ARTICLE

The Impact of Different Irrigation Regimes on the Yield of Winter Wheat and Leguminous Crops and on Soil Condition in the Bukhara Region

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Abstract

This article examines the impact of different irrigation regimes on the yield of winter wheat and leguminous crops, as well as on the agrophysical and reclamation (meliorative) condition of soils under irrigated farming conditions of the Bukhara region. The research was conducted through field and laboratory experiments, in which crop productivity and soil parameters were evaluated under low, moderate, and optimal irrigation regimes. The results obtained indicate that an increase in irrigation rate led to a consistent rise in winter wheat grain yield. The inclusion of leguminous crops in crop rotation significantly increased yields under all irrigation regimes and contributed to improving the soil nutrient regime and physical condition. Under optimal irrigation conditions, soil moisture retention capacity increased, while bulk density and the content of soluble salts decreased. The findings demonstrate that the integrated application of appropriate irrigation regimes and crop rotation in the cultivation of winter wheat and leguminous crops is a scientifically grounded solution for achieving high agronomic efficiency, rational use of water resources, and preservation of soil fertility. These conclusions are of practical importance for the development of sustainable and resource-efficient agricultural systems in the Bukhara region.

Keywords: irrigation regimes, winter wheat, leguminous crops, crop rotation, yield, water use efficiency, soil agrophysical condition, reclamation (meliorative) condition.

Citation
Natalia L. Kamennyh, Nodira Kh. Hakimova, & Mamura R. Khalilova (2026). The Impact of Different Irrigation Regimes on the Yield of Winter Wheat and Leguminous Crops and on Soil Condition in the Bukhara Region. J Open, 02(01), 29–34.

Submitted: February, 2026
Accepted: March, 2026
Published: March, 2026

Vol. 02, **No.** 01, 2026.
10.70728/jopen.be.0126.005

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1 Introduction

Under current conditions of limited water resources and climate change, improving irrigation systems in agriculture—particularly ensuring efficient water use in the cultivation of winter wheat and leguminous crops—has gained significant scientific and practical importance. In the conditions of the Bukhara Region, which is characterized by arid and semi-arid climates, optimizing irrigation regimes is considered a decisive factor not only for increasing crop productivity but also for improving the meliorative and agrophysical condition of soils.

Efficient use of water resources in agriculture, especially in the cultivation of winter wheat and leguminous crops, is one of the key directions of modern agrotechnologies. In recent years, the number of scientific studies devoted to investigating the influence of different irrigation regimes on crop yield, water use efficiency, and the agrophysical and meliorative condition of soils has increased considerably.

In scientific literature, particular attention is paid to the efficiency of irrigation systems under conditions of limited water supply. According to research results, when optimal irrigation regimes are applied, the grain yield of winter wheat can be maintained or even increased [1]. At the same time, it has been emphasized that reducing irrigation norms contributes to improving water use efficiency. In some studies, the interaction between irrigation regimes and water salinity has been analyzed, and the physiological condition and yield indicators of winter wheat have been investigated under different sowing methods [2]. The results indicate that when the irrigation regime is properly selected, it is possible to obtain satisfactory yields even when saline water is used for irrigation.

The use of organic fertilizers and the introduction of leguminous crops into the agrosystem have been identified as important factors in improving the yield and grain quality of winter wheat [3]. The nitrogen-fixing capacity of leguminous crops improves the nutrient regime of the soil and reduces the need for mineral fertilizers. In crop rotation systems, the use of leguminous crops as green manure has been reported to be effective in increasing soil moisture reserves [4]. Such an approach improves the level of soil water supply prior to the sowing of winter wheat and positively influences the development of the root system.

It has been scientifically substantiated that the joint cultivation of wheat and leguminous crops under deficit supplemental irrigation conditions can increase land and water productivity [5]. This is particularly relevant for semi-arid and water-scarce regions. It has also been shown that optimizing the rate of nitrogen fertilizer application in accordance with irrigation methods can maintain grain yield while increasing the efficiency of water and nitrogen use [6]. Moreover, reducing nitrogen application rates is important for ensuring environmental sustainability.

