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IRRIGATION METHODS INFLUENCE ON WATER PRODUCTIVITY, AND FRUIT YIELD AND QUALITY OF APPLE CULTIVAR GOLDEN DELICIOUS

V.A. ZHARKOV[1], E.D. ZHAPARKULOVA[2], M. MIRDADAYEV[1], A. SHAIMERDENOVA[3*], A.B. BEISENKULOVA[1], and P.A. KALASHNIKOV[1]

[1]Kazakh Scientific Research Institute of Water Economy, Taraz, Kazakhstan
[2]Kazakh National Agrarian Research University, Almaty, Kazakhstan
[3]Department of "History of Kazakhstan, General Education Disciplines and Information Systems," Kazakh Automobile and Road Institute, Almaty, Kazakhstan
[*]Corresponding author's email: shaimerdenova.aig@yandex.ru
Email addresses of co-authors: vazharkov@mymail.academy, edzhaparkulova@mymail.academy, mmirdadayev@mymail.academy, ashaimerdenova@mymail.academy, pakalashnikov@mymail.academy

SUMMARY

This study aimed to identify irrigation strategies that optimize water use while maintaining favorable growing conditions for apple production and providing a reliable agronomic background for varietal evaluation. Field experiments took place during 2016–2018 on mature Golden Delicious trees grafted on MM106 rootstock. Comparing four irrigation treatments included drip irrigation, sprinkling, combined drip–sprinkling irrigation (drip at air temperatures ≤25 °C and sprinkling at >25 °C), and surface furrow irrigation (control). During the experiments, the soil moisture maintenance in the root zone was within the optimal limit. The study recorded data on microclimatic parameters (air temperature and humidity), plant water-regime indicators (leaf water content, transpiration intensity, relative turgidity deficit), yield, fruit size, sugar content (°Brix), and irrigation water productivity. The highest apple fruit yield emerged in the combined irrigation (about 19.7 t ha^{-1}), followed by sprinkling and drip irrigation, while surface irrigation produced the lowest yield. Drip irrigation required the least water and resulted in the highest fruit sugar content, whereas surface irrigation showed the lowest water-use efficiency and fruit quality. Overall, combined irrigation proved the most effective method in hot, low-humidity environments, providing a balance between water savings, yield, and fruit quality.

Keywords: Irrigation methods, water productivity, apple fruit yield and quality, sugar content, microclimatic conditions, water regime of plants

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Key findings: Combined drip-sprinkling irrigation most effectively mitigated heat and humidity stresses, resulting in the highest water productivity and fruit yield of the apple cultivar Golden Delicious under arid conditions. Drip irrigation minimized water use and produced fruits with the highest sugar content, while surface irrigation was the least efficient.

INTRODUCTION

Apple is a versatile and typical fruit, found in the human diet almost year-round, with valuable composition. It provides about 60 calories and contains proteins, carbohydrates, antioxidants, naturally occurring sugar, fibers, organic acids (such as pectin and ascorbic acid), and vitamins (E, B, and A). Furthermore, it is rich in minerals, such as potassium, calcium, magnesium, zinc, iron, and copper (Rich composition of apples, n.d.; Brix scale—how to choose the perfect fruit and vegetables?, n.d.).

Currently, the area of apple orchards in Kazakhstan is around 35,700 ha. In 2020, the harvests from these orchards were 259,100 tons of apples. Concurrently, the population consumes 344,300 tons of apples per year, accounting for imports from foreign countries (Ovchinnikov *et al*., 2015). Saturation of the domestic market is natural due to new intensive orchards on an area of 6,600 ha, concentrated in the main horticultural regions, such as Almaty, Zhambyl, and Turkestan Oblasts, and in Shymkent, Kazakhstan (Kyzylorda-News.Kz, 2021).

Increasing water shortages and drought-stress conditions worldwide, including Kazakhstan, especially in arid and semi-arid regions, highlight the need for optimal irrigation water use and for improving fruit yield and quality-related traits (Sezen *et al*., 2011). At present, to enhance the productivity of water and land resources, shifting to water-saving practices is vital. The main objectives of water conservation are saving irrigation water, increasing water use efficiency, and improving the productivity of water and land use to increase farming communities' net profit (Pulatov, 2017).

Currently, the primary methods used in irrigating different crops are surface irrigation, sprinkling, and micro-irrigation (i.e., drip irrigation), with the combined method (drip-sprinkling) also in use. In surface irrigation, water flows over the soil surface under the influence of gravity. Sprinkling transpires by spraying water drops. Micro-irrigation is frequent irrigation by dripping and spraying water, which usually only wets the concerned part of the soil (Miller, 1973; Mekonnen and Hoekstra, 2011). With combined methods of irrigation, aside from drip irrigation at high air temperatures, applying sprinkling helps improve microclimatic conditions for plant growth and development (Mayer *et al*., 2015).

