**Results of Research on The Implementation of Water-Saving Technologies in Furrow Irrigation for the Cultivation of Agricultural Products**

Mokhira Pulotova 1, a), Aziz Abduganiev2

1 Bukhara State Technical University, Bukhara, Uzbekistan

2 Tashkent Institute of Engineers of Irrigation and Agricultural Mechanization National Research University, Tashkent, Uzbekistan

a) Corresponding author: [mohirapr@gmail.com](mailto:mohirapr@gmail.com)

**Abstract**. This research is dedicated to the results of work conducted on the implementation of water-saving technologies in furrow irrigation for the cultivation of agricultural products. The study explores the possibilities of enhancing irrigation efficiency and conserving water resources through the use of anti-seepage screens based on a polymer-polymer complex. Based on laboratory and practical experiments, methods have been identified to reduce technological losses in furrow irrigation, prevent soil waterlogging and salinization, and improve yields while optimizing irrigation rates. The research holds significant importance in the semi-arid climate conditions of Uzbekistan, particularly for water-intensive crops like cotton, contributing to water resource conservation and the development of sustainable agriculture.

**INTRODUCTION**

In the context of Uzbekistan, cloud technologies, the Internet of Things (IoT), and artificial intelligence (AI) are increasingly being utilized in horticulture (fruit and vegetable cultivation) to manage water (irrigation) and mineral resources (fertilizers). These approaches are aimed at addressing issues such as water scarcity and inefficient resource use, relying on precision agriculture trends. For instance, real-time monitoring is conducted using satellite data and IoT sensors, which can optimize water and fertilizer management, potentially increasing yields by 20–50% and reducing costs[1]. Through cloud platforms, IoT sensors collect data on soil moisture, temperature, and weather, enabling the control of automated irrigation systems. For example, when combined with drip irrigation, satellite imagery can reduce water consumption by 30–50%[2]. This is particularly important for horticulture (e.g., vineyards and orchards) in water-scarce conditions, as precise water delivery to root zones helps prevent runoff.

Uzbekistan is a country located in a semi-arid region with a hot, dry, arid climate and uses water from two major transboundary rivers, the Syr Darya and the Amu Darya, as well as internal rivers and underground sources, for agricultural needs. Irrigated agriculture in Uzbekistan is of key importance for life. The Concept of Water Management Development in the Republic of Uzbekistan for 2020–2030 approved by the Decree of the President of the Republic of Uzbekistan dated July 10, 2020 No. UP-6024 (Concept [1]) notes that irrigation is the largest consumer of water in the republic and more than 90% of all water resources of Uzbekistan are spent on it, although the volume of water withdrawal for irrigation purposes in the country has decreased by more than 13 billion m3 since 1980, and the volume of water consumed per hectare in the republic has decreased from 18 thousand m3 /ha in 1991 to 10.2 thousand m3 /ha in 2018[1]. Nevertheless, the industry is increasingly competing with industrial and drinking water supply, hydropower and especially the consumption of the natural complex. In this regard, the issue of saving water resources due to their deficit through the use of irrigation systems in agriculture, which would provide agricultural crops with water to maintain a given level of minimum moisture capacity during the most critical periods of their growth and development, is becoming increasingly acute every year. As noted (I.V. Olgarenko [2], A.N. Babichev [3], S.M. Pochovian [4]), the timing, frequency, and irrigation rates during irrigation depend on the groundwater level, agrochemical properties of soils, weather and climate conditions, and the growth and development phases of agricultural crops. And the use of a differentiated irrigation regime to maintain a given level of pre-irrigation moisture allows increasing the productivity of agricultural crops, the quality of the resulting products while reducing irrigation and watering rates, and the number of irrigations (A.V. Tashchilina [5], O.E. Yasonidi [6]). Current state of the problem under consideration. As rightly noted in (Concept [1]), today irrigation of agricultural crops in the existing irrigation systems of the Republic, despite the measures taken, remains insufficiently effective, which is due to their low technical level, the lack of high-quality management of water use and distribution processes, large water losses leading to a rise in the level of groundwater in irrigated areas, and the processes of salinization and waterlogging of soils. Therefore, the primary tasks of increasing the technical level of irrigation systems are the development of a set of measures to minimize or completely eliminate technological losses.

