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APLICAREA COMPOSTULUI OBȚINUT DIN NĂMOL URBAN CA FERTILIZANT ÎN PLANTAȚIILE DE MĂR

USE OF URBAN SLUDGE COMPOST AS FERTILIZANT ON APPLE ORCHARDS

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Abstract

This study shows the influence of compost fertilization derived from sludge obtained from wastewater treatment on the nutrition of an eight-year-old apple orchard, 'Jonathan' cv. A field experiment was conducted to demonstrate the beneficial and negative aspects of (urban) sludge compost fertilization in apples and to assess the risk of soil contamination with heavy metals from municipal sewage sludge compost. The experimental factor was the compost with the following gradations: V1 = 0 t/ha, V2 = 20 t/ha, V3 = 40 t/ha, V4 = 60 t/ha, V5 = 80 t/ha. After two years (2019-2021) from soil fertilization with compost, the nitrogen content of the leaves increased in the treatment with the maximum fertilization dose (80 t/ha) by 30% compared to the unfertilized control, while the phosphorus content of leaves increased by 80% compared to non-fertilization control. The potassium content of the leaves increased by 36% in the 80 t/ha treatment compared to the unfertilized control, but still remained at a deficit level. The results showed that growth and yield were improved by using sewage sludge compost. However, sewage sludge compost applications have not significantly altered the heavy metal content of plant tissues. The concentration of heavy metals in the soil did not exceed the maximum permissible thresholds according to standards established in other EU countries, where compost from sewage sludge is considered product, not waste. However, the calculation of the Igeo index (geoaccumulation index of heavy metal in soil) showed certain levels of soil pollution already installed with Cd Zn, Pb in all variants fertilized with compost.

Cuvinte cheie: fertilizare, compost, nutriţie, poluarea solului, metale grele.
Key words: fertilization, compost, nutrition, soil pollution, heavy metals.

1. Introduction

Due to the nutrient content and the important intake of organic matter, large amounts of sludge can be used in fruit growing as fertilizer. One of the most pressing problems could be solved or alleviated: the elimination of residual sludge from wastewater treatment facilities, to avoid incineration or other costly and polluting processes (Wei and Liu, 2005; Bowszys et al., 2015; Adunga, 2016).

The application of residual sludge in fruit growing is an inexpensive method and is in line with the ecological principles of waste recycling, and at the same time can be a method of improving the physical, chemical and biological properties of the soil (Benitez et al., 2001). However, its effect apparently depends on pedological conditions and cultivated plant species. In order to minimize the negative effects of residual sludge on a soil, the characteristics of a given sludge and the critical concentrations of heavy metals must be taken into account. In the use of dehydrated sludge as fertilizer in agriculture, a number of issues related to its content in heavy metals, contaminant organic substances and pathogens remain to be solved.

With the accumulation of heavy metals in soils cultivated with fruit trees, especially over the adsorption capacity of the soil, losses are expected, causing contamination of surface water and groundwater. A high potential for toxicity to fruit trees, vines and cover crops used in orchards must also be considered (Brunetto et al., 2011; Brunetto et al., 2014), given the maximum values allowed for certain food contaminants (Commission Regulation EC 1881/2006).

The concentration of phytotoxic forms of heavy metals in the soil is influenced by the physico-chemical properties of the soil, such as particle size distribution, pH, organic matter content, sorption properties and redox potential (Stachowiak et al., 2015).

One ton of dry sludge contains on average 200 kg of organic matter, 6 kg of nitrogen (N), 8 kg of phosphorus and 10 kg of various soluble salts (Lixandru, 2005). In addition to the elements needed for plant growth, sludge can contain heavy metals and other pollutants in varying amounts.

The application of sewage sludge as well as compost from sludge is a problem, due to the potential release of toxic metals after the decomposition of organic matter (Vaca et al., 2011). If the maximum allowable quantities are exceeded, heavy metals can be harmful because they accumulate in soil plants and eventually reach human and animal organisms through agri-food products (Kudakawashe and

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Gumbo, 2014). However, the application rate of compost varies depending on the plant species, as their tolerances to heavy metals are different (Chu et al., 2017).

Excess nitrogen present in sludge and compost, respectively, can also cause groundwater contamination by leaching nitrates (Moretti et al., 2015). Nitrates can also be leached from excess fertilizers (Domnariu et al., 2020).

The effects of compost from urban sludge on soil properties are mainly related to the rate of application and chemical composition of the compost, but soil organic matter and clay content are other key factors governing changes in soil fertility. If the cumulative concentrations exceed certain values, the effect on the soil can be negative, affecting the respiration process (microbial measure of soil activity), reduced activity of nitrogen-fixing bacteria or microbial biomass (Carmo et al., 2016). The negative effects of sludge on soil fertility properties are associated with a sudden increase in pH, which can reach the alkaline range and reduce the availability of trace elements (Dikinya and Mufwanzala, 2010). Research has established that with increasing soil pH, the solubility of most macroelements will decrease, leading to low concentrations in the soil (Neina, 2019).