In apple orchards, surface irrigation on the loess plateau in China revealed low water use efficiency. The fruit quality and yield depend on the amount of water supplied, considering the phases of apple trees' growth and development (Zhong *et al*., 2019). The surface irrigation method also requires volumes of water. The sprinkling method, when compared with the surface drip and subsoil drip irrigation on the efficiency of water use and tree growth, subsoil drip irrigation consumed 37% and 27% less water than sprinkling and surface drip irrigation, respectively. Subsoil drip irrigation also provides fewer sunburnt fruits and fewer weeds than sprinkling and surface drip, thus becoming recognized as the most effective irrigation method for apple orchards (Han *et al*., 2018).

Water-saving irrigation is an important way to ensure the sustainable development of the apple industry. Apple yield under drip and sprinkling irrigation increased by 12.1% and 8.2%, respectively. However, in general, the drip and sprinkling irrigation contribute to apple tree growth and improve fruit quality and yield. Overall, the drip irrigation emerged as better than sprinkling irrigation for water saving and apple fruit yield (Chen *et al*., 2018).

In orchards, the drip irrigation saves freshwater, allows precise rate control, delivers water and nutrients directly to the root zone, reduces losses, maintains optimal root-zone moisture, and enables fertigation (Suleimanov, 2019). Nowadays, the growers are shifting from surface to drip irrigation in Türkiye, increasing leaf nutrient concentration in apple trees (Uçgun *et al*., 2018). China applies water-saving irrigation on 37.8 million ha, including drip and sprinkling (Regnum, 2021). Subsoil irrigation can provide a continuous supply and reduce soil evaporation; however, it is costly despite proven applicability (Finger *et al*., 2015). In the Mediterranean region of Türkiye, both drip and sprinkling irrigation methods improved the yield and quality under water scarcity conditions (Sezen *et al*., 2011).

However, drip irrigation does not regulate the open-field phytoclimate during extreme heat, inhibiting crop growth and development, and yield falls. In arid climates, sprinkling can maintain soil and air moisture, improving microclimate, intensifying physiological processes (including photosynthesis), and increasing productivity (Kalashnikov *et al*., 2017). Micro-sprinklers used in irrigating the *Pouteria sapota* in arid regions reduced heat and drought effects (-1 °C – -3 °C; +11%–-17% RH), enhanced leaf physiology, and improved yield and quality (Liu *et al*., 2021). Sprinkling was highly essential for trees and vineyards in the USA and can also protect against frost; periodic sprinkling during the hottest hours (> 25 °C) can reduce temperature stress and raise yield by 20%, with positive evaluation in apple orchards (Boman *et al*., 2012; Finger *et al*., 2015; Han *et al*., 2018).

Sprinkling also proved effective within combined irrigation systems, helping in achieving stable and higher yields (Khasan *et al*., 2020), with various technical solutions being proposed (Balgabev *et al*., 2018; Melikhova, 2019; Zharkov *et al*., 2021). Combined irrigation has shown the highest effectiveness for crops in Volgograd Oblast (Ovchinnikov *et al*., 2015) and positive yield effects in apple orchards of Southern Kazakhstan (Angold and Zharkov, 2014). Overall, the combined irrigation can better reduce water costs and maintain optimal near-surface temperature and humidity during hot daytime hours, proving suitable in growing seasons with air temperature (> 25 °C) and relative humidity (≤ 30%). The combined irrigation system should account for natural and economic conditions, crop biology, and crop growth stages. Based on these considerations, the consequent research aimed to evaluate existing orchard irrigation methods for water productivity and yield and fruit quality of apple cultivar Golden Delicious to identify the most effective irrigation method.

MATERIALS AND METHODS

Plant material and procedure

Apple field trials commenced during 2016–2018 in an orchard at the Kazakh Scientific Research Institute of Water Economy, Taraz, Southern Kazakhstan, on a 0.5-ha pilot plot (3.0 m × 2.5 m spacing). The research used apple cultivar Golden Delicious trees planted in 2007 and MM106 rootstocks. The experimental region has a sharply continental, arid climate—mean annual precipitation was 287 mm (168 mm during the growing season), with average temperatures of −5.1 °C in January and +23.4 °C in July (up to 45 °C in summer). About 90 days per year have relative humidity below 30%, and the sum of temperatures above 5 °C during the growing season averages 3720 °C. Soils were medium loams (17.7% sand, 27.7% clay, and 54.6% silt/dust), with organic matter (0.88%), bulk density (1.36–1.46 g/cm³), low moisture capacity (~19%–20%), non-saline, and gravel (60–70 cm depth). These support the need for water-saving irrigation and microclimate-improving methods under heat and low humidity conditions.