To improve irrigation technologies through furrow systems in viticulture, research is conducted to measure parameters such as the rate of water absorption by the soil, the advance and recession of water flow, the time and uniformity of soil wetting. These parameters and irrigation performance indicators for vineyards are considered when implementing water-saving methods using polymer complexes, and their optimal components are studied.

Lysimetric experiments were conducted to investigate the impact of polymer complex-based screens on the soil's filtration capacity.

**EXPERIMENTAL RESEARCH**

The most important feature of the irrigation regime for agricultural crops on meadow soils is accounting for the share of nearby groundwater used by plants in their total water consumption. In cases of insufficient moisture, plants utilize groundwater in the active soil layer, which is also used for evaporation from the soil surface. When developing an irrigation regime (irrigation rates, timing, and duration), it is necessary to determine the components of the water balance to achieve high cotton yields.

In conditions where additional groundwater supply is available, the water balance equation is applied for calculations:

; (1)

bu yerda:

Eb – hisob davri uchun umumiy suv sarfi (suvga bo‘lgan umumiy ehtiyoj);

P – shu davr ichida ob- havo yog‘ingarchiliklari;

W₁ – davr boshida ildizlar joylashgan qatlamdagi nam zaxirasi;

W₂ – davr oxirida ildizlar joylashgan qatlamdagi nam zaxirasi;

G – yer osti suvlaridan ildizlar joylashgan qatlamga kirib keladigan nam miqdori;

M – hisob davri davomiyligiga bog‘liq ravishda sug‘orish normasi;

F – ildizlar joylashgan qatlamdan pastga chuqur qatlamlarga ketadigan suv oqimi (chuqur oqim).

The total water consumption in lysimeters is determined as the sum of the water supplied to the field to replenish groundwater expenditure during different growth phases of grapevine seedlings.

The groundwater consumption in the water use of grapevine seedlings is determined based on the volume of water supplied to maintain the groundwater level.

Water infiltration beyond the root zone in lysimeters is determined depending on the changes in groundwater levels after irrigation.

By determining the values of Eb and G during different growth phases of cotton, the groundwater utilization coefficients (Kg) are calculated.

(2)

When groundwater is located close to the surface, the amount of groundwater utilization is determined using the following ratio:

(3)

By substituting into the water balance formula (3), we determine the irrigation and watering norms.

(4)

by taking W1 - W2 = δ (where δ represents the moisture deficit), we obtain the following result.

(5)

When F ≈ 0, i.e., under optimal water supply conditions, we obtain the following result:

(6)

The optimal water supply is determined using expression (6). This formula is widely used in developing irrigation regimes for cotton in the region under consideration.

Lysimetric studies were conducted, where two lysimeters with surface area dimensions of 0.6 x 0.6 m² and a height of 1.2 m were established on the experimental plot. The lysimeters were filled with light loamy soil, followed by slight compaction of the soil, and then moistened with water (to achieve the natural bulk density).

The results of the lysimetric experiments provided the following findings on the rate of water absorption into the soil and the filtration time, with comparisons between the control and the experiment presented in Table 1.

**TABLE 1.** The rate of water absorption and the filtration time through ordinary soil and soil treated with a PK (polymer complex) solution (depth 1-1,5 m)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Serial number  of portions of water application | Amount of water, liters | Ordinary soil (control) | | PK (polymer complex) applied to the soil surface | |
| K (mm/min) | t (s) | K (mm/min) | t (s) |
| 1 | 1 | 480 | 52 | 240 | 95 |
| 2 | 1 | 470 | 55 | 230 | 110 |
| 3 | 1 | 460 | 58 | 220 | 125 |
| 4 | 1 | 450 | 61 | 210 | 140 |
| 5 | 1 | 440 | 63 | 205 | 160 |
| 6 | 1 | 430 | 65 | 195 | 175 |
| 7 | 1 | 420 | 68 | 190 | 190 |
| 8 | 1 | 410 | 70 | 185 | 210 |
| 9 | 1 | 400 | 72 | 180 | 235 |
| 10 | 1 | 395 | 74 | 175 | 260 |
| 11 | 1 | 390 | 76 | 170 | 290 |
| 12 | 1 | 385 | 78 | 165 | 320 |