Council Directive 1999/31/EC on the landfill (waste landfills) required a reduction in the amount of biodegradable waste by 75% by 2006, by 50% by 2009 and by 35% by 2016, compared to the total amount of biodegradable municipal waste produced in 1995. The best method of recovery of organic waste of all kinds is composting (Dumitru and Simota, 2011). The Quebec Bureau of Standardization defines compost as a solid mature product resulting from composting which is a process driven by bio-oxidation of the solid heterogeneous organic substrate including a thermophilic phase. Haug (2018) describes composting as a biological decomposition and stabilization of organic substances, under conditions that allow the development of thermophilic temperatures as a result of the production of biological heat; the final product thus obtained is stable, free of pathogens and plant seeds, and can be beneficially applied to agricultural land.

The purpose of composting varies from sanitation, elimination of pathogens or harmful organisms, insect larvae, intestinal reducing the volume of waste (Dumitru and Simota, 2011). The use of compost leads to improved soil structure, improved excessive textures, improved aeration and increased water storage capacity, increased soil fertility and stimulated the development of a healthy root system of plants. Organic matter applied through compost provides food for soil microorganisms, and nitrogen, phosphorus and potassium will be produced naturally and soil amendment will not be necessary.

Ispas et al. (2020) and Lassoued and Bilal (2021) also investigated environmental problems arising when using irrigation water or sewage sludge on some crops like vegetables and wheat.

The objective of this study is to evaluate the effect of applying different doses of compost from urban sludge derived from wastewater on soil fertility and tree nutrition, in a seven-year apple plantation, 'Jonathan' cultivar, in order to reduce residual deposition and to prevent degradation of the environment.

2. Material and methods

2.1. Study Area

The present study was carried out at the Research Institute for Fruit Growing Pitesti, Romania (44° 51′ 30” N, 24° 52” E), in a seven-year apple plantation. The experiment was organized on a wet phreatic aluviosol, formed on fluvial deposits, with a loamy-sandy texture.

The field was located in a meadow terrace of the Argeș River.

The planting distance of the apple trees is 3.5 m x 1.25 m and the density is 2,285 apple trees/ha.

The shape of the crown was a slender spindle.

To study the effect of compost applied as fertilizer, a single-factor experiment was designed (five experimental variants with four replicates), the experimental factors being the doses of urban sludge compost, with the following graduations:

V_1 = compost, 0 t/ha (unfertilized control)
V_2 = compost, 20 t/ha
V_3 = compost, 40 t/ha
V_4 = compost, 60 t/ha
V_5 = compost, 80 t/ha

The five experimental variants were placed randomly, in four replicates.

From an agrochemical point of view, the soil falls into the class of acidic soils, with an acidic to strongly acidic reaction, a low-very low humus content in the arable horizon, a very low nitrogen supply, low phosphorus and potassium contents, as can be seen in Table 1.

2.2. Soil Sampling and Laboratory Analysis

The compost applied in the experimental variants comes from the sludge obtained at the Mioveni wastewater treatment plant. Regarding the dry matter (d.m.), the content of the compost is 1.52% N of d.m., 1.38% P-P_2O_5 of d.m., 0,675% K-K_2O of d.m., organic carbon 21.5% of d.m. In terms of heavy metal content, this compost is within the maximum limits accepted in EU countries (EC 889/2008), values that

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do not exceed the maximum limits allowed for sludge that can be applied on agricultural land, namely: 10 mg/kg Cd, 50 mg/kg Co, 500 mg/kg Cr, 500 mg/kg Cu, 1200 mg/kg Mn, 100 mg/kg Ni, 300 mg/kg Pb and 2000 mg/kg Zn (Dumitru, 1990). However, there are very high aluminum content (Al=24048.30 mg/kg) and iron content (Fe=17961.9 mg/kg), often with phytotoxic effects and which could cause environmental problems, especially for acid soils.

Before applying the compost, the soil chemical properties were analyzed using the following methods described by Florea et al. (1987): total nitrogen by Kjeldahl method (Kjeldahl, 1883); extractable phosphorus (P-AL) by Egnér - Riem Domingo method (Egnér et al., 1960), by which the phosphates are extracted from the soil sample with a solution of acetate - ammonium lactate at pH=5.75, and determined colorimetric phosphate anion extracted as molybdenum blue (Egnér et al., 1960); exchangeable potassium (K-AL) by Egnér - Riem Domingo method by which the hydrogen and ammonium ions of the extraction solution replace by exchange the exchangeable potassium ions in the soil sample which are thus passed into the solution (Egnér et al., 1960). Potassium dosing in the solution thus obtained is done by flame emission photometry.-organic carbon - wet oxidation method followed by titrimetric dosing by Walkley - Black, (Gogoasa modification) and humus (deduced by calculation from organic carbon); soil pH, soil: water ratio=1:2.5 by the potentiometric method; mobile aluminum by the Sokolov method (Sokolov, 1939); sum of exchangeable bases and hydrolytic acidity (Kappen method), base saturation degree (determined by calculation, depending on the sum of bases).

2.3. Vegetable material Sampling and Laboratory Analysis

In August, leaf samples were collected from which the level of supply of plants with nutrient macro-elements (nitrogen, phosphorus and potassium -total forms) was determined by the following methods: total nitrogen - Kjeldahl method (Kjeldahl, 1883); total phosphorus - colorimetric method (Egnér et al., 1960); total potassium - the method of dosing by flame emission photometry (Egnér et al, 1960);

The chemical analysis of heavy metals (total amounts) for both plant and soil was performed at National Research and Development Institute for Soil Science, Agrochemistry and Environment Bucharest.