Four irrigation treatments compared for water productivity and apple fruit yield and quality were a) drip, b) sprinkling, c) combined (drip at ≤ 25 °C; sprinkling at > 25 °C), and d) surface furrow irrigation (control). The 3-year experiment had four replications; each treatment used 210 m² with 28 measured trees. Soil moisture in the 0–50 cm root zone remained at 75%–80% HB in all the experimental variants. Irrigation scheduling for drip/sprinkling/combined treatments depended on daily apple water use estimated from the

GGI-3000 evaporometer readings plus meteorological data. Metering of applied water occurred daily, and tracking soil moisture used sensors (plus gravimetric checks every 10 days). Surface irrigation used 35 m furrows (15 cm deep) on a 0.006 slope, with regulated flow, while triggered timing was at 50%–60% HB, calculating rates using the standard soil-moisture deficit formula.

Data analysis

All the recorded data underwent the analysis of variance (ANOVA) following Dospekhov (1985). Measured features included microclimate (air temperature/humidity at 0.5 m and soil temperature), tree water status (leaf water content, transpiration, absorption, and relative turgidity deficit), vegetative growth, yield (total harvest weighing), and fruit sugars (°Brix).

RESULTS

With all applied irrigation methods, the daily observations based on temperature and relative humidity in the surface air layer showed considerable variations took place from 1300 h to 1700 h. The dynamics of variations in temperature and relative air humidity at 0.5 m from the soil surface as per experimental variants appear in Figures 1 and 2. The results revealed that in the daytime, the maximum air temperature difference reached 5.2 °C between surface irrigation and sprinkling, and the difference between the values of air humidity reached 21%. Smaller differences for these indicators were noticeable between drip and combined irrigation (2.5 °C and 11%, respectively). However, by comparing with sprinkling, the air temperature in the drip irrigation variant was higher (by 3.6°C), while the air humidity decreased up to 15%. The observations on temperature and air humidity in the combined irrigation, compared with sprinkling, disclosed smaller differences, and the air temperature was higher (by 1°C), and its humidity decreased to 4%.

Sprinkling in variant 2 and additional sprinkling in variant 3 during the growing season of apple trees positively affected the water regime and growth and development of plants. The water regime assessment of apple trees according to the experimental variants depended on the level of watering, the intensity of transpiration, the scope of the water deficit, and the relative turgidity of leaves. Observations on the leaves' water content as per experimental variants showed the lowest water content in the case of surface irrigation (and not more than 62%) (Figure 3). With sprinkling, the water content increased to 72%; in combined irrigation, it reached 69%; and for drip irrigation, it did not exceed 65%. This revealed that better conditions resulted in the sprinkling and combined irrigation variants for apple trees' growth and development.

Sprinkling in variant 2 and additional sprinkling during the apple growing season in the drip irrigation option had a positive effect on transpiration intensity (Figure 4). The transpiration intensity of apple tree leaves at 1300 h in the area of sprinkling (variant 2) varied, from 42.0 to 47.8 g/m^2 per hour, and with combined irrigation in variant 3, it was 40.0–45.6 g/m^2 per hour. However, at the site of drip irrigation, it decreased to 38.0–43.0 g g/m^2 per hour. With surface irrigation, transpiration intensity did not exceed 32.0 to 40.6 g/m^2 per hour. Increased transpiration in the area of sprinkling and combined irrigation occurs not only by maintaining stable moisture content of the plant's root zone throughout the growing season but also increases the relative humidity of air, reducing its temperature.

The deficiency of relative turgidity also serves as an indicator of watering of apple tree leaves, showing the amount of water needed to reach the turgid state of the plant leaves (Figure 5). According to observations, the deficit of relative turgidity in the midday hours did not exceed 14.6% in the sprinkling variant and 14.0% in the combined irrigation area. With surface and drip irrigation, the deficit of relative turgidity rose to 20.6% and 18.8%, respectively. Thus, the water quantity required for the complete saturation of apple tree leaves during sprinkling and combined irrigation was less than that of the drip and surface irrigation methods.

