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"Chemical Composition Of Soil Solution And Its Role In The Formation And Maintenance Of Soil Fertility"

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Abstract

This article examines the chemical composition of soil solution and its role in maintaining soil fertility and plant nutrition. The study focuses on the formation of soil solution, the concentration and mobility of macro- and micronutrients, as well as the influence of pH, moisture, salinity, mineral and organic fertilizers on its chemical properties. Particular attention is paid to the role of soil solution in the availability and uptake of essential nutrients by plants. Changes in the ionic composition and concentration of dissolved substances under different soil and environmental conditions are also considered. The analysis demonstrates that the study of soil solution is an important tool for assessing nutrient availability, soil fertility, and the effectiveness of agrochemical practices. Understanding the chemical characteristics of soil solution can contribute to more efficient nutrient management, sustainable soil use, and improvement of crop productivity.

Keywords: Soil solution, soil fertility, chemical composition, nutrients, macroelements, microelements, pH, soil salinity, ion composition, plant nutrition.

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Introduction. Soil is a dynamic and complex natural system in which physical, chemical, and biological processes interact continuously. The soil solution represents the mobile liquid phase of this system and plays a central role in the transport, transformation, and availability of nutrients to plants. Its chemical composition is determined by the interaction of soil minerals, organic matter, microorganisms, atmospheric inputs, irrigation water, and applied fertilizers. Consequently, the quantitative and

qualitative characteristics of the soil solution provide important information about nutrient availability, soil chemical status, and the potential productivity of agricultural soils. The soil solution contains dissolved inorganic and organic compounds, including major cations such as Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, and NH_4^{+}, as well as anions such as NO_3^{-}, $H_2PO_4^{-}/HPO_4^{2-}$, SO_4^{2-}, HCO_3^{-}, and Cl^{-}. The concentrations of these ions are highly dynamic and may vary considerably in response to soil moisture, pH, redox conditions, temperature, microbial activity, organic matter decomposition, and fertilizer application. The equilibrium between the soil solid phase and the soil solution is particularly important because it regulates the release and retention of nutrients and thereby influences their accessibility to plant roots. Nutrient availability cannot be assessed solely on the basis of the total concentration of an element in soil. The chemical form, solubility, mobility, and interaction of nutrients with soil colloids largely determine the fraction that can potentially be absorbed by plants. In this regard, the soil solution serves as an immediate source of mineral nutrients for plant roots. Variations in its ionic composition may therefore affect root nutrient uptake, physiological processes, biomass formation, and ultimately crop productivity. The relationship between soil solution chemistry and plant nutrition is especially important for nitrogen, phosphorus, and potassium, which are required in relatively large quantities during crop development. Soil reaction is another critical factor controlling the composition and behavior of the soil solution. Changes in pH can modify the solubility of mineral compounds, the charge characteristics of soil colloids, microbial activity, and the mobility of both macro- and micronutrients. Phosphorus availability, for example, is strongly influenced by soil pH and by its interactions with calcium, iron, and aluminum compounds. Similarly, the mobility of micronutrients such as iron, manganese, zinc, and copper depends substantially on the chemical conditions prevailing in the soil solution. The chemical composition of the soil solution is also of particular importance in irrigated agricultural systems. Irrigation with mineralized water, excessive fertilizer application, inadequate drainage, and high rates of evapotranspiration can increase the concentration of soluble salts in the root zone. The accumulation of sodium, chloride, sulfate, and other soluble ions may adversely affect soil structure, osmotic conditions, and plant water and nutrient uptake. Therefore, characterization of the soil solution can contribute to the early identification of unfavorable changes associated with salinity and to the development of more effective irrigation and fertilization strategies. Despite the importance of soil solution chemistry, its composition is characterized by considerable temporal and spatial variability. Short-term changes in soil moisture following irrigation or precipitation may substantially alter ion concentrations, while seasonal

