RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
58 (2) 820-829, 2026
http://doi.org/10.54910/sabrao2026.58.2.32
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

WATER-SAVING IRRIGATION TECHNOLOGIES EFFICIENCY IN THE IRRIGATED LANDS WITH POTATO CULTIVATION IN KAZAKHSTAN

A.Zh. SMANOV*, K.M. YERZHANOVA, T.A. ATAKULOV, D. JUNISKHAN, and A.S. TOLEKOV

Department of Agronomy, Breeding and Biotechnology, Kazakh National Agrarian Research University, Almaty, Kazakhstan
*Corresponding author's email: sso-kz@mail.ru
Email addresses of co-authors: sso-kz@mail.ru, tastanbek.atakulov@kaznaru.edu.kz, zh.duks@gmail.com, aidos.tolekov@gmail.com

SUMMARY

This study examined the effect of water-saving irrigation technologies on potato crops, carried out at the Kazakh Research Institute of Potato and Vegetable Growing, Almaty, Kazakhstan. The maintenance of soil moisture at the field capacity of 70%–72% required 5–6 irrigations (500–670 m^3/ha) under furrow irrigation, 21–25 irrigations of 93–97 m^3/ha under drip irrigation, and 18–20 irrigations of 158–164 m^3/ha under sprinkler irrigation. The results showed sprinkler irrigation reduced water use by 10%–15%, while drip irrigation saved 37%–40% compared with the traditional furrow irrigation. Both irrigation technologies promoted intensive plant growth, robust biomass formation, and higher yields. On average, during 2022–2024, potato yields increased by 4.9–5.1 t/ha with sprinkler and drip irrigation relative to furrow irrigation. The findings revealed water-efficient irrigation systems significantly enhanced productivity and resource efficiency in potato farming. Therefore, the sprinkler and drip irrigation technologies emerged as highly recommended for use in agricultural enterprises and smallholder farms engaged in potato production across Kazakhstan.

Keywords: Potato, water-saving, sprinklers, drip irrigation, irrigated agriculture, soil moisture, furrow irrigation, crop biomass and yield

Key findings: The study confirmed that water-saving irrigation technologies (sprinkler and drip systems) considerably reduced water use and improved potato growth, yield, and profitability compared with the traditional furrow irrigation. The results underscore the need for broader implementation and continuous optimization of modern irrigation systems across the diverse irrigated regions of Kazakhstan.

Communicating Editor: Dr. Himmah Rustiami

Manuscript received: October 09, 2025; Accepted: January 19, 2025.

Citation: Smanov AZH, Yerzhanova KM, Atakulov TA, Juniskhan D, Tolekov AS (2026). Water-saving irrigation technologies efficiency in the irrigated lands with potato cultivation in Kazakhstan. *SABRAO J. Breed. Genet. 58 (2) 820-829. http://doi.org/10.54910/sabrao2026.58.2.32*.

INTRODUCTION

Kazakhstan has characteristics of substantial arid and semi-arid zones where irrigation plays a vital role in maintaining crop productivity and ensuring food security. More than 70% of the country's arable land sits in regions with insufficient precipitation, recognizing irrigation as a key factor for sustainable crop production (World Bank, 2023). However, outdated infrastructure, excessive water losses, and inefficient water distribution systems considerably reduced the efficiency of irrigated agriculture (Karatayev *et al.,* 2022). According to estimates made recently, 40%–45% of irrigation water is lost during transportation and field application, primarily due to open canals, seepage, and evaporation (Hadidi *et al.,* 2022). These important challenges necessitate modernization and adoption of water-saving technologies (WSTs) as a scientific base for land and water management.

Water-saving technologies, such as drip and sprinkler irrigation, subsurface irrigation, automated water distribution systems, and canal lining, have proven to reduce water losses and improve water-use efficiency (Wang *et al.,* 2024). Globally, the transition to WSTs has resulted in a 25%–40% reduction in irrigation water use with increased crop yields (FAO, 2021). However, adoption of these technologies remains limited in Kazakhstan, as the use of modern irrigation systems only exists in 20% of irrigated lands, while most lands still rely on traditional surface methods (Atakulov *et al.,* 2024). In Kazakhstan, the surface water resources average 95–100 km³ per year, forming only 56 km³ within the country, while the remainder comes from neighboring states. Therefore, due to limited water resources, irrigated lands account for less than 6.5% of the total arable lands in the country. These irrigated arable areas provide about 40% of crop production in value terms. Recognizing this, the Government of Kazakhstan has launched several national programs to promote WSTs, including subsidies covering up to 80% of the cost of the drip and sprinkler irrigation systems (Ministry of Agriculture of Kazakhstan, 2024).