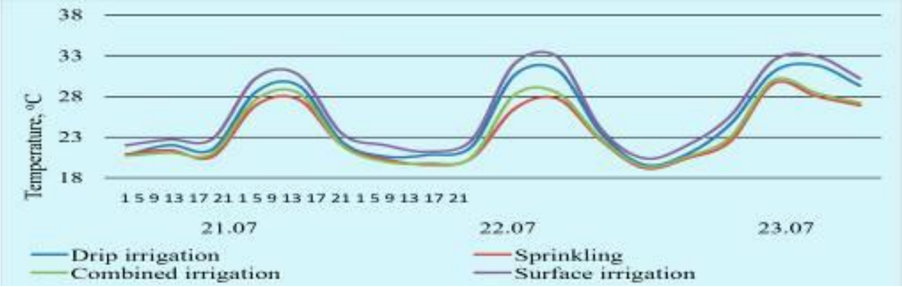

Figure 1. Dynamics of air temperature changes at 0.5 m (2016).

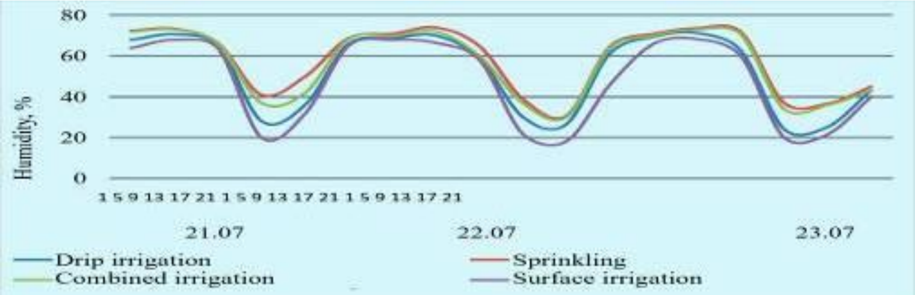

Figure 2. Dynamics of air humidity changes at 0.5 m (2016).

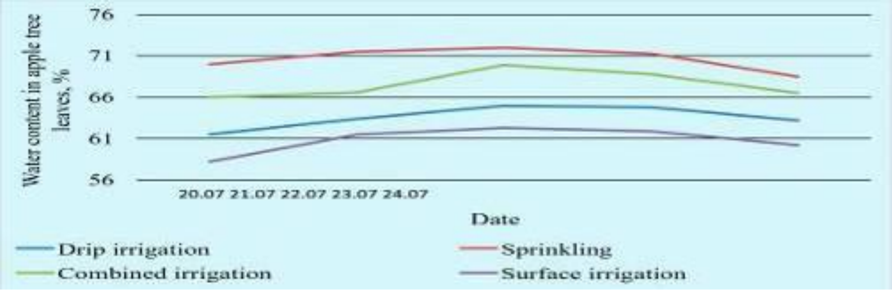

Figure 3. Dynamics of water content changes in apple tree leaves as per the variants of the experiment (2018).

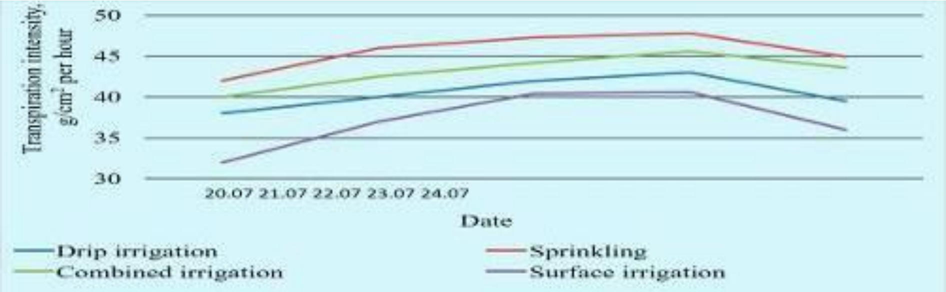

Figure 4. Dynamics of transpiration intensity in apple tree leaves as per the variants of the experiment (2018).

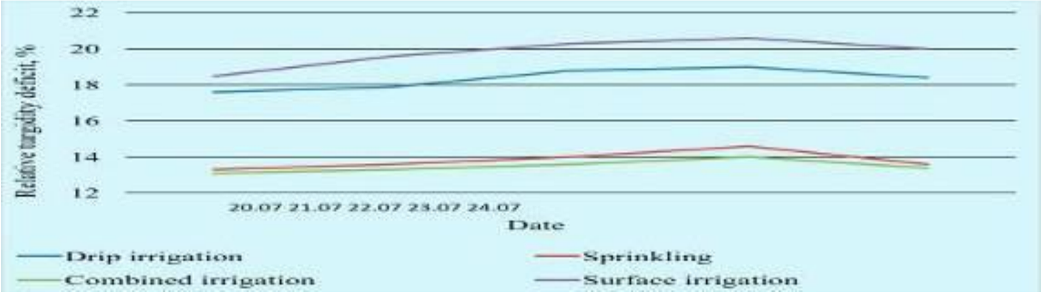

Figure 5. Relative turgidity deficit of apple tree leaves at 1300 h (2018).

