Changes in the composition and concentration of soil solutions in seasonal dynamics of irrigated agriculture

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Abstract. The investigation focused on examining the seasonal fluctuations in the chemical composition and concentration of soil solutions in irrigated automorphic soils within diverse agricultural zones. It was observed that the composition, concentrations, and relative ratios of various compounds in the soil solutions undergo seasonal variations throughout the growing season, influenced by the process of plant nutrition. The initial stages of the growing season exhibited elevated concentrations of soil solutions, gradually declining towards lower concentrations as the growing season advanced and approached its conclusion. These fluctuations are indicative of dynamic changes in the soil's chemical profile, influenced by the varying nutritional demands of plants at different stages of growth. The observed patterns underscore the intricate interplay between plant development and the temporal dynamics of soil solution constituents. This study enhances our understanding of the seasonal nuances in soil chemistry, emphasizing the importance of considering the temporal dimension in agricultural soil management practices to optimize plant nutrition and overall crop health.

1. Introduction

Presently, a pivotal focus of the nation's development strategy revolves around the modernization and intensive growth of agriculture, entailing profound structural reforms and the dynamic expansion of agricultural production. Within agricultural production, soil stands out as the primary resource, and the optimization of soil solution for plant nutrition, particularly its properties, stands as a crucial guarantee for achieving high-quality yields. The soil solution assumes a paramount role in the soil formation process, where chemical and biological transformations of organic and mineral compounds occur through direct interaction with the liquid phase of the soil. This function can be broadly termed the transformation function [1–3]. The soil solution, comprising cations (Ca2+, Mg2+, Na+, H+, NH4+, K+) and anions (HCO3, Cl-, NO3, SO4, H2PO4-) from various substances, facilitates the dissolution and transformation of aluminosilicates and hydroxides via complex formation, hydrolysis, ion exchange, and other reactions. It serves as the primary medium wherein distinct physicochemical reactions drive elementary soil-forming processes[4–6]. The liquid phase, being the primary environment for physicochemical reactions in soil, inherently mirrors the essential features of modern soil formation based on its composition and properties. This liquid phase not only influences the migration flows of substances within the soil and landscape but also plays a pivotal role in transportation. Solutions impact transport processes in products resulting from dissolution, leaching, exchange, and hydrolysis arising from the interaction between solid and liquid phases of soil. These processes form the foundation for the composition of gravitational runoff from soils into streams and rivers within the catchment basin. The informational role of soil solutions stems from their transformation and transportation functions, reflecting the ongoing processes in soil under the specific conditions of biogeocenoses. Changes in soil due to biological, chemical, and physicochemical processes manifest in the composition of its liquid phase [7–10]. Given the potential for optimizing soil solution for plant nutrition, understanding the impact of natural and anthropogenic factors on soil solutions becomes imperative. In the realm of agriculture, a key objective is to preserve the condition of soil solution for optimal plant nutrition. Hence, the study of the composition and concentration of soil solution, its variations in diverse agricultural contexts, and the creation of a favorable state for plant nutrition based on this knowledge emerge as urgent tasks in agriculture. Review of literature sources indicates that soil solution studies have been conducted at the Dokuchaev Soil Institute (Russia) by A.A. Kizilova, P.I. Shavrigin, and at the University of Nottingham by D.M. Bonito, M.E. Essington, yielding valuable data on soil solutions specific to their respective regions. A.V. Smagin suggests that the equilibrium