changes in temperature, crop uptake, microbial activity, and evapotranspiration can further modify the chemical equilibrium of the soil environment. A comprehensive assessment of these processes is therefore necessary for a better understanding of nutrient cycling and for the development of sustainable soil management practices. The study of soil solution is consequently relevant not only to fundamental soil science but also to applied agricultural research. Information on the concentration and composition of dissolved ions can be used to evaluate nutrient availability, identify risks of salinization or nutrient imbalance, and optimize the application of fertilizers and irrigation water. Such an approach is particularly important under conditions of intensive agriculture, where maintaining soil fertility while minimizing environmental losses has become a major scientific and practical challenge. The objective of this study is to examine the chemical composition of the soil solution, characterize the major factors controlling its ionic composition and chemical properties, and evaluate its significance for soil fertility and plant nutrient availability. The study also aims to emphasize the potential of soil-solution analysis as a diagnostic approach for assessing changes in the soil nutrient regime and for improving scientifically based soil and crop management practices.

Literature Review on the Research Topic. The soil solution has long been recognized as a fundamental component of the soil system because it provides the immediate environment through which soluble nutrients, salts, and other chemical compounds are transported and made available to plant roots. Classical soil science studies established that the chemical composition of the soil solution is not independent of the solid phase but is governed by continuous processes of dissolution, precipitation, adsorption, desorption, ion exchange, and biological transformation. These processes determine the concentration and activity of nutrients in the soil solution and consequently influence their availability to plants. The concept of soil solution chemistry has been developed substantially through studies of nutrient dynamics and soil fertility. According to established principles of soil chemistry, the concentration of a nutrient in the soil solution represents only a fraction of its total content in soil; however, this fraction is particularly important because it is directly involved in nutrient transport toward plant roots. The equilibrium between exchangeable and solution-phase ions determines the replenishment of nutrients removed from the soil solution through plant uptake. This dynamic equilibrium is especially significant for potassium, calcium, magnesium, and ammonium, whose availability is strongly influenced by cation-exchange processes. Research on nitrogen dynamics has demonstrated that the soil solution is an important medium for the

movement of inorganic nitrogen, particularly nitrate (NO_3^-) and ammonium (NH_4^+). Nitrification, mineralization, immobilization, and plant uptake continuously modify the concentration of inorganic nitrogen in soil water. Nitrate is highly mobile and can move readily with percolating water, creating a potential risk of nutrient losses through leaching. In contrast, ammonium is generally retained more strongly by negatively charged soil colloids. Consequently, soil texture, organic matter content, moisture regime, microbial activity, and fertilizer application substantially influence the concentration and mobility of nitrogen compounds in the soil solution. Phosphorus behaves differently from highly mobile nutrients because of its strong interaction with soil minerals and organic components. Numerous studies have shown that phosphorus availability is controlled by adsorption–desorption reactions and by precipitation and dissolution processes involving calcium, iron, and aluminum compounds. Only a relatively small proportion of total soil phosphorus is generally present in the soil solution at any particular time. Nevertheless, this fraction plays an important role in maintaining the concentration gradient required for continuous phosphorus uptake by plant roots. Soil pH is among the major factors regulating phosphorus solubility and therefore represents a key parameter in evaluating phosphorus availability. Potassium is another major nutrient whose availability is closely related to soil-solution chemistry. Soil potassium occurs in several pools, including solution, exchangeable, non-exchangeable, and structural forms. The soil solution represents the most immediately available pool, while exchangeable potassium can replenish the solution as potassium is removed by plant uptake. Studies of potassium dynamics indicate that the balance among these pools depends on clay mineralogy, cation-exchange capacity, soil moisture, potassium fertilization, and crop demand. Therefore, measuring only total potassium concentration may not adequately characterize its nutritional availability to crops. The role of soil pH in regulating nutrient availability has received extensive attention in the scientific literature. Soil pH influences mineral dissolution, ion exchange, microbial processes, and the chemical speciation of nutrients. The availability of many micronutrients, including iron, manganese, zinc, and copper, generally decreases as soil pH increases, whereas certain elements may become more soluble under acidic conditions. Consequently, the chemical reaction of the soil solution is considered one of the key indicators for interpreting nutrient availability and identifying potential nutrient deficiencies or toxicities. Electrical conductivity is widely used as an indirect indicator of the total concentration of dissolved ions in soil solution. An increase in electrical conductivity generally reflects an increase in the concentration of soluble salts, although the relationship depends on the composition and mobility of individual ions. Research

