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DRIP IRRIGATION'S INFLUENCE ON CHERNOZEM SOIL: ELECTROPHYSICAL AND SALINITY DYNAMICS

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Abstract

The study of the influence of drip irrigation on electrophysical parameters and water-soluble salt content in soil and strawberry plants (petioles and fruits) under different fertilization systems is presented. The mineralization and pH of the water used to irrigate the strawberries were measured. The increased content of water-soluble sodium cation salts in irrigation water leads to soil salinization (typical chernozem) and an increase in its amount in the thickness of 0-50 cm during the study period. At the same time, the electrical conductivity of the soil-water suspension decreases. Water pH and salt pH tend to change to an alkaline reaction. The highest amount of calcium, sodium and potassium cations is found in the plants of the control variant, the lowest - in the mineral and organic-mineral variants, and the intermediate amount - in the organic system of fertilization with drip irrigation. Adjusting and regularly monitoring the salinity and pH of irrigation water will help grow healthy and beautiful plants, and plant sap analysis complements soil solution analysis.

***Key words**: chernozem, drip irrigation, pH, soil conductivity, water-soluble salts.*

INTRODUCTION

Soil is the most key component of agricultural biocenoses. The condition and nature of the soil cover, its water, air, salinity, nutrient, thermal and microbiological regimes and its bioproductivity have a critical impact on crop yields.

Irrigation is the most powerful factor of human intervention in the natural environment and a strong factor in the transformation of chernozem soils. Irrigation, by increasing water inputs into the landscape, can significantly alter soil characteristics. These alterations include changes in soil morphology, such as the formation of dense soil layers or the breakdown of aggregates, as well as shifts in soil composition, such as the accumulation of salts or the loss of organic matter (Zeng et al., 2013).

In contemporary agriculture, drip irrigation technology is rapidly gaining popularity due to its numerous benefits. Drip irrigation ensures optimal moisture conditions for plant roots over extended periods. This fosters both robust physiological activity and enhanced crop development (Yan et al., 2022). In this context, local irrigation methods ensure minimal environmental impact on the landscape and soils, while maintaining optimal crop productivity, and are the most appropriate and promising in terms of conserving soil and land resources with naturally insufficient and unstable atmospheric moisture (Brovarets, 2017; Neilsen et al., 2004).

Salinization, a major consequence of irrigation, refers to the accumulation of easily soluble salts such as sodium carbonate, chlorides, and sulfates in the soil. Primary or residual salinization occurs when salts build up in the soil column due to natural processes or the intrusion of saline groundwater and surface water. For instance, in arid and semi-arid regions, high evaporation rates can draw salts from deeper soil layers to the surface, leading to primary salinization. Similarly, the use of saline irrigation water can contribute to the accumulation of salts in the soil over time. This accumulation of salts negatively affects soil health by hindering water and nutrient uptake by plants, ultimately reducing crop yields and potentially leading to land degradation. Soils are considered saline if they contain more than 0.1% by weight of salts toxic to plants or more than 0.25% of salts in the dense residue. The main mechanism of this process is the introduction of salts in dissolved form with irrigation water and the precipitation of salts in the soil column from mineralized groundwater. Large areas of irrigated land become unsuitable for cultivation due to the accumulation of large amounts of salts in the soil.

The accumulation of salts in the soil is activated in the first years of irrigation and decreases 3-5 years after the start of irrigation (Neilsen et al., 2004). Over time, the soil salinity regime reaches a dynamic equilibrium.

The process of sodium sorption in irrigated soils starts with active absorption in the first 2-3 years of irrigation, then slows down and reaches a quasi-stationary state in 3-5 years (Gamkalo, 2009). The duration of irrigation also affects the progression of salinity and salinization processes deeper in the soil profile.

The soil parameters most affected by drip irrigation are primarily the amount and composition of water-soluble salts and carbonate content. According to scientific sources, drip irrigation with water of different content and quality in Ukraine shows trends in the accumulation of water-soluble salts in the soil, changes in the composition of their absorption complex, i.e. the development of salination and salinization processes.

The underestimation of the possible negative impact of drip irrigation on soil properties due to the low irrigation rates compared to traditional methods and the local character of soil moisture makes research on this issue irrelevant. However, the localized nature of the wetting and the much larger specific volumes of water applied to the wetted part of the soil surface are associated with the potential risk of negative soil effects from drip irrigation.

So far, the technical and technological aspects of using this method of supplying moisture to plants have been well studied. At the same time, various aspects of the impact of drip irrigation on the dynamics and direction of processes in soils during long-term use of this irrigation method, and differences in their direction both in the wetting zones and beyond, remain insufficiently studied.

To improve soil fertility and obtain high and stable crop yields, it is necessary to create favourable chemical, physico-chemical and physical properties of irrigated chernozems based on the study of the nature and direction of their changes (Dehtiar’ov et al., 2021; Zhernova et al., 2022).

The aim of the study is to investigate the effect of drip irrigation on soil electrophysical parameters and water-soluble salt content under different fertilization systems, as well as to determine the degree of water mineralization and pH.

MATERIALS AND METHODS

For the fourth consecutive year, garden strawberries (*Fragaria ananassa*) have been cultivated at the "Dokuchaevske Experimental Field" Educational, Research and Production Center (ERPC) of the State Biotechnological University, located in the forest steppe zone of Ukraine (49.899434, 36.452007). This research employed both field and laboratory methods to investigate the effects of drip irrigation and fertilizer application on strawberry growth and yield (Figure 1).