Fruit samples were also collected and biometric and production determinations (weight, production/tree) were performed. The increase in growth of the trunk cross sectional area of the trees under study was also determined.

2.4. Statistical Analyses

Statistical analyze was performed with an IBM SPSS (SPSS 14) software. The results of field estimates and chemical analyzes performed on soil, plant, fruit samples, collected from the experimental variants, were processed using the variance analysis method and the multiple comparison method. In order to systematize and process the large data volume of analyzes on the physical and chemical characteristics of soil, on trees, fruits and other results, generalizations were made, with the data being presented in tables representing their variations depending on the experiment and agrochemical-agrotechnical measures applied.

3. Results and discussions

3.1. Correlations between the biological indicators analyzed after the compost application to 'Jonathan' apple cv.

As expected, two distinctly significant positive correlations (**) are observed between the cross-sectional area of the spring tree trunk and the growth spurt, and between the cross-sectional area of the autumn tree trunk and the growth spurt (Table 2). This shows a favorable effect of the compost fertilization on tree growth.

In the second year of experimenting with fertilizing with increasing doses of compost, there is no influence of the application of compost on cross sectional area, on growth spurt or on fruit production.

3.2. Correlations between agrochemical indicators obtained in soil and plant material (leaf) after application of compost to 'Jonathan' apple cv.

The tests on the correlation between the indicators tested in the experiment, presented in Table 1, express the existence of distinctly significant positive interdependencies (with a significance threshold of 99%) between the doses of compost administered and all agrochemical indicators studied, except mobile aluminum. The increasing doses of compost bring a significant, increasing intake of nutrients (nitrogen, phosphorus, potassium) but also of organic carbon, respectively humified organic matter as well as basic elements in the soil (table 3).

A distinctly significant negative correlation is observed between the mobile aluminum content in the soil and the compost dose. It is known that the basic elements in the soil (calcium, potassium, phosphorus) block mobile aluminum in hard soluble compounds, and the compost used as fertilizer contains large amounts in these elements (Ca=12398.30 mg / kg su, P_2O_5 =1.38 %, K_2O=0.675% of su) as shown by the chemical analysis performed by INCDPM Bucharest. The compost also contains large amounts of aluminum (Al=24048.30 mg/kg d.m.). The distinctly significant negative correlation clearly highlights the fact that aluminum, in increasing quantities, is trapped in hardly soluble compounds by increasing amounts of basic elements, so that the mobile aluminum content (existing in the soil solution) is decreasing with increasing the dose of compost applied. The same blocking phenomenon in sparingly soluble compounds is highlighted by the distinctly significant negative correlations obtained between mobile aluminum and all the basic elements in the soil fertilized with increasing doses of compost (P_2O_5, K_2O), but also with nitrogen and organic carbon in the soil.

The soil aluminum is also significantly correlated with the nutrients in the leaf (N, P, K), which demonstrates the already known fact that the aluminum in the soil prevents the assimilation of N, P, K in the leaf.

In acid soils the soluble inorganic phosphorus is fixed by aluminum and iron. In agricultural practice, to overcome this problem, acid soils are fined with limestone to block aluminum and iron, but the practice is not economical (Zhao, 2018). Phosphorus availability is influenced by soil organic matter, pH and Al, Fe, Ca (Smithson, 1999). Soil reaction pH, Al, Fe, P are the properties of the soil related to each other. Their role in plant growth and development is very important. Limestone and humus are commonly used amendments to increase soil pH and phosphorus solubility and to suppress the solubility of aluminum and iron in the soil. Compost brings large amounts of calcium into the soil, but also aluminum and iron.

It is known that excess aluminum is toxic to most plants. The main symptom of aluminum phytotoxicity is inhibition of root growth, which can occur at a concentration of up to μM, within 1 hour (Matsumoto, 2000; Kochian et al., 2005; Ma, 2007).

The roots are the main organ through which plants take nutrients from the growing environment, so the toxicity of aluminum inevitably affects the ability of plants to obtain nutrients from acidic soils. due to the small volume of roots. On the other hand, aluminum can directly affect the transport and metabolism of nutrients inside plants. The interactions between aluminum and nutrients often occur in soil and plant (Zhao et al., 2014).

More than 100 scientific papers have reported Al-N interactions emphasizing the importance of this topic. Older studies show that aluminum has reduced nitrogen uptake through roots and translocated it to shoots (Gomes et al., 1985; Pintro et al., 1996).

