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Influence of low-pressure drip irrigation of agricultural crops on agromeliorative indicators of soils in the conditions of the Kazakhstan part of the Aral Sea Region

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ABSTRACT

This paper presents the results of the experimental study on the use of low-pressure drip system for irrigation of sorghum and rice crops. The experimental studies have been conducted on moderately clayey soil. In the case of shortage of irrigation water, the use of low-pressure drip system for irrigation of agricultural crops has been considered. Grain growing such as sorghum and rice using the drip irrigation method has shown that in the Aral Sea Region, where the air temperature is very high and very dry, its environmental conditions are unfavorable, keeping the air humidity in the ground layer within acceptable limits for plants, provides flexible regulation of the water reserve in the root layer of soil. These crops are good phytomeliorants and a reliable means of controlling salinization of irrigated lands.

Key words: Drip irrigation, Dripper, Experiment, Regime, Water, Water consumption, Rate, Agronomic amelioration, Sweet Sorghum.

INTRODUCTION

It is common knowledge that hydromelioration affects the water regime of soils, changing the components of the water balance of the territory. Irrigation is a method of artificial redistribution of surface and ground water runoff and atmospheric precipitation using various technological methods and hydraulic structures in order to regulate water, air, thermal, food, salt, microbiological regimes of soils and microclimate to increase water availability and productivity of cenoses, preserve and increase soil fertility with observance of environmental protection. Water deficiency in the southern regions of Kazakhstan determines the need to construct water storage reservoirs that hold back floods in order to use rationally river runoff. Naturally, they have both positive and negative impacts on the environment (Mustafayev *et al.* 2025).

As early as 10,000 BC, people used water runoff at different stages of its formation for irrigation of lands. Initially, water runoff was used to increase the productivity of cenoses, then agrocenoses, natural lemons that formed in closed depressions of river floodplains and flooding by storm and flood waters (Angelakis *et al.* 2020; Ahmed *et al.* 2020).

Since the second half of the last century, pump water intakes from rivers and water storage reservoirs have been used for irrigation of lands, which are supplied to watersheds through pressure pipelines and used for irrigation.

New types of irrigation are being developed, such as subsoil, sprinkling and drip irrigation, operating in pressure mode.

MATERIALS AND METHODS

Modern irrigation is an artificial redistribution of runoff and its return to the spillway areas to the places of its initial formation. These waters differ sharply in quality, structure and properties from atmospheric (rains) precipitation and contain increased amounts of salts, organics, suspended materials, which are very toxic, radioactive and contaminated with pathogenic microflora. Such waters, when coming into contact with the soil, have a negative impact on it, that is, deep filtration begins and the runoff of waste water is formed, which is discharged through canals into water bodies and watercourses. Entering water bodies and watercourses, they sharply worsen the quality of water, disrupt the natural quantitative and qualitative relations of the ecosystem, and destroy flora and fauna. The negative impact of such waters on soil and nature is not the same for different methods of irrigation and watering, but it is always present. It is theoretically and practically impossible to eliminate these negative impacts of irrigation under the existing scientific justification.

Evaporation of moisture from the soil surface occurs under variable geological and climatic conditions, being exposed to a large number of natural factors. Due to periodic atmospheric precipitation, moisture accumulates in the soil layer of landscape systems and under the influence of the energy resources of the sun, moisture evaporates from the soil surface. The ratio of annual precipitation to evaporation from the soil surface shows the natural water availability of the soil system and its qualitative value is determined according to the formula of N.N. Ivanov (Ahmad *et al.* 2024):

$$Ky= Qc/ Eo \qquad (1)$$

where: Qc is the annual value of precipitation (mm); Eo is the annual evaporation from the soil surface (mm), which is determined by the formula of N.N. Ivanov: $Eo = 0.0018 \times (t+25)2 \times (100-a)2$, where: t- average monthly air temperature (°C); a- average monthly relative air humidity (%).