Figure 1. Location of the study area

The "Dokuchaevske Experimental Field" ERPC was selected for this study due to its representative soil and climatic conditions typical of the forest steppe zone. By conducting research at this location, the findings can be applied to a wider range of strawberry cultivation areas in similar environments. Strawberry plants are highly susceptible to salt damage. While all irrigation water contains dissolved mineral salts, the concentration and composition of these salts can differ significantly. Higher salt concentrations in irrigation water led to increased salinity problems in the root zone. Factors influencing root zone salinity include water quality, fertilizer application rates, and irrigation depth.

It is important to note that it is not only drought in the soil that affects strawberry yields, but also drought in the atmosphere. When the air temperature is between 28-30ºC, additional watering should be done in addition to the main watering.

The "Roxanne" strawberries were irrigated using a drip irrigation system (Figure 2). The strawberries were cultivated on raised ridges covered with black PVC sheeting to suppress weeds and conserve soil moisture. A drip irrigation hose was positioned in the center of each ridge beneath the sheeting to deliver water directly to the plant roots. The strawberry plants were arranged in two rows per ridge, spaced 25 cm apart, with a 25 cm gap between the rows.


Figure 2. General view of a strawberry field

Drip irrigation keeps the topsoil constantly moist at the capillary moisture capacity level, but keeps the space between the rows dry, which helps to reduce weeds. The advantages of drip irrigation are water savings, i.e. minimal evaporation from the free surface, no soil crust and preservation of the soil structure.

The experimental design incorporated the following drip-irrigated variants:

Control: strawberries grown without any fertilizer application. This variant serves as a baseline to assess the effects of fertilization.

Mineral System: nitroammophoska (N16P16K16) applied at a rate of 400 kg/ha. This variant evaluates the impact of mineral fertilizer on strawberry growth and yield.

Organic-Mineral System: a combination of mineral fertilizer (nitroammophoska (N16P16K16) at 400 kg/ha) and organic fertilizer (semi-rotted manure at 50 t/ha). This variant investigates the potential synergistic effects of combining mineral and organic fertilizers.

Organic System: semi-rotted manure applied at a rate of 50 t/ha. This variant assesses the effects of organic fertilization on strawberry growth and yield.

The experimental field is characterized by typical chernozem, a fertile black soil rich in organic matter known for its excellent water-holding capacity and nutrient content.

During 2018-2020, analytical studies were conducted on soil, irrigation water, and strawberry plants (petioles and fruits) using portable equipment to assess various parameters:

- electrical conductivity, total dissolved solids, salinity, and pH were measured using the EZODO 8200M conductometer (Figure 3).
- the content of calcium, sodium, and potassium cations in the soil, petioles, fruits, and irrigation water was determined using HORIBA LAQUAtwin ionometers: Na-11 (Na^+); K-11 (K^+), and Ca-11 (Ca^{2+}) (Figure 4).

Figure 3. EZODO 8200M

Figure 4. HORIBA LAQUAtwin ionometers

The results were summarized in 2024 within the project "Development of measures to ensure sustainable productivity of agrophytocenoses under the influence of abiotic and biotic stress factors" (state registration number 0124U000457).

RESULTS AND DISCUSSIONS

Dynamics of changes in soil electrophysical parameters

A modern soil monitoring system on agricultural land includes a system for monitoring, collecting, processing, transmitting, storing and analyzing information on changes in soil quality and fertility, and for developing practical and scientifically based recommendations for decision-making on the prevention and elimination of various types of negative processes.

High agricultural productivity is only possible with comprehensive soil management and prevention of soil degradation. This is done through ongoing research into the use of agrochemicals on farmland, based on monitoring the condition of the soil cover and developing proposals for the effective and environmentally friendly use of agrochemicals.

Comprehensive soil analysis, including determination of basic and additional agrochemical parameters (soil pH, organic matter, content of available forms of nitrogen, phosphorus, potassium, trace elements, sulphur, electrical conductivity, and soil texture) to determine soil potential and optimize mineral nutrition for plants (Yatsuk et al., 2019).

The research conducted from 2018 to 2020 examined the changes in electrophysical parameters in soil where garden strawberries were cultivated (Figures 5, 6 and 7). Electrophysical parameters, such as electrical conductivity, offer insights into the soil's ability to retain and transport water and nutrients, crucial factors for plant growth. Focusing on the control variant which represents the typical cultivation practices without any experimental treatments we observed fluctuations in these parameters across different soil depths and years. In 2020, the highest values were recorded at depths of 30-40 cm and 40-50 cm, reaching 249 and 302 µs/cm, respectively. This suggests potentially higher salt concentrations or compaction at these depths. Interestingly, the ridge part of the field showed the highest value in 2018, measuring 268 µs/cm (Figure 5).