Laboratory experiments to study the rise of salts from sub-arable soil layers and methods to prevent them, using an in-soil screen based on a polymer-polymer complex, were conducted in Wagner vessels with dimensions of 0.57×0.57×1.1 m and in lysimeters. Three Wagner vessels and three lysimeters were used for the experiments. They were filled with light loamy soil, and 250 g of table salt (NaCl) was placed at the bottom 60 cm of the vessels and lysimeters. In the experimental variants, the soil at a depth of 40 cm was covered with a PK solution at a rate of 0.6 liters per square meter. Both the control and experimental vessels were irrigated with equal portions of 21 liters, calculated per 1 hectare.

**TABLE 2.** Physico-chemical properties of the polymer–polymer complex (for horticulture in Uzbekistan)

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **№** | **Composition of PPC (PC:FT:sand), %** | **Strength, MPa** | **Water absorption, %** | **Water resistance, rel. units** | **Total porosity, %** |
| 1 | 10:15:30+MFS | 96 | 2.6 | 0.82 | 39 |
| 2 | 15:20:30+MFS | 99 | 2.2 | 0.91 | 38 |
| 3 | 20:25:30+MFS | 112 | 2.0 | 0.94 | 40 |
| 4 | 25:25:30+MFS | 98 | 2.3 | 0.86 | 37 |
| 5 | 30:30:30+MFS | 96 | 2.5 | 0.72 | 36 |

Soil samples for chemical analysis were collected from each vessel using a soil auger with threefold repetition and were mixed according to individual soil layers before conducting the analysis.

Soil samples for chemical analysis were collected from each vessel using a soil auger, with individual soil layers mixed and conducted with up to three repetitions.

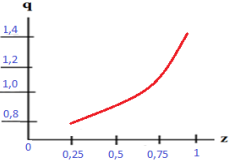
The average amounts of Cl and SO₄ in the 0–100 cm horizon were determined as follows: the thickness of the characterized horizon was multiplied by the content of a given ion in mg·eq, then all resulting products were summed, and the total was divided by the thickness of the entire layer (Table 2). Subsequently, the ratios of the derived average indicators for the respective ions in the specified layer were examined, and the chemical composition of that soil layer was established.

Table 2 data shows that the polymer-based irrigation pipe is fully suitable for irrigating vine seedlings in horticultural crops in terms of its physicochemical properties.

It should be emphasized that studying the swelling properties of polymer complex product samples, i.e., structural research, is certainly of great interest. The swelling property is directly related to the structure of the initial components (MFS and Na-CMC) as well as the material's own structure, which significantly determines its field of application.

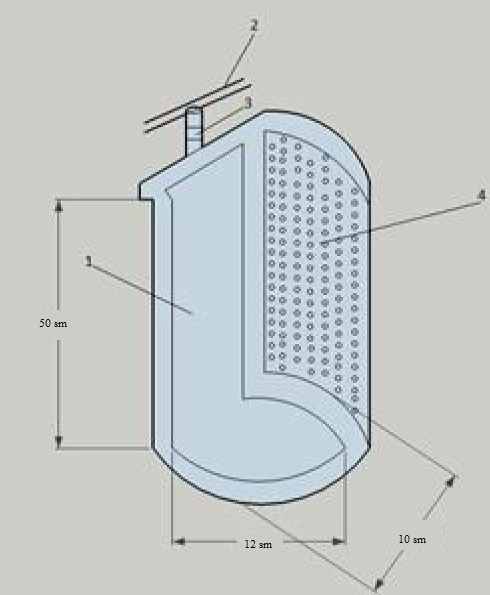
**RESEARCH RESULTS**

We studied various samples of **polymer complex (PC)** compositions, which swelled uniformly in a salt-free aqueous medium with **pH = 6**. As can be seen from **Figure 1**, the composition of the PC samples varied within the range of **0.25–0.67**, and the introduction of an excess amount of **Na-CMC (z > 0.5)** increased the swelling capacity of the sample. This makes it possible to use **PPC products** for the **manufacture of irrigation flumes** (see Fig. 1).



