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Water Saving with Combined Irrigation Methods

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Abstract: In the conditions of arid zones of irrigated agriculture, during the cultivation of horticultural and other crops, high air temperatures (over 25-30ºC) and low relative humidity (less than 20-30%) are observed during the vegetation period of plants. In these circumstances, the combined irrigation method using drip irrigation and sprinkling allows optimizing the use of water during drip irrigation at air temperatures below 25-30ºC and improving the microclimate through sprinkling at air temperatures above 25-30ºC. The study aims to determine the effect of the combined irrigation method on the microclimate, water regime of plants, and water productivity compared to the drip irrigation system. The key research method employed is a field experiment conducted on a specially allocated plot of land to establish differences between the two methods of irrigation. The field experiment presupposes an exploratory study and quantifies the effect of the new technology of irrigation of apple trees to objectively justify the implementation of this scientific development in agricultural production. The combined method of irrigation provides a decrease in air temperature by 1.5-2.1°C and increases air humidity by 10-17% in the surface air layer, improving the water regime of plants and increasing the apple yield by 10.7-17.9% against drip irrigation, while reducing water consumption per production unit by 4.0-10.1%. The method of combined irrigation is thus recommended for use in the arid zone of irrigated agriculture.

Keywords: Combined Irrigation Method, Technical Equipment, Apple Orchard, Research, Irrigation Water Productivity

Introduction

In arid zone conditions, which conventionally include geographical areas with low humidity, farming is possible only with artificial humidification. The climate of arid zones is characterized by high air temperatures with large daily fluctuations and small amounts of precipitation (about 100-200 mm) or complete lack thereof.

The basis of effective irrigated farming in such conditions is the best possible conservation of water and its productive use (FAO, 2018).

Regarding the applicability of irrigation methods in such zones, irrigated agriculture mainly uses the following five methods of irrigation: Surface irrigation, drip irrigation, conventional periodic sprinkling, fine sprinkling, and subsurface irrigation.

The technologies of surface irrigation and conventional sprinkling, which are based on the periodic accumulation of water in the soil, provide intermittent introduction and expenditure of water with great amplitude. Meanwhile, the manner of distribution of water by these methods causes overwatering of the active soil layer after irrigation and a lack of moisture at the end of the inter-irrigation period. Such a regime of water supply leads to stressful situations in the development of plants, which ultimately reduces their productivity.

Drip and subsurface irrigation ensure optimal soil moisture, yet the problem of the microclimate, which determines the yields of crops, remains unaddressed. These types of irrigation are not effective enough in conditions of high air temperatures (above 25-30°C) and low humidity. Under stressful conditions, the growth of several crops slows down and the process of photosynthesis drastically decreases, which affects yields (Ahmed Mohammed *et al*., 2020).

Optimal conditions for crop development in arid climate areas are created by measures aimed at maintaining an optimal water regime of soil and plants. Such a plant regime can be achieved only if the soil and environment (air) are sufficiently moist. These conditions can be created by fine-dispersed sprinkling. This type of sprinkling provides an optimal water regime in the soil, as well as improves the microclimate in the environment of plant development by reducing air temperature and increasing its humidity (Angold *et al*., 2016).

Analysis of information on the state of irrigated agriculture and the applicability of irrigation methods in the world shows the following.

According to the Food and Agriculture Organization of the United Nations FAO (2020), irrigated agriculture accounts for more than 70% of global water withdrawals (2019-2020). In the meantime, a high and even very high level of water stress is observed on 171 million ha (62% of the total irrigated arable land area), with total water withdrawals exceeding 50% of renewable water resources FAO, (2020). In this context, the highest priority should be given to encouraging those methods of agricultural practice that improve water productivity. This includes the rehabilitation and modernization of existing irrigation infrastructure and the introduction of innovative technologies.

Of the total number of countries in the world, eleven countries located in Asia and North Africa face a double problem: Both the frequency of severe droughts and the level of water stress are high there. These countries include Yemen, Saudi Arabia, Uzbekistan, the Syrian Arab Republic, Afghanistan, Iran, Egypt, Morocco, Pakistan, Kazakhstan, and Turkey. In nine out of these eleven countries, 100% of irrigated land suffers from high or very high-water stress. In Kazakhstan, the share of such lands is 80%, and in Turkey–72%. In these countries, it is critical to ensure proper accounting of water resources and their clear allocation, the introduction of modern technologies, and a transition to less water-intensive crops requiring less irrigation FAO (2020).

Low water efficiency is noted in surface irrigation of apple trees on the Loess Plateau in China. Here, the fruit quality and yield of apple trees depended on the amount of water supplied, taking into account the phases of apple tree development (Zhong *et al*., 2019).

Studies on the effects of different irrigation methods (drip irrigation, sprinkling, and surface irrigation) on growth, fruit quality, and yield of 9-year-old Fuji/Malus robusta Yanfu 10 apple trees show that drip irrigation and sprinkling increase yield by 12.1 and 8.2%, respectively, compared with surface irrigation. Surface irrigation methods require large quantities of water to keep apple orchards irrigated. A comparison of the effectiveness of sprinkling, surface drip, and subsurface drip irrigation methods on water use efficiency, tree growth, and yield of Fuji apple trees on the M9 rootstock demonstrates that the method of subsurface drip irrigation consumes 37 and 27% less irrigation water compared to sprinkling and surface drip irrigation, respectively. With subsurface drip irrigation, there is less sunburn and fewer weeds compared to sprinkling and surface drip irrigation. This method can be used as an effective approach to reduce the amount of irrigation water in apple orchards and minimize weed growth (Chen *et al*., 2018).