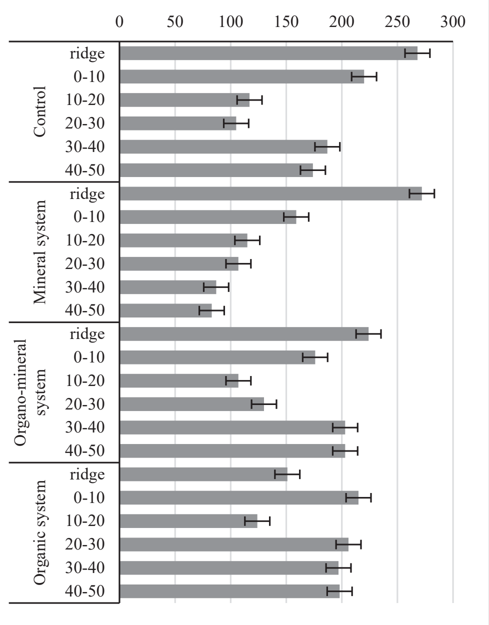

Figure 5. Change in electrical conductivity of typical chernozem in 2018, µs/cm

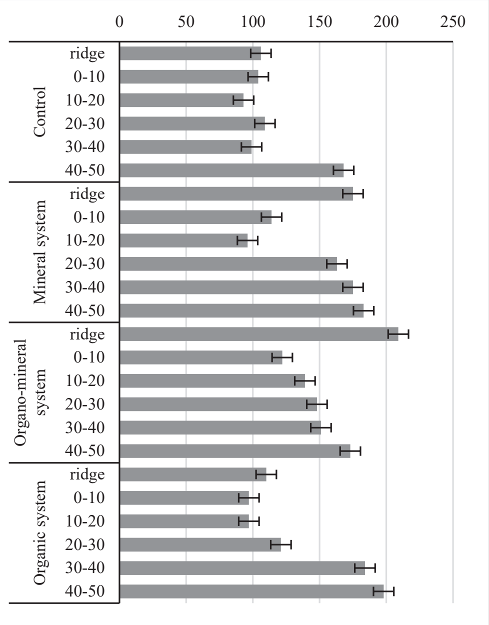

Figure 6. Change in electrical conductivity of typical chernozem in 2019, µs/cm

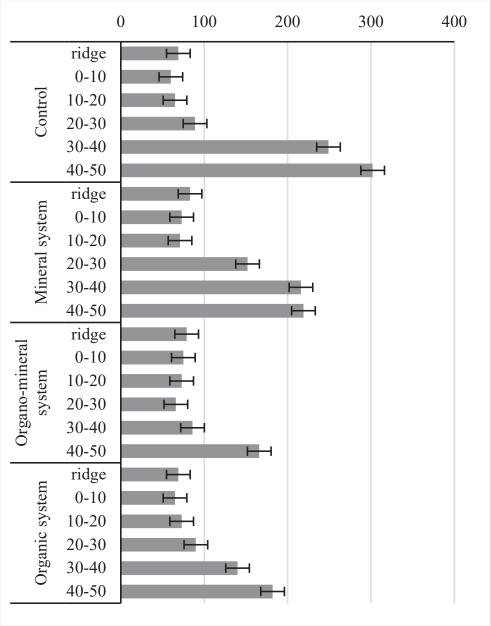

Figure 7. Change in electrical conductivity of typical chernozem in 2020, μs/cm

Conversely, the lower soil layers exhibited average electrophysical parameter values in 2018 and 2019. The lowest values were consistently found in the middle layer in 2018 and the upper layer in 2019 and 2020, ranging from 60 to 106 μs/cm. These variations highlight the dynamic nature of soil properties and their potential influence on strawberry growth (Figure 5 and 7).

The dynamics of the maximum values of the variant with mineral fertilizers shows the highest values in the ridge part in 2018 with 272 μs/cm and the lowest in 2020 with 219 μs/cm. The average electrical conductivity of most of the samples analyzed in 2019 is 163-183 μs/cm (Figure 6).

The lowest values in the soil thickness from 10 to 50 cm in 2018 were 83-115 μs/cm and in the upper part up to 20 cm in 2020 were 71-83 μs/cm.

In 2018, the highest electrical conductivity of soil-water suspensions was observed in the organic-mineral fertilizer variant in the upper and lower parts of the depth studied. In most cases, electrical conductivity averaged 122-151 μs/cm in 2019 and low 66-86 μs/cm in 2020.

The organic fertilizer variant displayed a distinct pattern in electrophysical parameters. In 2018, this variant showed the highest electrical conductivity values, ranging from 197 to 215 μs/cm in certain soil layers, with an overall average conductivity of 124-151 μs/cm. This suggests that organic fertilizers may have initially increased the soil's electrical conductivity. However, in 2019 and 2020, the lowest values were observed in the upper soil layers (20-30 cm), decreasing to 97-110 μs/cm and 65-90 μs/cm, respectively. Conversely, the deeper soil layers (30-50 cm) exhibited the highest conductivity, reaching 182-198 μs/cm. This shift in conductivity over time and depth may indicate changes in the soil's properties due to the continuous application of organic fertilizers (Figure 6 and 7).

Thus, in most cases, the electrical conductivity of soil-water suspensions decreased in 2020 compared to 2019 and 2018. The largest changes occurred in the control variant in the ridge part, where values decreased from 268 μs/cm in 2018 to 69 μs/cm in 2020, the mineral system variant (decrease of 189 μs/cm) and the organo-mineral variant (decrease of 146 μs/cm). On the contrary, there was an increase in electrical conductivity in 2020 compared to previous years in the lower investigated layer of the control and mineral fertilizer system. The 30-40- and 40-50-centimetre thicknesses of the organic fertilizer variant have been almost constant for three years.

Total dissolved solids and salinity indicators show a similar trend in the dynamics of change, but with slightly different numerical values.

Dynamics of the content of water-soluble salts of sodium, calcium, and potassium cations in soil

The soil parameters most affected by drip irrigation are primarily the amount and content of water-soluble salts and carbonates. According to scientific sources, drip irrigation with water of different composition and quality in Ukraine shows trends in the accumulation of water-soluble salts in the soil, changes in the composition of their absorption complex, i.e. the development of salination and salinization processes. The speed and direction of these processes depend on quantitative and qualitative indicators of irrigation water, irrigation regime, amount and type of autumn and winter rainfall (Balyuk et al., 2009).

For example, in 2018, the highest water-soluble sodium salts were observed in the control 360 ppm and mineral 300 ppm systems in the ridge. In 2019, these values decreased slightly but were also the highest in the control 172 ppm, organo-mineral 200 ppm and organic 166 ppm systems in the ridge. In 2020, in the control and organic systems, the highest values were recorded in the lower part of the profile, up to 200-220 ppm. In the first two years, the lowest values were observed in the 30-40 cm and 40-50 cm depths in the soil of all fertilization systems studied, while in the third year, the lowest values were observed in the top layer (ridge).

