SIR Publishers
CENTER FOR INTERNATIONAL SCIENTIFIC PUBLICATIONS
JOURNAL OF AGRICULTURE AND LIFE SCIENCES
ISSN(Online): 2984-6706
Volume-9, Issue-01, Published |11-02-2026|

PHYSICAL AND MECHANICAL PROPERTIES OF SOIL IN TILLAGE AND THEIR IMPACT ON WORK EFFICIENCY AND CROP PRODUCTIVITY

Xurramov Ruziboy Jo'ra o'g'li
Lecturer of the Faculty of Mechanical Engineering and Mining, Termez State University of Engineering and Agrotechnologies, Termez, Uzbekistan

ANNOTATION

In the research, the main physical and mechanical properties of soils in the Surkhandarya region—including loess, saline and solonchak, mountain and foothill, sandy and loamy soils—were analyzed in terms of density, porosity, moisture status, compaction level, plasticity, and susceptibility to erosion.

Keywords: soil, density, porosity, fertility, productivity, physical-mechanical, saline, mountain, foothill, technology

ANNOTATSIYA.

Tadqiqotda Surxondaryo viloyatidagi bo'z, sho'r va sho'rtob, tog' va tog'oldi, qumloq va qumoq tuproqlar-ning zichligi, g'ovakligi, suv holati, siqilish darajasi, plastiklik va eroziyaga ko'rinishi kabi asosiy fizik-mexanik jihatdan tahlil qilingan.

Kalit so'zlar: tuproq, zichlik, g'ovaklik,unumdorlik, hosildorlik, fizik-mexanik, sho'r, tog', tog'oldi texnika**.**

АННОТАЦИЯ.

В исследовании были проанализированы основные физико-механические свойства почв Сурхандарьинской области, включая бозовые, солончаки и засоленные, горные и предгорные, песчаные и суглинистые почвы, такие как плотность, пористость, влажность, степень уплотнения, пластичность и подверженность эрозии.

Ключевые слова: почва, плотность, пористость, плодородие, продуктивность, физико-механические, засоленные, горная, предгорная технология.

INTRODUCTION

At present, the development and application of combined machines characterized by high productivity and operational quality, as well as energy- and resource-saving performance, play a leading role in preparing land for sowing. Considering that *approximately 1.6 billion hectares of land worldwide are cultivated annually for sowing agricultural crops* [1], the introduction of energy- and resource-efficient combined machines with high work quality and productivity for land preparation and sowing is regarded as an important task. In this regard, significant achievements have been attained in developed foreign countries such as the USA, Germany, the United Kingdom, the Russian Federation, and others. Particular attention is being paid to the development and application of combined agregates capable of performing strip tillage and sowing technological processes for land preparation [2].

Worldwide, targeted scientific research is being conducted to develop resource-saving technologies for preparing land for repeated cropping and to create new models of technical means that implement these technologies. Additionally, research efforts are focused on establishing scientific and technical foundations for improving existing machines in order to ensure their resource efficiency during operation. Within this framework, the development of a resource-saving technology for preparing fields for sowing in a single pass, the design of a combined aggregate scheme capable of ensuring high-quality execution of the technological process, and the substantiation of parameters of working bodies that provide resource efficiency during interaction with the soil are considered among the most pressing scientific challenges [1].

The southern regions of Uzbekistan are characterized by diverse natural conditions in terms of soil structure and mechanical properties. The soil characteristics of these regions are primarily determined by their geographical location, climate, relief, and hydrological conditions. A moderately continental climate, with a high number of sunny days, dry summers, low precipitation in winter, and increased rainfall during spring and autumn, is one of the key factors influencing changes in soil tillage technologies. Moreover, the abundance of sunny days leads to a rapid decrease in soil moisture, which in turn causes irrigation-related challenges—an issue that has been confirmed by scientific studies [2]. Consequently, the development and practical implementation of modern resource-saving technologies remain highly relevant. Prior to applying specialized technologies, it is essential to study soil structure, fertility, moisture content, hardness, as well as its mechanical and chemical composition, as these factors constitute the fundamental basis for assessing the effectiveness of their application.

MATERIALS AND METHODS

The region is located in the southern part of Uzbekistan and is characterized by a diverse geomorphology, including mountainous areas, foothill lowlands, and desert zones. Consequently, the region exhibits a wide variety of soil types. Based on their properties and distribution, the soils of the region can be classified into four main groups.