Subsurface irrigation of cotton in West Texas, USA, has been shown to improve water use efficiency in the face of scarce groundwater supplies (Lamm *et al*., 1995).

The applicability of subsurface irrigation of crops has been proven in Australia. However, this method is noted to have high economic costs (Finger *et al*., 2015).

Drip irrigation and sprinkling in the Mediterranean region of Turkey have provided an acceptable increase in crop yields and quality is given water-stressed conditions (Sezen *et al*., 2011).

Sprinkling creates an optimal water regime in the soil, as well as an improved microclimate in the environment for plant development by lowering air temperature and increasing air humidity (Kalashnikov *et al*., 2017).

Sprinkler irrigation is the preferred method of irrigating tree crops in the United States because it offers a higher degree of frost protection than drip irrigation (Boman *et al*., 2012).

Regarding the technologies of sprinkling, we should note the following. Although all types of sprinkling, in particular, the conventional periodic sprinkling, do improve the microclimate of land plots in which they are used, the level of these favorable changes is not always sufficient to provide high productivity for plants.

Conventional sprinkling provides a periodic accumulation of water in the upper layers of the soil; it moistens not only the soil but also the plants. Frequent irrigation in small portions affects the microclimate of the surface air layer during irrigation, improves the water regime of plants, and increases the productivity of crops. In this, improvement of the microclimate mainly occurs during irrigation and within one or two days after watering (Angold *et al*., 2016).

Pulse sprinkling enables a daily continuous supply of water to plants and soil and allows the creation of the necessary microclimate in the environment of plant development and activates the physiological processes of plants in conditions of high air temperature and low humidity (Angold and Zharkov, 2014; Kalashnikov *et al*., 2020a, 2020b). Compared to conventional sprinkling, this method of sprinkling raises the productivity of crops to 120-180% and reduces water consumption per unit of production by 30-40%.

Fine (aerosol) irrigation involves periodic wetting of plant leaves and stems with small doses of fine water particles, thus reducing air and plant temperatures and enhancing plant photosynthesis. The technology of fine-dispersed sprinkling is intended for the irrigation of crops cultivated in the open field and film and winter greenhouses. Fine-dispersed irrigation of pear orchards in the Kabardino-Balkarian Republic contributed to the improvement of the microclimate and an increase in the growth of annual shoots and yields. The yield increases totaled 57.2 q/ha compared to the unirrigated plot (Khazhmetov *et al*., 2006).

Analysis of the advantages and drawbacks of the considered methods of crop irrigation gives grounds to suggest that to provide flexible regulation of the environment of plant growth in the face of high temperatures and low air humidity, it is advisable to use a combined method of irrigation using drip irrigation and sprinkling.

At the moment, the combined irrigation method is applied in Russia and Kazakhstan.

For combined irrigation (a combination of drip irrigation and fine sprinkling) to reduce temperature stress and increase moisture on the soil surface, Russia has developed the BAU-1 m set, which includes a spray nozzle system of combined irrigation for the cultivation of vegetable crops and a dripper for combined irrigation. The proposed technical solutions for a combined irrigation system allow to increase the operational reliability of the system, provide plants with soil moisture, and make it possible to regulate the temperature and nutrient regime of plants, which allows for obtaining a stable crop yield and ensuring environmental safety (Melikhova, 2019).

The effectiveness of combined irrigation (drip irrigation with fine sprinkling) on the crops of sugar corn, bell pepper, and strawberry is confirmed in the conditions of the Volgograd region (Russia). The technology ensured the production of two fully formed cobs on sugar corn plants, the yield of sweet peppers averaging 60.8 t/ha, in contrast to 56.3 t/ha with drip irrigation, and a 12.3% increase in strawberry yield (Ovchinnikov *et al*., 2015).

The research aims to assess the impact of the combined method of irrigation with drip irrigation and sprinkling on the microclimate, plant water regime, and water productivity in an apple orchard in a region with high daytime air temperatures and low humidity.

Materials and Methods

Research on the combined drip-sprinkling method of irrigation in comparison to drip irrigation was conducted at the experimental production plot of the fruit orchard of the Kazakh Scientific Research Institute of Water Economy (Taraz, Republic of Kazakhstan) in 2016-2018. The land plot is occupied by apple trees of the variety Golden Delicious on low-growing rootstock MM106 planted in 2007 with the 3.0 × 2.5 m scheme of planting.

The climate of the area under study is characteristically continental, which is typical of Southern Kazakhstan and owes to the influence of deserts on the one hand, and high mountains on the other. This continentality is expressed by frequent and abrupt changes in daily and annual air temperatures, rather severe and relatively short winters, and long, sultry, and extremely dry summers. According to climatic characteristics, high air temperatures (up to 43°C) with an average relative humidity of 30.7-49% were observed in the studied area during the growing season of apple trees. The average annual precipitation in the region is 287 mm, including 168 mm during the growing season.

