# Evaluation of Nutritional Regime in Sandy Soils Based on Fertilizer Application Rates

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**Abstract.** The assessment of soil fertility and its ability to support high agricultural yields is primarily determined by the availability of essential nutrients in forms accessible to plants. Therefore, agrochemical analysis of sandy soils, which provides insights into the dynamics of mobile nutrient forms such as nitrogen, phosphorus, potassium, and organic matter, is crucial for informed fertilizer management. In this context, a systematic approach to determine the optimal fertilizer rates and their application methods is fundamental to achieving sustainable crop production. The enrichment of sandy and sandy-loamy soils through targeted agrotechnological practices and innovative technologies plays a pivotal role in restoring and enhancing soil fertility. Additionally, effective strategies to protect against sand erosion, optimise irrigation practices, and apply fertilisers in appropriate quantities and proportions are crucial for increasing yields, particularly in cotton cultivation. This research addresses these challenges, emphasizing the importance of a balanced approach to fertilizer use and the development of sustainable agricultural practices for cotton production under irrigated conditions.

## 1 Introduction

The effective utilisation of lands characterised by degraded reclamation states and low fertility remains a pressing issue in contemporary agriculture. Sandy and sandy-loamy soils, particularly those prone to wind erosion and sand dune formation, require specialized management techniques to enhance their productivity. Through the application of various agrotechnical measures, these soils can be enriched with essential nutrients, and innovative technologies can be employed to restore and improve their fertility. Additionally, mitigating the adverse effects of wind erosion and sand encroachment, especially on low-fertility sandy lands, is a critical challenge for sustainable agriculture. The development of effective technologies for the application of fertilizers—such as nitrogen (N), phosphorus (P), potassium (K), and local organic amendments (e.g., manure)—in optimal ratios, along with

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appropriate application timings, is essential for maximizing the yield potential of crops like cotton and wheat, and carrot particularly under irrigation.

It has been established that subsurface tillage, combined with stubble retention, plays a vital role in protecting soils from erosion and degradation. Many significant experiments hold by researchers. [1]. In Uzbekistan, pioneering studies on soil erosion were conducted by [2] and others, contributing valuable insights into the causes and management of soil erosion in arid regions. Furthermore, the work of scientists underscored the importance of organic matter [3], clay minerals [4], and crop rotations in improving soil structure [5], [6] and water retention properties, which ultimately enhances crop yield potential [7].

Numerous scientists have also investigated the role of soil structuring and fertilization practices in maintaining soil fertility [8], [9]. Studies by [10], among others, demonstrated the positive effects of organic fertilizers on soil's water- physical properties, especially in gravelly and sandy soils [11], [12]. Additionally, research conducted in India and the USA has shown that certain psammophyte plants can help stabilize moving sands, offering a potential solution to the challenges of soil erosion [13], [14]. These studies make a significant contribution to the ongoing efforts to address the fertility challenges of sandy soils and enhance crop production in arid regions.

## 2 Materials and Method

The experimental work was conducted in accordance with the standard agricultural practices outlined by the Ministry of Agriculture of Uzbekistan and the guidelines set forth by the Uzbek Cotton Growing Research Institute for conducting field and vegetation experiments with cotton. The methodology followed was consistent with the protocols established in Methods of Field and Vegetative Experiments with Cotton (Tashkent, 1973), and incorporated principles from established scholars such as B.A. Dospekhov, K. Mirzajonov, and V.P. Kondratyuk. These methodologies emphasize precise experimental design and rigorous data collection, ensuring reliable and reproducible results.

Field experiments were conducted at selected locations known for their sandy and sandy-loamy soil types, which are typical of the regions studied. Soil properties were carefully monitored, with particular attention to the physical, chemical, and water-physical characteristics crucial for cotton growth, including soil texture, pH, organic matter content, and nutrient availability.

In these experiments, cotton (Gossypium spp.) was cultivated using recommended seeding rates, irrigation schedules, and fertilization protocols, while ensuring adherence to soil conservation practices. Fertilizer treatments, including nitrogen (N), phosphorus (P), potassium (K), and organic amendments (such as manure), were applied according to the recommended rates and methods, with adjustments made based on specific soil nutrient profiles. The study also examined the effects of varying fertiliser ratios and application timings on cotton growth and yield, as well as the efficiency of water use under different irrigation practices.

In addition to these field-based procedures, vegetation experiments were conducted under controlled conditions to assess the influence of various soil treatments and agrotechnical practices on cotton seedling development, root growth, and overall plant health. The experimental design employed both factorial and randomised block designs to ensure statistical robustness and minimise experimental error.