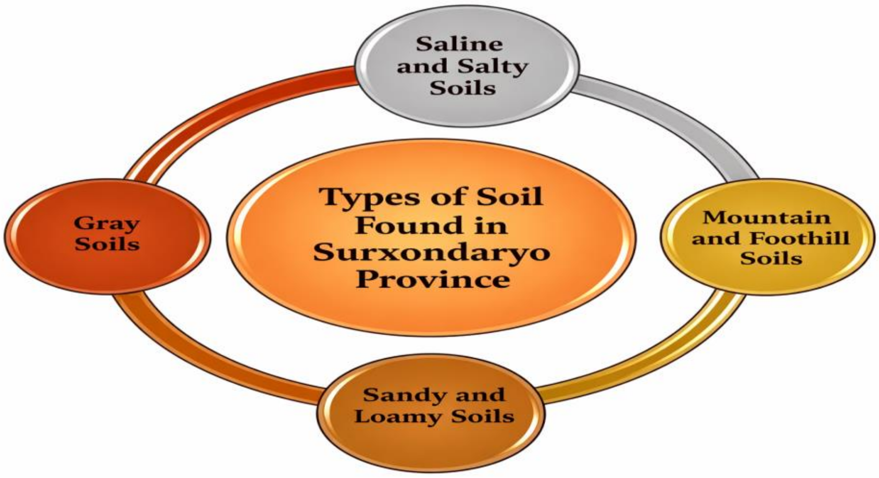

Figure 1. Distribution of soil types in the Surkhandarya region

Gray Soils: Gray soils are widely distributed in the foothill and lowland areas of the region. They are rich in mineral content and, with proper irrigation and agronomic management, can achieve high crop yields.

Saline and Solonetz Soils: These soils are found primarily in the lowland areas near the Amu Darya basin, including the districts of Muzrabot, Sherabad, Qiziriq, and Termez. Soil salinization represents a critical issue for agricultural productivity in these areas.

Mountain and Foothill Soils: Distributed across the eastern, northern, and northwestern parts of the region, these soils mainly consist of fragmented shallow parent materials. Steep mountain slopes in these areas are highly susceptible to erosion.

Sandy and Loamy-Sandy Soils: Found in desert and semi-desert zones, such as Termez, Jarqorg'on, and Angor, these soils exhibit high water permeability. However, they have low fertility due to rapid leaching of nutrients.

Due to the diversity of soil types in the region, soil structure and physico-mechanical properties vary significantly, necessitating tailored tillage and management practices for each soil type.

JOURNAL OF AGRICULTURE AND LIFE SCIENCES
ISSN(Online): 2984-6706
Volume-9, Issue-01, Published |11-02-2026|

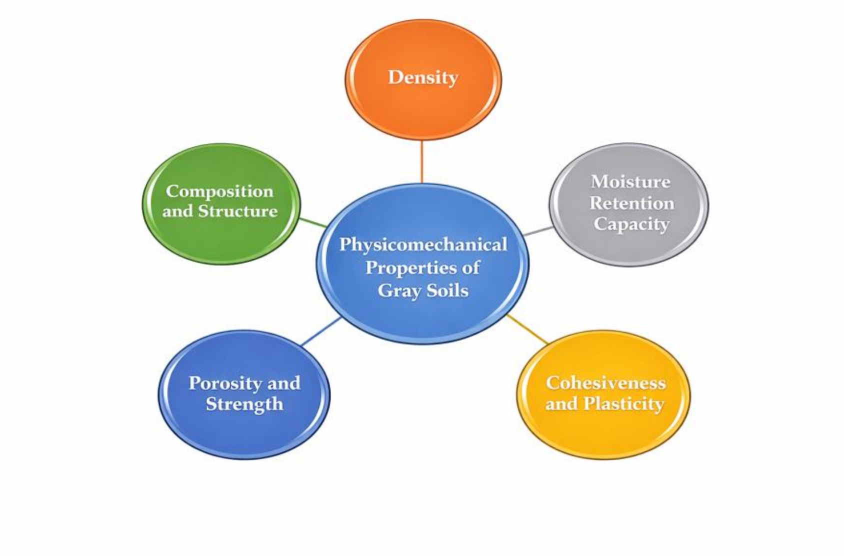

Figure 2. Physico-Mechanical Properties of Soils

Physico-Mechanical Properties of Gray Soils

Composition and Structure: Gray soils are primarily composed of a mixture of clay, sand, and gravel, often exhibiting a clay-sandy or sandy-clay texture. The clay fraction (particles smaller than 0.002 mm) ranges from approximately 20–40%, while the sand fraction (0.05–2 mm) accounts for 50–70%. In the Surkhandarya region, particularly in the foothill areas, gravel and stone fractions are more prevalent in the soil composition.