The 'Water Resources Management Concept of Kazakhstan 2024–2030' primarily aims to expand the irrigated arable areas equipped with water-saving systems to 1.3 million hectares by 2030, reduce the canal water losses from 50% to 25%, and rehabilitate the major hydraulic infrastructure (Government of Kazakhstan, 2024). These newly adapted measures respond to multiple pressures—declining inflows from transboundary rivers, growing population and agricultural demands, and enhancing the effects of climate change on regional hydrology systems (Mukhtarova and Tussupova, 2023).

Despite these current positive policy initiatives, several barriers still hinder the widespread adoption of WSTs. Numerous irrigation systems are in poor condition, smallholders face financial and technical constraints, and local production of high-quality irrigation components is limited (Baimukhanov *et al.,* 2022). Moreover, the lack of digital water formulation and insufficient farmer training are also other constraints on the operational efficiency of existing irrigation systems (Atakulov *et al.,* 2022). Therefore, for achieving national water-efficiency objectives, Kazakhstan must combine technological modernization with coordinated institutional support, integrated policy management, and enhanced farmer training programs. The persistent shortage of water resources is largely because of the inefficient use of irrigation water, necessitating a transition toward modern and resource-saving approaches.

Recent research underscores that sustainable agriculture productivity and environmental resilience depend upon the rational use of natural resources, including the adoption of innovative water-saving technologies (Rajkovic *et al.,* 2023). In this context, a proposal emerged for an integrated framework for irrigated agriculture as a conceptual model aimed at improving water-use efficiency and productivity in staple food crops. Particular emphasis centered on water-saving irrigation technologies applied to crops, such as potatoes, which are strategically important for food security in Central Asia. The implementation of water-saving irrigation systems has a projection of reducing water consumption by approximately 25%–30%, enabling the expansion of irrigated lands to up to 2.5 million hectares by 2030, while simultaneously enhancing agricultural sustainability and crop productivity (Akhmetova *et al.*, 2015, 2018).

In this context, water-saving technologies represent a cornerstone for the sustainable and efficient use of irrigated lands in Kazakhstan. Their potential benefits for mitigating water scarcity and enhancing crop productivity have reached wide recognition. However, systematic assessments of the current level of WST adoption, their field-scale efficiency, and the institutional and technical barriers limiting their widespread implementation in Kazakhstan remain limited. The WSTs offer a pathway to mitigate water scarcity, enhance crop productivity, and ensure the long-term resilience of agroecosystems under changing climatic and socio-economic conditions. Therefore, the presented study sought to analyze the current state of WST adoption in Kazakhstan, evaluate their efficiency under practical farming conditions, identify key barriers to implementation, and provide evidence-based recommendations for improving the sustainable management of irrigated arable lands.

MATERIALS AND METHODS

In Southern and Southeastern Kazakhstan, various climatic factors affected the development of irrigated agriculture. In this territory, the moisture availability is largely dependent on the natural precipitation, which, unfortunately, mostly has an extremely uneven distribution. Thus, in the plains (desert and semi-desert zones), the annual precipitation varies from 160 to 200 mm, while in the foothill and mountain zones, it ranges from 400 to 500 mm. For assessing the moisture availability of the territory, applying a moisture coefficient proceeded, expressed as a functional relationship.

$$К_у = \frac{\Sigma \text{Po} + Wn}{\Sigma \text{E}}$$

Whereas Ky = moisture coefficient of the warm period, ΣPo = total atmospheric precipitation during the period from April to September (mm), Wn = productive soil moisture reserves at the beginning of April (mm), and ΣE = sum of monthly evaporation values for the period from April to September.

The said research studies comprising the adaptation and improvement of water-saving technologies commenced on the potato crop at the Kazakh Research Institute of Potato and Vegetable Growing, Almaty, Kazakhstan. The objects of the presented study were the potato cultivar Aksor, drip, sprinkler, and furrow irrigation technologies, and foothill dark chestnut soils of Southeastern Kazakhstan. The said research institute sits on the northern slope of the Ile Alatau at an altitude of 1000–1050 m above sea level. The climate is sharply continental, with an average July temperature of 22 °C–24 °C.