Data on crop yields, growth parameters (such as plant height, leaf area, and root development), and soil fertility dynamics were collected regularly throughout the growing season. The results were analysed using standard agronomic statistical methods to evaluate the effectiveness of different treatments, enabling the development of best practices tailored to sandy soils under irrigation conditions.

The adherence to these established methods ensured a high level of scientific rigour in the experimental process, contributing to a comprehensive understanding of the nutritional regime and agrotechnical practices necessary to enhance cotton production in degraded, low-fertility sandy soils.

## 3 Results and Discussions

### 3.1 Dynamics of nitrate nitrogen in sand

The soils of Central Asia are characterised by high biological activity, which leads to the rapid mineralisation of humic substances and the accumulation of nitrogen in forms readily assimilated by plants. Under these conditions, organic and ammoniacal nitrogen from fertilizers undergo rapid oxidation to nitrate salts. The mobile forms of nitrogen in these soils are predominantly nitrates, due to the pronounced process of nitrification.

It has been observed that during the summer months, ammoniacal nitrogen from mineral fertilizers is typically converted to nitrate compounds within a few days after application. Nitrates, being highly soluble in soil moisture, are not retained by the soil and readily move along the soil profile under the influence of precipitation and irrigation water. During the autumn-winter and early-spring periods, the leaching of nitrate nitrogen into deeper soil horizons can extend to depths of 1.5 to 2.0 meters or more. In cases where the groundwater table is shallow, this leaching may lead to groundwater contamination, posing significant environmental risks.

During the summer, due to significant evaporation from the soil surface, nitrates that have been washed in are rapidly drawn back to the surface, accumulating in the dried topsoil layer. The consistent application of mineral fertilisers increases the concentration of both gross and mobile forms of nutrients in the soil, thereby enhancing their solubility and availability.

However, the depletion of organic matter through erosion suppresses microbiological processes within the soil, reduces its capacity for nitrification, and diminishes the nitrate content. This, in turn, negatively impacts the nitrogen nutrition of plants, which is essential for maintaining optimal agricultural productivity.

Despite extensive research on the dynamics of mobile forms of nitrogen across different soil and climatic zones, this study represents the first investigation of this issue in the deflated hilly-dune sands of Central Fergana. The data obtained on the dynamics of mobile forms of nitrogen in these sands are crucial for determining optimal nitrogen fertiliser application rates, with the goal of enhancing agricultural productivity while mitigating potential environmental impacts.

The findings of our research regarding the dependence of nitrate nitrogen dynamics on fertilizer application rates are presented in Figure 1. The content of nitrate nitrogen in the sand under fertilised conditions was found to be directly proportional to the amount of fertiliser applied. At application rates of 150, 200, and 250 kg/ha of nitrogen, combined with phosphate and potash fertilizers, a significant difference was observed in the nitrate nitrogen content within a 1-meter depth of sand. This difference was evident across all phases of plant development. Specifically, at a rate of N-250, P2O5-175, K2O-125 kg/ha, the nitrate nitrogen content in the 1-meter layer of sand was 15.1 mg/kg at the 2-4 true leaf stage, 11.8 mg/kg at the budding stage, 15.7 mg/kg during flowering, and 8.6 mg/kg at the end of the growing season. In contrast, when using N-200, P2O5-140, K2O-100 kg/ha combined with 40 tons of manure per hectare, the nitrate nitrogen content in the sand at the aforementioned stages was 15.4, 11.7, 17.2, and 9.0 mg/kg, respectively.

The highest nitrate nitrogen content was observed in the 1-meter sand layer in treatments that combined mineral fertilisers (N–200, P2O5–140, K2O–100 kg/ha) with 40 tons of manure per hectare.

The seasonal dynamics of nitrate nitrogen across different experimental treatments revealed that, irrespective of the fertilizer application rates, nitrate accumulation is most pronounced during the spring and summer, reaching a peak during the 2-4 true leaf and flowering stages of cotton. At the end of the growing season, nitrate content decreases due to temperature effects, reduced microbial activity, and the removal of nitrates by plant uptake (Fig. 1).

This observed trend in the content of nitrate nitrogen in the sand was consistent across all years of the study and the vegetative experiments conducted.

### 3.2 Dynamics of Mobile Forms of Phosphorus in Sand

Phosphorus fertilizers applied to the carbonate soils of Central Asia undergo significant transformations, altering their solubility and bioavailability. These changes result from complex chemical, physical, and microbiological processes that occur in the soil when fertilisers are introduced. Understanding these processes is crucial for optimising phosphorus management and enhancing soil fertility in the region.

