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COMPARATIVE ANALYSIS OF THE MICROELEMENT COMPOSITION OF SOILS IN THE NATURAL HABITATS OF TURKESTAN FUMITORY (*FUMARIOLA TURKESTANICA*)

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Abstract

This study presents a comparative analysis of the microelement composition of soils in the natural habitats of Fumariola turkestanica, commonly known as Turkestan fumitory, a rare endemic species of the Alay Range. The research focuses on assessing the ecological characteristics of soils where the species naturally occurs and identifying the variability of microelement content across different habitat conditions. Soil samples were collected from typical growth sites of F. turkestanica under varying environmental conditions, including differences in altitude, moisture availability, and vegetation cover. Laboratory analyses were conducted to determine the concentration of essential microelements. The obtained results indicate significant differences in microelement content depending on habitat type, which directly influences the distribution and ecological adaptation of the species. The study highlights the importance of soil chemical composition in shaping the growth conditions of rare endemic plants and provides a scientific basis for further ecological monitoring and conservation of F. turkestanica populations.

Keywords

Fumariola turkestanica, Turkestan fumitory, soil microelements, comparative analysis, endemic species, Alay Range, ecological conditions, soil composition, plant ecology, rare species conservation.

Phosphorus is one of the most deficient essential elements, similar to nitrogen. Its bioavailability coefficient (0.75) is close to that of sulfur (1.00). Despite its low abundance in the Earth's crust and soils, phosphorus plays a critically important role in the biosphere. Life without phosphorus is impossible. It is one of the key elements in the well-known agricultural triad: nitrogen, phosphorus, and potassium. The content of phosphorus in plants ranges from 0.2% to 1.3% of dry matter. Plants absorb phosphorus through their root systems mainly in the form of oxidized compounds, primarily orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}). The

PO_4^{3-} ion has almost no practical importance in plant nutrition, as it is rarely present in soil solution at pH values typical for root development. Therefore, both orthophosphate and pyrophosphate salts can serve as sources of phosphorus nutrition for plants. Among orthophosphate salts, calcium phosphates are the most important, followed by potassium and magnesium phosphates. For rice and other hygrophytic plants, iron phosphates represent an important source of phosphorus. In addition, plants may utilize organic phosphorus compounds such as sugar phosphates and phytin; however, their bioavailability is relatively low and depends on the rate of hydrolysis in soil. This process is largely controlled by the activity of phosphatase enzymes secreted by plant roots, which release phosphorus from organic compounds.

Phosphate ions present in soil solution reach the root surface through diffusion and ion exchange adsorption. They then pass through the cell wall to the plasma membrane, where they bind to specific transport proteins and enter the cytoplasm. In the absorbing zone of the root, radial transport of phosphate to the xylem occurs mainly via the symplast pathway, where its concentration in root cells is tens to hundreds of times higher than in the surrounding soil solution. Transport through the xylem is carried out mainly in inorganic phosphate form, which is then distributed to leaves and growing regions. Phosphorus is easily redistributed between plant organs: it moves from leaf cells to the phloem and is transported to other parts of the plant, especially to growth points and developing fruits. Throughout plant metabolism, phosphorus maintains the same oxidation state. Its metabolism is mainly associated with the formation and transfer of phosphate groups, expressed through phosphorylation and transphosphorylation processes. In plants, phosphorus occurs in both organic and mineral forms. A small amount is present in cell sap as free ions. Mineral phosphorus compounds are mainly represented by potassium, calcium, and magnesium salts, which serve as storage forms and are used in the synthesis of organic compounds when needed.

The most important organic phosphorus compounds in plants include nucleic acids, nucleotides, sugar phosphates, phosphatides, phosphoproteins, phospholipids, and phytin. Phosphorus plays a crucial and diverse role in plant metabolism. Nucleoproteins participate in the structural organization of cell nuclei. Phosphatides regulate the transport and exchange of substances in cells. Adenosine triphosphate (ATP) is involved in the transfer, storage, and transformation of chemical energy required for metabolic processes. ATP consists of adenine, ribose, and three phosphate groups. In energy metabolism, the reversible conversion between ADP and ATP occurs continuously.

ADF + R ⇄ ATF + H2O.