The field experiments and laboratory studies proceeded using the following generally accepted classical methods: a) methodology of Experimental Work in Vegetable and Melon Growing (Belik, 1992), b) methodology of Field Experimentation (Dospekhov, 1985), and methodology of Agrochemical Research (Yudin, 1981). The vegetative irrigation rates, when determined, depended on the soil moisture deficit between the upper limit of soil moisture (field capacity) and the pre-irrigation moisture level (Kostyukov, 1988).

In evaluating the effectiveness of water-saving irrigation technologies (WSTs) on potato production, conducting a field experiment used a randomized complete block design with three replications. The total experimental area was 1.5 ha, and each accounting plot measured 84 m² (4.2 m × 20 m). The potato cultivar Aksor succeeded in its planting with a row spacing of 70 cm and an in-row plant spacing of 30 cm, resulting in a planting density of 47,600 plants per hectare. Throughout the growing season, soil moisture under different irrigation treatments underwent maintenance at 70%–72% of field capacity.

Figure 1. Potato crop under a) Furrow irrigation (control), b) Drip irrigation, and c) Fine-dispersed sprinkler irrigation.

Mineral fertilizer applications were uniform across all treatments at N120, P120, and K120 kg ha^{-1} of active ingredient (Figure 1). Data obtained from the experiment incurred analysis of variance (ANOVA), with treatment means compared at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

The pertinent research aimed to study the irrigation regimes of potatoes based on the recorded data and determine the effectiveness of water-saving technologies. In the experimental plots, the systematic measurements of soil moisture under different variants made it possible to establish the timing and irrigation rates for the potato crop. During the potato-growing season, the study carried out different numbers of irrigations, associated with the duration of the growing period and the water requirement of the potato crop. Under the furrow irrigation system ("irrigation depth," m^3/ha per event), five to six irrigations took place during the growing season, with irrigation rates of 500–670 m^3/ha, while the total irrigation norm amounted to 3250–3620 m^3/ha (Figure 1, Table 1).

The dynamics of irrigation water consumption by the potato crop over three consecutive growing seasons (2022–2024) under different irrigation systems—traditional furrow irrigation, sprinkler irrigation, and drip

Table 1. Irrigation water consumption during the growing season based on the potato irrigation systems (m³/ha).

Irrigation methods		Annual indicators		
		2022	2023	2024
1. Furrow irrigation (traditional irrigation, control)		3450	3250	3620
2. Sprinkler irrigation (fine-dispersed sprinkling)		3150	2916	3098
3. Drip irrigation using tape technology		2340	2044	2190
Irrigation water savings under sprinkler	m^3/ha	300	334	522
Irrigation during the season	%	10	11	15
Irrigation water savings under drip	m^3/ha	1110	1206	1430
Irrigation during the season	%	33	37	40

irrigation using tape technology—are available in Table 1. The data clearly revealed the progressive efficiency gains achieved through the application of water-saving technologies compared with the traditional surface method. In previous studies, drip irrigation with foliar mineral fertilizer reduced total water use by about 30%–35% in maize crops, consistent with our observed savings under drip vs. furrow irrigation. Their findings also enunciated that soil cultivation methods coupled with efficient irrigation can improve soil water reserves under Southeastern Kazakhstan's conditions, aligning with the latest results that drip and sprinkler technologies maintain higher moisture with fewer losses (Kudaibergenova *et al.,* 2023).

Under the drip irrigation system, 21–25 irrigations continued during the potato-growing season, with irrigation rates of 93–97 m³/ha, while the total irrigation magnitude ranged from 2044 to 2340 m³/ha. Compared with the traditional furrow irrigation, the drip technology system allowed savings of 1110–1430 m³/ha of irrigation water, which corresponds to 33%–40%. With sprinkler irrigation, 18–20 irrigations proceeded during the potato-growing season, with irrigation rates of 158–164 m³/ha, while the total irrigation amount ranged from 2916 to 3150 m³/ha. In sprinkler irrigation, water savings amounted to 300–522 m³/ha, which corresponds to 10%–15% (Table 1). Furrow irrigation, used as the control, which exhibited the highest seasonal water consumption, ranged from 3250 m³/ha (2023) to 3620 m³/ha (2024). These irrigation values reflect the typical water use level for potato crops in southern and southeastern irrigated zones of Kazakhstan, where surface irrigation dominates and substantial water losses are robust due to infiltration, percolation, and evaporation (Sotnikov *et al.,* 2024).