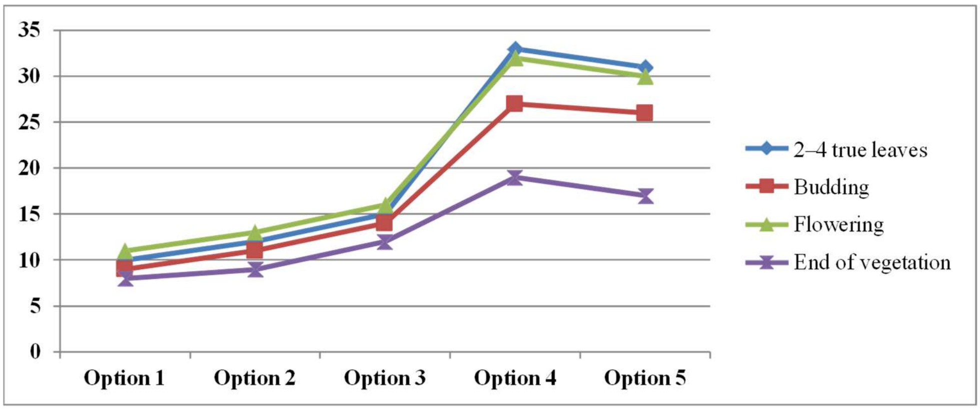


**Fig. 1.** Dynamics of nitrate nitrogen in the sand depending on fertilizer rates.

Phosphorus in the soil is primarily fixed by calcium and magnesium, with lesser contributions from aluminum and iron. Additionally, microorganisms contribute to phosphorus fixation by converting mineral phosphorus into organic forms, which are not directly available to plants. Upon the death of these microorganisms, the organic phosphorus is mineralised again into forms that are accessible to plants. However, the total phosphorus content in the soil is not a definitive indicator of soil fertility. Rather, it is the specific forms of phosphorus compounds, their mobility, and their availability to plants that are crucial in assessing soil fertility.

For optimal plant growth and development, it is essential to consider not only the overall nutrient content but also the seasonal dynamics of these nutrients in the soil. The nutrient requirements of plants fluctuate throughout their growth stages, and the timing and availability of nutrients must align with these needs. The dynamics of soil phosphates are influenced by several factors, including the concentration of electrolytes in the soil solution, the nature of soil colloid surfaces, and their electrokinetic properties. These properties can fluctuate not only over long periods but also on a short- term basis, particularly in the summer, when microbial activity peaks and rapid physical, chemical, and biochemical processes occur due to changes in the soil's water and thermal regimes.

Water-soluble forms of phosphorus fertilizers, when applied to the soil, are strongly absorbed and fixed by the soil. The extent of phosphate fixation is dependent on factors such as soil type, temperature, moisture content, and the specific forms of phosphorus fertilizers used. The addition of phosphorus fertilisers significantly increases the concentration of bioavailable phosphorus in the soil, thereby improving plant phosphorus nutrition. Regular use of mineral fertilisers enhances the solubility and mobility of both gross and mobile forms of nutrients.

### 3.3 Impact of Erosion, Fertilization, and Seasonal Phosphorus Dynamics

Erosion exerts a significant influence on the phosphorus content of soils. Phosphorus losses due to erosion are generally proportional to the amount of soil lost per unit area. Erosion of fine mineral and organic-mineral particles, along with organic matter, leads to substantial phosphorus losses, as these particles contain the majority of phosphorus compounds in the soil.

Research has shown that the total phosphorus content varies less across the soil profile compared to organic matter and nitrogen. Thus, in contrast to organic matter and soil nitrogen, the difference in the content of total and mobile phosphorus due to soil erosion in the plow layer is less pronounced across the entire soil depth. The lower concentration of mobile phosphates in eroded soils helps explain the higher effectiveness of phosphate fertilisers when applied to eroded soils across different soil types and agricultural zones.

Phosphorus is one of the most limiting nutrients for plant growth, making the management of phosphorus fertilizers particularly crucial. To ensure efficient nutrient use, it is crucial to study and apply differentiated fertilisation strategies that take into account the specific availability of phosphorus in the soil. Understanding the dynamics of mobile phosphates in soil is crucial for their efficient and effective use. This is particularly important in sandy soils, such as those found in Central Fergana, where such studies have not been previously conducted.

The results of our agrochemical research on the seasonal dynamics of mobile phosphates in the sands of Central Fergana are presented in Figure 2. These findings demonstrate that, under the conditions of planned hilly-dune sands, an increase in the rate of applied phosphorus fertilizers leads to a higher concentration of mobile phosphorus in the 0-30 cm soil layer.