The soils of the experimental-production area in terms of mechanical composition consist of medium loams containing 17.7% of sand, 27.7% of clay, and 54.6% dust. The content of organic matter amounts to 0.88%. The density of soil is 1.36 g/cm^3 in the 0-50 cm layer and 1.46 g/cm^3 in the 0-100 cm layer. The lowest moisture capacity of the soil layer in the 0-50 cm layer is 19.6% of dry mass, and that of the 0-100 cm layer is 19.08%. The soils are not saline (the sum of salts does not exceed 0.114 g/L). According to the morphological description of soil sections, pebbles appear from a depth of 60-70 cm, which indicates the need to use water-saving technologies, such as drip irrigation and low-intensity sprinkling, to irrigate fruit crops on the site.

On the experimental-production plot, the following technological schemes (versions of the experiment) of apple-tree irrigation were studied:

Version 1: Drip Irrigation (DI)
Version 2: Drip-Sprinkling Irrigation (DSI)

The experiments were carried out with four repetitions. The research was short-term and continued for 3 years. Studies on the different versions of the experiment were conducted at the same time. When air temperature was under 25-30ºC, the irrigation schedule in the versions of the experiment was the same. With air temperatures higher than 25-30ºC, additional sprinkling was carried out in version 2 to improve the microclimate in the development environment of apple trees. The physical and water-physical properties of soils were determined at the beginning of vegetation. Readings of the GGI 3000 evaporometer, which measures evaporation from the water surface and atmospheric precipitation, as well as meteorological observations, were registered daily. Observations of the microclimate were performed for 3-5 days during the period with high daytime air temperatures. Observations of the growth of annual shoots of apple trees, bole circumference, and tree height were carried out every ten days. The amount of water supplied to the plots was monitored daily by water meters. Soil moisture readings on moisture sensors were taken daily. Soil moisture was monitored every ten days by the thermostat-weight method. Observations of the water regime of apple trees were performed on days with daytime air temperature over 25ºC. The timing of apple tree yield records was determined by the degree of apple ripening. The principle of experiment repetition was based on the presence of four plots within four repetitions to eliminate the influence of random factors on the results of the experiment. The planning of the experiment was carried out with consideration of the specificity of experiments with fruit trees (Dospekhov, 1979). The studies were conducted on a drip and drip-sprinkling irrigation plots with an area of 210 m^2 proceeding from the placement of 28 trees on each variant. Each tree was to have a water outlet that would provide both drip irrigation and sprinkling.

The technologies of drip irrigation and drip-sprinkling irrigation in the different versions of the experiment were realized with the technical means of irrigation systems (Zharkov *et al*., 2012a, 2012b) having water intake points with pressure-generating devices, command pulse generators, distribution pipelines, irrigation pipelines with water outlets, and additional pressure-generating devices with air temperature sensors (Fig. 1a).

Water outlets in irrigation systems have outlets for drip irrigation when the main pressure generator is operating and sprinkler nozzles operating when an additional pressure generator is connected. To ensure a constant volume of water supply to the plants, the water outlets are equipped with waterproof elastic balls, which, when compressed, accumulate water in their bodies (Fig. 1b).

The irrigation system (Fig. 1a) operates in the following way. When water is supplied from the water intake point (1) By the pressure generator (2) Through the command pulse generator (5), The distribution (6) And irrigation (7) Piping and water outlets (8) Are filled with water. The hull (13) Of the water outlet (Fig. 1b) is filled with water through the inlet of the cover (10) As the unilateral sleeve (11) Moves towards the adapter (12). Skirting the edges of the Sleeve (11), Water goes into the hull (13), Squeezing the waterproof elastic ball (15). The hull (13) Is filled up to the set parameters while the water outlet to the atmosphere through the adapter (12) Is shut off. The adapter (12) Has a spring-loaded sprinkler nozzle (17) And a drip (16), which can be connected to the irrigation tube with several additional drips.

Once the body (13) Of the water outlet is filled, a depressurization pulse is sent to the pipeline network by the command pulse generator (5). Due to the difference in pressure in the body (13) of the outlet and the pipeline network, the sleeve (11) Moves towards the cover (10). Water from the hull (13) Flows into the adapter (12) And then through the drip chamber to the atmosphere. Drip irrigation is carried out.

With air temperatures above 25oC, the air temperature sensor (4) (Fig. 1a) connects an additional pressure generator (3) Of the irrigation system. Water is supplied to the network of irrigation pipelines and outlets with the pressure of pressure generators 2 and 3. Increased pressure is created in the body of the water outlet (13). Once the body of the water outlet (13) (Fig. 1b) is filled up, a depressurization pulse is sent to the pipeline network. As the sleeve (11) Returns to the starting position, water from the hull of the water outlet (13) Goes into the adapter (12) And then to the atmosphere, as the spring of the sprinkler nozzle (17) Is released. Sprinkling is performed. With the further decrease of pressure, the sprinkler nozzle returns to its initial position, and the remaining water is supplied to plants through the drip (16). The process of irrigation continues in the same manner.

In this, version of drip irrigation during the vegetation period of apple trees, the main pressure generator is the only one working. In the version of drip-sprinkling irrigation, water is supplied to the irrigation system by the main pressure generator during drip irrigation and with the additional pressure generator during sprinkling.

