IMPLEMENTATION OF WATER-SAVING IRRIGATION TECHNOLOGIES TO IMPROVE RESOURCE USE EFFICIENCY AND ENSURE NATIONAL FOOD SECURITY

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Abstract. *This article examines the effects of irrigation methods and irrigation technique elements used in the management of intensive apple orchards under the conditions of typical sierozem and meadow-sierozem soils of the Tashkent region on seasonal water consumption and fruit yield, as well as the role of intensive horticulture in ensuring national food security. In the foothill zones with typical sierozem soils, the use of cross-blocked furrows aimed at preserving soil fertility and reducing irrigation erosion, and under meadow-sierozem soils with close groundwater occurrence, the application of drip irrigation technologies reduced soil particle washout by 31.3–38.7%, total water consumption by 7–13%, seasonal irrigation water use by 25–52%, and increased yield by 9.2–12.8 t/ha.*
Keywords: *intensive apple orchards, cross-blocked furrows, drip irrigation, food security, irrigation, yield.*

Introduction. Over the past decade, factors threatening food security worldwide, namely a decline in agricultural crop productivity as a result of global climate change, population growth (by 2050 the world population will approach nearly 10 billion), reduction of irrigated areas and intensification of land degradation processes, increasing water scarcity, and sharp price fluctuations in international markets, have turned food security policy into an important global issue. In arid regions, ensuring food security is directly related to the efficient use of land and water resources. Climate change, population growth, degradation of irrigated lands, and water scarcity are intensifying pressure on natural resources. Under the conditions of Uzbekistan, more than 70% of agriculture relies on irrigated lands, while a significant portion of annual renewable water resources is formed from transboundary sources. From this perspective, the intensification of horticulture is not only a factor of agrarian modernization but also a strategic necessity for ensuring national food security.

According to FAO (2022), the World Bank (2023), and other international sources, high-density intensive orchards can increase land productivity by 2.5–3 times and water-use efficiency by 40–60%. However, under the conditions of Central Asia, the effectiveness of these systems has not been sufficiently studied. The relevance of this research lies precisely in this aspect – scientific assessment of the agrotechnical, water-saving, and environmental efficiency of intensive orchards based on region-specific field experiments. Agriculture plays a crucial role in ensuring food security worldwide, since all food products are produced on irrigated lands. Therefore, the development of the agrarian sector serves as an important factor in providing humanity with food.

Global climate change has a serious impact on freshwater scarcity and food security. Meeting the population’s demand for food products and ensuring efficient use of irrigated lands and water resources are among today’s most important tasks. Under climate change conditions, it

becomes necessary to fully utilize existing opportunities and apply advanced technologies in agricultural production.

Materials and Methods. According to United Nations data, one-quarter of the world's population does not have access to adequate nutrition, which poses a threat not only to socio-economic stability but also to national security. Developing and low-income countries suffer the most from food crises. Developed countries possess more tools to combat inflation; therefore, food inflation in these countries is 2–2.5 times lower compared to other parts of the world. Despite deep reforms being implemented in the country, droughts, water scarcity, and sharp increases in air temperature lead to imbalances between production costs and market prices of agricultural products.

Currently, one of the most pressing issues for the global community is ensuring food security. Global climate change, population growth, inefficient land use, and rising food prices pose new and complex challenges for countries. Under such conditions, the development of various agricultural sectors, particularly intensive horticulture, is of great importance in providing the population with healthy, nutritious, and high-quality food products and ensuring food security. Ensuring food security is a strategically important component of national policy and one of the key conditions for economic and social stability and state independence.

Food security is closely linked to the intensification of agricultural production, efficiency of social production, and stabilization of population incomes. Therefore, addressing such global problems requires not only agricultural intensification but also improving living standards, environmental protection, expanding gross domestic product production, and strict monitoring of population and domestic market demand to stimulate the production of food products in the required volumes. One of the main directions for increasing agricultural efficiency in the country is the development strategy of intensive horticulture and intensive agricultural technologies. Field experiments were conducted from 2015 to 2025 under various soil and climatic conditions, including typical sierozem and meadow-sierozem soils. The studies compared traditional irrigation methods with drip irrigation and cross-blocked furrow irrigation, while soil moisture was monitored in calculated layers of 0.5, 0.8, and 1.0 m.