In spring, when cotton plants reached the 2-4 true leaf stage, the application of phosphorus fertilizers at rates of 105, 140, and 175 kg/ha increased the mobile phosphorus content in the 0-50 cm depth of sand. Specifically, the mobile phosphorus content at these application rates ranged from 1.4 to 17.5 mg/kg, depending on the fertiliser rate applied.

This trend in the dynamics of mobile phosphorus was consistently observed during the phases of budding, flowering, and at the end of the growing season across all research years, both in field and vegetative experiments. The highest levels of mobile phosphorus were recorded in treatments where mineral fertilizers were applied in combination with 40 tons per hectare of manure. However, by the end of the growing season, mobile phosphorus content decreased sharply, likely due to phosphorus uptake by plants, temperature effects, and reduced microbial activity.

The application of 40 tons per hectare of manure (Option 10), in combination with N-350, P2O5-250, and K2O-170 kg/ha of mineral fertilisers, resulted in an increase in the mobile phosphorus content in the sand compared to the treatment with only mineral fertilisers applied at the same rates (Option 8). Specifically, the mobile phosphorus content in the sand in Option 10 was 18.0 mg/kg at the start of the growing season and decreased to 16.3 mg/kg by the end of the season. In contrast, the addition of 40 tons per hectare of manure raised the mobile phosphorus levels to 21.4 mg/kg at the beginning of the growing season, which decreased to 19.5 mg/kg by the end.

The same correlation between the application of mineral and organic fertilizers and mobile phosphorus content was observed across all research years and in the vegetative experiment. These results underscore the importance of nutrient management strategies that incorporate both mineral and organic fertilisers to optimise phosphorus availability and enhance soil fertility in the sandy soils of Central Fergana.

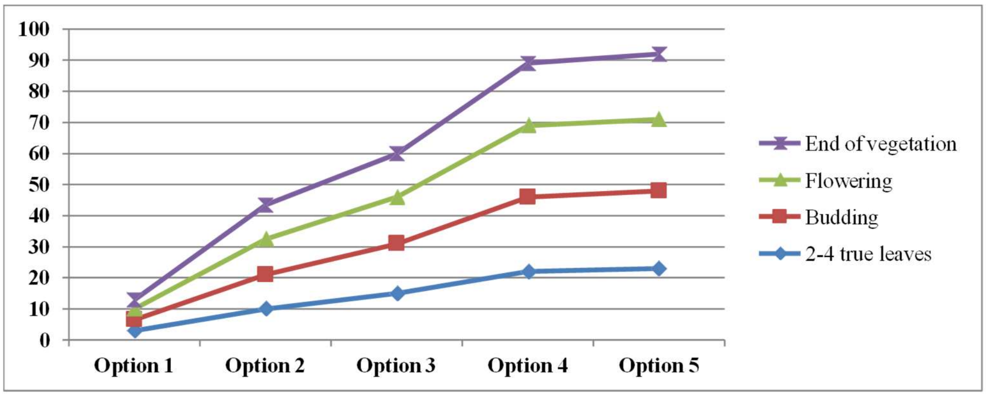


**Fig. 2.** Dynamics of mobile phosphorus in the sand depending on fertilizer rates.

### 3.4 Dynamics of Exchangeable Potassium in Sandy Soils

The study of exchangeable potassium in soil is crucial for understanding the effectiveness of potash fertilizer applications and determining the availability of potassium for plant uptake. When potash fertilizers are applied, easily mobile forms of potassium are fixed within the soil matrix. The degree of potassium fixation is influenced by several factors, including fertilizer application rates, the duration of interaction with the soil, the soil's mechanical composition, the anion associated with potassium, and the specific fertilizers used.

Environmental factors, including soil moisture content and temperature, also influence the mobility of potassium in the soil. Higher humidity and temperature tend to increase the availability of exchangeable potassium, promoting its mobility in the soil. Conversely, periodic drying of the soil can lead to the fixation of potassium, reducing its availability to plants.

The dynamics of exchangeable potassium in sandy soils, specifically in the deflated grumous barchan sands of Central Fergana, have not been extensively studied before [2]. The seasonal dynamics of exchangeable potassium in these soils are illustrated in Figure 3, providing insight into the behaviour of this critical nutrient in arid regions.

### 3.5 Impact of Fertilizer Application on Exchangeable Potassium Content

The content of exchangeable potassium in the sand is directly proportional to the rates of potash fertilizers applied. As observed in the experiments, when 75 kg/ha of $K_2O$ was applied in combination with N at 150 kg/ha and $P_2O_5$ at 105 kg/ha, the content of exchangeable potassium in the 0-30 cm soil layer was 60 mg/kg at the 2-4 true leaf stage. This decreased progressively to 55 mg/kg at budding, 50 mg/kg at flowering, and 40 mg/kg at the end of the growing season.