conducted in irrigated and arid agricultural systems has demonstrated that excessive salt accumulation can reduce the osmotic potential of the soil solution and restrict plant water uptake. High concentrations of sodium and other soluble ions may additionally cause structural degradation and deterioration of soil physical properties. For this reason, electrical conductivity and the concentrations of major soluble ions are frequently used in the assessment of soil salinity. The literature also emphasizes the importance of irrigation water quality in determining soil-solution chemistry. Continuous application of water containing dissolved salts can gradually modify the ionic composition of the root-zone solution, particularly where drainage is insufficient. The processes of evaporation and plant transpiration concentrate soluble salts in the soil, while rainfall or excessive irrigation may promote their redistribution or leaching. Thus, the interaction between irrigation regime, soil hydraulic properties, drainage, and evapotranspiration is an important determinant of the temporal dynamics of soil-solution composition. Organic matter represents another major factor influencing soil-solution chemistry. The decomposition of organic residues releases soluble organic compounds and mineral nutrients, while humic substances can interact with metal ions and modify their mobility. At the same time, microbial processes associated with organic matter decomposition regulate nitrogen and sulfur transformations and contribute to changes in soil pH and redox conditions. These interactions demonstrate that soil-solution chemistry cannot be adequately understood without considering the biological component of the soil system. Recent approaches to soil fertility assessment increasingly emphasize the need to integrate chemical measurements with information on nutrient fluxes, plant uptake, and environmental conditions. Traditional soil testing commonly focuses on extractable or exchangeable nutrient pools in the solid phase, whereas soil-solution analysis provides complementary information about the nutrients that are actually present in dissolved form. Combining these approaches can improve the interpretation of nutrient availability and help distinguish between soils with similar total nutrient contents but different capacities to supply nutrients to crops. At the same time, the existing literature indicates that soil-solution composition is highly variable in both space and time. Differences in soil texture, mineralogy, organic matter, moisture, crop type, fertilization, irrigation, and climatic conditions can produce substantial changes in ionic concentrations. This variability creates methodological challenges for sampling and analysis and highlights the importance of standardized procedures when comparing results among soils, seasons, or agricultural management systems. Overall, the literature demonstrates that soil solution is a central component linking soil chemical properties with plant nutrition and soil fertility. Its composition

reflects the combined effects of mineral weathering, ion exchange, organic matter decomposition, microbial transformations, fertilization, irrigation, and plant uptake. However, further integrated research is needed to clarify the relationships between soil-solution chemistry, nutrient availability, salinity development, and crop productivity under specific agroecological conditions. Such research can provide a scientific basis for improving fertilizer-use efficiency, optimizing irrigation management, preventing nutrient losses, and maintaining the long-term fertility and sustainability of agricultural soils.

Research Medhodology. The study was conducted to determine the chemical composition of the soil solution and to assess its role in soil fertility and plant nutrient availability. The research methodology included soil sampling, extraction of the soil solution, laboratory analysis of its chemical properties, and statistical processing of the obtained data. Soil samples were collected from the root-zone layer of agricultural soils at selected sampling sites. Several individual samples were collected from each sampling area and thoroughly mixed to obtain representative composite samples. The collected samples were placed in clean, labeled containers and transported to the laboratory for further analysis. Before analysis, the samples were cleared of plant residues and other visible impurities and prepared in accordance with standard soil analytical procedures. The soil solution was extracted using the soil–water extraction method. A constant soil-to-water ratio was maintained for all samples to ensure comparability of the analytical results. After mixing, the soil suspension was allowed to equilibrate, followed by filtration to separate the liquid phase from soil particles. The obtained filtrate was subsequently used for chemical analysis. The pH of the soil solution was determined using a calibrated digital pH meter. Electrical conductivity (EC) was measured to characterize the concentration of soluble salts and ionic components in the soil solution. Before measurements, the analytical equipment was calibrated using appropriate standard solutions. The concentrations of the major soluble cations, including calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+}), were determined using standard laboratory analytical methods. The major soluble anions, including nitrate (NO_3^{-}), chloride (Cl^{-}), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^{-}), were also determined. The concentrations of available nitrogen and phosphorus were evaluated due to their important role in plant nutrition and soil fertility. The obtained chemical parameters were evaluated in relation to the main soil properties, including soil reaction, organic matter content, soil texture, and available nutrient concentrations. Particular attention was given to the relationships among pH, electrical conductivity, soluble ions, and nutrient availability. The influence of