Conversely, the highest levels of water-soluble calcium salts were found in the 30-40 cm and 40-50 cm thickness sections of all the variants studied over the three years. In the same period, the lowest calcium salt content was found in the ridge part and up to the limit of 10-20 cm of the control variant of the experiment 88-106 ppm.

The content of water-soluble potassium salts was not detected in any of the samples analyzed, with the exception of two. For example, the lowest potassium content in the first year of the study was found in the control and organic-mineral fertilized plots, at 8-10 ppm in the samples taken from the ridge.

The reason for the increased content of water-soluble salts in the soil is therefore the irrigation with mineralized water, which was confirmed by the analysis of the content of soluble salts (electrical conductivity, total dissolved solids, salinity as well as calcium, sodium and potassium) in the irrigation water.

Dynamics of soil pH

The chemical properties of the aqueous soil solution are determined by the acidity or alkalinity of the soil (soil pH); the salinity or total salt content of the soil; the content of inorganic trace elements, such as most alkaline earth metals, transition metals and heavy metals; and the content of organic trace elements.

According to the Food and Agriculture Organization of the United Nations (FAO), only 1/10 of the world's soils have favourable acid-base conditions for growing major crops. At the same time, more than a third of the world's soils are characterized by various forms of 'acid stress' associated with changes in the actual and exchangeable acids present in natural soils.

Acidification of the pedosphere is a global environmental problem. However, most scientists tend to believe that it is of natural rather than anthropogenic origin. Even small changes in natural biogeochemical cycles have a much greater effect on the acid-base balance of soils and surface waters than acid precipitation.

In recent years, however, the rate of acidification of the pedosphere and the biosphere in general has increased. As a reliable relationship between precipitation acidity and changes in the pH of different environmental components can rarely be established, it is advisable to compare the acid-base properties of soils under different anthropogenic pressures.

Plants are the main source of hydrogen ions that cause the acidification of the environment. During their vital activity, they exchange them for equivalent amounts of biophilic ions: Ca^{2+} for $2H^+$, K^+ for H^+, etc. This is what cationic plant nutrition looks like. It is characteristic of most trees. In contrast, herbal plants are characterized by a mixed - cationic-anionic - type of nutrition. In addition to H^+, they actively release OH^- and HCO_3^- into the environment. This mechanism is based on the need to maintain a certain electrical potential across the membranes of root cells to protect them from electrical damage (Gamkalo, 2009). The phenomenon described is called 'trophic acidification' - a shift in the acid-base balance of the soil towards an acid reaction - and is a criterion for an integrated assessment of soil health. Therefore, quantitative assessment of active (water extract pH) and exchangeable (salt extract pH) soil acidity is a prerequisite for determining the edible comfort and ecological quality of the soil in general.

In control, there is a general tendency towards acidification in the lower soil layers. For example, at depths of 30-40 cm and 40-50 cm, the water pH decreased significantly from 8.81 and 8.70 to 7.55 and 7.42. Up to a depth of 20-30 cm there is no increase in pH. The indicator ranges from 7.32 to 7.94.

The mineral system shows a general increase in alkalinity at most depths, apart from 30-50 cm where a slight acidification is observed. The maximum increase in alkalinity is observed at a depth of 20-30 cm from 7.81 to 8.45.

The organo-mineral system shows a general increase in alkalinity at all depths over the years of investigation. The maximum values were recorded at a depth of 30-40 cm, where the water pH increased from 7.21 to 8.20, and 40-50 cm - the reaction changed from 7.33 to 8.47.

In the organic system we have a significant increase in alkalinity at all depths. In contrast to the other variants, the maximum increase in water pH is observed in the crestal part, from 7.24 to 8.45.

In the control, there is a general tendency towards acidification at most depths, except at 20-30 cm, where the salt pH increases from 5.66 to 5.92. This is particularly noticeable at depths of 30-40 cm and 40-50 cm, where the salt pH has decreased significantly from 7.79 to 6.68 and from 7.64 to 6.52 respectively.

The mineral system shows a general increase in alkalinity at most depths. The soil reaction changes from slightly acidic to slightly alkaline from the surface down to 20-30 cm. A slight acidification of 0.15-0.17 units is observed at depths of 30-50 cm.

The organic-mineral system shows a general increase in alkalinity at all depths. Over the years of research, the salt pH increased from 5.97 to 6.35 in the crestal part and from 6.12 to 6.34 in the 0-10 cm part. There is also an increase in alkalinity of more than one unit from 6.71 to 7.75 at a depth of 40-50 cm.

The organic fertilizer system demonstrated a notable increase in soil pH across all depths, indicating a shift toward alkalinity. Over the research period, an average increase of 0.50 to 1.00 pH units was observed. This change moved the soil reaction from slightly acidic to nearly neutral. So, in most cases, over the years of research, we have seen a change in the pH water and pH salt towards an alkaline reaction.

Electrical Conductivity (EC), Total Dissolved Solids (TDS), Salinity (Salt) and water suitability for irrigation

In drip irrigation systems, where watering is frequent, the electrical conductivity (EC) of the irrigation water can be considered a reliable indicator of the soil solution's EC. This is because the frequent application of water closely maintains the equilibrium between the two. Crops have established thresholds for EC, beyond which their growth is inhibited. To estimate potential yield loss due to salinity, measuring the EC of the irrigation water provides a practical alternative to measuring the EC of the soil (Bedernichek et al., 2009; Hamkalo et al., 2012).

By comparing the water's EC with the established limits for soil EC, one can assess the risk of salinity-induced yield reduction. If the water's EC is lower than the threshold value, yield reduction due to salinity is unlikely. However, if the water's EC exceeds the limit, it indicates potential salinity stress, which can hinder water and nutrient uptake by the plants, ultimately leading to reduced yields.