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In comparison, when the fertilizer application was increased to 100 kg/ha of $K_2O$, along with 200 kg/ha of nitrogen and 140 kg/ha of phosphorus, the content of exchangeable potassium was higher. At the 2-4 true leaf stage, the potassium content was 55 mg/kg, and it remained more stable across the growing season: 50 mg/kg at budding, 55 mg/kg at flowering, and 50 mg/kg at the end of the growing season.

These findings indicate a clear relationship between the amount of potash fertilizer applied and the availability of exchangeable potassium in the soil. The dynamics of potassium content are also influenced by the plant's developmental stages, with notable variations in potassium levels across different growth phases. These results are crucial for optimising potassium fertilisation practices in sandy soils, particularly in regions such as Central Fergana, where nutrient dynamics can be highly variable.

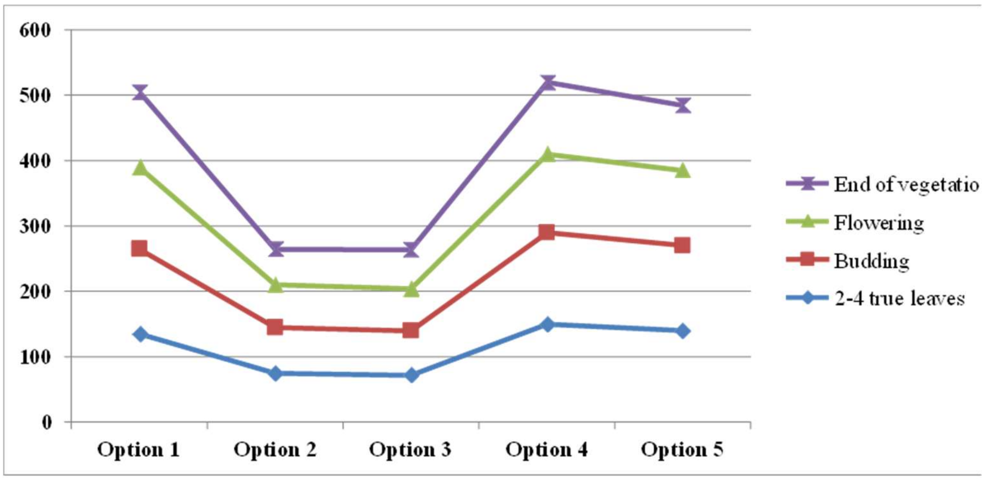


**Fig. 2.** Dynamics of exchangeable potassium in the sand depending on fertilizer rates.

It is essential to note that, with the increase in applied phosphorus and nitrogen fertiliser rates, while maintaining a constant potassium application rate, the content of exchangeable potassium in the soil at the 2-4 true leaf stage shows a slight increase. Specifically, when applying 250 kg/ha of nitrogen (N), 175 kg/ha of phosphorus ($P_2O_5$), and 125 kg/ha of potassium ($K_2O$), the content of exchangeable potassium in the sand at the 2-4 true leaf stage was observed to be 60 mg/kg. However, this value declined during subsequent plant growth stages, reaching 50 mg/kg at budding, 40 mg/kg at flowering, and 35 mg/kg at the end of the growing season.

Furthermore, the introduction of organic manure resulted in a notable increase in exchangeable potassium content throughout the growing season. The data indicate that the application of manure enhances the potassium availability in the sand, mitigating the decrease observed under solely mineral fertilizer treatments.

This trend in the dynamics of exchangeable potassium, influenced by varying fertiliser rates and the inclusion of organic amendments, was consistently observed across all years of the study, under controlled experimental conditions. These findings highlight the importance of balancing mineral and organic fertilisation strategies to optimise potassium availability in sandy soils, particularly in environments with dynamic nutrient cycles.

## 4 Conclusion

The optimal application rates of mineral fertilizers that positively influence cotton yield on the planned sandy soils with a natural shield are found to be N-200, $P_2O_5$-140, $K_2O$-100 kg/ha, in combination with 40 t/ha of manure. Under these conditions, the average cotton yield increases by 2.9–5.2 c/ha compared to the control. The application of these optimal fertiliser rates, which include both mineral fertilisers and organic amendments (such as manure), not only enhances yield but also improves the technological properties of the cotton fibre. Thus, any deviation from these optimal fertilizer norms—either an increase or a decrease—results in a detrimental effect on both cotton yield and fiber quality. This highlights the critical importance of maintaining balanced fertilisation practices to ensure both high productivity and superior fibre quality.

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