsorbed, whereas Cd and Co exhibit higher mobility in alkaline conditions. Copper in soil predominantly binds to organic ligands and iron hydroxides (Stojanova et al., 2024).

It has also been demonstrated that complexes of harmful elements present in fertilizers can, in many cases, pose a greater risk to health than individual elements at the same concentrations. Therefore, in assessing standard contaminants in fertilizers, it is practical to determine a cumulative pollution index (Zc), analogous to soil assessments. For fertilizers, the permissible value of cumulative contamination should be accepted as $Z_o < 16$. Consequently, for local organic fertilizers, limiting indicators characterizing the sanitary status of clean soils can be

legitimately applied as factual criteria for assessing their purity (Khan et al., 2024; Stojanova et al., 2024a; Stojanova et al., 2026).

Table 3. Mobility of microelements in soil depending on pH

Soil Acidity	Practically Immobile	Slightly Mobile	Mobile
Acidic, pH < 5.5	Mo	Pb, Cr, Ni, V, As, Se, Co	Sr, Ba, Cu, Cd, S, Ni, Zn, Hg
Slightly Acidic to Neutral, pH 5.5–7.5	Pb	Sr, Ba, Cr, Ni	Zn, V, As, S
Alkaline to Strongly Alkaline, pH 7.5–9.5	Pb, Ba, Co	Co, Mo, Hg, Zn, Ag, Sr, Cu, Cd	Mo, V, As, S

It should be noted that soils with higher cation exchange capacity (CEC) and buffering capacity, as well as elevated levels of organic matter, phosphates, and carbonates, tend to immobilize a larger proportion of potentially toxic heavy metals within the pedo-adsorption complex. This results in reduced mobility and bioavailability of elements such as As, Cd, Cu, Mn, Ni, Pb, and Zn, thereby minimizing their uptake by plants and limiting the risk of leaching into soil and groundwater. Moreover, soil texture, mineral composition, and pH fluctuations significantly influence the partitioning between mobile and stable forms of these metals, which must be taken into account when assessing ecological risks or establishing MAC/ODC values (Mensah and Amoakwah, 2024). Experts should consider these interactions in combination with land use, fertilization practices, and potential cumulative contamination from anthropogenic sources, to ensure accurate and protective environmental standards and to support sustainable agricultural and urban soil management (Table 1).

Standards for Technogenic Radionuclides in Soil and Fertilizers

Although the presence of the most hazardous technogenic radionuclides, such as ^{137}Cs and ^{90}Sr , is strictly prohibited in uncontaminated soils, global atmospheric fallout and anthropogenic activities have led to their detectable occurrence even in regions with relatively favorable radiological conditions (Edomskaya et al., 2022). For example, the actual specific activity of the topsoil horizon, considering ^{90}Sr , averages 2.4–4.3 Bq/kg (0.02–0.04 Ki/km²), while for ^{137}Cs it ranges from 5.6–13.9 Bq/kg (0.05–0.12 Ki/km²), resulting in a combined total activity for these technogenic radionuclides of 12–18 Bq/kg of soil, or 0.07–0.16 Ki/km² (Vakuloskii et al., 1998). These values, while below immediate

hazard thresholds, must be considered in long-term ecological and agricultural planning due to potential bioaccumulation in soil-plant-animal systems and their contribution to cumulative radiation doses (Tsukada et al., 2023).

The fundamental principle of sanitary-hygienic assessment of the biological safety of organic fertilizers, as well as their safe handling, is that their application must not contribute to deterioration of soil quality, compromise environmental integrity, or increase radiological or chemical risks for humans and animals. Raw materials intended for organic fertilizers, such as livestock manure and poultry litter, must be sourced exclusively from farms and households certified free from zoonotic and anthroozoonotic diseases, thereby minimizing potential biological contamination. Prior to application, these raw materials must undergo mandatory disinfection procedures, which may include thermal drying, controlled composting, or other scientifically validated methods, ensuring both microbiological safety and chemical stability (Chen and Jiang, 2014).

In addition, the presence of harmful substances—including radionuclides, heavy metals, and pathogenic microorganisms—within organic fertilizers must not exceed the regulatory limits established for clean agricultural soils, urban soils, and recreational areas (CSTEE, 2002). Compliance with these standards ensures that the introduction of organic amendments does not elevate the content of hazardous or limiting agents in soil beyond acceptable thresholds, thereby protecting ecosystem functions, plant and animal health, and human safety (Vakuloskii et al., 1998). Continuous monitoring and risk assessment are essential, particularly in regions affected by legacy contamination or high anthropogenic load, to maintain long-term soil quality and prevent secondary pollution.

Conclusion

Healthy soil is defined as regulatory-compliant soil that does not contain prohibited levels of xenobiotic or natural compounds, technogenic radionuclides, or biological agents. The regulatory maximum permissible concentrations (MPC) and orientation allowable concentrations (OAC) of soil pollutants serve as official factual criteria for soil health, limiting the content of both natural and xenobiotic contaminants. These standards provide a framework for a differentiated assessment of the ecological and hygienic status of agricultural and urban soils.

Regional monitoring of soil health allows for an objective evaluation of: (a) the ecological status of urban soils and recreational areas, and their safety for the surrounding social environment; and (b) the potential losses and reduction in crop quality resulting from hygienically substandard soils.

In cases of technogenic soil contamination, soil health must be monitored through systematic soil-ecological surveillance. The proposed methodology for assessing the health of agricultural and urban soils enables a more objective understanding of their role in soil conservation and protection. It also supports the development of operational forecasts for the dynamics of soil quality, and the formulation of scientifically grounded, economically feasible strategies for soil remediation and restoration.

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