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thermodynamics categories are instrumental in describing the individual states and processes of interaction within soil systems. In soil chemistry, ambiguity persists in defining "soil solution," often interpreted as soil moisture in various forms of soil composition and properties. A.E. Vozbutskaya considers "liquid phase of soil" and "soil solution" to be analogous terms. The Explanatory Dictionary of Soil Science defines soil solution as "water found in soil and containing organic and mineral substances and gases in a dissolved state". Water, a critical factor in chemical weathering of minerals, initiates the process where ions in solid phases transition into a solution. The ions forming weak bonds predominantly remain in the solution, while those forming strong bonds lead to the formation of new solid phases [11]. R.W. Pearson, quoted by Orlov, characterizes soil solution as a "quasi-equilibrium solution of electrolytes that exists in soil under the condition of its incomplete saturation with moisture". A similar interpretation is found in the dictionary "Biosphere: pollution, degradation, protection," defining soil solution as a "solution of chemicals in water, in quasi-equilibrium with the solid and gaseous phases of soil, partially or completely filling its pores." D.S. Orlov aptly defines soil solution as the liquid part of soil under natural conditions. These definitions capture specific aspects of the soil solution system but lack strict precision, leaving questions about whether all forms of water in soil should be attributed to soil solution. Several foreign scientists have significantly contributed to isolation methods and the study of composition and dynamics of soil solutions. However, in Uzbekistan's soils, especially in irrigated areas, soil solution research is lacking. The method of water extracts remains crucial for monitoring soil salt status and provides data on soil solution concentrations reflecting the actual conditions for plant growth in specific soil types. Authors are studied the impact of plant residues on humus quantity and quality, as well as humification degree in cotton, alfalfa, and ephemera, affecting organic matter content in soil at a low concentration of soil solution. Their research calculated the humification coefficient for different plant parts, contributing valuable insights to soil management practices. Additionally, S. Sidikov, M. Ermatova, N. Tashmetova explored the chemical composition and concentration of soil solution in desert zone soils under intensive farming, finding that both low and high concentrations negatively impact plant development, emphasizing the importance of an optimal concentration for promoting nutrient absorption and ensuring high crop yields [10–11].

2. Methods

The focus of this investigation is the experimental site at the Department of Soil Science of the National University of Uzbekistan, named after Mirzo Ulugbek. The study centers on typical old-irrigated gray soils, soil solution, anions, cations, the Namangan-77 cotton variety, agrotechnical measures, and mineral fertilizers. The primary aim is to scrutinize the composition and concentration of soil solution, discerning variations across diverse agricultural contexts [8,9]. To attain this objective, several tasks were undertaken, including the implementation of a field experiment on old-irrigated typical gray soil, determination of soil solution composition and concentration, exploration of the impact of soil solution's chemical composition and concentration in various agricultural settings, and identification of seasonal fluctuations based on agricultural backgrounds and the cotton plant's growth stages. In natural soils, the influence of the solid and gas phases, coupled with the natural vegetation cover, shapes the soil solution. Conversely, irrigated soils introduce additional factors related to agricultural practices such as tillage, fertilizer application, and irrigation. A comprehensive study of soil solution extends beyond the solid phase, encompassing the liquid and gaseous phases due to their constant interconnection. From an agrochemical and plant nutrition standpoint, a thorough understanding of soil solution properties—concentration, chemical composition, osmotic pressure, and their dynamics—is imperative [5;7]. The vitality of plants and microorganisms hinges on soil solution, serving protective, regulatory, and nutritional functions. The scientific novelty of this research lies in the isolation and examination, for the first time, of the composition and concentration of soil solution in irrigated typical serozem conditions. The investigation further elucidated the influence of diverse agricultural backgrounds on the chemical composition and concentration of soil solution, unveiling seasonal variations during the cotton plant's growth stages [4;6]. The investigation involved employing well-established techniques in agrochemistry for the isolation, identification, and quantification of soil solutions, along with their temporal variations. Theoretical and Practical Implications. The findings carry significant theoretical and practical implications, offering insights into the exchange reactions within the soil-absorption complex. They shed light on the interplay between absorbed ions and those present in the solution, providing a nuanced understanding of the impact of fertilizers, irrigation, and processing techniques on these processes. Furthermore, the results contribute to the scientific foundation for judicious fertilizer application and cultivation practices. Lastly, their relevance extends to educational contexts, particularly in higher educational institutions, where they can enrich the learning experience.