Based on the use of the natural humidity factor and meteorological data, for their calculation, it is possible to estimate the natural water availability of specific irrigation zone systems, that is, if the monthly precipitation does not coincide with the monthly evaporation rate, then there is a need for irrigation reclamation.

Academician A.N. Kostyakov, the founder of reclamation science, indicating the factors that should be influenced, as well as noting the tasks of increasing soil fertility, gave a classical definition of the essence of irrigation – "irrigation reclamation has the task of ensuring and regulating the necessary water and associated thermal and nutrient regimes in certain agricultural areas of soil fertility, and obtaining high and sustainable crop yields" (Nathanail & Bardos 2005).

According to the definition of M. Gol, professor of the University of Prague, "irrigation is nothing more than a technical measure by which a person, while obtaining food for themselves and taking care of environmental protection, influences natural conditions and improves them."

The peculiarity of M. Gol's definition lies in the ecological approach to solving the irrigation problem. After all, experiments show that irrigation can also lead to negative consequences, therefore, nature protection is also necessary during irrigation. It is necessary to understand not just soil moistening, but targeted regulation of soil moisture within the required limits for plants. These tasks can be solved on the basis of hydrometric regime that provides a certain heat-moisture rate in certain agroclimatic conditions.

According to domestic and foreign scientists, the main task of the hydrometric regime of irrigated lands, which are an element of meliorative ecology, as one of the areas of general ecological science is "the study of complex of measures to achieve optimization of all natural functions of the meliorative landscape and on their background to provide targeted regulation and management of plant life and soil-forming process with the management of soil-plant-atmosphere processes in real time."

The regulated factor is the hydrometric regime of irrigated lands, which is changed by supplying certain quantities of water for irrigation. Then the radiative index of dryness will change:

$$RM = R/ h\,(Oc + Qp); \tag{2}$$

where: RM is the radiative index of irrigated area; Qp is the water-delivery value (m^3); Oc is the annual value of precipitation (mm); h is the latent heat of evaporation; R is the radiation balance of the geographic space for the target year.

Academician I.P. Aidarov (Aidarov 1985) based on analysis and many years of experience has managed to calculate the water-delivery value (Qp) for the estimated natural zones at R/hQc = 0.9-desert zone (R = 251-253 kJ cm^{-2} per year; h = 300)_Qp = 8-10 thousand m^3 ha^{-1}. For the dry zone (at R = 167-209 kJ cm^{-2}, h = 300)_Qp = 3-6 thousand m^3 ha^{-1}. For the steppe zone (R = 159-176 kJ cm^{-2} per year; h = 300)_Qp=1-3 thousand m^3 ha^{-1}. These data show that irrigation in the desert zone is the main source of moisture for crop plants, and in the steppe zone irrigation serves only as a supplement to natural precipitation.

The main object of impact and the main means of production when irrigating agricultural lands is soil, which acts as the main connecting and stabilizing component of the geosystem. Due to the fact that soil is at the contact of the atmosphere, lithosphere and hydrosphere, biochemical reactions take place here. In addition, the soil cover acts as a primary accumulator and geochemical barrier for a variety of pollutants entering landscapes. This can serve as a source of degradation and fertility of soils with loss or function of sanitary cleaning, neutralization of pollutants.

Soil is a component of the environment that is subject to environmental regulation. The importance of soil in agricultural production is determined by its main asset, fertility, which is the ability of the soil to satisfy the needs of plants with all the necessary elements of food, water, air, and to create favorable chemical, physical and biological conditions for normal growth and development of plants. However, it should be noted that minerals do not serve as food for plants, and macro - and microelements are fertilizers, thanks to which plants receive additional energy for their development.

The development of the doctrine of soil fertility is closely connected with the name of the Russian soil scientist V.R. Williams (Tokarev *et al.* 2020). He studied the formation and development of fertility during the soil formation process in agricultural use.

Soil fertility is influenced by direct and indirect factors: direct factors are the organic matter content, water saturation and air permeability (aeration); indirect factors are the degree of activity of soil microorganisms and methods of cultivation (Venot *et al.* 2017).