Compost, like the sludge it comes from, is a source of phosphorus and trace elements for the soil. The mobile phosphorus content in the soil increased significantly in the variants fertilized with compost 40 t/ha and compost 60 t/ha by 10 times, compared to the unfertilized control. In the 80 t/ha compost variant, the mobile phosphorus content increased only four times compared to the unfertilized control. The problem aluminum content from soil remains in the following years, for observation and monitoring: in the fertilized soil with the maximum dose established in the experiment there is a blocking of phosphorus by aluminum introduced into the soil in very large quantities, with dose of 80 t compost/ha.: in the fertilized soil with the maximum dose established in the experiment there is a blocking of phosphorus by aluminum introduced into the soil in very large quantities, with dose of 80 t compost/ha. The phenomenon of phosphorus blockage by some aluminum species present in the acid soils is known (Borlan, 1973). The problem is the very high content of aluminum in the compost that reaches the soil. In acidic soils, acidity is often associated with the presence of mobile aluminum and mobile manganese, which above certain limits have a harmful effect on agricultural plants (Kochian et al., 2015). Ragland and Coleman (1959) showed that mobile aluminum has both a direct action of destroying young roots, accompanied by abnormal plant development, and an indirect action contributing to the decrease of phosphorus absorption capacity by plants. Mihailescu et al., (2003) showed the connection between the presence of mobile aluminum on an albic luvosoil and blocking of mobile phosphorus into the soil, bringing to the fore the idea that the presence of mobile phosphorus in the soil moderates the negative influence of aluminum in plant nutrition. The chemical composition of the compost, in terms of metals content was established based on chemical analyzes performed at the National Research and Development Institute for Soil Science Agrochemistry and Environment Bucharest. So that the concentration of heavy metals in the compost used is the following: Cadmium 1.04 mg/kg of dry matter, Chromium 38.75 mg/kg of dry matter, Cobalt 8.04 mg/kg of dry matter, Copper 72.36 mg/kg of dry matter, Lead 32.21 mg/kg of dry matter, Manganese 446.14 mg/kg of dry matter, Nickel 29.53 mg/kg of dry matter, Zinc 557.00 mg/kg of dry matter, Mercury 0.18 mg/kg of dry matter. There are very high concentrations of aluminum in compost (Al=24048.30 mg/ kg from dry matter) and iron (Fe=17961.9 mg/kg from dry matter), elements whose effect is often phytotoxic and which could pose problems for soils fertilized with this compost, especially for acid soils.

Acid soils are characterized by a deficiency of nutrients and toxicity of metals such as Mn, Fe and Al, aluminum being the main limiting factor for plant growth and development in acid soils (Kochian et al., 2004, Gupta et al., 2013, Bose et al., 2015). The total concentration of aluminum in the soil and the aluminum species depend on the pH and chemical environment of the soil solution (Kisnieriene and Lapeikaite, 2015). The toxic effect of different forms (species) of aluminum on plant growth decreases in the following order: Al^{3+}, $Al(OH)^{2+}$, $Al(OH)^{+2}$, $Al(OH)^{-4}$. At a low pH (around 4.3) trivalent aluminum Al^{3+}

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predominates, which has the greatest impact on plant growth. In contrast, precipitated or chelated aluminum with organic compounds is not toxic to plants (Nogueirol et al., 2015). At a pH higher than 5-6, the dominant species are $Al(OH)_2^+$, $Al(OH)^{+2}$ which are not as toxic as Al^{3+} (Kinraide, 1991, Delhaize and Ryan, 1995, Brautigan et al., 2012, Hagvall et al., 2015, Kisnieriene and Lapeikaite, 2015). Polycationic Al (charge >2) is rhizotoxic as are other polyvalent cations (Kinraide, 1991).

It was first recognized over 100 years ago that soluble aluminum levels increase in acid soils (Veitch, 1904) and that it is toxic to plant growth, the main effect being inhibiting root growth (Daikuhara, 1914; Miyake, 1916; Magistad, 1925; Kopietke et al., 2016).

The chemical analysis of the soil fertilized with increasing doses of compost, however, did not detect high contents of mobile aluminum in the analyzed soil, the highest value being 15.45 mg/kg mobile Al for the variant fertilized with 60 t/ha compost.

In this case, the very high level of aluminum in the compost is not found as a high content in the soil fertilized with increasing doses of compost. Most probably these are forms of aluminum adsorbed in the structure of the compost or in the clay-humic complex.

One of the most important factors controlling the immobilization (sorption) and mobility of heavy metals in the soil is pH (Kukier and Malcom, 2004). Increasing the pH of the soil with increasing the dose of compost has led to a decrease in the absorption of heavy metals in plants. Distinctly significant negative correlations are observed between pH and heavy metals contained in the leaf and soil (Table 4). On the other hand, low pH values can increase the toxicity of metals due to their increased mobility (Seutjens et al., 2002; Amini et al., 2010).

After two years (2019-2021) from soil fertilization with compost, the nitrogen content of the leaves increased in the treatment with the maximum fertilization dose (80 t/ha) by 30% compared to the unfertilized control, while the phosphorus content of leaves increased by 80% compared to non-fertilization control. The potassium content of the leaves increased by 36% in the 80 t/ha treatment compared to the unfertilized control, but still remained at a deficit level (Figures 2 and 3).

3.3. Contamination Assessment Methodology

3.3.1. Geoaccumulation index of heavy metal in soil (Igeo)

The Igeo is used in order to assess the degree of accumulation of heavy metals. At first, the Igeo was used for the ecological risk assessment of sediments (Müller, 1969). It was also used for the assessment of the contamination of soil (Huang et al., 2011), sewage sludge (Latosinska et al., 2020) and sewage sludge ash (Latosinska et al., 2020). The Igeo is described in the equation (Hakanson, 1980, Xiao et al., 2015):

$$Igeo = log_2 \frac{Cn}{1.5*Bn} \quad (1)$$

where: Cn-content of a given element from the group of heavy metals contained in sewage sludge, mg/kg d.m.; Bn-content of a given element from the group of heavy metals present in the soil, mg/kg d.m. (Table 5). The constant value 1.5 is introduced for better analysis of the natural variability of the content of the chosen substance in the environment.