The main objectives of the research were to scientifically substantiate optimal irrigation methods and irrigation technique elements in an intensive horticulture system aimed at efficient land use, obtaining higher yields per hectare compared to traditional orchards, applying modern technologies such as drip irrigation, soil moisture control, rational use of mineral and organic fertilizers, producing high-quality, early-ripening, export-oriented, environmentally friendly fruits meeting market demand, selecting high-yielding, early-maturing, and disease-resistant varieties, and ensuring yield stability from year to year.

Seasonal crop water consumption was calculated based on soil water balance, transpiration intensity, evapotranspiration, crop growth stages, agro-technical practices, and climatic conditions. Calculations were performed using FAO-recommended methods, including Penman–Monteith, Blaney–Criddle, Hargreaves formulas, as well as CropWAT and AquaCrop software.

Results. The experimental fields in Qibray and Middle Chirchik districts of Tashkent region are characterized by typical sierozem, meadow-sierozem, and light sierozem soils. These soil types differ in physical-mechanical and agrochemical properties, water permeability, and reclamation potential, which allowed evaluation of the effectiveness of water-saving technologies under different natural conditions. The total area of the Tashkent region is 1,526.1 thousand hectares, of which 338.4 thousand hectares are irrigated lands used mainly for growing cotton,

cereals, rice, perennial plants, as well as household and various agricultural crops. The main sources of water in the region are the Chirchik-Akhangaran and Syrdarya rivers.

In the regions where the research was conducted, the mechanical composition of the soil, its physical, hydrophysical, physico-chemical and other properties were studied. Accordingly, the soils of the first experimental field (Kibray district) consist of a mechanically heavy clay layer 1.0 m thick, and the soils of the second experimental field (Middle Chirchik district) consist of medium—loamy loamy soils (Fig. 1).

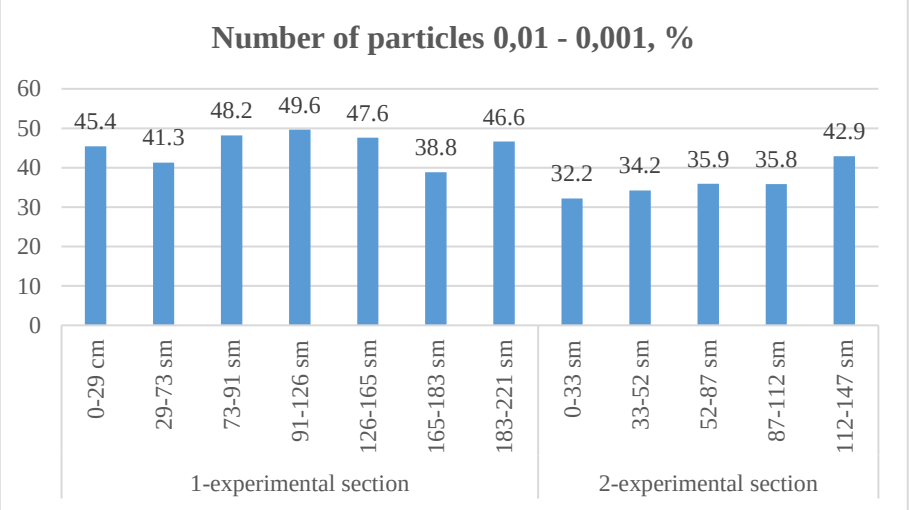


Figure 1: Mechanical composition of the soil in the experimental plots.