The current level of scientific studies and experience in irrigated farming make it possible to regulate the soil-forming process taking into account the main components of the reclamation regime– water, salt, nutrient, air, thermal and microbiological.

Soil fertility is the result of the soil-forming process, which is composed of a set of closely interrelated biological, chemical and physical processes, and the soil itself is an integral part of the biosphere mechanism, an accumulator, distributor and transformer of energy, including solar energy, which is one of the main factors in the formation of agricultural yield (Zhang *et al.* 1997; Bogardi *et al.* 2012).

The main concept of land reclamation in Kazakhstan is the most efficient use of irrigation water to obtain a unit mass of products, as well as the creation of conditions for the soil-forming process, providing the possibility of expanded reproduction of soil fertility in the process of farming. For this purpose, it is necessary to preserve the atmospheric regime of soil formation, maintain the mineralization of groundwater at a depth of more than 2.5-3.0 m in order to prevent the possibility of secondary soil salinization with minimum consumption of irrigation water, reduce the leaching of nutrients beyond the root layer and reduce the removal of chemical elements with drainage water outside the irrigated areas (Mustafayev *et al.* 2025).

The Kazakhstan part of the Aral Sea region is located in the south of Kazakhstan, along the lower course of the Syr Darya River, which is the only source of irrigation and the second most water-abundant river in Central Asia. The Syr Darya River flows through the territories of 4 sovereign states of Central Asia - Kyrgyzstan, Tajikistan, Uzbekistan and Kazakhstan.

The rise of irrigated farming in Kazakhstan is not possible without the widespread introduction of new generation irrigation systems, which should be based on indicators of high productivity, reliability, efficiency, environmental safety, adaptability to natural conditions and forms of management and ease of maintenance with a minimum of labor costs.

To a large extent, these requirements are met by drip irrigation, which, according to domestic and foreign scientists and their experience in using drip irrigation, is water- and energy-saving, environmentally friendly method of irrigation (Brits 2024).

In this regard, at present, there is an urgent need for scientific experimental substantiation of the elements of processes and technology of drip irrigation, of the degree of regulation of plant life by factors to create a technology for obtaining programmable yields of agricultural crops, as well as their availability for mainstream use in the soil and climatic conditions of Kazakhstan.

The effectiveness of drip irrigation, as compared to sprinkling, is based on the flow of water into the root zone of the plant, the amount and frequency of water supply is regulated in accordance with the needs of the plant. Water is supplied to all plants evenly. Non-irrigated (unwatered) strips between allow the farmer to work in the field at any time, that is, to till the soil, spray and gather the harvest even when irrigation is carried out.

By drip irrigation, the root system develops better than by any other type of irrigation, and, in the vicinity of the humidifier (dripper), the plant roots develop thicker, due to good aeration of the soil around the roots (Chaiyadee *et al.* 2013; Brits 2024). There is a rapid and intensive absorption of nutrients due to the high development of the root system around the humidifiers (drippers).

By drip irrigation, the soil temperature is higher than by sprinkling or flooding, so it is possible to achieve early ripening of many agricultural crops. Drip irrigation allows to moisten large areas at the same time, without affecting the pressure in the general water supply system and there is no need for a special drainage system (Chaiyadee *et al.* 2013; Mustafayev *et al.* 2025).

As has been established by many scientists, the use of water in drip irrigation is more efficient compared to any other irrigation method. The degree of saving irrigation water largely depends on climatic conditions; the higher the temperature and the drier the region, the higher the efficiency of drip irrigation. According to Rain – Bird (USA; Brits 2024), the water use efficiency (WUE) in drip irrigation is 85-95%, which provides significant environmental advantages.

On average, the irrigation rate for drip irrigation is reduced by 20-50% compared to other irrigation methods; in some cases, more significant water savings are observed - up to 75-90%.

According to observations of scientists in the USA, water consumption with drip irrigation is on average 60% less than with sprinkling irrigation. The results of numerous farming experiments in the USA and Austria show that drip irrigation allows to reduce irrigation rates by 41-47% compared to sprinkling irrigation and by 52-60% compared to surface irrigation methods (Brits 2024).