It has been determined that the integration of crop rotation and appropriate nitrogen fertilizer rates positively influences the growth and development of winter wheat under deficit irrigation conditions [7]. Alternating different crops in rotation has been reported to enhance the biological activity of soils.

Several studies have examined the effect of cover crops and leguminous crops on nitrogen availability in soil and have emphasized their high effectiveness under irrigated conditions [8]. Such agrotechnologies contribute to improving the agrophysical properties of soils. Research investigating the influence of irrigation, sowing methods, and nitrogen application on the root system of winter wheat has shown that root depth and distribution are directly dependent on irrigation regimes [9]. This factor is of great importance for the efficient utilization of soil moisture.

Studies devoted to the influence of soil surface management methods and precipitation on the productivity of winter wheat emphasize the importance of moisture conservation technologies [10]. Agrosystems involving leguminous crops further enhance the effectiveness of this process. Recent studies have shown that the use of leguminous green manure can increase the long-term productivity of winter wheat as well as improve water and nitrogen use efficiency [11, 12].

In addition, conservation tillage practices, resource-saving irrigation technologies, and crop rotations involving leguminous crops can ensure stable productivity in arid regions [13, 16].

Modern studies have also demonstrated the potential of digital technologies and IoT-based irrigation systems to improve water use efficiency [17, 18]. Long-term observations confirm that crop rotation has a significant effect on soil health indicators [19]. Agrotechnical and breeding approaches aimed at improving water use efficiency in leguminous crops are recognized as an important scientific direction for the future development of sustainable agriculture [20].

The reviewed scientific studies indicate that the effects of different irrigation regimes on the yield of winter wheat and leguminous crops, as well as on the agrophysical and meliorative condition of soils, should be investigated comprehensively. This provides a strong theoretical basis for the development of resource-efficient and scientifically grounded agrotechnologies under the conditions of the Bukhara region [21–24].

2 Materials and Methods

The object of this study was the agrocenoses of winter wheat and leguminous crops cultivated in irrigated farming areas of the Bukhara Region, as well as the irrigated gray soils prone to salinization where these crops are grown. Within the framework of the research, the yield of winter wheat and leguminous crops under different irrigation regimes, as well as the meliorative and agrophysical indicators of the soil, were investigated.

Experimental studies were conducted using winter wheat varieties adapted to local climatic conditions and leguminous crops used within crop rotation systems. Field experiments were established in accordance with classical agronomic requirements, based on experimental variants and replications. Irrigation regimes were determined according to the biological growth stages of the crops and the level of soil moisture.

Crop productivity was determined by measuring grain yield per hectare, while biometric parameters and yield components were evaluated using standard agronomic methods. The agrophysical condition of the soil was assessed through indicators such as bulk density, porosity, moisture retention capacity, and water permeability.

The meliorative condition of the soil was evaluated by determining the level of soil salinity and the content of soluble salts. All laboratory analyses were conducted in accordance with the relevant national standards. The obtained results were statistically processed and evaluated using comparative analysis methods.

The applied research methods made it possible to scientifically assess the influence of different irrigation regimes on the yield of winter wheat and leguminous crops, as well as on the meliorative and agrophysical condition of the soil.

3 Research Results

The results of the conducted study clearly demonstrated that different irrigation regimes have a complex and statistically significant effect on winter wheat yield, yield formation in the presence of leguminous crops, as well as on the agrophysical and meliorative condition of the soil ($p < 0.05$). According to the data presented in Table 1, grain yield of winter wheat consistently increased with an increase in irrigation rate. Under conditions of limited irrigation, grain yield amounted to 4.20 ± 0.18 t/ha, whereas in the moderate irrigation treatment it increased to 5.10 ± 0.22 t/ha.