Electrical conductivity was measured in microSiemens (µs/cm). The unit of mineralization is usually milligrams per liter (mg/l). Salinity can also be expressed in parts per million of water particles (ppm). The ratio between mg/l and ppm is almost the same - 1 mg/l = 1 ppm.

During the electrophysical analysis of the water, it was found that the electrical conductivity is 1047 µs/cm, the total amount of all salts dissolved in the water is 708 mg/l (ppm) and its salinity reaches 540 mg/l (ppm).

The maximum value of water conductivity when strawberries are grown on loamy soils (such as the typical chernozems of the experimental field) is 900 µs/cm. In our case, the value is 147 µs/cm higher. For further cultivation, it is therefore necessary to normalize the level of electrical conductivity of the irrigation water according to the stage of development and variety of garden strawberries.

In addition, water can be classified as medium saline based on the number of dissolved salts (electrical conductivity in the range of 650-1300 µs/cm).

Therefore, determining the actual salinity of the irrigation water through its electrical conductivity becomes crucial for making informed decisions about crop suitability. If salinity exceeds the tolerance of the desired crop, alternative salt-tolerant crops, such as barley or cotton, could be considered to maintain yields. This proactive assessment helps ensure sustainable agricultural practices and optimizes crop production in varying salinity conditions.

The water mineralization rate for strawberry plants is 1260-1540 mg/l (ppm). This means that the salinity of the water is 1.6-2.0 times lower than optimal.

Plants need not only constantly access to minerals, but also the conditions in which they can be well absorbed. The most important parameter in determining the availability of nutrients to the plant is the pH of the water. The optimum pH of the aqueous solution is different for each type of plant; for some crops it is around 6.8-7.5, for others around 5.5-6.8.

The optimum pH for strawberries is around 6.00. According to the measurement results, the pH of the irrigation water is 6.78, which is 0.78 units higher than the optimum value.

Different chemicals can be used to adjust the pH of the water. For example, you can lower the pH by adding phosphoric, nitric or citric acid to the water. To raise the pH, add baking soda, carbonate or potassium hydroxide.

Using the electrical conductivity indicator, you can quickly determine the suitability of water for irrigating the proposed crop with a known soil particle size distribution, assess a yield reduction or select an alternative crop.

Calcium, sodium, and potassium content of irrigation water

The total content of water-soluble salts, or salinity, indicates the toxicity of water irrigation to agricultural crops and the risk of soil salinization. Prolonged irrigation with high salinity water contributes to the accumulation of salts in the upper layers of the soil, which disrupts the stability of agroecosystems and reduces the yield and quality of crop production. Excessive salt content in irrigation water reduces the osmotic activity of plants and prevents normal soil aeration. The concentration of water-soluble salts in irrigation water, which can be used without restriction, should not exceed 450 mg/l. Water with a concentration of water-soluble salts up to 2000 mg/l is considered to be of limited use for irrigation. The use of water with a salt content of more than 2000 mg/l is risky and strictly limited. The salinity of irrigation water is not strictly regulated by state standards in Ukraine, but for drip irrigation the optimum salinity of water is up to 1000 mg/l (Hamkalo, 2000).

The content and ratio of cations and anions in irrigation water is of great importance in assessing its effect on the soil-plant system. Thus, an excessive content of monovalent sodium and potassium cations compared to divalent calcium and magnesium cations indicates a risk of disruption of soil permeability, soil structure, development of peptization processes, transition of soil colloids to an unnatural ash state, etc. In addition, the increased content of hydrocarbonates, against a background of high concentrations of monovalent sodium and potassium cations in irrigation water, contributes to a more pronounced deterioration of soil permeability.

In turn, changes in soil conditions affect plants: their growth and development deteriorate (sometimes to the point of complete failure), yields decrease, and the quality of the crop deteriorates significantly. The effect and interaction of monovalent and divalent cations in irrigation water is assessed by the sodium adsorption ratio. This considers the electrical conductivity of the irrigation water (EC_W), which is a proxy for the salinity of the water, and the absorption capacity of the soil.

Elevated levels of hydrocarbonate, sulphate and chloride anions in irrigation water indicate potentially high mineralization and the presence of toxic salts. Even tiny amounts of these salts can be harmful to plants. The complete absence of these elements is detrimental to crops, but their levels should not exceed the maximum allowable concentration. The content of non-toxic salts (calcium sulphate, calcium bicarbonate, etc.) up to 1 g/l is safe for plants (Hamkalo et al., 2012; Shum et al., 2013). Thus, the water used for irrigation contains a small amount of water-soluble potassium salts - 6 mg/l (ppm); much more water-soluble calcium salts - 93 mg/l (ppm); and most of all water-soluble sodium salts - 190 mg/l (ppm) (Table 1).

Table 1. Cation content in irrigation water, mg/l (ppm)

Cation content	Na	Ca	K
	190	93	6

The calcium (Ca^{2+}) content of irrigation water affects the hardness of the water. Excessive amounts of calcium salts can cause damage to irrigation systems, particularly by depositing on the nozzles of sprinklers or other irrigation equipment. Using such water to prepare fertilizer solutions, particularly sulphate fertilizers, can lead to the formation of calcium sulphate and affect the pH of the soil.

High sodium (Na^{+}) in irrigation water displaces calcium and magnesium from the soil colloidal absorption complex and increases the sodium content. If such water is used over a long period, salinization of the soil can occur.

The potassium (K^+) content of irrigation water is usually low, and its infiltration into the soil increases the supply of this element. However, too much potassium together with sodium cations in relation to the total cations can lead to salinity.