The classification of the heavy metals Igeo is: < 0 - no pollution; 0 – 1 - no pollution, low pollution; 1 – 2 - moderate pollution; 2 – 3 - moderate or high pollution; 3 – 4 - high pollution; 4 – 5 - high or very high pollution; > 5 - very high pollution (Xiao et al., 2015).

The data presented in Table 5 show that the contents of heavy metals in the experimentally fertilized soil with increasing doses of compost are within the maximum allowed limits. However, Igeo values for some metals in the fertilized soil indicate a certain degree of soil pollution with heavy metals from the administered compost. The degree of pollution can evolve towards unfavorable effects on the soil and on the ecosystem as a whole with the increase of the doses of compost administered (over 60 t/ha). Heavy metals are blocked (adsorbed) in organomineral complexes and can be desorbed by changes in environmental conditions (soil pH, precipitation, soil type, cultivated species). Repeated applications of metal-contaminated sewage sludge can have a drastic effect on soil levels of trace elements and lead to serious toxicity effects in plants. In some cases, land can be rendered sterile. There is a dearth of information relating to the rates at which potentially toxic-elements commonly present in sewage sludge become immobilised in soils (Purves,1986).

The content values of the heavy metals in the soil, presented in Table 5, do not exceed the maximum limits allowed for soils fertilized with urban mud (Ilie et al. 2007).

Given the multitude of sources of heavy metal loading of the soil (industrial emissions, chemical fertilizers, irrigation water, manure) and the fact that some sources cannot be removed, it is necessary to limit the amount of metals applied with the sludge, so that Ilie et al. (2007) recommends the following maximum permissible heavy metal limits in soil: 10 mg/kg As, 3 mg/kg Cd, 30 mg/kg Co, 100 mg/kg Cr, 100 mg/kg Cu, 2 mg/kg Hg, 1000 mg/kg Mn, 5 mg/kg Mo, 50 mg/kg Ni, 100 mg/kg Pb.

4. Conclusions

The application of compost from the sludge obtained from wastewater treatment on acid soils ameliorated soil reaction in the sense of increasing pH values due to the alkaline elements contained into the compost.

Fertilization with increasing doses of compost increased the soil humus content. The aport of macro-elements in to the soil is also significant.

The incorporation of compost into the soil also improved the sum of bases, base saturation, cation exchange capacity.

The mobile phosphorus content from soil increased significantly in the 40 t compost / ha and 60 t compost/ha fertilized variants ten times compared to the unfertilized control. In the 80 t compost/ha variant, the mobile phosphorus content increased fourfold compared to the unfertilized control.

The leaf nitrogen content increased in the maximum fertilization dose (80 t/ha) variant by 30% compared to the unfertilized control, and the leaf phosphorus content increased 4 times at the same variant compared to the non-fertilized control.

The leaf potassium content increased in the 80 t/ha fertilized variant compared to the unfertilized control by 36%, but it remained at a deficient level and this is due to the low natural soil fertility.

The content of heavy metals in the soil did not exceed the maximum permitted thresholds in the standards set in other EU countries, where compost from sewage sludge is considered product, not waste.

Using of compost derived from sludge obtained from wastewater treatment increases the soil content in some nutrients, but the starting with the dose of 40 t/ha, certain degrees of soil pollution are installed with Cd, Pb and Zn. In the case of Cd, soil pollution occurred at a dose of 20 t/ha of compost.

It was observed that in the first year the soil contamination with Cd, Pb, Zn appeared at a dose of 60 t / ha, compared to the second year when it was installed moderately from a dose of 40 t/ha. This shows that heavy metals are trapped in insoluble compounds and are made available with changing environmental conditions.

We do not recommend exceeding the dose of 40 t/ha, once every 3 years.

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Tables and Figures

Table1. Agrochemical soil properties

Soil depth (cm)	Acidity indicators					Fertility indicators			
	pH	Sum of bases SB (me/100 g sol)	Extractable Acidity Ah (me/100 g sol)	Base saturation V (%)	Mobile aluminum Al^{3+} (mg/kg)	Total nitrogen content N_t (%)	Total phosphorus content P_2O_5-P (mg/kg)	Potassium K_2O-K content (mg/kg)	Humus content (%)
0-20	5.4	14.21	2.67	84.19	11.00	0.08	20	148	1.58
20-40	5.2	6.0	9.7	38.21	11.81	0.07	18	130	1.20

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Table 2. Correlations between biometric indicators analyzed after compost application to the 'Jonathan' variety orchard

		Compost dose (t/ha)	Trunk cross-sectional area in the spring 2020 (cm^2)	Trunk cross-sectional area in the autumn 2021 (cm^2)	Growth increase of the cross-sectional area 2021 (cm^2)	Fruit production in the 2021 (t/ha)
Compost dose (t/ha)	Pearson Correlation	1	0.042	0.047	0.044	0.049
	Number	100	87	87	87	85
Trunk cross sectional area in the spring 2020 (cm^2)	Pearson Correlation	0.042	1	0.962 (**)	0.524 (**)	0.207
	Number	87	87	87	87	85
Trunk cross sectional area in the autumn 2021 (cm^2)	Pearson Correlation	0.047	0.962 (**)	1	0.736 (**)	0.135
	Number	87	87	87	87	85
Growth increase of the cross sectional area 2021 (cm^2)	Pearson Correlation	0.044	0.524 (**)	0.736 (**)	1	-0.093
	Number	87	87	87	87	85
Fruit production in the 2021 (t/ha)	Pearson Correlation	0.049	0.207	0135	-0.093	1
	Number	85	85	85	85	85