Cultivated soils are assessed on a quality scale (bonite scores) from 60 to 65. The average water permeability is average. The average porosity of the soils is 45-47%, and the natural moisture in the soil layer ranges from 18 to 23.5% relative to the soil mass. Water consumption by agricultural crops varies during the growing season, depending on the stages of plant development. The time of water consumption depends on the biological characteristics of each crop. The water requirement rate for cereals, cobs, legumes and similar crops per hectare is determined by the following formula:

$$M = 100 * a * h * (W_{\max cap.} - W_{pre\ irr} + k. \quad (1)$$

When calculating the seasonal water balance of agricultural crops in a village, factors such as the intensity of transpiration, evapotranspiration, the need for water at different stages of plant growth, agrotechnical techniques and climatic conditions play an important role. Calculations are based on evapotranspiration (ET method). This method is based on the Penman-Monteith, Blaney-Criddle and Hargreaves formulas recommended by the FAO for determining the total evaporation of moisture from the surface of plants.

$$ET_c = ET_0 * K_c \quad (2)$$

Here: ETc is the actual water consumption of the crop (mm), ET0 is the base evaporation (mm), Kc is the culture coefficient (varies depending on the stages of active growth).

The method of determining the soil moisture balance (water balance equation) includes the calculation of soil moisture deficiency.

$$W_1 + P + I = ET + R + D + W_2 \quad (3)$$

In this regard: W_1, W_2 - soil moisture at the beginning and end of the season; P - precipitation; I - volume of irrigation water; ET - seasonal evaporation; R - radiation of the soil surface; D - drainage losses. In addition, there are methods based on determining biomass production depending on the seasonal water supply of crops, calculations based on lysimetric

measurements, methods based on aerodynamics and energy balance, and the Penman-Monteith method is currently widely used. When determining the total volume of water supplied to plants (evapotranspiration), adjustments are made based on coefficients affecting the reflection of soil moisture by plants and climatic conditions. Taking these coefficients into account, the total volume of water (mm) is determined as follows.

$$ET = k_b\, k_0\, ET_0 \qquad (4)$$

At this point: k_b is the biological coefficient expressing the influence of plants; k_0 is the microclimate coefficient; ET_0 is the potential evaporation, mm. There are several methods for determining the water balance and evapotranspiration of crops in our climatic conditions. Among them, the widely used method based on the simplified formula of A.M. and S.M. Alpatiev for calculating water consumption and evapotranspiration belongs to N.N. Ivanov.

$$ET_0 = \sum d\omega \qquad (5)$$

Where: ET_0 - evaporation, mm; KPR - coefficient has 0.61-evaporation per year ratio; $\sum d\omega$ is the sum of the air humidity deficit for the billing period, mm. Determining the order of irrigation of crops using the cropwat and aquacrop programs developed by the International Food and Agriculture Organization of the United Nations (FAO).de: ET0 - evaporation, mm; KPR - coefficient has 0.61-evaporation per year ratio; $\sum d\omega$ is the sum of the deficits:

$$W_{r,t+1} = W_{r,t} + (P - RO) + I + CR - E - T_r - DR \qquad (6)$$

Here: P is the amount of precipitation; RO is evaporation from the surface of reservoirs; CR is the capillary rise of groundwater; E is moisture retention from the soil surface; Tr is plant transpiration; DR is deep filtration; $W_{r.t.}$ is the amount of water in the active layer. In our experiments, we determined that the total water consumption of a crop using the field water balance method is:

$$E = AP + W + M + W_{gr} + W_{sisi} \qquad (7)$$

In this part: E is the total water consumption due to evaporation; AR is the amount of water used due to transpiration; A is the coefficient indicating how much water is used from the leaf; R is the amount of natural water; W is the amount of moisture used by the root layer of the plant; W = Wi — Wk is the amount of moisture, used at the beginning and end of the growing season; M is the irrigation coefficient; W_{gr} is the amount of soil water used; W_{sis} is the water consumption for irrigation. Measures to increase soil fertility are divided into agrotechnical and agro-reclamation. In the accumulated irrigation experience, methods of using intensive irrigation to prevent erosion of water resources and irrigation systems, as well as elements of the organization, sequence and technical methods of irrigation have been studied. If 3.0 cm of water accumulates in a measuring vessel at a flow rate of 0.218 l/sec or 13.08 l/min, then if there are 25 intensive irrigation sites in the 4x2.5 scheme, this will amount to 5.45 l/sec or 0.21 m^3 per minute (figure 2).