irrigation and fertilizer application on the concentration of soluble salts and nutrients in the soil solution was also assessed. Quality control procedures were applied throughout the laboratory analyses. Analytical instruments were calibrated before measurements, and repeated determinations were performed where necessary. Mean values were calculated from replicate measurements to improve the reliability of the obtained results. Statistical analysis was performed using descriptive statistical methods. Mean values, standard deviations, minimum and maximum values, and coefficients of variation were calculated for the investigated parameters. Correlation analysis was used to determine relationships between soil-solution pH, electrical conductivity, major ions, and nutrient concentrations.

Table 1. Main Chemical Components of Soil Solution and Their Functional Significance

N	Component	Main Forms	Functional Significance in Soil
1	Calcium	Ca^{2+}	Contributes to soil structural stability and plant nutrition
2	Magnesium	Mg^{2+}	Essential for chlorophyll formation and plant nutrition
3	Potassium	K^{+}	Regulates water balance, enzyme activity, and plant metabolism
4	Sodium	Na^{+}	Serves as an important indicator of soil salinity and sodicity
5	Ammonium	NH_4^{+}	An important mineral form of nitrogen available for plant uptake
6	Nitrate	NO_3^{-}	A highly mobile form of nitrogen and an important source of plant nutrition
7	Sulfate	SO_4^{2-}	An important source of sulfur for plant nutrition
8	Bicarbonate	HCO_3^{-}	Influences soil alkalinity and carbonate-related processes
9	Chloride	Cl^{-}	Essential in small amounts; excessive

			concentrations may cause salinity stress
10	Phosphate	$H_2PO_4^-$, HPO_4^{2-}	Important forms of phosphorus available for plant uptake

Table 1 summarizes the major inorganic ions commonly occurring in the soil solution and their principal functional significance for soil chemical processes and plant nutrition. The soil solution constitutes the aqueous phase of soil and serves as a dynamic medium through which nutrients are transported to plant roots and participate in a range of physicochemical and biochemical processes. The concentrations and relative proportions of these ions vary considerably with soil properties, including pH, texture, organic matter content, mineral composition, moisture regime, fertilization, and irrigation.

Staristical Analysis. The experimental data were subjected to statistical analysis to determine the significance of differences among the studied treatments and to assess the relationships between the measured soil and plant parameters. Descriptive statistics, including the mean and standard deviation were calculated for each experimental treatment. The statistical significance of differences among treatment means was evaluated using analysis of variance. When significant differences were detected, the means were compared using an appropriate post-hoc multiple comparison test. The level of statistical significance was set at $p < 0.05$. Where appropriate, correlation analysis was performed to determine the strength and direction of relationships between soil chemical properties, nutrient concentrations, and plant growth parameters. Prior to statistical analysis, the data were examined for conformity with the assumptions of the applied statistical methods, including normality and homogeneity of variance. Statistical analyses were performed using appropriate statistical software. The selection of statistical procedures was based on the experimental design and the nature of the variables analyzed.

Table 2. Ionic Composition of the Soil Solution and Its Significance for Plant Nutrition

No.	Component	Main ionic form	Functional significance
1	Calcium	Ca^{2+}	Contributes to soil structural stability and is essential for plant growth and

			cell wall development
2	Magnesium	Mg^{2+}	Essential for chlorophyll formation and photosynthetic activity
3	Potassium	K^{+}	Regulates water balance, enzyme activity, and plant metabolic processes
4	Sodium	Na^{+}	Serves as an indicator of soil salinity and sodicity; excessive concentrations may impair plant growth
5	Ammonium	NH_4^{+}	An important inorganic form of nitrogen available for plant uptake
6	Nitrate	NO_3^{-}	A highly mobile form of nitrogen and an important source of plant nutrition
7	Sulfate	SO_4^{2-}	An important source of sulfur required for plant growth and protein synthesis
8	Bicarbonate	HCO_3^{-}	Participates in carbonate equilibria and influences soil alkalinity