At the same time, the ratio of calcium, magnesium, sodium and potassium cations in the water makes it possible to predict their effect on the soil and consequently on the plant.

In our studies, the ratio of water-soluble calcium salts to sodium (Ca:Na) in water is 1:2, and Ca:Na:K is 1:2:0.06. Thus, we can say that the increased content of water-soluble sodium salts in irrigation water leads to soil salinization and an increase in their amount in the studied soil thickness during the research period.

Calcium, sodium and potassium content of strawberry plants

Regular monitoring of essential nutrients like nitrate nitrate (NO_3^-), potassium (K^+) and calcium (Ca^{2+}) in various components of the strawberry production system plant stems, soil solution, irrigation water, and wastewater offers multiple benefits. It not only contributes to achieving optimal yields and fruit quality but also helps reduce fertilizer costs and minimize environmental impact.

Strawberry plants require adequate root space and a balanced supply of nutrients for optimal growth, fruit quality, and yield. Soil pH plays a crucial role in nutrient availability. For instance, nitrate (NO_3^-) influences fruit size, potassium (K^+) affects flavor, and Ca^{2+} contributes to firmness. Maintaining the correct soil pH ensures that these nutrients are readily available to the plants in the right proportions, preventing competition or incorrect assimilation. In addition to pH, careful and frequent monitoring of electrical conductivity is vital, as strawberry plants are sensitive to high salinity levels. By managing both soil pH and electrical conductivity, growers can optimize nutrient availability and create a favorable environment for strawberry production.

Plant sap analysis is a valuable tool for growers to actively manage nutrient levels and refine their fertilizer strategies. By providing a snapshot of the nutrients currently available to the plant for growth and development, this method can quickly identify nutrient deficiencies or excesses. However, to gain a more complete understanding of the plant's nutritional status, it's essential to consider the soil environment as well.

Soil analysis offers crucial information about the overall nutrient levels and salinity within the soil. It also helps assess the potential for nutrient leaching outside the root zone. Analyzing the soil solution, the water held in the soil that carries dissolved nutrients absorbed by the roots provides further insights into the actual nutrients accessible to the plants.

Combining plant sap analysis with soil and soil solution analysis empowers growers with a comprehensive picture of nutrient dynamics. This integrated approach enables more informed decisions about fertilizer application, ensuring that plants receive the necessary nutrients at the right time and at the right amounts.

To assess the nutritional status of strawberry plants, sap analysis was conducted using a calibrated LAQUAtwin pocket meter. This meter measures the ion concentrations in the sap, providing insights into nutrient availability. Before conducting the analysis, the meter was calibrated according to the manufacturer's instructions to ensure accurate readings.

A consistent sampling protocol is crucial for obtaining reliable results. The last mature trifoliate leaf was selected for analysis because it serves as the best indicator of essential nutrients like phosphorus (P), potassium (K), and calcium (Ca). The petiole of this leaf is specifically used to determine the levels of nitrate-nitrogen (NO_3-N). For optimal sampling, the plant's temperature should be between 20-25°C. This standardized approach ensures consistent and comparable results across different measurements.

The examination of the content of cations in the stems should be carried out in accordance with the following scheme:

1. Sample collection: gather the two most recently mature trifoliate leaves, along with their petioles, from 20 different strawberry plants. This ensures a representative sample of the plant population. Tear the petioles from the plant near the crown to avoid damaging the main stem.
2. Sample preparation: separate the petioles from the leaves and cut them into small pieces to increase the surface area for sap extraction.

3. Sap extraction: place the petiole pieces in a garlic press or hydraulic press and apply pressure to extract the sap.
4. Measurement: place a drop of the extracted sap directly onto the corresponding sensors of the LAQUAtwin pocket meter. The meter will provide readings for the different cations present in the sap.
5. Analysis: compare the obtained results with the reference values provided in Table 2. This comparison helps assess the current nutritional status of the plants.
6. Cleaning: rinse the sensors thoroughly with clean water before testing another sample or storing the device. This prevents cross-contamination and ensures accurate reading for future measurements.

Table 2. Reference nutrient levels for petiole sap in strawberry cultivation (Cadahía et al., 2008)

Days after sowing	NO_3-N	P	K
	ppm		
30	500-700	150-350	4000-5000
60	550-750	150-350	4000-5000
90	400-600	150-350	4000-5000
120	500-300	150-350	4000-5000

In addition to plant sap analysis, monitoring the soil solution provides valuable information for optimizing irrigation programs and nutrient management strategies. While soil solution analysis may not reflect the overall nutrient reserves in the soil, it offers insights into the nutrients readily available to plants at a given time. Specifically, soil solution analysis helps growers fine-tune their fertilizer applications and irrigation practices. For example, by tracking nitrate levels in the soil solution, growers can identify potential issues with nitrogen management. Excessive nitrate accumulation in the root zone can lead to nutrient imbalances and environmental concerns due to leaching.

Soil solution analysis allows for timely adjustments to fertilizer application rates, ensuring that nitrogen is supplied in the right amounts at the right time. Furthermore, monitoring salinity levels in the soil solution helps prevent the adverse effects of high salt concentrations on strawberry growth. By tracking these key parameters, growers can make informed decisions to maintain a balanced and productive growing environment.

While potassium and calcium are predominantly bound to soil particles, making their levels in the soil solution less indicative of their overall availability to plants, regular monitoring of these nutrients in the soil, irrigation water, and wastewater remain crucial. This comprehensive assessment provides a broader understanding of their presence and potential movement within the growing system.

Monitoring salinity levels in the soil solution allows for proactive management of potential salinity issues. By detecting rising salinity levels early on, growers can take corrective actions, such as adjusting irrigation practices, before they negatively impact plant health, yield, or fruit quality. This preventive approach helps maintain optimal growing conditions and ensures consistent production.