Soil moisture in the 0-50 cm layer (the layer where the root system of apple trees is mainly located) on the experimental-productions sites in the two versions was maintained at the level of 75-80%. Soil moisture readings were taken by soil moisture sensors.

Daily water supply to the experimental plots was established based on daily consumption of water by apple trees per meteorological factors according to the GGI 3000 evaporometer assessing evaporation from the water surface and atmospheric precipitation and recalculated to actual irrigated areas. When applying irrigation rates to the variant of drip-sprinkling irrigation, irrigation water consumption for the formation of the microclimate was considered.

Combined irrigation was carried out with drip irrigation during the growing season with air temperatures below 25°C and with additional low-intensity sprinkling introduced during the daytime hours with air temperatures above 25°C and relative humidity less than 20-30%. Both in plots with drip irrigation and combined irrigation, watering through water outlets accounted for the area of soil moistening based on the radius of irrigation zones. The irrigation area in the two versions of the experiment was calculated by summing up the irrigation areas of all water outlets. On the drip irrigation plot, the plants were watered through water outlets throughout their vegetation period.

The research process also involved the assessment of changes in air temperature and humidity, which affect the conditions of plant growth and development during periods with air temperatures over 25°C and humidity below 20-30%, as well as indicators of plant water regime, apple tree yield, and irrigation water consumption per unit of production.

Meteorological observations and microclimate observations were made on special sites located within the contours of moistening of the soil by technical irrigation means. Observations of air temperature and humidity were carried out using aspiration psychrometers, hygrographs, and thermographs at 0.5 m from the soil surface.

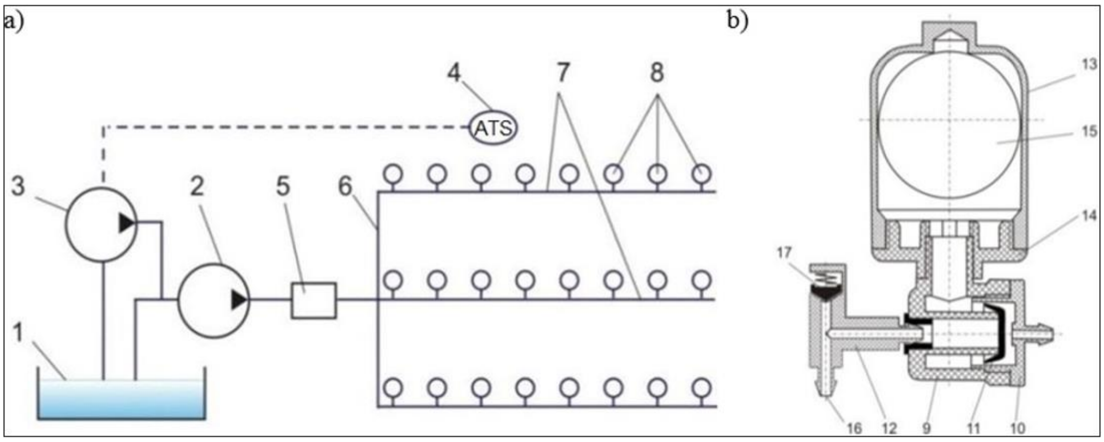

Fig. 1: Drip and drip-sprinkling irrigation systems (a) scheme of the irrigation system; (b) water outlet). 1–Water intake point; 2-Pressure generator; 3-Additional pressure generator; 4-Air temperature sensor; 5-Command pulse generator; 6-Distribution piping; 7-Irrigation piping; 8–Water outlets; 9-Hull; 10–cover; 11-Unilateral sleeve; 12–Adapter; 13-Hydraulic accumulator; 14–Cover; 15-Waterproof elastic ball; 16–Drip; 17–spring-loaded sprinkler nozzle

To characterize the water regime of apple trees, we assessed water content in the leaves of apple trees, the intensity of leaf transpiration, water absorption, and the deficit of the relative turgescence of the leaves according to the conventional methodology (Miller, 1973).

The growth of annual shoots of apple trees, trunk circumference, and tree height was determined for all the studied trees.

The yield of apple trees was determined by the method of continuous counting by weighing fruits from all trees from the studied land plots.

The volume of water supplied to the experimental sites was controlled by water meters. Water for the pressure generators was supplied from a pipeline network connected to a storage tank.

Statistical analysis of experimental data was performed using the analysis of variance by the method of B. A. Dospekhov (1979). The method involved the analysis of data for every year and total yields for the entire period of the experiment by variants of the experiment taking into account the performed repetitions. Calculations were performed using the Excel computer program.

Results

The conducted experiments establish that for medium loam soil, the area of moistening by water outlets in the variants of the experiment equals 1.33 m^2 with the radius of the soil moistening contour being 0.65 m. With 28 water outlets for land plots of 210 m^2, the area of irrigated land in the experiment versions was 37.20 m^2. The regime of water supply was adjusted depending on the moisture content in the root-containing layer of soil in the wetting zone at a distance of half the radius of the contour of moistening by the technical means of irrigation.

Observation of the temperature and relative humidity of air in the ground layer on a per diem basis reveals that the greatest change in these values both with drip and drip-sprinkling irrigation is observed between 1 and 5 p.m. Figure 2 and 3 show the dynamics of changes in the temperature and relative humidity of air at a height of 0.5 m from the soil by the variants of the experiment.