In previous studies, similar magnitudes of water savings (≈30%–40%) were notable under drip vs. surface irrigation in potatoes and other vegetable crops in South-East Kazakhstan, validating the present study results (Aitbaeva and Buribaeva, 2012, 2013). Similarly, the arid regions demonstrated that sprinkler systems can reduce evaporation and runoff losses, producing 10%–20% water savings, which corresponds well with the presented results based on sprinkler irrigation (Wang *et al.,* 2024). These findings confirm that the adoption of sprinkler and drip irrigation systems constitutes a practical and effective pathway for water conservation and the rational use of irrigated lands in Kazakhstan. In particular, the application of water-saving irrigation technologies resulted in a reduction of irrigation water use by approximately 25%–30%, while simultaneously increasing potato yield by 15%–20% compared with conventional irrigation practices. Such water-saving technologies, when supported by appropriate policy incentives and farmer training programs, can considerably contribute to achieving the country's strategic goal of expanding irrigated areas while reducing total water consumption (Government of Kazakhstan, 2024).

The biometric studies demonstrated that water-saving irrigation technologies had a significant impact on the potato plant's biomass formation. Drip and sprinkler irrigation systems promoted the development of more robust potato plants, positively influencing their growth and development compared with furrow irrigation. At the stage of intensive tuber formation, the average plant height under furrow irrigation was 60.2 cm, whereas drip and sprinkler irrigation resulted in greater plant heights of 61.4 cm and 61.8 cm, respectively (Table 2). This enhanced vegetative growth showed an association with improved resource utilization, leading to a 15%–20% increase in potato yield and a 25%–30% improvement in water-use efficiency compared with the traditional furrow irrigation system. Overall, multi-year results confirmed the higher agronomic and water-use efficiency of water-saving irrigation technologies relative to conventional irrigation practices.

Thus, the average potato yield under furrow irrigation was low (22.4 t/ha) compared with drip irrigation (27.5 t/ha) and under a fine-dispersed sprinkling system (27.3 t/ha) (Table 3). Under the traditional furrow irrigation system (control), the average main stem height was 60.2 cm, with 6.0 stems and 14.9 leaves per plant. Both sprinkler and drip irrigation systems slightly increased the plant height to 61.8 and 61.4 cm, respectively. Although the differences in stem height appear modest (around 2%–3%), however, they reflect improved plant hydration and nutrient uptake due to more uniform soil moisture distribution. According to Doszhanova *et al*. (2025), the improved soil water-physical properties under efficient irrigation and soil management led to increased vegetative biomass in Southeastern Kazakhstan. The increased leaf area and stem number under drip and sprinkler systems in irrigated agriculture also align with the leaf and stem count improvements in this latest study (Murtazin *et al.,* 2025).

In potatoes, the number of stems and leaves per plant displayed a significant increase under modern and water-saving irrigation methods. Potato plants under sprinkler irrigation had 6.6 stems and 15.6 leaves, while those under drip irrigation had 6.2 stems and 15.1 leaves. These parameters revealed enhanced vegetative vigor and photosynthetic capacity, which are critical determinants of the tuber yield. Leaf length and total leaf area per plant serve as important indicators of photosynthetic potential. Compared with furrow irrigation, in potato plants leaf length increased from 22.8 to 23.7 cm under drip irrigation and 24.4 cm under sprinkler irrigation. Similarly, the total leaf area per plant rose from 728.3 cm² (in the control) to 742.2 and 747.3 cm² under drip and sprinkler irrigation systems, respectively.

These gains (approximately 2%–3%) may be due to the better water availability and reduced physiological stress, promoting larger and more active assimilative surfaces in potato crops. However, the most pronounced effect of the different irrigation systems was evident in the number and weight of tubers per plant. Traditional furrow irrigation produced an average of 6.3 tubers per plant, with a total weight of 350.8 g. However, the number of tubers and tuber weight significantly increased in both drip (8.7 tubers and 409.4 g) and sprinkler (8.8 and 408.2 g) irrigation systems, respectively. With better moisture stability, such improvement in vegetative traits and yield was also in previous studies' reports stating increased leaf area and greater tuber yield under efficient irrigation systems (Aitbaev *et al.,* 2011; Aitkulov *et al.,* 2023).

The results further detailed that adopting water-saving irrigation systems not only conserves water (Table 1) but also enhances the biomass formation and tuber yield potential in potatoes (Figure 2). Improved vegetative growth leads to a larger assimilative surface, which supports greater biomass accumulation and higher tuber initiation rates per plant. Overall, both drip and sprinkler irrigation systems significantly improved the potato plant growth and yield-related traits relative to the furrow irrigation (control). This confirms that optimizing soil-plant water relations during the tuber formation stage is critical for achieving higher potato productivity under Kazakhstan's arid and semi-arid conditions.