Excessive irrigation leading to waterlogging can also be detrimental. It washes essential nutrients, including fertilizers, out of the root zone, reducing their availability to plants. Moreover, this leaching process poses environmental risks, such as groundwater pollution. Analyzing the soil solution throughout the growing season helps identify potential nutrient deficiencies or excesses, enabling timely adjustments to irrigation and fertilization practices.

Regarding the calcium content in strawberry petioles, the organic fertilization variant exhibited the highest levels, reaching up to 104 mg/l (ppm) (Figure 8). In contrast, the mineral fertilization variant showed the lowest calcium content, averaging 79 mg/l (ppm). The control variant and the organic-mineral system variant had slightly higher calcium levels, measuring 82 mg/l (ppm) and 84 mg/l (ppm), respectively. These variations suggest that different fertilization regimes can influence calcium uptake and accumulation in strawberry plants. Further investigation is needed to understand the underlying mechanisms and implications of these differences.

Compared to the highest calcium content, the sodium content of strawberry plants in the organic system variant is 60 mg/l (ppm) (Figure 9). The value is even lower, at 56 mg/l (ppm), in the variant with simultaneous application of organic and mineral fertilizers. A slight increase in the indicator is observed in the variant with mineral fertilization - 69 mg/l (ppm). The highest amount of sodium in petioles was found in the control variant of the experiment - 87 mg/l (ppm).

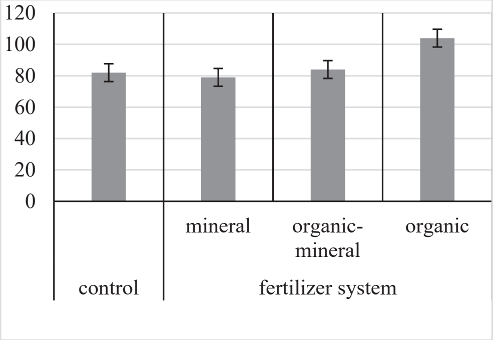

Figure 8. Calcium content in strawberry petioles, mg/l (ppm)

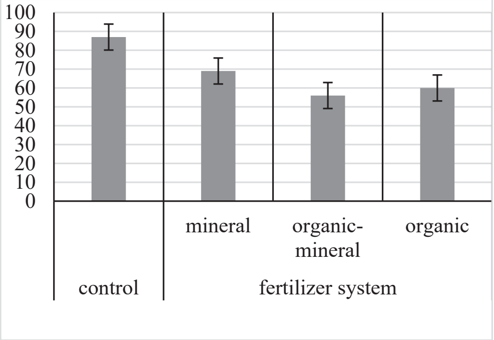

Figure 9. Sodium content in strawberry petioles, mg/l (ppm)

The potassium content of strawberry petioles is at least 20 times higher than that of calcium and sodium (Figure 10). The highest amount of potassium was found in the plants of the control variant - 2600 mg/l (ppm), and the lowest - 2167 on average - in the variant with the organic-mineral system. Average values of 2300 mg/l (ppm) were obtained for two variants with mineral and organic fertilizer application systems.

Based on the data presented in Figure 10, we can say that at least the amount of potassium in the petioles of garden strawberry plants is almost 2 times less than the optimum value.

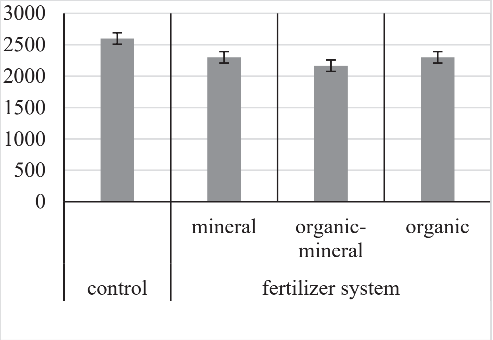

Figure 10. Potassium content in strawberry petioles, mg/l (ppm)

While the analysis of cations in strawberry fruits follows a similar procedure to petiole analysis, with no significant deviations, the specific steps involved are as follows:

1. Sample collection: gather fruit from various strawberry plants to ensure a representative sample.
2. Sap extraction: place small pieces of the fruit in a garlic press or hydraulic press and apply pressure to extract the sap.
3. Measurement: place a drop of the extracted sap directly onto the corresponding sensors of the LAQUAtwin pocket meter.
4. Cleaning: rinse the sensors thoroughly with clean water before testing another sample or storing the device. This prevents cross-contamination and ensures accurate reading for future measurements.

The highest level of calcium in garden strawberry fruit was found in the control variant of the study at 24 mg/l (ppm). The level is slightly lower, at 5 mg/l (ppm), in the variant with the mineral fertilizer system. The lowest level of calcium in the sap analysis was found in the variant with simultaneous application of organic and mineral fertilizers - 13 mg/l (ppm). The calcium content in the fruit is about 20 mg/l (ppm) when an organic fertilizer system is used (Figure 11).

The sodium content is 3.75 times higher than the calcium content in strawberries from the control variant of the study. The element content was also almost three times lower in the mineral and organo-mineral fertilizer variants - 27 mg/l (ppm). In the samples of fruit from the organic fertilization system, we have 39 mg/l (ppm) of sodium, which is two times less than in the control variant (Figure 12).