Density: The bulk density of gray soils (in a dry state) typically ranges from 1.2 to 1.5 g/cm³. High density indicates soil compaction and low water permeability. The porosity of these soils is around 40–55%, with most pores being small capillary voids, which enhance the soil's water-holding capacity, while large air-conducting pores are relatively few.

Water-Holding Capacity: Gray soils exhibit moderate water retention due to a low content of organic matter (humus 0.5–2%). The soil moisture capacity (water retention limit) is approximately 15–25%, which increases the need for irrigation. In the arid climate of Surkhandarya, these soils dry quickly, intensifying evaporation. Water permeability is low to moderate (0.1–1 mm/min), and the high clay content slows the percolation of water to deeper layers, increasing the risk of salinization.

Mechanical properties:

Hardness and Strength: Gray soils are moderately hard when dry but exhibit increased plasticity when moistened. Their mechanical strength is low, particularly in erosion-prone areas, such as mountain slopes, where the soil is easily washed away.

Figure 3. Cross-sectional View of Soil Hardness

SIR Publishers
CENTER FOR INTERNATIONAL SCIENTIFIC PUBLICATIONS
JOURNAL OF AGRICULTURE AND LIFE SCIENCES
ISSN(Online): 2984-6706
Volume-9, Issue-01, Published |11-02-2026|

Gray soils are prone to compaction, particularly when agricultural machinery is used or excessive irrigation is applied. In compacted soils, air permeability and root development are significantly reduced.

Adhesion and Plasticity: In gray soils with a high clay content, adhesion is elevated, causing the soil to become sticky when wet. The plasticity index ranges from approximately 7–15%, indicating the soil's ability to undergo deformation.

Erosion Resistance: Gray soils are generally weak against wind and water erosion due to a low content of organic matter and stable aggregates. In the Surkhandarya region, wind erosion is widespread, exacerbated by the Afghan wind and seasonal rainfall.

Physico-Mechanical Properties of Saline and Solonetz Soils

Figure 4. Condition of Saline Soil

Physical Properties:

Composition and Structure: Saline and solonetz soils generally exhibit a clay-sandy or clayey texture. The clay fraction (particles smaller than 0.002 mm) ranges from 30–50%, while the sand fraction (0.05–2 mm) accounts for approximately 40–60% (Figure 2). In saline soils, sodium salts ($NaCl$, Na_2SO_4) are abundant, leading to a dispersed soil structure. In solonetz soils, the salt content is lower than in saline soils but still affects fertility.

Density: The bulk density of these soils in a dry state ranges from 1.3 to 1.6 g/cm³. The high density of saline soils is associated with salt-induced compaction and low organic matter (humus) content. Porosity is approximately 35–50%, with small capillary pores predominating. Salt crystals bind soil particles together, reducing the number of large air-conducting pores and limiting root respiration.

Water-Holding Capacity: Saline soils have a high water retention capacity (20–30%), as clay and salts retain water. However, much of this water is bound to salts and is physiologically unavailable to plants. In solonetz soils, the proportion of plant-available water is slightly higher, but fertility remains low without irrigation [3].

Water Permeability: Water permeability is very low (0.05–0.5 mm/min), as clay and sodium salts compact the soil and impede water infiltration into deeper layers. This condition exacerbates salinization, as salts are not leached effectively [4].

Color and Structure: Saline soils are light gray, whitish, or yellowish, often with visible surface salt deposits (white patches). Solonetz soils are slightly darker (grayish-gray). The structure is typically blocky or dispersed, and aggregates are unstable due to low organic matter content.

Mechanical properties:

JOURNAL OF AGRICULTURE AND LIFE SCIENCES
ISSN(Online): 2984-6706
Volume-9, Issue-01, Published |11-02-2026|

Hardness and Strength: In a dry state, saline soils are very hard because salt crystals bind the soil particles together. When moist, they become plastic and sticky due to their clay content, which makes soil cultivation more difficult. Solonetz soils are slightly less hard but remain compacted when dry [3].

Compressibility: Saline soils are highly prone to compaction, especially under irrigation or when heavy machinery is used. Compacted soils exhibit reduced air and water permeability, negatively affecting root development [4].

