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Soil Salinization and Problems with Cherry Plants

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ABSTRACT **Original research paper**

The present study analyzes the mineral and chemical composition of the soil in cherry plantations in a region with clay soils. The soil has a neutral to low-acidic pH (5–7), high electrical conductivity (EC = 2.190 mS/cm) and contains increased amounts of nitrates and chlorides, indicating excessive use of mineral fertilizers and extraction of chlorine minerals from the surrounding rocks. The main mineral is montmorillonite – a clay silicate that plays a key role in ion-cation exchange and the maintenance of soil fertility. The presence of the mineral halite (NaCl) has been found in the root tissues of cherry trees, which indicates the accumulation of salts affecting plant health. The study highlights the importance of the interaction between mineral composition, soil chemical properties and climatic conditions that determine the adaptation and development of cherry plantations. The results contribute to a better understanding of soil processes and can support the optimization of agrotechnical measures in the region.

Keywords: Soils, Montmorillonite, Halite, Cherries, Salts, Agrochemistry.

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Introduction

Soils in areas with cherry plantations play a key role in the development and productivity of plants, and their composition and physicochemical properties determine the quality of the final product. The present study aims to analyze the mineral and chemical composition of the soil and the state of soil solution and plant juices in cherry orchards in a particular region, paying special attention to the influence of the accumulation of salts and mineral compounds.

Particular attention is paid to the role of the clay mineral montmorillonite, which plays an important role in ion-cation exchange and nutrient retention, as well as sodium chloride (halite), which is found in the root zone of trees. Understanding these processes and ingredients is essential to optimize agrotechnical practices and reduce the negative effects of salinity and other stressors on plants.

The present study uses chemical analyses, microscopic observations and a geochemical approach to assess soil composition and its impact on plant development, while also considering the possible consequences of climatic conditions and water regime.

For example, Blanke & Kunz (2017) ***analyzed*** 60-year weather data (19562015) and phenological data for cherries – dates of flowering, full bloom, risk of late frosts.

Wenden et al. (2017) made the determination of phenological stages and cherry varieties, which are good indicators (early/late flowering) for observations of climate change.

Drogoudi et al. (2017). ***They did a study*** of the change in flowering dates of different varieties of cherries over a 31-year period (19842015) in Greece; average temperature and flowering progress.

Rolbiecki, et al. (2023) Investigate the water needs of cherry trees according to warming forecasts; useful if you look at stress, water conditions, and adaptation.

In particular, the relationship between soil salinization and cherry plantations has been examined by Ertürk et al. (2007). Examination of cherry graft material (*Gisela* 5, which is *Prunus cerasus* × *Prunus canescens*) at different concentrations of NaCl (0, 50, 100, 150 mM). Results: growth and chlorophyll content decrease with increasing salt stress; there are visible symptoms of damage; elevated levels of oxidative stress markers (malondialdehyde, etc.) are also observed.

Another team that has published on the topic is Paradakis et al. (2018). Hydroponic experiment: at 60 mM NaCl, changes in growth, water ratio in plants, chlorophyll, a nutrient mineral ingredient → observed. Result: plants are quite sensitive; Growth and chlorophyll decrease after a few days of the onset of salt stress

Xu, J. et al. (2024) did a new study (2024) applying salicylic acid to cherry grafts (rootstocks) under salt stress. Observed benefits: better photosynthetic performance, increased activity of antioxidant enzymes, better management of Na^+ toxicity, regulation of stress-mediated genes.

Chun Tao Hong et al. (2014) studied **changes in the physiology and biochemistry of cherry rootstocks under salt stress**. Various physiological and biochemical indicators (antioxidants, enzymes, chlorophyll level, etc.) were studied at different concentrations of NaCl.

Sotirov & Stoeva, 2024 and Sotirov (2023a,b) provide information on an increase in the amount of mineral salts in cherry fruit juices beginning to link them to soil salinization resulting from climate change.