During daytime hours, the difference in air temperature between the options of drip-sprinkling irrigation and drip irrigation is found to reach 2.1°C in the surface air layer, and the difference between the values of air humidity amounts to 17%. It should also be noted that in the version of drip irrigation (version 1), the dynamics of microclimate indicators are more steady in contrast to the drip-sprinkling method, which is explained by only one method of irrigation being used. Additional sprinkling carried out on the drip-sprinkling irrigation plot during the strenuous period of apple trees' vegetation has a positive effect on the water regime, growth, and development of plants.

The results of observations of water content in apple-tree leaves by experimental variants shown in Fig. 4 demonstrate that water content in leaves on the drip-sprinkling irrigation site (version 2) ranges between 68.0 and 72.2% compared to 60.0-63.8% of the drip irrigation plot, which indicates better conditions for the development of apple trees.

Additional sprinkling performed during the strenuous period of apple trees' vegetation on the drip-sprinkling plot was also beneficial for the intensity of leaf transpiration (Fig. 5). With drip-sprinkling irrigation, the intensity of transpiration of apple-tree leaves at 1 p.m. amounts to 44.0-47.2 g/m^2 per h, whereas on the drip irrigation site, it goes down to 36.0-42.2 g/m^2 per h.

It seems that the increase in the transpiration of apple-tree leaves on the drip-sprinkling plot owes not only to the stable moisture content in the root zone of plants throughout the growing season but also a rise in relative air humidity and a decrease in air temperature. Moreover, such values are observed on the drip-sprinkling site only in the period when additional sprinkling is carried out to reduce the impact of stressful weather conditions on plants. During the rest of the vegetation period, the values of transpiration by apple-tree leaves differ insignificantly across the two plots (within 1-5%).

Lack of moisture in both soil and air leads to its deficit in plant tissues, so one of the indicators of water availability in plants is the water absorption capacity of leaves. Additional sprinkling in the daytime hours of the hot period of apple-tree vegetation in the drip-sprinkling irrigation version has a corresponding effect on the microclimatic indicators in the environment of plant development and leads to a change in the indicators of water deficiency in plant tissues.

Analysis of the obtained data reveals a significant dependence of the process of water uptake by plant leaves on their supply of water.

In the conducted experiments, the lowest water absorption capacity of apple-tree leaves (reaching 0.3 g/g of dry weight) is recorded in the conditions of additional sprinkling in the drip-sprinkling version (Fig. 6).

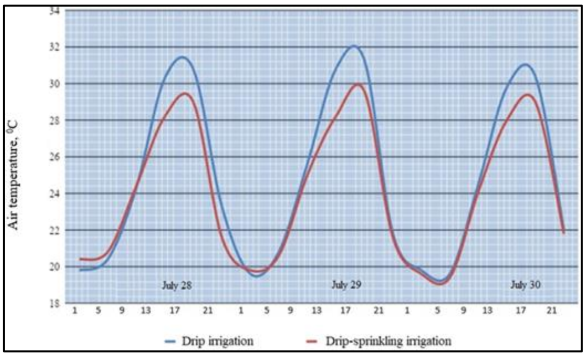

Fig. 2: Dynamics of air temperature change at 0.5 m altitude (2016)

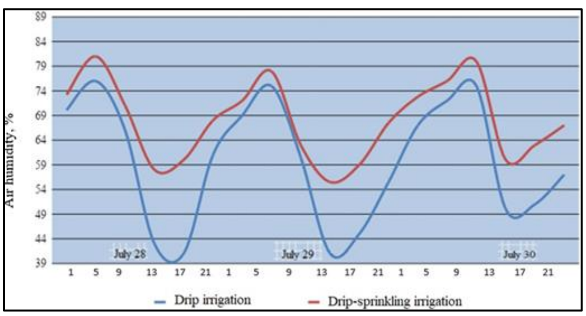

Fig. 3: Dynamics of air humidity at 0.5 m altitude (2016)

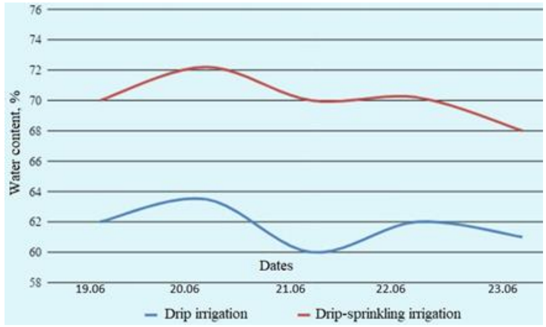

Fig. 4: Water content in apple tree leaves at 1 p.m. (2016)

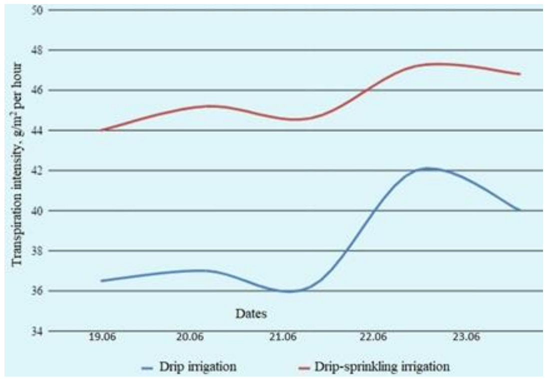

Fig. 5: Intensity of transpiration of apple-tree leaves at 1 p.m. (2016)