Drip irrigation enables to maintain the most favorable regime of water and nutrients supply for the irrigated crop. The root zone is optimally moistened throughout the vegetation period, especially during critical phases of plant development. Optimization of the regime of supplying plants with water, air and nutrients determines their uniform growth and development, which leads to a significant increase in the yields of gross and commercial products.

The results of experiments conducted in various soil and climatic conditions of the USA and Australia clearly demonstrate the high response of all agricultural crops to drip irrigation (Chaiyadee *et al.* 2013). Along with the increase in yields, there is also an improvement in the quality of the resulting products due to the constant maintenance of optimal water, air and nutrient regimes of the soil.

Also, accelerated growth and development, as well as the size of the fruits of agricultural crops, were revealed due to the exclusion of the impact of the “saturation-wilting point” cycles on the crop and the absence of soil moisture tension. Many scientists express the opinion that the acceleration of growth and development is explained by the fact that the plant does not spend energy on “searching” for water by the root system, since the roots are almost constantly in a humid environment. Accelerated ripening of plant fruits is explained by the fact that due to moistening, with drip irrigation, only parts of the soil surface adjacent to the wetting zone of areas are lower, and the average temperature of the soil surface remains high.

Keeping the soil surface dry between rows creates unfavorable conditions for the growth of weeds, which makes it possible to sharply reduce the use of herbicides and decrease the amount of auxiliary work. In addition, the water supplied to the drip irrigation system is thoroughly filtered, preventing the entry of weed seeds into the fields together with the irrigation water (Batishchev 2018). They have certain advantages of moistening the leaves, and insecticides and fungicides are not washed off from the leaves of plants, compared to sprinkling irrigation.

Widespread introduction of drip irrigation method in plant growing practice makes it possible to significantly decrease fertilizer doses by supplying them directly to the root system and thereby reduce the region of plant alimentation. Reducing fertilizer doses with the drip irrigation method does not create conditions favorable for weed growth, and makes it possible to reduce the negative impact of agricultural production on the environment (Sun *et al.* 2022).

Analyzing the results of the above studies, we can conclude that drip irrigation, in contrast to surface irrigation methods and sprinkling, has a number of advantages:

- maximum preservation of the soil structure and its air regime during irrigation against the background of the absence of soil crust;
- reduction of evaporation to a minimum during irrigation;
- lack of conditions for germination of annual weeds due to the drying of the surface soil in the inter-row spaces;
- supplying irrigation water in pure form or mixed with fertilizers directly to the root zone of plants;
- prevention of re-salinization of soils;
- improvement of the soil temperature regime, contributing to the early ripening of agricultural crops;
- up to 90% absorption of nutrients supplied with irrigation water by plants;
- very high coefficient of land use (CLU);
- possibility of use in any land forms and in any soil and climatic conditions, achieving maximum success in arid zones;
- significant increase in crop yield.

RESULTS AND DISCUSSION

Our experimental studies on the use of a low-pressure drip system for irrigation of forage crops of sorghum and rice were carried out in 2020-2021 on the private sector, located near the experimental field of the Kazakh Scientific Research Institute of Rice Growing (KazSRI Rice) named after Ybyrai Zhakhaev, in the village of Karaultobe, 7 km from Kyzylorda City.

To study the forage crop of sorghum, we focused on the varieties “Keshen” and “Kazakhstanskaya – 20”, which were recommended for cultivation in Almaty, Zhambyl, Turkestan and Kyzylorda regions of Kazakhstan (Massatbayev *et al.* 2016, Tazhenova *et al.* 2021). The varieties “Syr Suluy” and “Ai Kerim”, bred by scientists of LLP “Kazakh Scientific Research Institute of Rice Growing named after Y. Zhakhaev” were chosen as rice varieties (Tazhenova *et al.* 2021, Shomantaev & ogly Mustafayev 2021).

The climate of the region is very dry, in November - March there is up to 152-159 mm of precipitation per year, and in April - October 129-255 mm per year. The sum of positive air temperatures is above 10 °C, reaches 3800-4600 °C.