2. Materials and methods

Cherry massifs with an area of 15 acres of various varieties have been studied, located immediately north of the village of Stensko, Kyustendil municipality (Bulgaria), in the area of "Kaina Chuka", owned by a farmer. The massifs are located on a southern slope at the foot of a high hill, with a slope of about 30°, which ends with a depth of about 15 m of a ravine.) (FAO-ISRIC-IUSS, 2006). The chemical composition of the agricultural soil in the cherry massifs has been determined. Information from the analysis of 6 samples of two dead trees (2 soils of 30 cm and 60 cm, 2 root-basic, lateral, additive and 2 leaf and 2 fruits) taken from a depth of 30-60 cm, and leaf from all types of branches was used.

Digital instruments were used as follows: Brix refractometer (%) to measure total Brix sugar content (%), conductor to determine total acidity (pH), electrical conductivity (mS/cm), total dissolved solids (ppm), total salt content (ppm), specific gravity (S.G.) and redox potential (Eh).

The content of nitrates and nitrites in water was measured using test strips ranging 0-10-25-50-100-250-500 mg/l. Arsenic content in water was measured using test strips with a range of 0.005-0.0010-0.0025-0.05-0.1-0.25-0.5 mg/l. Zinc content in water was measured using test strips with a range of 0-4-10-20-50 mg/l. Lead content in water was measured using test strips with a range of 20-40-100-200-500 mg/l (Blei-test). The manganese content in the water is measured using test strips with a range of 2-5-20-50-100 mg/l. The zinc content in the water is measured using test strips with a range of 0-4-10-20-50 mg/l. The lead content in the water is measured using test strips with a range of 20-40-100-200-500 mg/l. The manganese content in the water is measured using test strips with a range of 2-5-20-50-100 mg/l. The content of sulfates and sulfites in the water was measured using test strips with a range of 200-400-800-1200-1600 mg/l for SO_4 and 10-40-80-180-400 mg/l for SO_3. Ascorbic acid in water was measured with test strips in the range 0-25-50-100-200-400 mg/l. Bromine was determined by test strips from the range 0-0.5-1-2-6-10-20, fluoride 0-25-50-100-200 and iodine 0-0.02-0.04-0.08-0.10-0.15.

For microscopic soil surveys, a DigiScope 2.0 digital microscope was used. Cherry juice (100%) is obtained by cold pressing method with a single-shaft juicer.

The studied plot is characterized by the following agrochemical indicators: According to the Protocols for soil analysis and Agrochemical characteristics of the soils from the same massif No. 149/21.09.2012, the soil has a low phosphorus reserve and an average potassium reserve. The mineral nitrogen content is very low and decreases in depth, with its content ranging from 24.2 to 12.7 mg/kg. The content of mobile phosphorus in the horizon is 0.6-3.7/100 g of soil, and the subordinate layer is 0.1-1.5 mg/100 g. The content of exchangeable potassium changes in depth. Its amount ranges from 10.22-22.2 mg/100 g of soil. It is concluded that the soil is suitable for growing the fruit type of cherry, but it is necessary to apply organo-mineral fertilization to the area to improve the soil diet.

The soil was examined with a tester. The pH of the soil reaction varies in a narrow range of 5.27-7.0 (between 6 and 7 in most cases) in water in the surface layer of 30 cm. In both layers, it is characterized as neutral. The microscopic content of humus is <1%. The soil is poor in humus, which predicts that humus as one of the two types of soil adsorbent is unlikely to significantly affect the ion-cation exchange between the roots of the tree and the soil. The parameters and chemical elements of the soil with an aqueous extract in a ratio of 1:1 were studied. For this purpose, rain was simulated by adding 100 g of distilled water to 100 g of soil to activate the exchange of cations and the formation of electrolytes necessary for the measurement.

Results and Discussion

Table 1 presents the results of the chemical analysis of the soil. The soil has a neutral to slightly acidic pH (5–7) and an electrical conductivity in an aqueous medium (EC) of 219 mS/cm. Total dissolved solids (TDS) amounted to 109 ppm. The concentration of nitrates is increased, which indicates excessive use of mineral fertilizers. Nitrites are absent and chlorine is in relatively high quantities – free chlorine 2.7 mg/l and total chlorine 2.5 mg/l, probably as a result of leaching from chlorine-containing minerals in the surrounding rocks. Cyanuric acid, an indicator of residues of plant protection products, has not been identified. The total alkalinity is high, with the calcium carbonate (CaCO3) content being 490 mg/l. Iron (Fe) is in low concentrations of 0.2 mg/l, arsenic 0.010 mg/l, and manganese (Mn) is present in moderation (5 mg/l), possibly as a result of magma activity in the region. Radioactivity is within normal ranges (0.16–0.20 µSv/h) and anthropogenic contaminants such as metals, ceramics, rubber and microplastics have not been detected. Some elements such as iodine, bromine, copper, fluorides, zinc, lead and ascorbic acid are below the detection threshold of the methods used (Table 1).