3. Results

Results of the study yielded data on the chemical composition and concentration of soil solution in irrigated automorphic soils. The study also explored the variations in the chemical composition and concentration of soil solution in response to different fertilizer application rates and throughout the cotton plant's growing season.

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Soil Solution Concentration: The concentration of soil solution exhibits considerable variability based on soil types and geographical locations, ranging from several tens of mg/l to several g/l. Saline soils can even reach concentrations of several hundred g/l. For a typical old-irrigated sierozem, the concentration of soil solution along the soil profile varies from 0.2 to 0.7 mg/l. It was observed that plants efficiently assimilate nutrients when the concentration ranges from 0.2 to 1.0 mg/l. Beyond this range, increased concentrations impede nutrient absorption by plants. Anion and Cation Content: In the studied old-irrigated typical sierozem, the soil solution exhibited varying content of anions and cations along the soil profile. The anion content included normal carbonates (0.022-0.027%), chlorine ions (0.002-0.003%), and sulphate ions (0.003-0.008%). Among cations, sodium ions ranged from 0.002 to 0.005%, magnesium ions from 0.001 to 0.003%, and calcium ions from 0.006 to 0.010% (Table 1).

Table 1. Concentration of soil solution in old-irrigated typical serozem,%

Depth, cm	HCO_3^-	CL^-	SO_4^{-2}	Na^+	Md^{+2}	Ca^{+2}
0-30	0.027	0.003	0.006	0.005	0.002	0.006
30-50	0.026	0.003	0.003	0.005	0.001	0.008
50-69	0.026	0.003	0.004	0.004	0.003	0.01
69-99	0.027	0.003	0.008	0.003	0.001	0.01
99-131	0.025	0.002	0.005	0.002	0.002	0.008
131-181	0.022	0.003	0.007	0.002	0.002	0.008

Soil solution, closely intertwined with the solid phase of soil, serves as a reflection of the biogeocenosis, exhibiting typical features influenced by interactions with atmospheric precipitation, living organisms, and vegetation. This dynamic medium undergoes changes induced by plants, as they extract essential elements and introduce others through intravital root secretions and leaf mold. Root respiration and the biota's vital activity release carbon dioxide and various organic exudates into the solution, alongside the decomposition of organic matter. The research revealed that plant development is hindered at low concentrations of soil solution, resulting in inadequate nutrient absorption. Conversely, high concentrations negatively impact plant health. Optimal concentration proves to be the most conducive environment for plant development, expediting nutrient absorption and ensuring prolific crop yields. Table 2 illustrates the average chemical composition indices of soil solution from the upper horizons of old-irrigated typical sierozem, derived from four field experiments.

Table 2. The chemical composition of soil solution in different agricultural backgrounds, mg/l

Variants	HCO_3^-	Cl^-	NO_3^-	SO_4^{-2}	PO_4^{-3}	NH_4^+	Ca^{+2}	Mg^{+2}	K^+	Na^+
The control	48.2	2.2	9.3	4	0.27	5	39.1	26.1	2.1	29.1
N_{200} P_{140} K_{100}	51.3	2.5	10.2	4.1	0.3	6	43.4	30.7	2.2	32
N_{250} P_{175} K_{125}	57.5	2.6	11.4	4.2	0.31	7.5	45.8	34.8	2.3	34.3
N_{300} P_{210} K_{150}	60.7	2.7	12	4.1	0.4	7.9	49.5	37.4	2.4	35.8

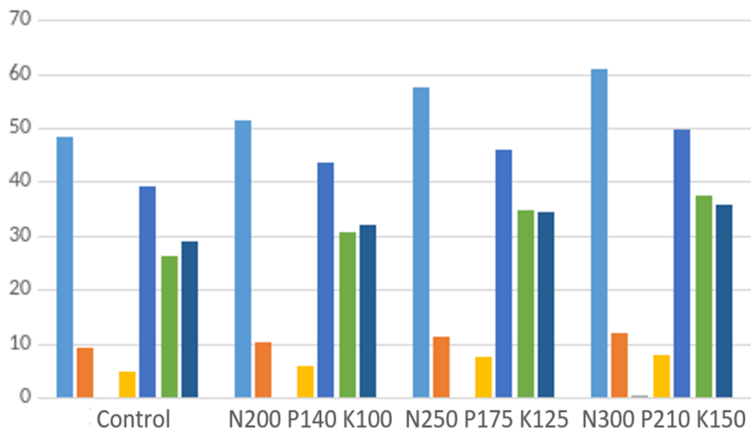

Fig. 1. Concentration of soil solution, mg/l (beginning of vegetation)