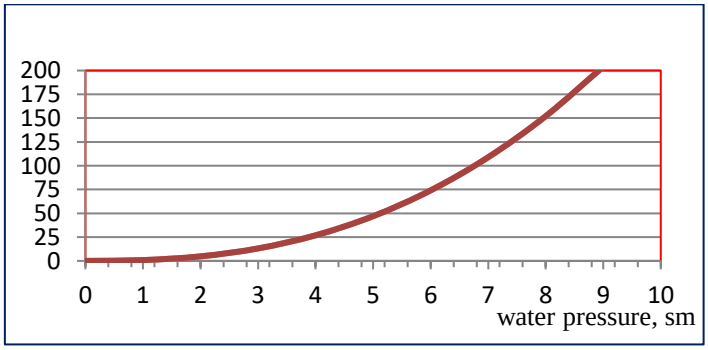


Figure 2. Water flow through the Thomson water meter 90⁰, l/min

At the experimental site, in the control version, the number of irrigations was 4 times, and the average irrigation rate was 650 m^3/ha, while seasonal water consumption averaged 2,580 m^3/ha per year. In the same experimental site, in the 3rd variant, where fruit trees received moisture to a depth of 0.8 m on loamy soil, the number of irrigations was 5 times, and the average seasonal water consumption was 2220 m^3/ha. In the 4th variant, that is, in the variant where the soil received moisture to a depth of 0.5 m on loamy soil, irrigation was carried out 6 times, and the total water consumption was 1970 m^3/ha.

In the area of Middle Chirchik, when processing two experimental plots in alluvial soils, apple orchards were intensively grown using an irrigation system that ensures the moisture content of soil layers 0.5-0.8 and 1.0 meters thick at the level of 75-80-70% of the field moisture capacity. As a result of the study, the influence of irrigation methods on the yield and seasonal water consumption of apple orchards was studied. The soil moisture content at a depth of 1.0 m is precisely controlled at the level of 75-80-70%, with 14 waterings, an average interval of 9-10 days between waterings and an annual water consumption of 1200 m^3/ha. In the monitoring variants, these indicators are slightly lower, namely: in the variant with a soil moisture content of 0.8 m, with precise watering, irrigation rates were 60-90 m^3/ha, the average interval of 8-9 days between watering and annual water consumption of 1020 m^3/ha (Fig. 3).

In experiment 1, conducted in Kibray district, the influence of irrigation methods and elements of irrigation equipment on apple yields was studied. The control group, in which moisture was provided on the calculated soil layer with a thickness of 1.0 m, showed an increase in yield by 70-70-65% compared with the traditional irrigation method using conventional seeders. Over 3 years, the average fruit yield was 23.4 tons per hectare, with each fruit weighing an average of 106 g. The variants irrigated using transverse barrier trays with moisture applied to the calculated 0.8 and 1.0 m thick layers showed higher average fruit weight — 124 g, 132 g, 109 g — and yields of 24.8, 30.7 and 29.0 tons, respectively (Fig. 4).