The soil and vegetation cover belongs to the desert zone and is characterized by significant diversity, being subdivided into two large areas including (i) moistened (hydromorphic): these are the soils of the agricultural belt; (ii) withered (subaerial), in some places with traces of ancient irrigation: this is the desert part. Despite the diversity, all plain soils have some common characteristics of agronomic importance.

Experimental studies were conducted on middle loamy soils. At the depth from 0 to 60 cm, the soils are highly saline with sulfate-chloride salinization, from 60 to 100 cm the soil is medium saline with sulfate salinization (Table 1). The soil of the experimental field is characterized by very low fertility: humus content is 0.28-0.43%; nitrogen 5.6-43.4 mg kg^{-1}; weight fraction of phosphorus 24.8-32.4 mg kg^{-1}; potassium - 116-226 mg kg^{-1}; pH = 6.5-5.8.

Table 1. Dynamics of soil fertility of the experimental plot for 2020-2021 study years.

Horizons (cm)	**Humus (%)**	**pH**	**Gross nitrogen (mg kg^{-1})**	**Gross phosphorus (mg kg^{-1})**	**Potassium (mg kg^{-1})**	**Salinity quality**	**Salinity level**	**Mechanical composition**
2020, spring (initial state)								
0-20	0.43	5.8	43.4	25.6	226.0	Sulfate-Chloride	Very strongly saline	Medium-textured loam
20-40	0.43	5.7	36.4	32.4	210.0	-	-	-
40-60	0.33	6.3	21.0	24.8	116.0	-	-	-
60-80	0.28	6.5	5.6	24.8	116.0	-	Medium saline	-
80-100	0.43	6.1	8.4	25.6	116.0	-	-	-
2021, autumn (after 2 years of irrigation)								
0-20	0.86	8.3	18.2	100.0	50.0	Sulfate	Very saline	Medium-textured loam
20-40	0.08	8.7	16.8	26.0	28.0	-	Medium saline	-
40-60	0.23	8.8	14.0	32.0	50.0	-	-	-
60-80	0.13	8.8	25.2	10.4	62.0	-	-	-
80-100	0.23	8.7	16.8	16.0	84.0	-	-	-

The reaction of the soil solution (pH) is one of the most important indicators of the chemical properties of soils and factors affecting the productivity of agricultural crops, that is, the interaction of its living organisms. The highest activity of microbiological processes is observed at pH = 6-8, and humification pH = 5-7.5. Maximum permissibility of nutrients: nitrogen: 6-8; phosphorus: 6.5-7.5; potassium: 7-8; calcium and magnesium: 7-8.5; copper and zinc: 5-7; iron: 4-6.5; molybdenum: 7-9.0 mg per 100 g of soil. The most favorable for plants in physiological terms is the reaction of the soil solution (pH) close to neutral.

One of the most important indicators of the salt regime is the exchange capacity of soil and the composition of exchangeable cations. The exchange capacity of soils is the total capacity of organic, mineral and organomineral colloids, that is, the total content of all exchangeable adsorbed cations in the soil is called the exchange capacity and is expressed in mg-eq per 100 g of soil. Desert soils contain the largest amount of organic matter, i.e., the greater the exchange capacity, the higher the soil fertility. The qualitative composition of the adsorbed cations depends on the soil type and is subject to the law of zonality.

The irrigated soils of the experimental field are represented by medium-textured loams and sandy loams characterized by extremely low fertility, low humus content of 0.43-0.74% in the plow layer -30 cm, with a sharp decrease in the lower horizons of 40-80 cm to 0.33%.

Assessing the given content of nutrient elements in the soil of the experimental field over the years of research (2020-2021), some features in the redistribution of these elements in the soil profile should be noted (Table 1). There is a decrease in gross nitrogen in horizons from 0 to 60 cm by an average of 43%, phosphorus 30%, potassium 53%, and there has been also a decrease in humus by 30% on average. An increase in the reaction of the soil solution (pH) from 5.7 to 8.7 has been observed.