The economic efficiency being an important indicator entailed calculations for this latest research work. Comparative analysis of the economic efficiency of the studied

Table 2. Potato morphological and yield-related traits under different irrigation systems (average of 2022–2024).

Irrigation methods	Main stem height (cm)	Number of stems	Number of leaves	Leaf length (cm)	Leaf area plant^{-1} (cm^2)	Tubers plant^{-1}	Tuber weight plant^{-1} (g)
Furrow irrigation (control)	60.2	6.0	14.9	22.8	728.3	6.3	350.8
Drip irrigation	61.4	6.2	15.1	23.7	742.2	8.7	409.4
Sprinkler irrigation	61.8	6.6	15.6	24.4	747.3	8.8	408.2

Table 3. Economic efficiency of potato cultivation under different irrigation systems (average of 2022–2024).

No.	Irrigation methods	Yield (t/ha)	Costs ha^{-1} (USD)	Whole sale selling price ha^{-1}	Obtained produce value ha^{-1} (USD)	Net income ha^{-1} (USD)	Profitability (%)
1	Furrow irrigation (control)	22.4	937	40 000	1886	929	99
2	Sprinkler irrigation	27.3	1083	40 000	2299	1192	110
3	Drip irrigation	27.5	1052	40 000	2316	1240	117

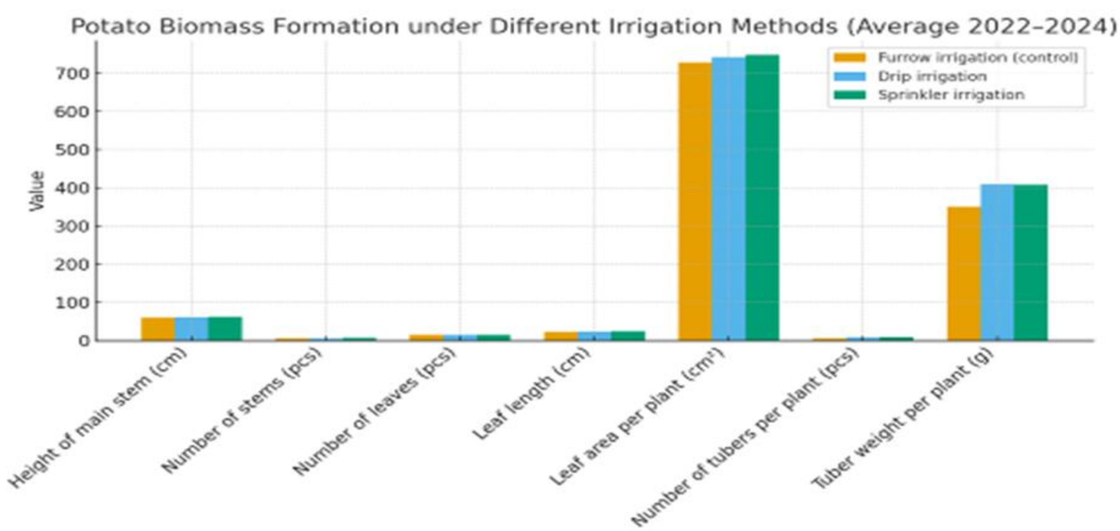

Figure 2. Potato growth traits and biomass under different irrigation systems (average of 2022–2024).

irrigation methods showed water-saving technologies ensured the highest efficiency (Figure 3). The maximum economic efficiency was noteworthy by using the drip irrigation technology (Table 3). The drip irrigation yielded the topmost net income (USD 1,108/ha), whereas under the furrow irrigation treatment, it amounted to USD 829/ha. The transition from traditional furrow irrigation to modern pressurized systems significantly