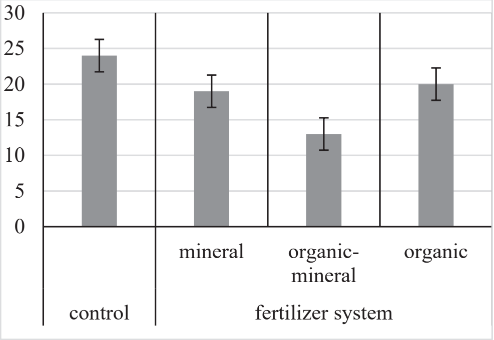

Figure 11. Calcium content in strawberry fruit, mg/l (ppm)

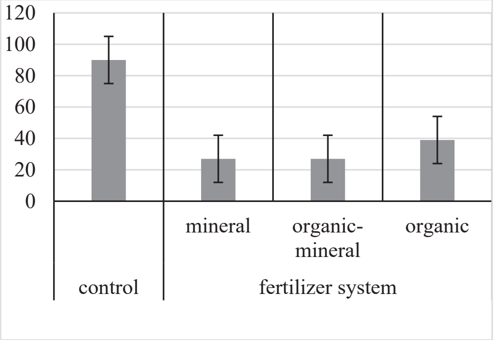

Figure 12. Sodium content of strawberry fruit, mg/l (ppm)

In contrast to the low potassium levels observed in the petioles, the strawberry fruits exhibited significantly higher potassium concentrations (Figure 13). The potassium content in the fruits ranged from 900 mg/l (ppm) to 1300 mg/l (ppm), demonstrating a substantial accumulation of this nutrient in the fruits. Among the different fertilization variants, the control variant showed the highest potassium content, averaging 1267 mg/l (ppm). The mineral fertilizer variant had the lowest potassium content, measuring 330 mg/l (ppm). The variants with organo-mineral and organic fertilization systems exhibited similar potassium levels, averaging 1107 and 1167 mg/l (ppm), respectively. These findings suggest that fertilization practices can significantly influence potassium uptake and distribution in strawberry plants. While the control variant showed the highest potassium content in fruits, the organic and organo-mineral systems also resulted in substantial potassium accumulation. The lower potassium levels in the mineral fertilizer variant may indicate a need for adjustments in fertilizer composition or application rates to optimize potassium availability for fruit development.

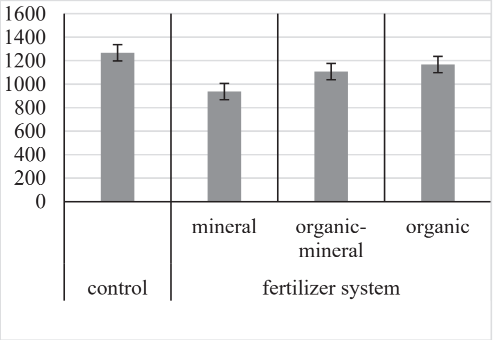

Figure 13. Potassium content of strawberry fruit, mg/l (ppm)

The analysis of strawberry fruits revealed distinct variations in cation content across the different fertilization variants. The control variant exhibited the highest concentration, followed by the organic system. The mineral and organic-mineral variants showed the lowest cation content. These differences highlight the influence of fertilization practices on nutrient uptake and accumulation in strawberry fruits, potentially affecting fruit quality and nutritional value.

CONCLUSIONS

This study revealed several key trends in the electrical conductivity of soil-water suspensions. Notably, most variants showed a decrease in electrical conductivity in 2020 compared to 2019 and 2018. This decline was particularly pronounced in the control variant's ridge part, where values dropped from 268 µs/cm in 2018 to 69 µs/cm in 2020. Similar reductions were observed in the mineral system variant (189 µs/cm decrease) and the organo-mineral variant (146 µs/cm decrease). Conversely, the lower soil layers of the control and mineral system variants exhibited an increase in electrical conductivity in 2020 compared to previous years. This contrasting trend suggests potential differences in soil properties or nutrient dynamics at varying depths. Interestingly, the 30-40 cm and 40-50 cm depths of the organic fertilizer variant maintained relatively constant electrical conductivity throughout the three-year study period. This stability may indicate a more balanced nutrient distribution and reduced leaching under organic fertilization. These findings highlight the dynamic nature of soil electrical conductivity and its response to different fertilization regimes. Further investigation is needed to elucidate the underlying mechanisms and their implications for optimizing nutrient management practices in strawberry cultivation.

According to preliminary research results, we can state that the increased content of water-soluble sodium salts in irrigation water leads to a slight salinization of soils and an increase in its amount in the studied soil layer during the research period (2018-2020).

Water pH and salt pH tend to change the reaction of the soil environment towards alkaline.

The water used for irrigation has the following electrophysical characteristics: electrical conductivity - 1047 µs/cm; total dissolved solids - 708 mg/l (ppm); salinity - 540 mg/l (ppm); pH - 6.78, which is characterized as water with an average level of dissolved salts.

The water used for irrigation has a small amount of water-soluble potassium - 6 mg/l (ppm); much more water-soluble calcium - 93 mg/l (ppm); and the highest amount of water-soluble sodium - 190 mg/l (ppm).

The potassium content of strawberry petioles is at least twenty times higher than that of calcium and sodium. In the control variant of the research, the cation content in the fruits of garden strawberries is the highest. The lowest levels of calcium and sodium are found in the fruit of plants from the organic-mineral fertilizer system and the mineral fertilizer system. The average calcium, sodium and potassium content of the organic fertilizer system among the variants studied.

Plant sap analysis offers real-time insights into the nutritional status of plants, enabling growers to fine-tune nutrient applications, optimize yield and quality, and potentially extend the fruiting season. By complementing soil solution analysis, plant sap analysis provides a comprehensive picture of nutrient dynamics, facilitating informed decisions about fertilizer management.

Maintaining optimal salinity and pH levels in irrigation water is crucial for cultivating healthy and productive plants. Regular monitoring and adjustments of these parameters ensure a favorable environment for nutrient uptake and overall plant growth.

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