Adhesion and Plasticity: Adhesion is high, particularly in wet conditions, as clay and sodium salts cause the soil to become sticky. The plasticity index is approximately 10–20%, higher in saline soils due to the abundance of sodium ions.

Erosion Resistance: Saline soils are highly susceptible to wind erosion because the dry soil surface disintegrates into fine dust particles. Resistance to water erosion is low, as salts do not stabilize soil aggregates. In the Surkhandarya region, wind erosion is a significant issue due to the Afghan wind.

Salt Content Effects: Saline soils contain 1–2% or more salts, which sharply reduce water and air permeability and lead to soil dispersion, disrupting soil structure. Solonetz soils have a lower salt content (approximately 0.3–1%) and are somewhat more suitable for agriculture. However, without proper reclamation and irrigation, their fertility remains low.

Figure 5. Mountain and Foothill Soils

Physical properties:

Composition and Structure: Mountain soils typically have a coarse texture, with gravel, stone, and sand fractions (0.05–2 mm) constituting 60–80% of the soil mass. The clay fraction (particles smaller than 0.002 mm) is approximately 10–30%, which reduces soil stickiness. Due to the weathering of parent rock (e.g., limestone, sandstone), the soil contains a substantial proportion of skeletal material (stones and gravel) [5].

Density: Soil bulk density ranges from 1.1 to 1.4 g/cm³, as the presence of organic matter and sand-gravel fractions renders the soil relatively soft. The steep slopes further reduce density due to continuous soil movement and erosion [6].

Porosity: Porosity is approximately 45–60%, with a predominance of large pores (macropores). This enhances water and air permeability but reduces water-holding capacity.

Water-Holding Capacity: Mountain soils have low water retention capacity (10–20%) due to the limited clay and organic matter content. The arid climate of Surkhandarya exacerbates this issue [6].

Water Permeability: Permeability is high (1–5 mm/min) because the sand and gravel fractions allow water to infiltrate deeper soil layers easily. This characteristic increases susceptibility to erosion, especially during heavy rainfall.

JOURNAL OF AGRICULTURE AND LIFE SCIENCES
ISSN(Online): 2984-6706
Volume-9, Issue-01, Published |11-02-2026|

Color and Structure: Mountain soils are light brown, grayish-brown, or reddish, depending on the composition of the parent rock. The structure is granular or blocky, and aggregates are unstable due to low organic matter (1–3%).

Mechanical properties:

Hardness and Strength: Dry mountain soils are moderately hard, but their mechanical strength is low due to the presence of gravel and stone fractions. The steep slopes facilitate soil movement (landscape erosion).

Compressibility: Mountain soils are not highly prone to compaction because sand and gravel fractions keep the soil loose.

Adhesion and Plasticity: Adhesion and plasticity are low, as the clay fraction is minimal. The plasticity index is approximately 5–10%, and under wet conditions, the soil rarely becomes sticky or clayey.

Erosion Resistance: Mountain soils are highly susceptible to water and wind erosion, especially on steep slopes. In Surkhandarya, seasonal rainfall and the Afghan wind increase soil washing and dust movement. Low organic matter content and sparse vegetation cover reduce overall soil stability.

Physical-Mechanical Properties of Sandy and Aeolian (Desert) Soils:

Despite relatively high total water-holding capacity, much of the retained moisture in saline soils was physiologically unavailable to plants. High plasticity and stickiness under moist conditions increased energy consumption during soil tillage and complicated the operation of combined agricultural machines.

Mountain and foothill soils showed coarse texture with a high content of gravel and stone fragments (Figure 4). These soils had high water permeability but low moisture retention capacity, making them highly susceptible to erosion processes, particularly on steep slopes.

Figure 6. Desert Soils

Physical properties:

Composition and Structure: Sandy soils contain 70–90% sand fraction (0.05–2 mm) and approximately 5–15% clay (<0.002 mm), with fine sand and minor clay particles present. Loamy-sandy soils have a similar composition, while loamy soils consist of over 90–95% sand, with very low clay and gravel content (below 5%). Both soil types are primarily composed of almost pure sand, exhibiting a light and loose structure, with minimal skeletal material (stones and gravel).

Density: Bulk density in sandy soils ranges from 1.3–1.5 g/cm³, whereas in loamy soils it ranges from 1.4–1.6 g/cm³. The high sand content maintains soil looseness and reduces density.

JOURNAL OF AGRICULTURE AND LIFE SCIENCES
ISSN(Online): 2984-6706
Volume-9, Issue-01, Published |11-02-2026|

Porosity is 40–50% in sandy soils and 35–45% in loamy soils, with macropores dominating, which enhances air and water permeability but reduces water retention capacity.