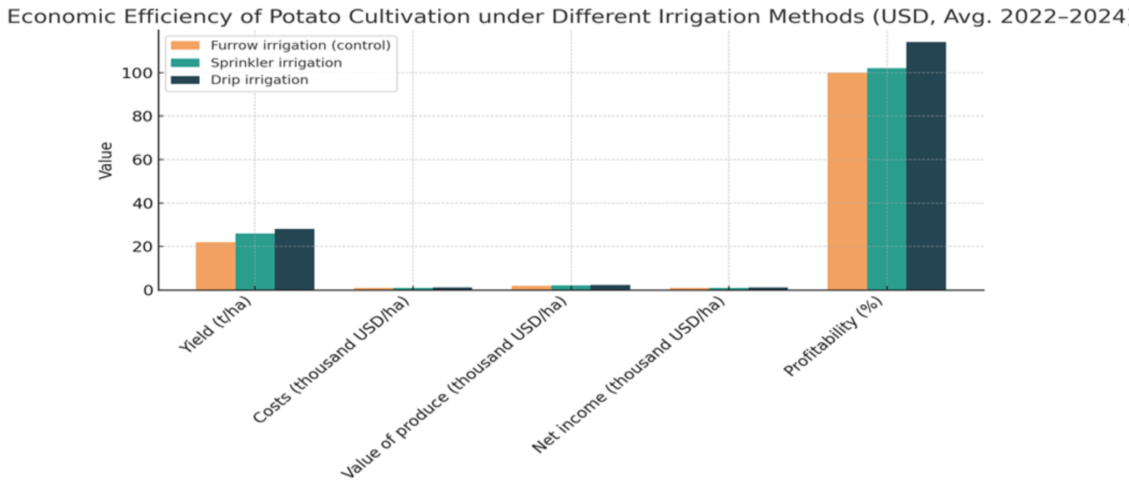

Figure 3. Economic efficiency of potato cultivation under different irrigation systems (average of 2022–2024).

increased the potato yield. Average yield rose from 22.4 t/ha under furrow irrigation to 27.3 t/ha under sprinkler irrigation and 27.5 t/ha under drip irrigation, representing yield enhancements of 21.9% and 22.8%, respectively. These results were consistent with the physiological data discussed in Table 2 and Figure 2, which demonstrated enhanced biomass formation, greater leaf area, and increased tuber weight under improved irrigation systems. Earlier research work by Anderson *et al*. (2013) showed that gains in net income accompany drip irrigation in maize under South Kazakhstan conditions, reinforcing our economic findings. Likewise, FAO reports of cost-benefit trade-offs in water-saving irrigations suggested that, though input costs rise, water, labor, and energy savings often produce net profitability similar to what emerged in the presented studies (FAO, 2021).

The three-year (2022–2024) study results vividly revealed the adoption of modern water-saving irrigation technologies (sprinkler and drip irrigation systems) significantly improves water-use efficiency, biological productivity, and the economic performance of potato cultivation under climatic conditions of Kazakhstan's irrigated zones (Kurishbaev *et al.,* 2025). At the regional level, the degradation of arable lands, overuse of water, and decline in soil moisture were the documented challenges in Central Asia and Kazakhstan, in particular (Seilkhan *et al.,* 2016). The promising research work, by demonstrating how improved irrigation regimes conserve water and enhance the potato plant's biomass, contributes evidence toward reversing degradation trends. Recovery of plant health and soil moisture is also vital for conserving medicinal and endemic species, and some studies reported assessing recovery of medicinal plants in the Kurti district, showing restoration efforts were possible where field conditions improve (Seilkhan *et al.,* 2018).

Furthermore, for rare and endemic species, anthropogenic stress (including irrigation practices) has been evident to affect the physiological features. Ydyrys *et al*. (2020a) studied such effects in Ile Alatau, and the finding declines under poor moisture/land management, which underscores the importance of maintaining soil and water quality even in cropping systems. Past studies also highlighted that geo-botanical assessments provide crucial baseline data for sustainable agriculture, and like the present results, these can help design irrigation systems that preserve biodiversity while increasing crop yields (Ydyrys *et al.,* 2020b, 2021). From a policy and practical perspective, the present economic analysis validates that even if operational costs for sprinkler and especially drip systems are non-trivial, returns occur from gains in yield, water savings, and improved profitability. These insights support institutional efforts, including those in the Government Program (2024), FAO recommendations (2021), and local case studies (Aitkulov *et al*., 2023).

The results indicated a significant correlation between the irrigation uniformity, physiological growth, and economic outcomes. The introduction of water-saving irrigation systems simultaneously reduced water consumption, increased yield potential, and enhanced farm income, thereby contributing to the sustainable intensification of irrigated agriculture in Kazakhstan (Smanov *et al.,* 2025). The study outcomes substantiate the national policy direction emphasizing the modernization of irrigation systems and the expansion of water-saving technologies under the Water Resources Management Concept of Kazakhstan 2024–2030. Widespread implementation of sprinkler and drip irrigation systems can reduce the pressure on limited water resources, improve agricultural productivity, and support long-term water and food security goals.