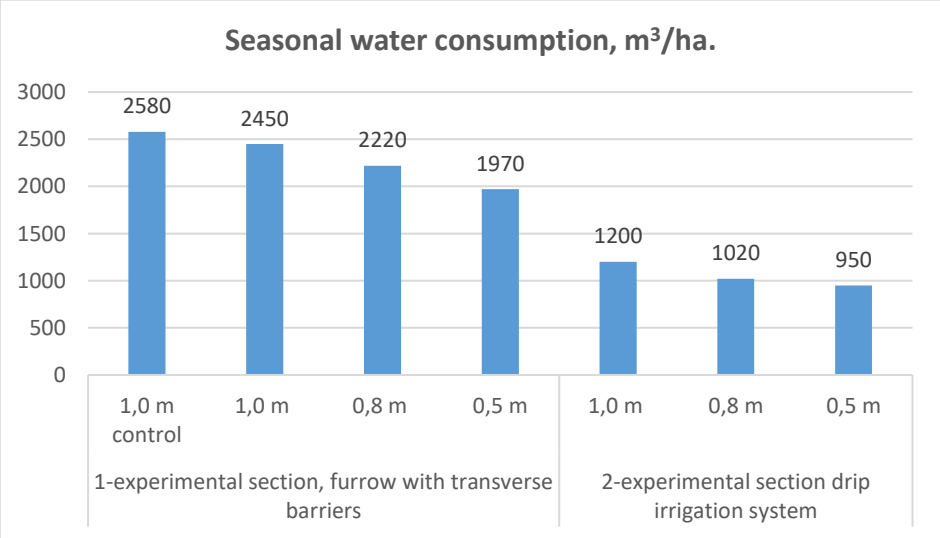


Figure 3. Seasonal irrigation rate in experimental fields, m^3/ha

In the 2nd experimental field in the conditions of meadow alluvial soils of the Tashkent region, the flowering period of the Golden apple tree occurred in the third decade of April and the first decade of May. Lowering the air temperature below 12 °C during the flowering period of apple trees negatively affects the development of flower buds, causing a delay in their opening, In the 2nd experimental field, in the conditions of meadow alluvial soils of the Tashkent region, the flowering period of the Golden apple tree fell on a third of the year. In Option 2, where irrigation

was carried out with 0.8 m of the calculated soil layer, the yield averaged 35.2 t/ha, the weight of one apple averaged 114.3 g. This indicator was 3.8 t/ha and 8.6 g compared with option 3, where irrigation was carried out with 0.5 m of the calculated soil layer, 1.0 m of soil layer was observed at 7.1 t/ha and 14.6 g higher than that of the control variant, irrigated with provision (Fig.4).

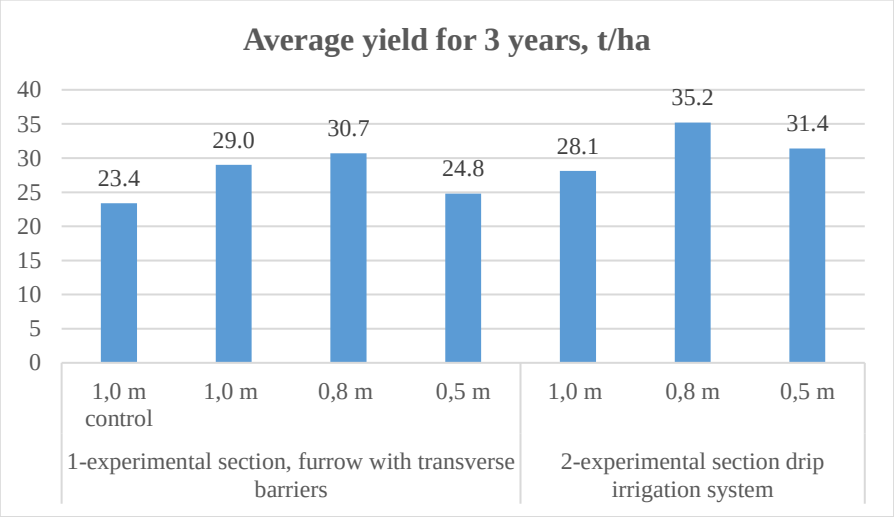


Figure 4. Average yield in experimental plots for 3 years, t/ha

When the seasonal water consumption of fruit orchards was determined in the experimental field (on typical sierozem soils with groundwater located at a depth of 15 m or deeper), plants in the control treatment (conventional furrow irrigation) used 18.0% of the soil moisture reserves. In Treatment 2, where irrigation was carried out using furrows with transverse barriers, wetting a 1.0 m soil layer, plants utilized 16.3% of the soil moisture reserves.