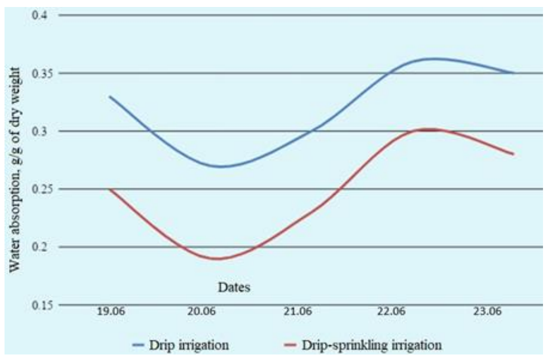

Fig. 6. Water absorption by apple tree leaves at 1 p.m. (2017)

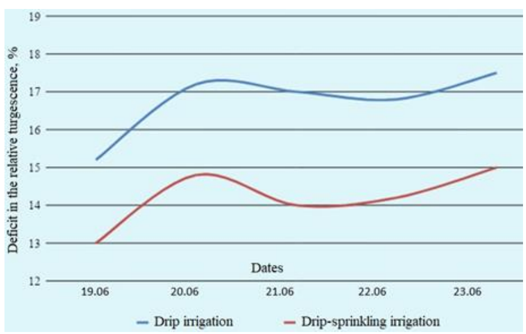

Fig. 7: Deficit in the relative turgescence of apple tree leaves at 1 p.m. (2017)

Table 1: Irrigation rate by versions of the experiment

Year of study	Experiment version	Readings of the GGI 3000 evaporometer	Irrigation rate, m^3/ha	Water consumption for the formation of a microclimate, m^3/ha	Irrigation rate including water consumption for the microclimate, m^3/ha
First	DI	5,186	861	-	861
	DSI	5,186	861	44	905
Second	DI	5,790	961	-	961
	DSI	5,790	961	58	1,019
Third	DI	4,327	718	-	718
	DSI	4,327	718	36.0	754

Table 2: Apple orchard yield, irrigation water consumption, and water productivity per production unit

Year of study	Land plot	Apple tree yields, q/ha	Irrigation rate including water consumption for the microclimate, m^3/ha	Water productivity per production unit, m^3/q
First	DI	172.1	861	5.00
	DSI	196.5	905	4.60
Second	DI	165.5	961	5.80
	DSI	182.9	1,019	5.57
Third	DI	180.5	718	3.98
	DSI	212.8	754	3.54

Another indicator of apple tree leaf watering is the deficit of relative turgescence, which indicates how much water is lacking for the leaves to reach their turgescent state.

Experimental data show that the deficit of relative turgescence in the midday hours reached 15.0% in the variant of drip-sprinkling irrigation and 17.6% in the variant of drip irrigation (Fig. 7).

Thus, the amount of water required to fully saturate the leaves of apple trees with water under drip-sprinkling irrigation is less than under drip irrigation.

Therefore, the experimental data suggest that the indices of plant water regime in the conditions of additional sprinkling during the hot period of vegetation in the variant of drip-sprinkling irrigation are better than in plants watered by drip irrigation. This observation applies to the indicators of water content in apple-tree leaves, their transpiration rate, the level of water absorption by the leaves, and their deficit of relative turgescence.

Improved parameters of the microclimate and the water regime of plants result in additional growth in annual shoots by 9.0-12.8%, in the circumference of apple tree boles by 9.6-10.8%, and in tree height by 6.8-9.8%.

Irrigation rates by years of study with 1,248 apple trees per 1 ha are determined according to the readings of the GGI 3000 evaporometer with a recalculation of the actual irrigated area. The actual irrigated area with 1,248 water outlets per 1 ha, determined by summing up the areas irrigated by each water outlet, is 1660 m^2.

Irrigation rates by the versions of the experiment, taking into account the consumption of water for the formation of a microclimate in the version of drip-sprinkling irrigation during high air temperatures (25°C and more) by years of research are shown in Table 1.

Differences in water consumption for the formation of the microclimate and off-site drift in the case of fine-dispersed sprinkling result from varying meteorological conditions at the time of irrigation.

Data on the yields of apple orchards, irrigation water consumption, and water productivity per production unit are shown in Table 2.

The yield of apple trees on the drip-sprinkling irrigation plot is found to be 10.7-17.9% higher than that on the drip irrigation plot.

It is also worth noting that on the site with drip-sprinkling irrigation, the average fruit weight exceeded the weight of fruit from the drip irrigation plot. Specifically, the average weight of fruits from the drip-sprinkling irrigation plot amounts to 142 g, while fruits from the drip irrigation plot do not exceed 135 g Furthermore, the weight of individual fruits on the lower branches of trees watered by the drip-sprinkling method reaches 179-184 g, while fruits on the site of drip irrigation are no heavier than 149 g.

The drip-sprinkling irrigation plot also demonstrates higher productivity of irrigation water when assessing its cost per unit of production. In the first year of research, the reduction of water costs per unit of production amounts to 0.4 m^3/q, in the second year it is found to be 0.23 m^3/q, and in the third year-0.44 m^3/q. Thus, the technology of combined drip and sprinkling irrigation is water-saving and ensures a reduction of water consumption per unit of production by increasing crop yield.