Table 2 shows that in 2023, the concentration of salts in the region's cherry juice used for the agri-food industry exceeds the total amount of dissolved solids. This ratio is less than one, which indicates an excess of salts, mainly NaCl, which are no longer soluble and crystallize due to saturation of the solution. In comparison, in previous studies (2020–2021), salts were found to make up about 30% of total solutes, with typical ratios being Cond./Salt=2, Cond./TDS=1.5, TDS/Salt=1.3. Current results show a buildup of salts, which negatively affects the quality of the sap and potentially the vegetation.

Table. 1 Measured parameters of aqueous extract of the soils from the study area.

Measured parameter	Acidity pH	Conductivity EC, mS/cm	Total Dissolved Solids TDS, ppm	Salt, ppm	Temperature t,°C air	Temperature t,°C water	Nitrite NO_3^-, mg/l	Nitrate NO_2^-, mg/l
Value	5.27-7.20	219	109	109	26.2	25.8	0.00	75

Free Cl, mg/l	Total Cl, mg/l	Combined Cl, mg/l	Cyanuric acid CYS mg/l	Bromine, mg/l	Total alkalinity $CaCO_3$, mg/l	Free Cu, mg/l	Total Cu, mg/l	Combined Cu, mg/l	Iron Fe, mg/l
2.7	2.5	0.02	<2.00	<0.02	490.00	<0.05	<0.05	<0.02	0.2

Point of Measurement	Dissolved oxygen O_2, %	Arsenic As, mg/l	Lead Pb, mg/l	Iodine, mg/l	Manganese Mn, mg/l	Zinc Zn, mg/l	Sulfate SO_4, mg/l	Sulfite SO_2^{2-}- mg/l	Fluoride, mg/l
Point 1	11.00	0.10	0.00	0.00	5.00	<0.02	0.00	0.00	0.00

Radiation background µSv/h	Radiation of soil extraction, µSv/h	Radiation of soil, µSv/h	Anthropogenic micro-detritus and micro-plastics, %	Hardness, mg/l	Redox potential Eh, mV	Ascorbic acid mg/l	Special Gravity, S.G.	Aroma, color, turbidity
0.16-0.20	0.16	0.16-0.20	0.00	90.00	199.00	0.00	0.998	grey, high

Table 2 Some measured technological parameters of cherry juice: total dissolved solids - TDS, total mineral salts - Salt and the ratio between them TDS/Salt for the last 5 years.

Year	**2020**	**2021**	**2022**	**2023**	**2024**
TDS, ppm	1660	1820	1560	1490	1560
Salt, ppm	1280	1400	1190	1510	1570
Ratio TDS/Salt	1.29	1.3	1.31	**0.98**	**0.99**

Mineral composition of the soil

The soil studied is mainly composed of the clay mineral montmorillonite. With a humus content of about 1%, it is this mineral that provides the vital ion-cation exchange in the root zone of cherry trees. Montmorillonite has been identified both macro- and microscopic and gives the soil its characteristic cinnamon color. Its chemical formula is (Na, Ca)0,3(Al, Mg, Fe)$_{2Si4O10}$(OH)$_2$xH2O, and the mineral is named after a settlement in France (Kostov, I., 1993).

Montmorillonite belongs to the group of smectites, clay minerals with a 2:1 layered structure and inflatable capacity, characterized by a negative charge due to the substitution of silicon with trivalent and divalent cations, as well as by the deprotonation of hydroxyl groups. Its crystals are very small (less than 0.2 μm) and possess perfect cleavage. Smectites have a soapy tactile appearance, which reflects their layered structure, which is arranged in bundles with different mesomorphic phases (Fig. 1).

The formation of montmorillonite requires an alkaline soil environment; under acidic conditions, kaolinite is formed. Montmorillonite is typical of bentonite clays that arise during the weathering of volcanic pyro clast from the Mesozoic and Cenozoic epochs (Kostov, I., 1993)..