Under the same irrigation method, in Treatment 3, with wetting of a 0.8 m soil layer, this indicator amounted to 15.7%, while in Treatment 4, where a 0.5 m soil layer was wetted using this method, the value reached 18.6%. In this experiment, the lowest amount of irrigation water used per 1 ton of yield (63.1 m³/t) was observed in Treatment 3, where irrigation was carried out using furrows with transverse barriers, providing moisture to a 0.8 m soil layer. In contrast, the highest irrigation water consumption (108.6 m³/t) was recorded in the control treatment, where irrigation was performed by conventional furrows, supplying moisture to a 1.0 m soil layer (Fig.5).

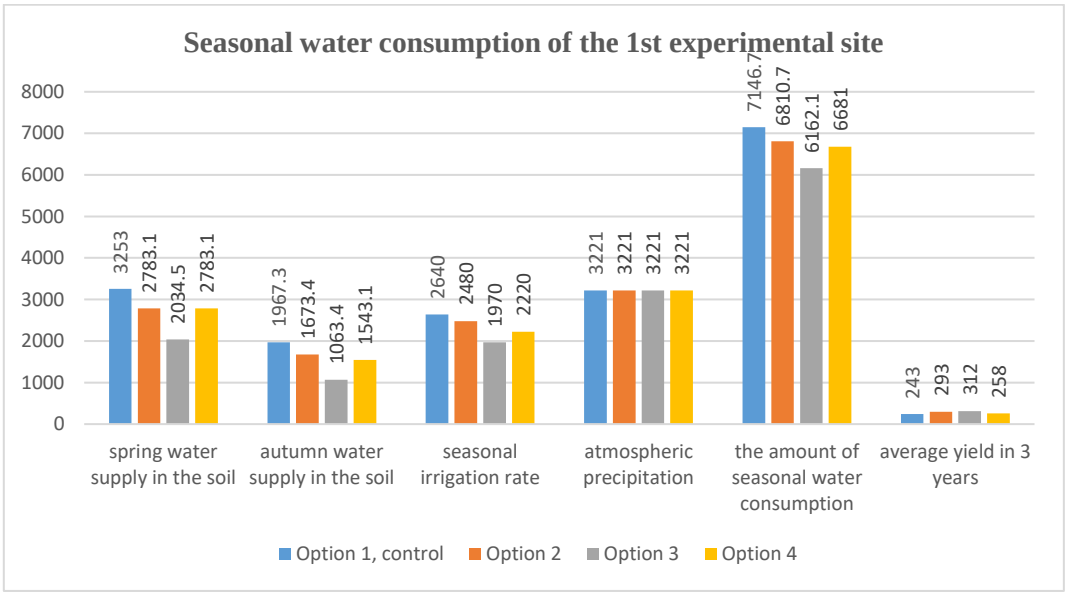


Figure 5. Seasonal water consumption by experimental field No. 1, located in Kibray district

In studies conducted under meadow–sierozem soil conditions, determination of fruit orchard water consumption in the first year of the experiment showed that the soil water permeability, bulk density, and mechanical composition had a significant influence on both water consumption and the amount of irrigation water applied. Some differences were also observed in the use of atmospheric precipitation by plants. In Treatment 1, where irrigation was applied by supplying moisture to a 1.0 m soil layer, plants utilized 54.8% of the precipitation. In Treatments 2 and 3, where the 0.8 m and 0.5 m soil layers were wetted, these values were 54.9% and 53.8%, respectively (Fig.6).