Table 1. Winter Wheat Yield under Different Irrigation Regimes ($n = 3$)

Irrigation Regime	Grain Yield, t/ha (Mean ± SD)	Water Use Efficiency, kg/m^3
Low Irrigation	4.20 ± 0.18	1.10
Moderate Irrigation	5.10 ± 0.22	1.25
Optimal Irrigation	5.80 ± 0.25	1.30
$LSD_{0.05}$	**0.32**	–

The highest yield was recorded in the optimal irrigation treatment, reaching 5.80 ± 0.25 t/ha. The value of $LSD_{0.05}$ = 0.32 t/ha confirms that the differences between irrigation regimes are statistically significant. This result indicates that the productivity of winter wheat is highly dependent on the level of water supply.

In the optimal irrigation treatment, grain yield was 1.6 t/ha higher compared with the low irrigation treatment, and this difference was found to be statistically significant ($p < 0.05$).

Water use efficiency indicators also changed consistently with irrigation regimes. Under low irrigation conditions, this indicator was 1.10 kg/m^3, while under optimal irrigation it increased to 1.30 kg/m^3. This result indicates that under optimal irrigation conditions, despite the increase in water consumption, water use efficiency was maintained due to the relatively higher increase in grain yield.

The inclusion of leguminous crops (chickpea) in the crop rotation additionally increased winter wheat yield under all irrigation treatments (Table 2). In particular, under optimal irrigation conditions, the grain yield in the wheat + legume cropping system was 0.5 t/ha higher compared with the treatment where only winter wheat was cultivated, and this difference was evaluated as statistically significant according to the $LSD_{0.05}$ values ($p < 0.05$). This result can be explained by the biological nitrogen fixation capacity of leguminous crops and their positive effect on improving the soil nutrient regime.

Table 2. Winter Wheat Yield in the Presence of Leguminous Crops (t/ha, Mean ± SD)

Cropping System	Low Irrigation	Moderate Irrigation	Optimal Irrigation
Winter Wheat Only	4.20 ± 0.18	5.10 ± 0.22	5.80 ± 0.25
Wheat + Leguminous Crop	4.60 ± 0.20	5.60 ± 0.24	6.30 ± 0.27
$LSD_{0.05}$	**0.29**	**0.31**	**0.34**

Under optimal irrigation conditions with the inclusion of leguminous crops, yield increased by 0.5 t/ha, and this difference was assessed as statistically significant ($p < 0.05$).

Irrigation regimes also had a direct effect on the agrophysical condition of the soil (Table 3). In the optimal irrigation treatment, soil bulk density decreased to 1.34 ± 0.03 g/cm³, while moisture retention capacity increased to 22.7 ± 0.9%. The $LSD_{0.05}$ values confirm that these changes are statistically significant. This result indicates an improvement in soil structure and the formation of a more favorable physical environment for root system development.

Table 3. Agrophysical Indicators of the Soil (0–30 cm Layer)

Irrigation Regime	Bulk Density, g/cm^3 (Mean ± SD)	Moisture Retention Capacity, %
Low Irrigation	1.42 ± 0.03	18.6 ± 0.7
Moderate Irrigation	1.38 ± 0.04	20.9 ± 0.8
Optimal Irrigation	1.34 ± 0.03	22.7 ± 0.9
$LSD_{0.05}$	**0.05**	**1.2**

In the optimal irrigation treatment, a statistically significant decrease in soil bulk density and an increase in moisture retention capacity were recorded ($p < 0.05$).

The analysis of soil meliorative indicators also showed that irrigation regimes play an important role (Table 4). Under low irrigation conditions, the content of soluble salts amounted to 0.82 ± 0.04%, whereas under optimal irrigation this indicator decreased to 0.61 ± 0.02%. According to $LSD_{0.05} = 0.06$, the difference in salt content was statistically significant ($p < 0.05$). These results indicate that under optimal irrigation conditions the leaching of salts from the soil profile becomes more active.