When developing watering regimes of drip irrigation, the fundamental points are the establishment of forming contours of moistening on the surface and in the depth of the soil. The proportion of the contour (S) subject to moistening was determined by the formula:

$$S\frac{n*W}{a*b}, \mathrm{m}^2 \tag{3}$$

where n: number of drippers; W: calculated moistening contour (m^2); “a” and “b”: crop planting plan (m^2; Massatbayev *et al.* 2016, Tazhenova *et al.* 2021).

Water is a component of all plant organs and plays an important physiological role, participating in photosynthesis and a number of other metabolic processes. By a lack of moisture, photosynthesis decreases, respiration increases, growth processes weaken, crop yield is sharply reduced and the quality of products deteriorates. Therefore, the soil water regime is a set of processes of water supply, movement and consumption in the soil.

The yield of sweet sorghum variety "Keshen" with a vegetation period of 111 days were: grain 35 hkg ha^{-1}, green mass 11,250 hkg ha^{-1}. Sorghum variety "Kazakhstan -20", with a vegetation period of 113 days were grain 62.5 hkg ha^{-1}; and green mass 12,500 hkg ha^{-1}.

Over the entire vegetation period, 3768.0 liters or 3.77 m^3 of water were supplied per 348 m^2 of the experimental field, if converted to a hectare - 783.3 m^3 of water.

Field experiments of the rice varieties "Syr Suluy" and "Ai Kerim" were carried out according to the requirements of the Methodology of Experimental Work.

With low water content in rice tissues, regular and ample irrigation is required. Scientists have found that per unit of dry matter, rice requires 80-82 times less water than wheat. Cultivated grain crops can develop normally at the lower pre-irrigation threshold of soil water of 60-65% field capacity (FC). Rice at such moisture content of pre-irrigation soil water can begin to decrease the growth of plant mass. A decrease in the moisture content in the root layer of the soil, when plants cannot receive moisture in full, leads to a violation of the water balance in the plant body and signs of wilting of rice appear. Therefore, many scientists believe that when growing aerobic rice, it is necessary to maintain the soil water regime not lower than 80% FC, thus improving the air and water regime of the soil, which has a favorable effect on the vital activity of rice (Olzhabayeva *et al.* 2016; Abdibay *et al.* 2024; Kuvatova *et al.* 2024).

From sowing to the beginning of thickening, the pre-irrigation moisture threshold was maintained up to 70% FC, from thickening to the end of milky ripeness - 80% FC, and from the end of milky ripeness to full ripeness of the grain - 70% FC. At the same time, the irrigation rate at 70% FC was from 19.14 to 20.0 m^3 per 348 m^2 of the experimental field, and at 80% FC - from 12.0 to 13.0 m^3. If converted to 1 ha, then at 70% FC it will be 546-575 m^3 ha^{-1}, at 80% FC - 345-373.6 m^3 ha^{-1}.

To maintain differentiated soil water regime according to the regulation of 70-80-70% FC, during the vegetation period, 3 irrigations at the rate of 575 m^3 ha^{-1} and 12 irrigations of 373.6 m^3 ha^{-1} (1725 m^3 ha^{-1} + 4483 m^3 ha^{-1}) were carried out and total irrigation rate of rice was 6208 m^3 ha^{-1} (Batishchev 2018).

On the saline lands of the Aral Sea region, with constant flooding, the irrigation rate of rice is 22500-24350 m^3 ha^{-1}, and the volume of discharge runoff is 1000 m^3 ha^{-1} (Sun *et al.* 2022).

CONCLUSION

Thus, our field studies have shown that cultivation of grain crops such as sorghum and rice using the drip irrigation method provides flexible regulation of water reserves in the root layer of the soil with maintenance of air temperature and humidity in the ground layer of air within favorable limits for plants. These crops are good phytomeliorants and a reliable means of controlling salinity of irrigated areas and are economically advantageous in the zone with unfavorable environmental conditions of the Aral Sea region.

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