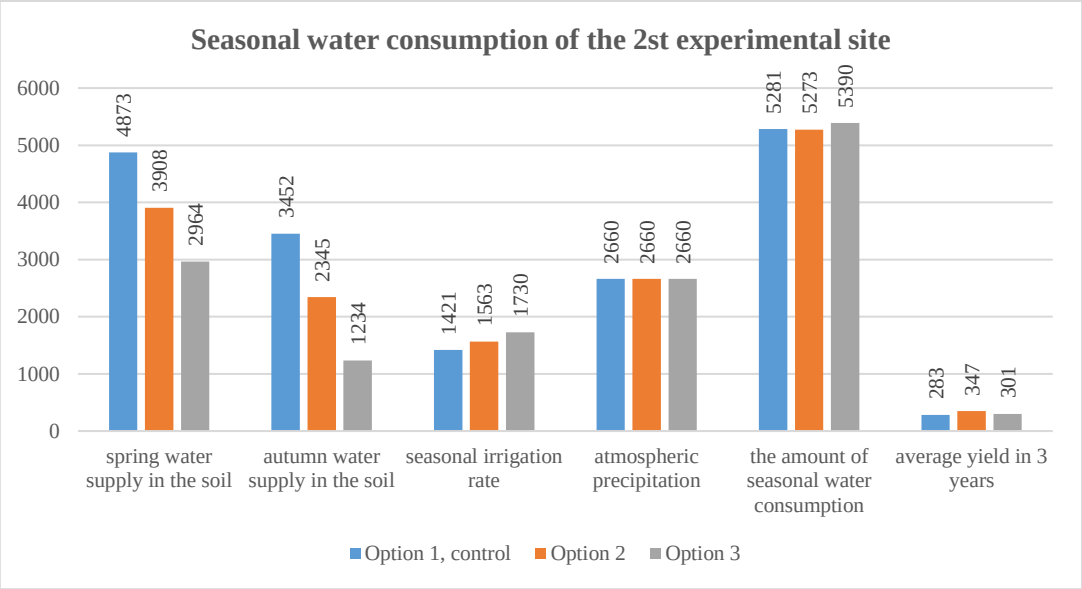


Figure 6. Seasonal water consumption by experimental field No. 2, located in Middle Chirchik district

In this experiment, to determine the efficiency of plants' use of seasonal water reserves, the amount of irrigation water consumed per 1 ton of yield was 42.4 m³/t in Treatment 1, while in Treatments 2 and 3 this indicator amounted to 30.3 m³/t and 33.2 m³/t, respectively.

Discussion. According to Clause 12 of the Presidential Decree of the Republic of Uzbekistan No. PF-36 dated February 16, 2024 "On additional measures to ensure food security in the Republic," tasks were assigned to develop high-yield, disease- and drought-resistant local varieties of key vegetable crops, establish seed production, adapt agriculture to global climate change, implement No-Till technologies on rainfed and water-scarce lands, and replace soil salinity leaching practices with biological methods.

According to the National Statistics Committee of the Republic of Uzbekistan, in January–March 2024, the volume of agricultural production amounted to 42,360.4 billion UZS, or 103.6% compared to the corresponding period of 2023, including crop production – 2,890.9 billion UZS (104.4%) and livestock production – 39,469.5 billion UZS (103.6%). The highest volumes of agricultural production were recorded in Samarkand (5,531.8 billion UZS), Tashkent (4,995.0 billion UZS), and Bukhara (4,038.7 billion UZS) regions. High growth rates were recorded in Namangan (104.4%), Navoi (104.4%), and Syrdarya (104.2%) regions. According to committee data, 86.1% of total agricultural food production is produced by farmer and household farms, 8.8% by farmer enterprises, and 5.1% by agricultural organizations.

Conclusions. When intensive apple orchards are irrigated using water-saving technologies (drip irrigation, furrow irrigation, furrows with transverse barriers, as well as furrow irrigation combined with black polyethylene mulch), the efficiency of tree water use from soil moisture,

atmospheric precipitation, and irrigation water increases. As a result, seasonal water consumption can be reduced by 12% to 52% compared with conventional furrow irrigation. Under the conditions of the Republic's irrigated typical sierozem, meadow alluvial, and light-colored sierozem soils, drip irrigation of intensive apple orchards, compared with the traditional method, reduces seasonal water consumption by up to 52%, decreases irrigation erosion processes by 100%, and ensures an increase in apple yield of 12.3 t/ha.

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