CONCLUSIONS

The integration of sprinkler and drip irrigation technologies provides a scientifically based and practically effective framework for improving water-use efficiency in irrigated agriculture. These advanced technologies significantly reduced water consumption and increased potato crop yields and profitability. Their implementation enhances environmental sustainability and supports the national strategies for water resource conservation. Thus, the sprinkler and drip irrigation systems emerged as the key tools for sustainable development of Kazakhstan's irrigated lands and for strengthening water and food security in arid and semi-arid regions.

REFERENCES

Aitbaev TE, Asanbekov AA, Aitbaeva AT (2011). Application of drip irrigation technology for potato cultivation in South-East Kazakhstan. *Recommendations*. Almaty, pp. 50.

Aitbaeva A, Buribaeva L (2013). Drip irrigation of potato and vegetable crops in the South-East of Kazakhstan. *World Appl. Sci. J.* 22(4): 512–517. doi:10.5829/idosi.wasj.2013.22.04.10138.

Aitbaeva AT, Buribaeva LA (2012). Efficiency of potato irrigation using fine-dispersed sprinkling in South-East Kazakhstan. *Bull. Agric. Sci. Kazakhstan* 5: 23–26.

Aitkulov B, Zhumabayev D, Sadykova L (2023). Assessment of water efficiency in irrigated agriculture of Southern Kazakhstan. *J. Arid Land Stud.* 45(2): 112–123. doi:10.1007/s40333-023-00512-8.

Akhmetova A, Mukhitdinov N, Ydyrys A (2015). Anatomical indicators of the leaf structure of *Ferula iliensis* growing in the Eastern part of Zailiyskiy Alatau (Big Boguty Mountains). *Pak. J. Bot.* 47(2): 511–515.

Akhmetova AB, Mukhitdinov NM, Ydyrys A, Ametov AA, Inelova ZA, Öztürk M (2018). Studies on the root anatomy of rubber producing endemic of Kazakhstan, *Taraxacum kok-saghyz* LE Rodin. *J. Anim. Plant Sci.* 28(5): 1400–1404.

Anderson K, Rausser G, Swinnen J (2013). Political economy of public policies: Insights from distortions to agricultural and food markets. *J. Econ. Lit.* 51(2): 423–477. doi: 10.1257/jel.51.2.423.

Atakulov T, Kaldybayev S, Yerzhanova K, Zholamanov K, Smanov A, Seytzhan A (2024). Evaluating the potential for multicropping in SE Kazakhstan: Double-cropping corn after winter triticale and winter oilseed rape. *SABRAO J. Breed. Genet.* 56(2): 673–680. doi:10.54910/sabrao2024.56.2.38.

Atakulov TA, Yerzhanova KM, Zholamanov KK, Smanov AZh (2022). Intensive use of irrigated lands in South-East Kazakhstan. *Bull. Korkyt Ata Kyzylorda Univ.* 3(62): 226–235.

Baimukhanov S, Yessenov A, Omarova G (2022). Barriers to the implementation of water-saving technologies in Kazakhstan's agricultural sector. *Cent. Asian Water J.* 8(1): 55–68. doi: 10.54688/cawj.2022.8.1.55.

Belik VF (1992). Methodology of Experimental Work in Vegetable and Melon Growing. Moscow: Agropromizdat.

Dospekhov BA (1985). Methodology of Field Experiments. Moscow: Agropromizdat.

Doszhanova A, Ospanbayev Z, Sembayeva A, Bekbauov M, Kazkeyev D, Myrzabek K, Duisenbekova O (2025). Effectiveness of biochar on degraded irrigated soils in

Southeast Kazakhstan. *SABRAO J. Breed. Genet.* 57(2): [in press].

FAO (2021). Irrigation and Water Management Report: Sustainable Water Use in Arid Regions. Rome: Food and Agriculture Organization of the United Nations.

Government of Kazakhstan (2024). Water Resources Management Concept of Kazakhstan 2024–2030. Astana: Ministry of Water Resources and Irrigation.

Hadidi A, Saba D, Sahli Y (2022). Smart irrigation system for smart agriculture using IoT: Concepts, architecture, and applications. The Digital Agricultural Revolution: Innovations and Challenges in Agriculture through Technology Disruptions, pp. 171–198.