**FIGURE 1.** Dependence of the expansion degree (q) of the polymer complex on the component ratio (z) (t₀ = 25 °C and expansion time = 40 minutes)

For grape seedling irrigation in horticulture, it is proposed to use irrigation flumes (1), which are placed sequentially along the furrows and installed on the mounds near the seedlings. This design does not interfere with agro-technical operations throughout the entire growing season. Water from the distributors (2) flows through a filter (3) into the irrigation flumes (1). The filter is made of polymer material, which prevents the clogging of the flume holes.

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**FIGURE 2.** General view of the irrigation flume made from a polymer complex (MFS) with the addition of phosphogypsum and sand

It is well known that, in practice, several types of equipment are used to install mole drains in saline soils at depths of 70–80 cm. However, they have some disadvantages, particularly the instability and rapid destruction of the drains, especially the collapse of their upper part.

Therefore, we set the task of reducing draft resistance and improving the operational performance of the mole drainage tool while simultaneously spraying a polymer complex solution to reinforce the upper part of the mole drain, thereby preventing collapse.

Linear regression model [7-11]:

*y ~ 1 + x1 + x2*

**TABLE 3.** Evaluation results of the regression model

Estimate SE t Stat p Value

(Intercept) 5 1.9021e-06 2.6287e+06 8.4963e-55

x1 0.02 2.4493e-09 8.1655e+06 3.155e-59

x2 1.0217e-16 7.3237e-09 1.3951e-08 1

Number of observations: 12, Error degrees of freedom: 9

Root Mean Squared Error: 1.59e-07

R-squared: 1, Adjusted R-Squared: 1

F-statistic vs. constant model: 3.28e+31, p-value = 1.32e-139



**FIGURE 3**. Regression model results

R2 Polynomial Regression = 0.9994

R2 Random Forest = 0.8527

R2 Gradient Boosting = 0.8334

R2 SVR (Support Vector) = 0.9420

R2 Neural Network Regression = 0.8417



**FIGURE 4.** Experimental results

--- MSE (X\_pred bo'yicha) ---

Linear: 12.85

Decision Tree: 10.11

Random Forest: 5.42

SVM: 7.25

Neural Net: 4.87

Fuzzy: 9.78

--- R2 (train) ---

Linear: 0.943

Decision Tree: 0.962

Random Forest: 0.982

SVM: 0.974

Neural Net: 0.987

Fuzzy: 0.958

**TABLE 4.** Evaluation metrics for machine learning models

|  |  |  |  |
| --- | --- | --- | --- |
| **Model** | **Accuracy (R²)** | **Error (MSE)** | **Evaluation** |
| Neural Network | 0.987 | 4.87 | Most accurate |
| Random Forest | 0.982 | 5.42 | Very good |
| SVM | 0.974 | 7.25 | Good |
| Decision Tree | 0.962 | 10.11 | Average |
| Fuzzy Logic | 0.958 | 9.78 | Average |
| Linear Regression | 0.943 | 12.85 | Simplest model |

Analysis:

1. \*\*Neural Network\*\* — lowest MSE ≈ 4.87 and R² ≈ 0.987 → highest accuracy.

2. \*\*Random Forest\*\* — very close results, performs consistently.

3. \*\*SVM and Decision Tree\*\* — moderately good performance.

4. \*\*Linear Regression and Fuzzy Logic\*\* — lower accuracy compared to simpler models [7-11].



**FIGURE 5**. Experimental results

Test Results:

Neural Net: MSE = 64.3695, R² = 0.8161

Random Forest: MSE = 858.5025, R² = -1.4529

SVM: MSE = 412.6214, R² = -0.1789

**CONCLUSIONS**

Lysimetric experiments conducted to study the impact of polymer complex (PC)-based screens on the soil's filtration capacity in viticulture revealed that the component ratio in the PC (0.25–0.67) and an excess amount of Na-CMC (z>0.5) significantly increase the swelling capacity of the samples. This property enables the effective use of PC-based screens in crop irrigation systems, particularly in water-saving trays. The experiments, considering parameters such as the soil's water absorption rate, the advance and recession of water flow, and the uniformity of soil wetting, confirmed that PCs can enhance water resource conservation and improve the quality of vineyard irrigation. This approach contributes to optimizing water management and increasing productivity in viticulture.

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