Table 3. Correlations between the average values of the studied agrochemical indicators
****Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)**

	Compost dose (t/ha)	pH	Al mob (ppm)	Humus (%)	Nt soil (%)	P-P_2O_5 soil (ppm)	K-K_2O soil (ppm)	P-P_2O_5 (% d.m. leaf)	K-K_2O (% d.m. leaf)	Nt (% d.m. leaf)	Ah me/100 g soil	SB me/100 g soil
Compost dose (t/ha)	1	0.216	-0.839 (**)	0.983 (**)	0.980 (**)	0.890 (**)	0.964 (**)	0.821 (**)	0.951 (**)	0.977 (**)	0.821 (**)	0.975 (**)
Sig. (2-tailed)		0.361	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
N	20	20	20	20	20	20	20	20	20	20	20	20
pH	0.216	1	-0.174	0.282	0.285	0.071	0.170	-0.005	0.231	0.201	0.170	0.217
Al mob (ppm)	-0.839 (**)	-0.174	1	-0.852 (**)	-0.861 (**)	-0.707 (**)	-0.755 (**)	-0.678 (**)	-0.820 (**)	-0.828 (**)	-0.543 (*)	-0.884 (**)
Humus (%)	0.983 (**)	0.282	-0.852 (**)	1	0.995 (**)	0.892 (**)	0.944 (**)	0.732 (**)	0.902 (**)	0.948 (**)	0.737 (**)	0.977 (**)
Nt soil (%)	0.980 (**)	0.285	-0.861 (**)	0.995 (**)	1	0.877 (**)	0.934 (**)	0.740 (**)	0.907 (**)	0.948 (**)	0.718 (**)	0.977 (**)
P-P2O5 soil (ppm)	0.890 (**)	0.071	-0.707 (**)	0.892 (**)	0.877 (**)	1	0.960 (**)	0.726 (**)	0.768 (**)	0.799 (**)	0.707 (**)	0.821 (**)
K-K2O soil (ppm)	0.964 (**)	0.170	-0.755 (**)	0.944 (**)	0.934 (**)	0.960 (**)	1	0.798 (**)	0.893 (**)	0.903 (**)	0.816 (**)	0.900 (**)
P-P2O5 (% d.m.leaf)	0.821 (**)	-0.005	-0.678 (**)	0.732 (**)	0.740 (**)	0.726 (**)	0.798 (**)	1	0.861 (**)	0.847 (**)	0.850 (**)	0.760 (**)
K-K2O (% d.m.leaf)	0.951 (**)	0.231	-0.820 (**)	0.902 (**)	0.907 (**)	0.768 (**)	0.893 (**)	0.861 (**)	1	0.974 (**)	0.837 (**)	0.925 (**)
Nt (% d.m.leaf)	0.977 (**)	0.201	-0.828 (**)	0.948 (**)	0.948 (**)	0.799 (**)	0.903 (**)	0.847 (**)	0.974 (**)	1	0.822 (**)	0.970 (**)
Ah me/100 g soil	0.821 (**)	0.170	-0.543 (*)	0.737 (**)	0.718 (**)	0.707 (**)	0.816 (**)	0.850 (**)	0.837 (**)	0.822 (**)	1	0.727 (**)
SB me/100 g soil	0.975 (**)	0.217	-0.884 (**)	0.977(**)	0.977 (**)	0.821 (**)	0.900 (**)	0.760 (**)	0.925 (**)	0.970 (**)	0.727 (**)	1

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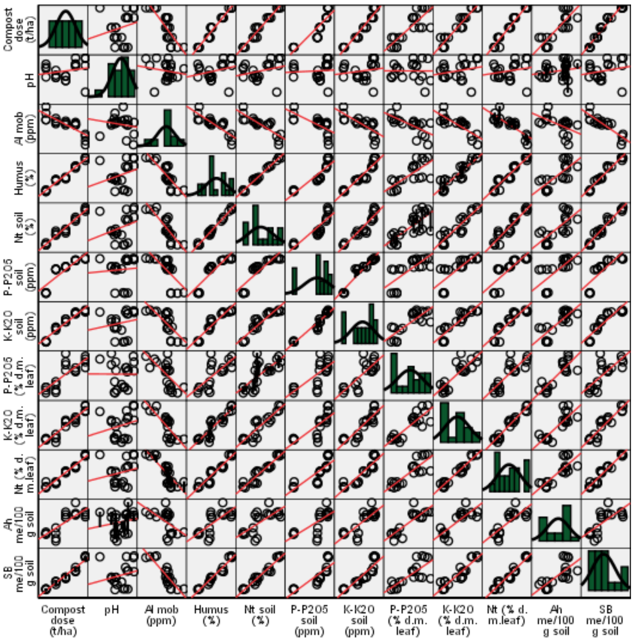

Fig. 1. Correlations between the average values of the studied agrochemical indicators
****Correlation is significant at the 0.01 level (2-tailed); *Correlation is significant at the 0.05 level (2-tailed)**

Table 4. Correlations between the average values of the heavy metals contained in the soil and in the leaf
****Correlation is significant at the 0.01 level (2-tailed);*Correlation is significant at the 0.05 level (2-tailed)**