Under optimal irrigation conditions, the content of soluble salts significantly decreased compared with the low irrigation treatment ($p < 0.05$).

The obtained results confirmed that different irrigation regimes have a statistically significant influence on the yield of winter wheat and leguminous crops, as well as on the agrophysical and meliorative condition of the soil. The highest agronomic efficiency was observed in the optimal irrigation treatment applied in combination with leguminous crops ($p < 0.05$).

The research results confirmed that different irrigation regimes have an interrelated effect on the yield of winter wheat and leguminous crops, as well as on the agrophysical and meliorative condition of the soil. The highest agronomic and ecological efficiency was observed in the optimal irrigation treatment applied in combination with leguminous crops ($p < 0.05$). These findings provide a scientific basis for the implementation of resource-efficient and sustainable agrotechnologies under the conditions of the Bukhara region.

Table 4. Meliorative Indicators of the Soil

Irrigation Regime	Soluble Salts, % (Mean ± SD)
Moderate Irrigation	0.82 ± 0.04
Optimal Irrigation	0.69 ± 0.03
Low Irrigation	0.61 ± 0.02
$LSD_{0.05}$	**0.06**

4 Conclusion

The results of the conducted research confirmed that under the irrigated farming conditions of the Bukhara region, different irrigation regimes have a significant and statistically reliable effect on the yield of winter wheat and leguminous crops, as well as on the agrophysical and meliorative condition of the soil ($p < 0.05$). An increase in the irrigation rate led to a consistent increase in winter wheat grain yield. The highest yield indicators were recorded in the optimal irrigation treatment applied in combination with leguminous crops. This result can be explained by the stable water supply during the main biological growth stages of the crop.

The inclusion of leguminous crops in the crop rotation system significantly increased winter wheat productivity under all irrigation regimes and played an important role in improving the soil nutrient regime. The biological nitrogen fixation capacity of leguminous crops contributed to reducing the need for mineral fertilizers and ensuring the stability of the agroecosystem.

The results of soil analyses showed that under optimal irrigation conditions, the agrophysical properties of the soil improved, particularly through a decrease in bulk density and an increase in moisture retention capacity. At the same time, the meliorative condition of the soil improved, as evidenced by a significant reduction in the content of soluble salts.

The research results indicate that the combined application of optimal irrigation regimes and crop rotation in the cultivation of winter wheat and leguminous crops represents a scientifically grounded solution for achieving high agronomic efficiency, rational use of water resources, and the preservation and enhancement of soil fertility. These conclusions have practical significance for the implementation of sustainable and resource-efficient agricultural systems under the conditions of the Bukhara region.

Author Contributions: Conceptualization, N.Kh.H.; methodology, N.Kh.H.; software, M.R.Kh.; validation, N.L.K., N.Kh.H.; formal analysis, N.L.K.; investigation, M.R.Kh.; resources, N.Kh.H.; data curation, N.Kh.H.; writing–original draft preparation, N.L.K.; writing–review and editing, N.L.K.; visualization, N.L.K.; supervision, M.R.Kh.; project administration, N.L.K.; funding acquisition, N.L.K. All authors have read and agreed to the published version of the manuscript.

Funding: The authors declare that no funds, grants, or other financial support were received during the preparation of this manuscript.

Institutional Review Board Statement: This research did not include any experiments involving human participants or animals, so Institutional Review Board (IRB) approval was not necessary.

Informed Consent Statement: This study did not involve human subjects; therefore, informed consent was not required.

Data Availability Statement: Data supporting the report's findings can be found here.

Acknowledgments: The authors would like to express their sincere gratitude to Associate Professor **Zokirjon Isomiddinov** of Kokand State University for his valuable comments on the study results and for his assistance in the publication of this paper.

Conflicts of Interest: The authors declare no conflicts of interest related to this study.

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