In the studied area, the soil contains volcanic rocks — tuffs, gravel and gravel of various sizes and colors (dark black, gray, green). The main mineral components are quartz, feldspar, biotite, muscovite and mineral aggregates of various sizes. The geodynamic map of Bulgaria shows the presence of late Eocene-Oligocene graben and volcanic fields, which supports the assumption of the presence of sodium montmorillonite in the soil of the region (Dabovski, et al. 1989).

Through digital microscopy, the presence of the mineral halite (NaCl) was found in the root tissues of dead cherry trees. Macroscopically, cubic-shaped white crystals are observed, which fluoresce faintly into light blue when irradiated with ultraviolet light (546 nm). Although no such fluorescence has been described in the literature for halite, an experiment with the addition of ordinary salt confirms similar properties.

A weakness of the current study is that the mineral composition was determined mainly by macro- and microscopic methods, without the use of optical or electronic scanning microscope, DTA analysis or X-ray diffraction. However, the coincidence with the chemical composition of the soil extract and the observed behavior of cherry trees supports the conclusions drawn.

Halite is a typical sediment-genetic mineral formed by the evaporation of salt water. It contains 39.34% sodium and 60.66% chlorine, crystallizes in cubic form, and is often associated with other salts such as sylvite (KCl). Halite is particularly common in areas with limited fresh water inflow, where the concentration of Na and Cl reaches saturation (Fig. 2).

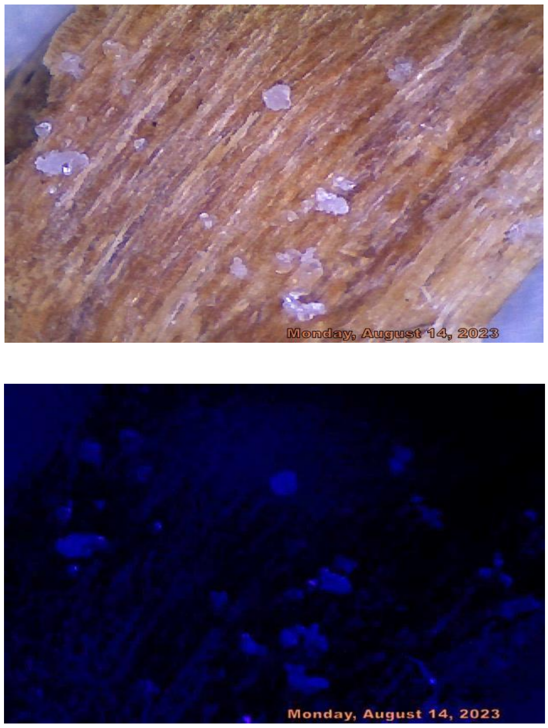

Fig. 1 Salt crystals added in the observationprobe for comparison: Left - white reflected light, air environment, magnification x30, Right - Ultraviolet light, air environment, magnification x30.

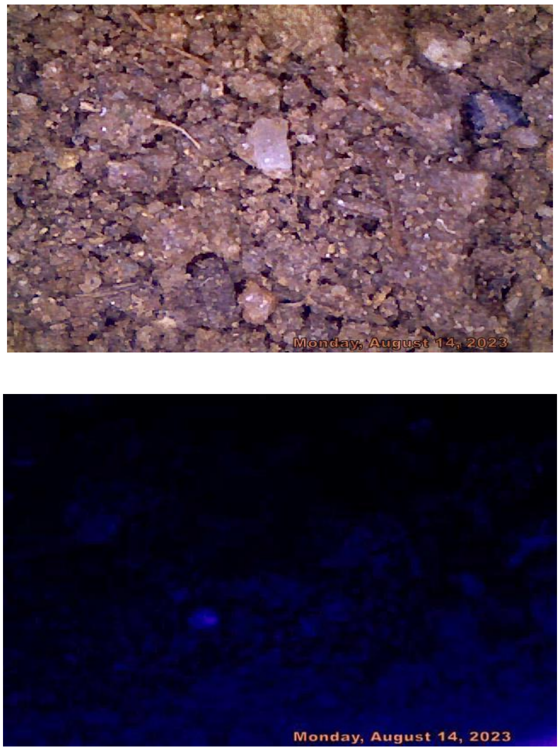

Fig. 2 Soil minerals – montmorillonite, quartz, and halite as solder between soil grains: Left - white reflected light, air environment, magnification x30, Right - Ultraviolet light, air environment, magnification x30.