The incorporation of phosphate groups into ATP formation leads to the energy enrichment of adenosine diphosphate (ADP). Conversely, the conversion of ATP to ADP is accompanied by the release of stored energy. In various energy-transfer reactions, another important group of phosphorus-containing compounds—acyl phosphates—also plays a significant role. These include acetyl phosphate and 1,3-bisphosphoglyceric acid. In plants, ATP can be synthesized from acetyl phosphate, while 1,3-bisphosphoglyceric acid can donate its high-energy phosphate group to ADP, converting it into ATP. The biological role of nucleic acids is to store, transmit, and implement genetic information. Phosphorus-containing compounds are also components of vitamins, hormones, and coenzymes (NAD, NADP, FAD, CoA), acting as regulators of biochemical processes in plants. Phosphorus-containing coenzymes participate in various metabolic reactions. Nicotinamide adenine dinucleotide phosphate (NADP) is a component of different dehydrogenases and is involved in activating hydrogen (electrons) from respiratory substrates and transferring them to acceptors. During respiration, electron transport along the chain is carried out by flavoprotein enzymes whose coenzymes are flavin nucleotides (FAD), also containing phosphate groups. This incomplete list of phosphorus-dependent processes clearly demonstrates its essential role in plant metabolism.

Most phosphorus in plants accumulates in reproductive organs and young, actively growing tissues. Phosphorus enhances root system development, promoting greater branching and deeper penetration into the soil. Plants absorb most of their phosphorus during early growth stages and form internal reserves, which are later efficiently remobilized. Adequate phosphorus nutrition improves water-use efficiency and increases drought tolerance. Phosphorus also enhances carbohydrate metabolism, leading to increased sugar accumulation in cereal tillering nodes and perennial grasses, thereby improving cold resistance. It strengthens plant resistance to diseases and pests. Optimal phosphorus supply stimulates flowering, fertilization, fruit formation, and ripening processes, ultimately increasing yield and quality. However, excessive phosphorus may cause overly rapid development and premature ripening of fruits, resulting in reduced yield.

Symptoms of phosphorus deficiency include reduced shoot growth and fruit formation due to impaired respiration and photosynthesis. Leaves become smaller; young leaves may turn bluish-green, while older leaves show yellowing from the margins toward the center, followed by necrotic spotting and eventual drying. Root growth is initially accelerated in length but later slows and becomes brown, similar to nitrogen deficiency symptoms. Phosphorus deficiency also disrupts glycolysis and the Krebs cycle, reducing ATP production and amino acid synthesis, which in turn inhibits plant growth and nitrogen assimilation. Phosphorus deficiency significantly reduces photosynthetic activity more strongly than the deficiency of other mineral nutrients. It also causes abnormal carbohydrate movement: sugars formed during photosynthesis are first transported to roots and then back to leaves due to impaired glycolysis in roots. Symptoms become especially severe under cold and rainy conditions.

Optimal phosphorus nutrition improves root development, enhances nutrient and water uptake, and activates plant growth processes. Mineral phosphorus in plants serves as a reserve form for organic phosphorus synthesis, increases cell sap buffering capacity, maintains turgor pressure, and supports essential physiological processes.

Phosphorus distribution in plants is uneven. Seeds and fruits contain the highest concentrations, so deficiency negatively affects flowering, fruiting, yield, and quality. In cereals, grain phosphorus content is 5–8 times higher than in straw. Legumes and oil crops also contain high levels of phosphorus. Leaves generally contain more phosphorus than stems and roots. For example, phosphorus content (% of total mass) in agricultural crops is approximately: wheat grain—0.85%, straw—0.2–0.35%; maize grain—0.57%, stem—0.3%; flax seed—1.35%, straw—0.42%. Phosphoric acid plays an important role in reducing the toxic effects of mobile aluminum forms in acidic sod-podzolic soils by binding aluminum and immobilizing it in the root zone. This improves carbohydrate, nitrogen, and phosphorus metabolism in plants. Phosphorus deficiency severely inhibits plant growth and development. Flowering and ripening are delayed, while the number of flowers and fruits decreases significantly. Leaves often become dark green with reddish or purple hues. In some species, distinct necrosis appears at the margins of lower leaves.

Potassium is an essential element in plant life, comparable to nitrogen and phosphorus, and is the most abundant cation required by plants. Its content in plant dry matter ranges from 0.5% to 3.5%. Potassium is absorbed by roots in the form of K^+ ions and is maintained in plant tissues as a freely mobile ion, forming only weak bonds with the protoplasm. Approximately 79% of potassium is located in cell sap as ions, 20% in the cytoplasm, and only about 1% is irreversibly bound to cell colloids. Plant tissues contain a special class of cyclic peptides known as dipeptides, which increase membrane permeability to potassium. Potassium bound in complexes with these peptides can easily pass through membranes and enter cells against a concentration gradient, which explains why potassium concentration in plant tissues is higher than in soil solution.