9	Chloride	Cl^-	Essential in small quantities; excessive concentrations may contribute to salinity stress
10	Phosphate	$H_2PO_4^-$, HPO_4^{2-}	Important inorganic forms of phosphorus available for plant uptake

The table presents the major inorganic ions commonly found in soil and their importance for soil properties and plant nutrition. These ions play different roles in maintaining soil quality, supporting plant growth, and influencing soil chemical conditions. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are important for maintaining soil structure and supporting essential physiological processes in plants. Potassium (K^+) plays a key role in water regulation, enzyme activation, and plant metabolism. Nitrogen-containing ions, particularly ammonium (NH_4^+) and nitrate (NO_3^-), are important sources of nitrogen required for plant growth. Sulfate (SO_4^{2-}) provides sulfur, which is necessary for protein synthesis, while phosphate species ($H_2PO_4^-$ and HPO_4^{2-}) provide phosphorus essential for plant development. Bicarbonate (HCO_3^-) affects carbonate equilibria and soil alkalinity. Sodium (Na^+) and chloride (Cl^-) are useful indicators of soil salinity, and their excessive concentrations may cause salinity stress and negatively affect plant growth. Overall, the presence and concentration of these ions provide important information about soil fertility, nutrient availability, salinity, and chemical conditions. Therefore, monitoring their concentrations is important for evaluating soil quality and understanding its suitability for plant growth.

Conclusion. The chemical composition of the soil solution plays an important role in the formation and maintenance of soil fertility. The soil solution contains essential nutrients that are directly available to plant roots. Major ions such as calcium, magnesium, potassium, ammonium, nitrate, sulfate, and phosphate support plant growth and development. At the same time, bicarbonate, sodium, and chloride influence soil pH, alkalinity, and salinity. The balance of nutrients in the soil solution is important for maintaining healthy soil and improving plant productivity. Both nutrient deficiency and excessive concentrations of certain ions can negatively affect plant growth. In particular, high concentrations of sodium and chloride can increase soil salinity and reduce the ability of plants to

absorb water and nutrients. The composition of the soil solution is continuously affected by mineral weathering, organic matter decomposition, fertilization, microbial activity, and water movement through the soil. Therefore, soil fertility is a dynamic process that depends on the interaction between soil minerals, organic matter, microorganisms, soil solution, and plants. In conclusion, studying the chemical composition of the soil solution is important for assessing soil fertility and nutrient availability. Regular monitoring of major ions, nutrient concentrations, pH, and salinity can help improve fertilizer management, reduce nutrient losses, and maintain soil productivity. Understanding these processes is essential for sustainable soil management and long-term agricultural production.

References

1. Sidikov, S., & Ermatova, M. (2019). Changes in the chemical composition and concentration of the soil solution of irrigated automorphic soils depending on the agro background and the period of the year. East European Scientific Journal, 7(47), Part 3.
2. Sidikov, S., Ermatova, M., Abdushukurova, Z. (2020). Method for optimization of composition and concentration of soil solution of irrigated soils for nutrition of plants. Solid State Technology, 63(4), 5162–5179.
3. Sidikov, S., Ermatova, M., Abdushukurova, Z., Ergasheva, O., Mahkamova, D., & Tashmetova, N. (2020). Degree of humification of cotton, alfalfa and ephemer organs, their effect on the content and composition of soil organic matter. Plant Cell Biotechnology and Molecular Biology, 94–102.
4. Sidikov, S., Ermatova, M., & Tashmetova, N. (2020). Optimization of the chemical composition and concentration of soil solution of soils of desert zone for nutrition of plants. PalArch's Journal of Archaeology of Egypt / Egyptology, 14247–14265.
5. Sidiqov, S., & Turaev, G. (2017). The role of soil solution in plant nutrition. In XXIV International Conference of Students, Postgraduates and Young Scientists "Lomonosov" (pp. 186–187). Moscow State University.
6. Smagin, A. V. (2003). Theory and methods for assessing the physical state of soils. Soil Science, (3), 328–341.
7. Snakin, V. V. (1989). Analysis of the composition of the aqueous phase of soils. Nauka.
8. Vozbutskaya, A. E. (1968). Soil chemistry. Higher School Publishing.
9. Ziyonet. (n.d.). Retrieved from https://www.ziyonet.uz