Water Retention Capacity: Water retention in sandy soils is low (10–15%) due to limited clay and organic matter content. In loamy soils, water retention is even lower (5–10%) because water drains rapidly. In the arid climate of Surxondaryo, these soils dry quickly, necessitating regular irrigation. Water permeability is very high: 5–20 mm/min for sandy soils and 20–50 mm/min for loamy soils. This characteristic prevents water retention but reduces the risk of salinization.

Mechanical properties:

Hardness and Strength: In dry conditions, sandy and loamy soils are loose and soft, with low mechanical strength. Upon wetting, strength further decreases due to minimal clay content, causing particles to remain unbound. These soils are prone to easy displacement and are susceptible to wind erosion.

Adhesion and Plasticity: Adhesion is negligible because of the minimal clay fraction. The plasticity index ranges from 0–5%, and in loamy soils it is nearly zero. Resistance to water erosion is low, as soil particles are easily washed away. The absence of vegetative cover or low organic matter content exacerbates erosion.

RESULTS AND DISCUSSION

The conducted study in the Surkhandarya region revealed significant variations in soil physico-mechanical properties across different soil types, reflecting their diverse formation conditions, parent material composition, and geomorphological position. The results provide insights into appropriate tillage strategies and resource-efficient technologies for land preparation.

Gray soils. Gray soils in foothill and lowland areas exhibited a mixture of clay, sand, and gravel, with clay content ranging from 20–40% and sand from 50–70%. The presence of gravel and stones was particularly noticeable in foothill zones. Bulk density ranged from 1.2 to 1.5 g/cm^3, with porosity around 40–55%, primarily in the form of small capillary pores. Water-holding capacity was moderate (15–25%), while water permeability was low to moderate (0.1–1 mm/min), indicating potential irrigation requirements (Figure 2).

Mechanically, gray soils were moderately hard when dry, with increased plasticity under wet conditions. The plasticity index of 7–15% suggested moderate deformability. Compaction was observed under heavy machinery or excessive irrigation, reducing aeration and root growth (Figure 3). Low organic matter and weak aggregate stability contributed to susceptibility to wind and water erosion, particularly on slopes affected by the Afghan wind. These findings suggest that gray soils require careful management, including timely irrigation, minimal compaction practices, and erosion control measures.

Saline and solonetz soils. Saline soils contained 30–50% clay and 40–60% sand, with abundant sodium salts ($NaCl$, Na_2SO_4), while solonetz soils had slightly lower salt content but still presented fertility challenges. Bulk density ranged from 1.3–1.6 g/cm^3, with porosity between 35–50%. High salt content induced soil compaction and reduced large pore availability, limiting root respiration and water infiltration (Figures 4).

Water retention in saline soils was high (20–30%), but much of it was physiologically unavailable due to salt binding. Water permeability was very low (0.05–0.5 mm/min), aggravating salinization risk. Mechanical properties indicated high hardness under dry conditions and plasticity when wet, with a plasticity index of 10–20%. Adhesion was elevated, particularly in wet soils, complicating tillage operations. Saline and solonetz soils demonstrated high susceptibility to wind and water erosion, highlighting the need for reclamation, proper irrigation, and agronomic management to improve productivity.

Mountain and Foothill Soils. Mountain and foothill soils exhibited coarse textures, with 60–80% gravel, sand, and stone fractions, and 10–30% clay, resulting in low stickiness. Bulk density ranged from 1.1–1.4 g/cm³, and porosity was relatively high (45–60%), dominated by macropores (Figure 5). Water retention was low (10–20%), while water permeability was high (1–5 mm/min), making these soils highly susceptible to erosion. Mechanically, these soils were moderately hard in dry conditions but had low strength due to the prevalence of gravel and stones. The steep terrain enhanced the likelihood of landscape erosion. Adhesion and plasticity were low, with a plasticity index of 5–10%, and soils rarely became sticky when wet. These characteristics indicate the importance of erosion control measures, such as contour tillage and vegetation cover maintenance, for sustainable land use in mountainous areas.