Discussion

The combined method of apple orchard irrigation using drip irrigation and sprinkling combines the benefits inherent in each technology individually. The technology of drip-sprinkling irrigation in the arid zone during the period with air temperatures over 25°C in the apple orchard is found to reduce the air temperature in the environment of plant growth and increase relative humidity, provide a better water regime for plants, stimulate growth processes of apple trees, and increase the yield of apple trees and irrigation water productivity. Specifically, the combined irrigation method results in a 1.5-2.1°C decrease in air temperature and a 10-17% rise in humidity in the surface air layer, as well as an improvement of the water regime of plants and an increase in apple yield by 10.7-17.9% compared to drip irrigation with a 4.0-10.1% reduction in water consumption per production unit.

When drip irrigation and sprinkling are used separately, the following features are noted.

Drip irrigation and sprinkling in the USA in orchards with Fuji apples/Malus robusta "Yanfu 10" ensured improvement of apple trees' growth processes, enhanced fruit quality, and increased yield by 12.1 and 8.02% compared to surface irrigation. At the same time, there was an increase in leaf area by 3.0 and 1.9%, a rise in leaf weight by 5.8 and 5.1%, and an elevation of chlorophyll content by 5.8 and 5.1%, respectively (Chen *et al*., 2018).

Drip irrigation and sprinkling in Turkey under conditions of water scarcity provide increased quality and yield of crops (Sezen *et al*., 2011). Sprinkling used in Kazakhstan provides an optimal water regime in the soil, improving the microclimate in the environment of plant development by lowering air temperature and increasing its humidity, which is especially important in the arid zone (Kalashnikov *et al*., 2017). Studies in the United States find that sprinkling tree plantations in the US ensure better protection of plants from frost compared to drip irrigation (Boman *et al*., 2012).

Combined irrigation (a blend of drip irrigation and fine sprinkling) has limited application since its effectiveness has not yet been fully proven, and there are also technical difficulties with the commissioning and maintenance of such systems.

In Russia, the effectiveness of combined irrigation compared to drip irrigation has delivered two fully formed cobs on sugar corn plants, the yield of sweet bell pepper averaging 60.8 t/ha compared to 56.3 t/ha with drip irrigation, and an increase in strawberry yield by 12.3% (Ovchinnikov *et al*., 2015).

Our research gives a positive assessment of the impact of the combined method of irrigation on the microclimate, water regime of plants, and water productivity in an apple orchard represented by the Golden Delicious apple trees on low-growing rootstock MM106 planted in 2007.

Limitations of the applicability of our study include the fact that such research was conducted in the arid zone only in the apple orchard. At present, this method of irrigation can be recommended for use in orchards of this zone. The use of combined irrigation on other crops was not considered.

Conclusion

The conducted study of the combined method of irrigation using drip irrigation and sprinkling in an apple orchard establishes that during the vegetation of apple trees, to save irrigation water, with air temperatures less than 25°C, it is necessary to use drip irrigation, while in conditions of air temperatures over 25°C, additional sprinkling is required to improve microclimatic indicators. This strategy provides better microclimatic indicators in the environment of plant development, improved water regimes of plants, increased yield of apple trees, and higher water productivity per unit of production. The described method of irrigation can be recommended for use in the arid zone of irrigated agriculture in the conditions of high air temperatures and low air humidity to increase the yield of apple trees. The applicability of the method under optimal climate conditions in irrigated agriculture is limited. Further research into the combined method of irrigation is recommended to assess its effects on other crops in the arid zone of irrigated agriculture.

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Author's Contribution

All authors equally contributed in this study.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues are involved.

References

Ahmed Mohammed, M. E., Refdan Alhajhoj, M., Ali-Dinar, H. M., & Munir, M. (2020). Impact of a novel water-saving subsurface irrigation system on water productivity, photosynthetic characteristics, yield, and fruit quality of date palm under arid conditions. *Agronomy*, 10(9), 1265. https://doi.org/10.3390/agronomy10091265

Angold, Y. V., & Zharkov, V. A. (2014). Special features of drip-sprinkler irrigation technology. Water Science and Technology: *Water Supply*, 14(5), 841-849. http://dx.doi.org/10.2166/ws.2014.041

Angold, Y. V., Zharkov, V. A., Kalashnikov, A. A., & Balgabayev, N. N. (2016). Features of impulse sprinkling technology. Water Science and Technology: *Water Supply*, 16(5), 1178-1184. http://dx.doi.org/10.2166/ws.2016.037

Boman, B., Sanden, B., Peters, T., & Parsons, L. (2012). Current status of microsprinkler irrigation in the United States. *Applied Engineering in Agriculture*, 28(3), 359-366. http://dx.doi.org/10.13031/2013.41495

Chen, R., Huang, Y., Ji, X., Xu, Y., Xue, X., & Wang, J. (2018). Effects of Different Irrigation Methods on Growth, Fruit Quality and Yield of Apple Trees. *Asian Agricultural Research*, 10 (1812-2019-028), 54-68. http://dx.doi.org/10.22004/ag.econ.281258

Dospekhov, B. A. (1979). Methodology of field experiment (with bases of research results statistical processing).