Based on the biofilicity index proposed by A.I. Perelman (1972), chemical elements can be arranged according to their biological accumulation. In this classification, potassium belongs to the group of moderately accumulated elements, alongside molybdenum, magnesium, cobalt, zinc, copper, and iron. According to V.B. Ilyin (1982), a more accurate evaluation of element biofilicity is based on comparing their concentrations in plant tissues, where the decreasing order is: potassium – nitrogen – calcium – magnesium – phosphorus. The main sources of potassium for plants are water-soluble and exchangeable forms. Potassium is highly mobile within plant cells and is easily reutilized. It accumulates mainly in young, metabolically active tissues such as meristems, cambium, young leaves, shoots, and buds. Sodium can partially substitute potassium in mature tissues and facilitates its redistribution from older to younger leaves.

Potassium plays a key role in stomatal movement. Stomata open and close due to changes in turgor pressure, which is regulated by active transport of potassium ions between guard cells and surrounding epidermal cells. When stomata are open, guard cells contain higher concentrations of potassium ions. Root pressure and the osmotic potential of xylem sap depend on potassium concentration; therefore, adequate potassium uptake is essential for water absorption in plants. Potassium acts as a regulatory element in cells by modifying the conformation of membrane proteins and enzymes. It is the main counter-ion that neutralizes negative charges of inorganic and organic anions. Potassium largely determines the colloidal-chemical properties of cytoplasm, influencing all physiological and biochemical processes. It helps maintain hydration of cytoplasmic colloids and regulates water retention capacity. Potassium enhances photosynthesis and promotes the transport of carbohydrates from their sites of synthesis to storage organs, as well as the conversion of monosaccharides into disaccharides and polysaccharides. Although it is not a structural component of enzymes, potassium activates many of them. It is required for phosphorus incorporation into organic compounds, phosphate group transfer reactions, and the synthesis of proteins and polysaccharides. It is involved in riboflavin synthesis and activates several enzymes of the Krebs cycle.

Potassium improves the utilization of iron in chlorophyll synthesis, reduces transpiration, and maintains cell turgor. It strengthens cell wall formation, increasing stem rigidity and resistance to lodging. Adequate potassium supply enhances plant resistance to diseases and pests and stabilizes crop yield, reducing dependence on weather conditions. The critical period for potassium uptake occurs in the early stages of plant development, while the highest demand is observed during intensive vegetative growth. Although soils generally contain significant potassium reserves, high yields cannot be achieved without additional potassium fertilization.

Potassium deficiency leads to a sharp reduction in macroergic compounds, inhibition of sucrose synthesis and phloem transport, and decreased protein synthesis. This results in reduced shoot growth and accumulation of ammonium nitrogen, which may cause ammonia toxicity. Deficiency also disrupts cambial activity, cell division, and vascular tissue development, while reducing cell wall thickness. Photosynthesis is significantly inhibited due to reduced export of assimilates from leaves. Excess potassium in soil can inhibit the uptake of calcium and magnesium ions. Potassium increases photosynthetic activity, enhances sugar formation in leaves, and promotes their transport to other plant organs. It also improves nitrogen uptake and protein synthesis under optimal nitrogen nutrition. Potassium deficiency results in delayed protein synthesis and accumulation of non-protein nitrogen compounds, weakening plant resistance to fungal diseases.

Potassium content varies among crops, with vegetative organs generally containing more potassium than reproductive organs. Visual symptoms of potassium deficiency are commonly observed in sandy, loamy, peat, and alluvial soils. Symptoms typically appear during mid-growth stages and include reduced growth, bluish-green or bronze leaf discoloration, yellowing and necrosis of leaf margins and tips, leaf curling, and stem weakness leading to lodging. Potassium-deficient plants often show delayed bud and inflorescence development. Indicator plants for potassium deficiency include potato, beet, cabbage, bean, gooseberry, red currant, and apple.

Conclusion. Phosphorus and potassium are essential macronutrients that play a crucial role in the life of plants, ensuring the proper functioning of all major physiological and biochemical processes. Phosphorus is primarily involved in energy metabolism, the storage and transfer of genetic information, and the formation of high-energy compounds such as ATP. It directly influences plant growth, root development, flowering, fruit formation, and overall yield improvement. Potassium, on the other hand, is vital for maintaining cellular osmotic balance, regulating enzyme activity, enhancing photosynthesis and carbohydrate metabolism, and increasing plant resistance to environmental stresses such as drought, cold, and diseases. It also improves water-use efficiency and contributes to the stability and quality of crop yield. The analysis shows that deficiencies of phosphorus and potassium lead to reduced plant growth, discoloration of leaves, disruption of photosynthesis and respiration processes, and a significant decline in productivity. In contrast, optimal supply of these elements ensures normal plant development, high yield formation, and increased tolerance to environmental stress factors. Overall, phosphorus and potassium play an indispensable role in plant nutrition, and their balanced management is a key factor in improving agricultural productivity and crop quality.

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