Geochemical aspects and cationic exchange in soil

A basic rule in geochemistry is that the adsorb ability of ions increases with an increase in their atomic volume, which is directly related to atomic weight. The classical order of the relative exchange adsorb ability of cations is: $Fe^{3+} > Al^{3+} > Ba^{2+} > Sr^{2+} > Ca^{2+} > Mg^{2+} > K^{+} > NH_4^{+} > Na^{+} > Li^{+}$ (Ganev, 1990).

The formation of clay minerals occurs during the weathering of igneous rocks in the earth's crust. This process has an important geochemical role by neutralizing the released strong bases in the reaction medium. If, for some reason, strong foundations are removed from the soil surface, for example, by strong washing in an intensive water regime, clay formation either does not take place or proceeds poorly, changing the direction of weathering (Ganev, 1990).

Clay minerals are characterized by varying magnitudes of highly acidic anions, which are formed depending on the amount of strong bases available to be neutralized. In the presence of a significant amount of bases, montmorillonite is formed, a mineral with a large amount of the highly acidic anion, while in an environment poor in bases, kaolinite is synthesized (Ganev, 1990).

Statistically, a relationship has been proven between the magnitude of the highly acidic anion and the basic richness of the environment, which is valid for different bioclimatic conditions — steppe black soils, plain and mountain forest soils (Ganev, 1990).

In baseline-rich soils, neutral to slightly alkaline montmorillonite dominates, while in acidic soils the main mineral is kaolinite. Despite the differences in adsorption processes, cation exchange remains a leading factor in the chemical reactivity of soils (Ganev, 1990).

Under specific conditions, such as prolonged and extreme rainfall, followed by a long period of high temperatures and poor drainage, sodium carbonate forms in the soil solution. It leads to the substitution of adsorbed alkaline earth cations with sodium and, accordingly, to the chemical precipitation of carbonates on colloidal surfaces (Ganev, 1990).

Physicochemical cation exchange can also be affected by chemosorption processes. For example, the hydroxide precipitation of aluminum cations creates a positively charged hydro-aluminum polymer that blocks cation exchange positions. In allophane soils (characteristic of volcanic materials), this process reaches a high degree of intensity (Ganev, 1990).

Conclusions:

1. The soil in the study area has a neutral to slightly acidic pH (5-7) and shows high electrical conductivity (EC=219 mS/cm), which is associated with an increased content of dissolved mineral salts (TDS=109 ppm), mainly sodium chloride (NaCl), which crystallizes upon saturation.
2. Excessive use of mineral fertilizers is observed, which is confirmed by the increased amount of nitrates and chlorine in the soil and in the soil solution.
3. The main mineral in the soil is montmorillonite, a clay mineral from the smectite group, which plays a key role in cationic exchange and maintaining soil fertility.
4. The soil contains a significant amount of halite (NaCl), which is established macroscopically and microscopically in the root tissues of cherry trees and is the result of evaporation and accumulation of salts in moist, poorly drained conditions.
5. The geological and mineralogical composition of the soil is related to the volcanic origin of the area, which determines the specific chemical and physics-chemical properties of the soil.
6. Adsorption and ion exchange processes in the soil are influenced by climatic conditions, and excessive precipitation can cause the substitution of alkaline earth cations with sodium and lead to the accumulation of sodium carbonate and a change in the structure of the soil.

4. Conclusion

The present study shows that the composition and characteristics of the soil in the cherry plantation area are influenced by the interaction between the volcanic origin of the soil, agrochemical practices and climatic conditions. The presence of montmorillonite and sodium halite determines the specific ionic dynamics and mineral balance, which is key to plant health and development. Excessive accumulation of salts, especially NaCl, and the influence of ion exchange on soil structure require controlled management of irrigation and fertilization to prevent negative effects on vegetation and fertility. Additional analyses with more advanced methods would contribute to a more precise determination of mineral composition and improved soil management.

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