Sandy and Loamy-Sandy (Desert) Soils. Sandy soils contained 70–90% sand and 5–15% clay, while loamy-sandy soils had 90–95% sand with minimal clay and gravel. Bulk density ranged from 1.3–1.5 g/cm³ for sandy soils and 1.4–1.6 g/cm³ for loamy-sandy soils. Porosity was 40–50% in sandy soils and 35–45% in loamy-sandy soils, with macropores predominating (Figure 6). Water retention was low (10–15% for sandy soils, 5–10% for loamy-sandy soils), while water permeability was very high (5–50 mm/min), necessitating frequent irrigation. Mechanically, these soils were soft and loose, with low strength and minimal adhesion and plasticity (plasticity index 0–5%). They were highly prone to wind and water erosion, and the absence of organic matter or vegetation cover exacerbated this vulnerability. These findings emphasize the need for adaptive tillage strategies, regular irrigation, and soil stabilization measures in desert and semi-desert zones. The results demonstrate that soil type, composition, and mechanical properties directly influence land preparation practices and crop productivity. Gray soils require management focused on maintaining aeration and preventing compaction. Saline and solonetz soils need reclamation and careful irrigation to mitigate salt-related stress. Mountain and foothill soils demand erosion control and contour-based tillage techniques, while sandy and loamy-sandy soils require frequent irrigation and measures to prevent wind erosion.

Integrating these findings with modern resource-efficient combined machines can enhance soil preparation quality and productivity while minimizing energy and water usage. Tailoring tillage operations to the physico-mechanical characteristics of each soil type ensures sustainable land management and long-term soil fertility in Surkhandarya's diverse agroecological zones.

CONCLUSION

The selection and effective implementation of soil tillage technologies primarily depend on the physico-mechanical properties of the soil, its agroecological condition, and the natural-climatic characteristics of the region. In this study, the physico-mechanical properties of gray, saline, mountain, sandy, and loamy-sandy soils in the Surkhandarya region were analyzed, with particular attention to parameters such as bulk density, porosity, water-holding capacity, compressibility, erosion resistance, and plasticity. Analysis of the data indicated that the specific balance of clay, sand, and gravel fractions in gray soils significantly affects their water retention and permeability characteristics. High density and low air conductivity in these soils can hinder root development. To restore such soils, reclamation measures, such as leaching, gypsum application, and proper irrigation systems, are required. In particular, the presence of physiological drought significantly limits plant growth. Mountain and foothill soils, due to their high susceptibility to erosion and skeletal structure, require erosion-protective technologies during tillage. This especially calls for contour tillage on slopes, maintenance of vegetative cover, and the use of minimal tillage methods. Sandy and loamy-sandy soils are distinguished by their light structure and high water permeability. Since they cannot retain water and nutrient reserves, these areas require regular and adequate irrigation, enrichment with organic fertilizers, and soil-compaction prevention measures. The development and implementation of modern energy- and resource-efficient technologies represent an important scientific and practical direction. Designing combined machinery and applying it in accordance with environmental conditions not only meets agro-technical requirements but also preserves ecological balance. Therefore, based on the results of this study, selecting appropriate tillage methods that consider the physico-mechanical condition of the soil during land preparation contributes to increased crop productivity while maintaining long-term soil fertility.

ACKNOWLEDGEMENT

The authors sincerely acknowledge the support and guidance provided by the staff of the Surkhandarya regional agricultural research institutions during fieldwork and data collection. We are grateful to all colleagues who contributed to soil sampling, laboratory analysis, and the preparation of figures and tables. Special thanks are extended to our academic mentors for their valuable advice and critical review of the study. The authors also appreciate the access to regional soil and climatic data, which was essential for conducting comprehensive research and analysis.

REFERENCES

1. Abdullaev, S.A., & Mamatov, F.M. (2009). *Soils of Uzbekistan and their Reclamation Status*. Tashkent: Fan Publishing.
2. Kuziev, R.K., & Sektimenko, V.E. (2004). *Fundamentals of Soil Science*. Tashkent: University Publishing.
3. *Ministry of Agriculture and Water Resources of the Republic of Uzbekistan*. (2015). Irrigated Lands and Soil Resources of Uzbekistan. Tashkent.
4. Pankov, M.A. (1974). *Physical Properties of Soils and Their Importance in Agriculture*. Moscow: Kolos.
5. Tashkent State Agrarian University. (2010). *Properties of Soils of Uzbekistan and Their Efficient Use*. Tashkent.
6. FAO (Food and Agriculture Organization). (2006). *Guidelines for Soil Description*. Rome: FAO.
7. Primkulov, B.Sh., Alimova, F.A., Saidova, M.T., Allanazarov, A.A., & Khurramov, R.J. *Investigation of Operating Environments for Operating Bodies with Low Tillage*.