Karatayev M, Clarke M, Satybaldin A (2022). Water-energy nexus and irrigation modernization in Central Asia. *Environ. Sustain. Rev.* 14(3): 211–224. doi: 10.1016/j.envsusrev.2022.03.012.

Kostyukov NA (1988). Approximate calculation of the critical parameters of shock-wave reflection in condensed media. *Combust. Explos. Shock Waves* 24(1): 65–68.

Kudaibergenova I, Kalashnikov A, Balgabaev N, Zharkov V, Angold E (2023). Effect of drip irrigation with foliar dressing of mineral fertilizer Kristalon and their impact on maize grain yield in Southern Kazakhstan. *SABRAO J. Breed. Genet.* 55(5): 1855–1864. http://doi.org/10.54910/sabrao2023.55.5.36.

Kurishbaev AK, Atakulov TA, Ryabtsev AD (2025). Problems and prospects for the development of irrigated agriculture in Kazakhstan. *J. Res. Results* 1: 1–12.

Ministry of Agriculture of Kazakhstan (2024). National Program for the Introduction of Water-Saving Irrigation Technologies. Astana: Official Press Release, May 2024.

Mukhtarova K, Tussupova K (2023). Climate change impacts on irrigation water resources in Kazakhstan. *Environ. Sci. Policy* 156: 78–88. doi: 10.1016/j.envsci.2023.02.006.

Murtazin Y, Kulagin V, Mirlas V, Anker Y, Rakhimov T, Onglassynov Z, Rakhimova V (2025). Integrated assessment of groundwater quality for water-saving irrigation technology (Western Kazakhstan). *Water* 17(8): 1232. https://doi.org/10.3390/w17081232.

Rajkovic J, Novakovic R, Grujic-Milanovic J, Ydyrys A, Ablaikhanova N, Calina D, Sharifi-Rad J, Al-Omari B (2023). An updated pharmacological insight into calotropin as a potential therapeutic agent in cancer. *Front. Pharmacol.* 14, 1160616. doi.org/10.3389/fphar.2023.1160616.

Seilkhan A, Mirzadinov IR, Mirzadinov MA, Kizdarbekova M (2016). Degradation of lands in Central Asia. Int. Multidiscip. Sci. GeoConf. Surveying Geol. Mining Ecol. Manag.

Seilkhan A, Mirzadinov R, Akso A, Abulgaziyev A, Kanat G (2018). Assessment of recovery of medicinal plants of the Kurti District of the Almaty Region, Kazakhstan. *Ecol. Environ. Conserv.* 24(4): 1653–1658.

Smanov AZh, Atakulov AT, Yerzhanova KM (2025). Efficient Use of Irrigated Lands in South-East Kazakhstan Based on Water-Saving Innovative Technologies. Monograph. Almaty: Kaz Agro Press.

Sotnikov E, Inelova Z, Miroshnichenko O, Trushel L, Umbetaliyev D, Shakibayev I (2024). Numerical models for solving water problems of irrigated agriculture in South-East Kazakhstan. *ES Food Agrofor.* 18: 1288.

Wang L, Zhao Q, Liu J (2024). Advances in water-saving irrigation technologies for sustainable agriculture. *Agric. Water Manag.* 298: 108755. doi: 10.1016/j.agwat.2024.108755.

World Bank (2023). Kazakhstan: Water Security Diagnostic. Washington, DC: World Bank Publ.

Ydyrys A, Abdolla N, Seilkhan A, Masimzhan M, Karasholakova L (2020a). Importance of the geobotanical studying in agriculture (with the example of the Sugaty Region). In: *E3S Web Conf. EDP Sciences* 222: 4003. https://doi.org/10.1051/e3sconf/202022204003.

Ydyrys A, Serbayeva A, Dossymbetova S, Akhmetova A, Zhuystay A (2020b). The effect of anthropogenic factors on rare, endemic plant species in the Ile Alatau. In: *E3S Web Conf. EDP Sciences* 222: 5021. https://doi.org/10.1051/e3sconf/202022205021.

Ydyrys A, Zhaparkulova N, Aralbaeva A, Mamataeva A, Seilkhan A, Syraiyl S, Murzakhmetova M (2021). Systematic analysis of combined antioxidant and membrane-stabilizing properties of several Lamiaceae family Kazakhstani plants for potential production of tea beverages. *Plants* 10(4): 666. https://doi.org/10.3390/plants10040666.

Yudin FA (1981). Methodology of Agrochemical Research. Moscow: Kolos, pp. 251.