	Compost	Cd*	Cu*	Co*	Mn*	Ni*	Pb*	Zn*	Cd**	Cu**	Co**	Mn**	Ni**	Pb**	Zn**
Compost	1	0.821 **	0.940 **	0.817 **	0.923 **	0.880 **	0.760 **	0.915 **	-0.719 **	0.798 **	0.759 **	0.760 **	-0.927 **	0.372	0.634 **
Cd*	0.821 **	1	0.907 **	0.495 *	0.651 **	0.528 *	0.476 *	0.763 **	-0.619 **	0.783 **	0.787 **	0.677 **	-0.81**	0.256	0.836 **
Cu*	0.940 **	0.907 **	1	0.675 **	0.811 **	0.718 **	0.637 **	0.872 **	-0.670 **	0.833 **	0.816 **	0.745 **	-0.897 **	0.364	0.795 **
Co*	0.817 **	0.495 *	0.675 **	1	0.939 **	0.953 **	0.511 *	0.705 **	-0.562 **	0.751 **	0.427	0.826 **	-0.576 **	0.320	0.453 *
Mn*	0.923 **	0.651 **	0.811 **	0.939 **	1	0.917 **	0.707 **	0.904 **	-0.508 *	0.845 **	0.481 *	0.739 **	-0.740 **	0.471 *	0.554 *
Ni*	0.880 **	0.528 *	0.718 **	0.953 **	0.917 **	1	0.662 **	0.720 **	-0.710 **	0.632 **	0.578 **	0.779 **	-0.726 **	0.280	0.350
Pb*	0.760 **	0.476 *	0.637 **	0.511 *	0.707 **	0.662 **	1	0.824 **	-0.356	0.378	0.431	0.184	-0.805 **	0.474 *	0.114
Zn*	0.915 **	0.763 **	0.872 **	0.705 **	0.904 **	0.720 **	0.824 **	1	-0.389	0.828 **	0.513 *	0.529 *	-0.837 **	0.556 *	0.615 **
Cd**	-0.719 **	-0.619 **	-0.670 **	-0.562 **	-0.508 *	-0.710 **	-0.356	-0.389	1	-0.376	-0.913 **	-0.774 **	0.729 **	0.091	-0.410
Cu**	0.798 **	0.783 **	0.833 **	0.751 **	0.845 **	0.632 **	0.378	0.828 **	-0.376	1	0.463 *	0.780 **	-0.602 **	0.428	0.889 **
Co**	0.759 **	0.787 **	0.816 **	0.427	0.481 *	0.578 **	0.431	0.513 *	-0.913 **	0.463 *	1	0.688 **	-0.832 **	-0.041	0.582 **
Mn**	0.760 **	0.677 **	0.745 **	0.826 **	0.739 **	0.779 **	0.184	0.529 *	-0.774 **	0.780 **	0.688 **	1	-0.571 **	0.080	0.731 **
Ni**	-0.927 **	-0.811 **	-0.897 **	-0.57 **	-0.740 **	-0.726 **	-0.805 **	-0.837 **	0.729 **	-0.602 **	-0.832 **	-0.571 **	1	-0.288	-0.524 *
Pb**	0.372	0.256	0.364	0.320	0.471 *	0.280	0.474 *	0.556 *	0.091	0.428	-0.041	0.080	-0.288	1	0.235
N	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Zn**	0.634 ***	0.836 **	0.795 **	0.453 *	0.554 *	0.350	0.114	0.615 **	-0.410	0.889 **	0.582 **	0.731 **	-0.524 *	0.235	1

*Cd, Cu, Co, Mn, Ni, Pb, Zn – mg/kg d.m. soil; ** Cd, Cu, Co, Mn, Ni, Pb, Zn – mg/kg d.m. leaf

Table 5. The content of heavy metals in the variants fertilized with different doses of compost, in the experiment placed on the Jonathan apple variety in the second year after fertilization, 2021 (average values)

Dose of compost applied (t/ha)	The analyzed metal	Heavy metal content of fertilized soil (mg/kg)	Heavy metal content of plant material (mg/kg of d.m.)	Heavy metal content of compost (mg/kg of d.m.)	Index Igeo	Degree of heavy metal pollution in the soil
V_1=0	Cd	0.142	0.062			
	Cu	60.1	459			
	Co	8.10	0.27			
	Mn	457	153			
	Ni	17.2	4.75			
	Pb	7.62	0.14			
	Zn	66	26.3			
V_2=20	Cd	0.086	0.071	**1.04**	3.11	high pollution
	Cu	57.9	501	**72.36**	0	no pollution
	Co	8.76	0.21	**8.04**	0	no pollution
	Mn	515	129	**446.14**	0	no pollution
	Ni	28.9	4.40	**29.53**	0	no pollution
	Pb	9.15	0.22	**32.21**	1.23	moderate pollution
	Zn	146	25.9	**557.00**	1.34	moderate pollution
V_3=40	Cd	0.358	0.063		0.95	low pollution
	Cu	64.9	621		0	low pollution
	Co	8.15	0.34		0	low pollution
	Mn	535	168		0	low pollution
	Ni	21.6	4.21		0	low pollution
	Pb	7.38	0.20		1.55	moderate pollution
	Zn	159	37.1		1.22	moderate pollution
V_4=60	Cd	0.337	0.052		1.05	moderate pollution
	Cu	59.4	531		0	no pollution
	Co	12.2	0.46		0	no pollution
	Mn	649	162		0	no pollution
	Ni	16.6	3.64		0.23	no pollution
	Pb	9.60	0.18		1.16	moderate pollution
	Zn	201	31.0		0.87	low pollution
V_5=80	Cd	0.282	0.054		1.3	moderate pollution
	Cu	58.6	641		0	no pollution
	Co	8.79	0.38		0	no pollution
	Mn	532	190		0	no pollution
	Ni	17.0	3.79		0	no pollution
	Pb	6.61	0.22		1.7	moderate pollution
	Zn	104	33.3		1.84	moderate pollution