FAO. (2018) "Training, Advisory, and Innovation Centre", 2018. Osobennosti orosheniia selskokhoziaistvennykh kultur: Poliv po borozdam, konturnoe oroshenie i poliv dozhdevaniem [Special features of crop irrigation: Furrow irrigation, contour irrigation, and sprinkler irrigation]. Food and Agriculture Organization of the United Nations, the Public Foundation Bishkek. ISBN: 9789251308172, pp, 31. http://old.belal.by/elib/fao/1082.pdf

FAO. (2020). The state of food and agriculture 2020. Overcoming water challenges in agriculture. Food and Agriculture Organization of the United Nations, Rome. ISBN: 9789251334416, pp, 210.

Finger, L., Wang, Q. J., Malano, H., Chen, D., & Morris, M. (2015). Productivity and water use of grazed subsurface drip irrigated perennial pasture in Australia. *Irrigation Science*, 33(2), 141-152. https://doi.org/10.1007/s00271-014-0454-0

Kalashnikov, A. A., Kurtebaev, B. M., Baizakova, A. E., & Kalashnikov, P. A. (2017). Specific features of the mist sprinkling technology. *Journal of Pharmaceutical Sciences and Research*, 9(9), 1498. https://www.jpsr.pharmainfo.in/Documents/Volumes/vol9Issue09/jpsr09091718.pdf

Kalashnikov, A., Baizakova, A., Kalashnikov, P., & Kudaibergenova, I. (2020a). The technology of drip irrigation of promising crops in the South of Kazakhstan. *Journal of Advanced Research in Dynamical and Control Systems*, 12(5 Special Issue), 1406-1418. https://doi.org/10.5373/JARDCS/V12SP5/20201900

Kalashnikov, A., Baizakova, A., Kalashnikov, P., & Rysmahanov, N. (2020b). Choosing promising fodder crops for short-term crop rotations with sprinkling irrigation. *Plant Cell Biotechnology and Molecular Biology*, 102-113. https://www.ikprress.org/index.php/PCBMB/article/view/5720

Khazhmetov, L. M., Shekikhachev, Iu. A., & Gubzhokov, Kh. L. (2006). Tekhnologicheskie i tekhnicheskie resheniia problem zashchity plodovykh nasazhdenii v gornykh sado-agrolandshaftakh [Technological and technical solutions for the protection of fruit plantations in mountain orchards and agricultural landscapes]. In: Proceedings of the International Scientific and Practical Conference "The Role of Environmental Management in Ensuring Sustainable Functioning and Development of Ecosystems", Part II. Moscow State University of Environmental Engineering, Moscow. ISBN-10: 5892311953, pp: 220-224. http://www.cnshb.ru/journals/2008/0204/01203231/01203231.pdf

Lamm, F. R., Manges, H. L., Stone, L. R., Khan, A. H., & Rogers, D. H. (1995). Water requirement of subsurface drip-irrigated corn in northwest Kansas. *Transactions of the ASAE*, 38(2), 441-448. https://doi.org/10.13031/2013.27851

Melikhova, E. V. (2019). The technology of combined irrigation of vegetable crops. *Ovoŝi Rossii*. https://doi.org/10.18619/2072-9146-2019-2-84-87

Miller, M.S. (1973). Letnie prakticheskie zaniatiia po fiziologii rastenii. Polevaia praktika: Posobie dlia stud. vuzov [Summer practical classes in plant physiology. Field practice: Handbook for university students]. 3rd ed., revised. Prosveshchenie, Moscow, pp: 208.

Ovchinnikov, A. S., Borodychev, V. V., Gurenko, V. M., & Mayer, A. V. (2015). Combined irrigation of crops. Proceedings of Nizhnevolzhsky Agro-University Complex: *Science and Higher Professional Education*, 2(38), 6-13.

Sezen, S. M., Yazar, A., Kapur, B., & Tekin, S. (2011). Comparison of drip and sprinkler irrigation strategies on sunflower seed and oil yield and quality under Mediterranean climatic conditions. *Agricultural Water Management*, 98(7), 1153-1161. http://dx.doi.org/10.1016/j.agwat.2011.02.005

Zharkov, V.A., Kalashnikov, A.A., Dzhumabekov, A.A., Grichanaia T.S., & Angold, E.V. (2012a). Orositelnaia sistema [Irrigation system]. Innovation patent of the Republic of Kazakhstan No. 26144. Intellectual Property Rights Committee of the Ministry of Justice of the Republic of Kazakhstan.

DOI: 10.3844/ojbsci.2022.415.424

Zharkov, V.A., Grichanaia, T.S., Angold, E.V., Kalashnikov, A.A., Kandrin N.I., & Sarsekeyev, S.S. (2012b). Impulsnyi kapelno-dozhdevalnyi vodovypusk [Pulse drip-sprinkler water outlet]. Innovation patent of the Republic of Kazakhstan No. 22850. Intellectual Property Rights Committee of the Ministry of Justice of the Republic of Kazakhstan.

Zhong, Y., Fei, L., Li, Y., Zeng, J., & Dai, Z. (2019). Response of fruit yield, fruit quality, and water use efficiency to water deficits for apple trees under surge-root irrigation in the Loess Plateau of China. *Agricultural Water Management*, 222, 221-230. https://doi.org/10.1016/j.agwat.2019.05.035