Table 2 reveals noticeable variations in the composition of soil solutions among different experimental variants. Specifically, all variants exhibit higher concentrations of calcium, magnesium, and potassium ions. The control variant shows the lowest levels of both anions and cations in the soil solution, while the introduction of fertilizers results in an increase in their concentrations. In the plow horizon of soils within the N300P210K150 variant, the content of HCO3 was 60.7 mg/l, NO3-12.0 mg/l, NH4-7.9 mg/l, Ca 49.5 mg/l, Mg-37.4 mg/l, and Na-35.8 mg/l. These values decreased down the soil profile. Under irrigated agriculture conditions, heightened biological activity leads to a higher concentration of soil solution. The development of virgin lands intensifies the nitrification process, enriching the soil solution with nitrates. Concurrently, an increase in calcium, magnesium, and potassium content is observed. Field experiment data illustrates that the composition of soil solutions, along with the concentration and ratio of various compounds, undergo seasonal variations during the growing season, primarily influenced by the process of plant nutrition (see Figs. 1, 2).

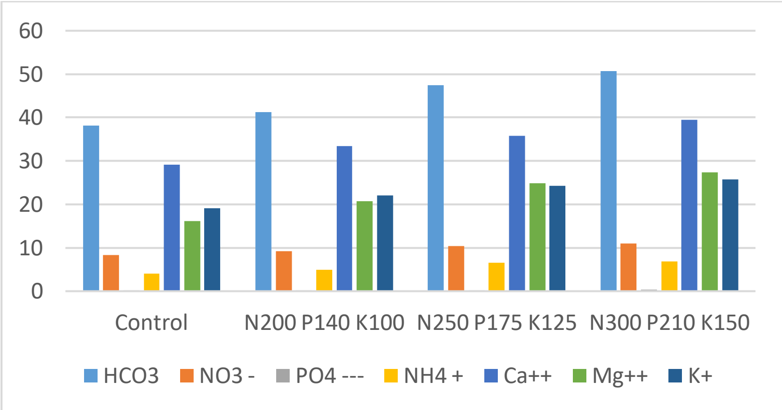

Fig. 2. Concentration of soil solution, mg/l (end of vegetation)

Significant alterations in the composition of soil solution become evident in the midst of the growing season, particularly in July and August. During this period, there is an augmentation in the nutrient content within the soil solution, accompanied by an intensified absorption function of the cotton root system. This phenomenon is closely associated with the culmination of the nitrification process in the soil, an upsurge in phosphatase activity, and an increase in carbon dioxide levels in the soil air. Consequently, there is a heightened presence of nitrogen, ammonium, and phosphorus in the soil solution. Concurrently, substantial modifications occur in the soil environment during mid-summer, leading to a shift towards an alkaline or weakly acidic state.

4. Conclusion

In subsequent growing seasons, the direct influence of the plant induces a decrease in the concentration of calcium ions and an increase in potassium ions within the soil solution. Consequently, the potassium-to-calcium ion ratio widens. The nutrient uptake by the root system is contingent on this ratio: a higher ratio in the solution corresponds to an increased absorption capacity of the roots, and vice versa.

It is noteworthy to mention that the composition of soil solutions, along with the concentration and ratio of various compounds, undergoes seasonal variations throughout the growing season. This fluctuation is driven by the process of plant nutrition. It was observed that the soil solution exhibits high concentration at the onset of the growing season, and subsequently diminishes in later stages of the growing season due to the direct impact of the plant.

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