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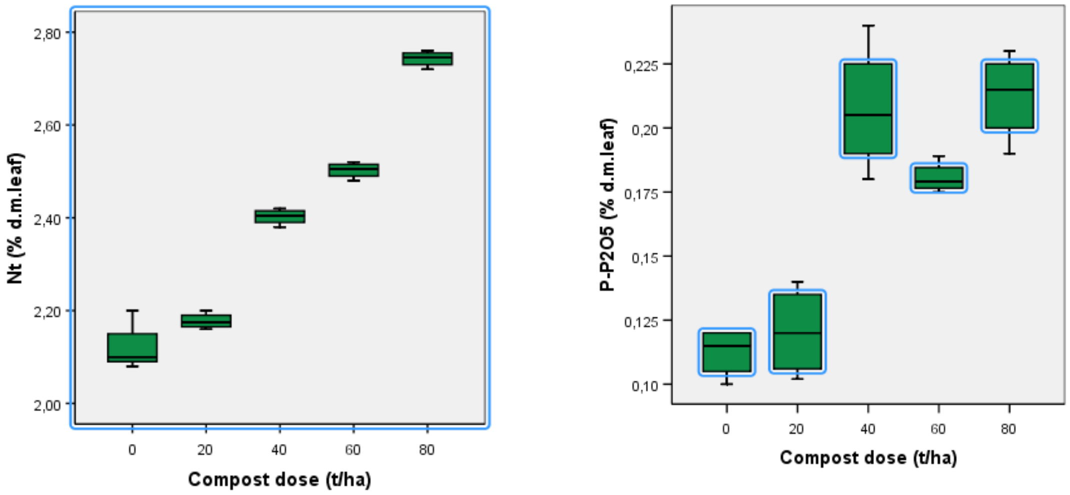

Fig. 2. Influence of compost dose on the nitrogen content (a) and phosphorus content (b) from apple leaf

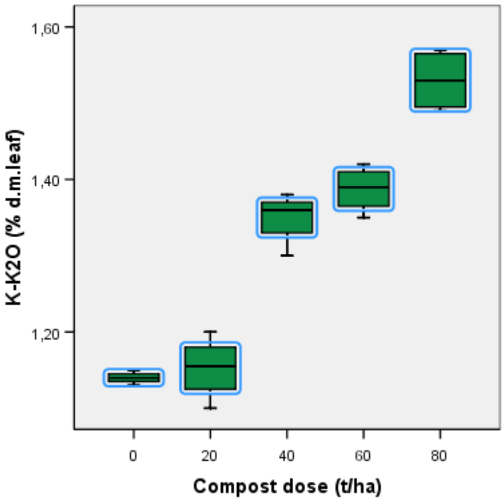

Fig. 3. Influence of compost dose on the potassium content from apple leaf

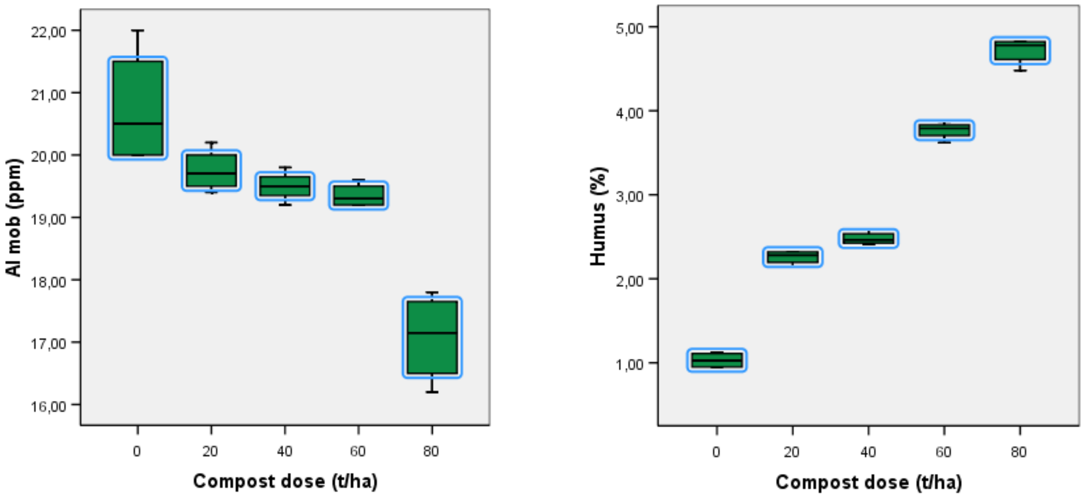

Fig. 4. Influence of the compost dose on the aluminum content and organic matter content from soil