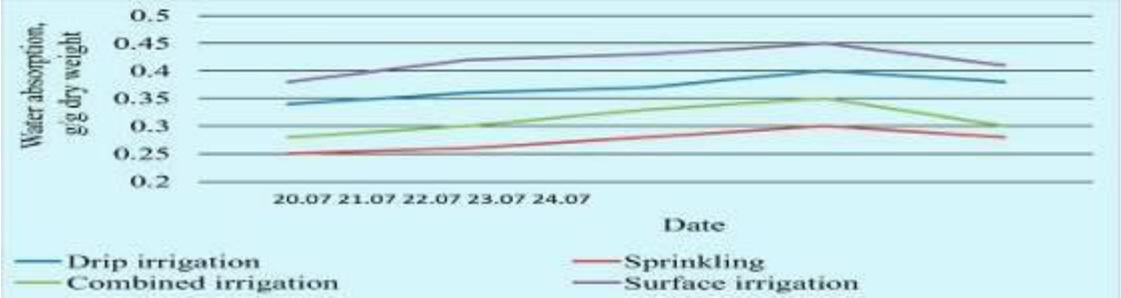

Figure 6. Water absorption by apple tree leaves at 1300 h (2018).

The lack of moisture in both the soil and air leads to a deficiency in plant tissues; therefore, the water-absorbing capacity of leaves is an indicator of the water supply of plants. Sprinkling and additional sprinkling during daytime hours of a hot period of the growing season of apple trees, the combined variant has a corresponding effect on microclimatic parameters in plant growth and development. This leads to considerable variations in indicators of its deficiency in plant tissues.

The obtained observations revealed a significant dependence of water absorption by plant leaves on their water supply (Figure 6). In the concerned experiments, the lowest water absorption capacity of apple tree leaves was evident during sprinkling (up to 0.30 g/g dry weight) and during additional sprinkling in the combined irrigation variant (up to 0.35 g/g dry weight). With drip irrigation and surface irrigation, these figures increased to 0.4 g/g dry weight and 0.45 g/g dry weight, respectively. Therefore, the results conclude that the indicators of the water regime of plants during sprinkling (variant 2) and additional sprinkling during the hot growing season in case of combined irrigation (variant 3) appeared better than the drip (variant 1) and surface irrigation (variant 4). This applies to indicators of water content in apple leaves, transpiration intensity, relative turgidity deficit, and water absorption by apple leaves.

Determining irrigation norms for drip, sprinkling, and combined irrigation by years of research with 1248 apple trees per hectare was reliant on the readings of the GGI 3000 evaporometer and recalculated for the actual irrigated area. The results expressed that for medium loams, the area of moistening with droppers and sprinkler nozzles according to the experimental variants was 1.33 m^2 with the radius of the soil moistening contour of 0.65 m. The number of water outlets on the experimental variants was 28 for the plot area of 210 m^2, and for the irrigated area, it was 37.24 m^2. The actual irrigated area with 1248 outlets per hectare succeeded in its determination by summing up the irrigated areas of each outlet (1660 m^2).

Table 1. Irrigation rate by the experimental variants.

Years	Variants	The GGI 3000 evaporometer readings	Irrigation rate (m^3/ha)	Water consumption for: microclimate formation*, filtration and discharge** (m^3/ha)	Irrigation rate considering water costs: microclimate*, filtration and discharge** (m^3/ha)
2016	1 (drip)	5186	861	-	861
	2 (sprinkling)	5186	861	172*	1033*
	3 (combined)	5186	861	44*	905*
	4 (surface)	5186	5186	777**	5963**
2017	1 (drip)	5790	961	-	961
	2 (sprinkling)	5790	961	240*	1201*
	3 (combined)	5790	961	58*	1019*
	4 (surface)	5790	5790	973**	6763**
2018	1 (drip)	4327	718	-	718
	2 (sprinkling)	4327	718	122*	840*
	3 (combined)	4327	718	36*	754*
	4 (surface)	4327	4327	636**	4963**

Irrigation norms for variants 2 and 3 emerged, considering the cost of water for microclimate formation. For surface irrigation along furrows in variant 4, irrigation rate estimates considered water losses for evaporation, filtration, and discharge at the end of the furrows. Based on the accepted lower and upper thresholds of soil moisture values, the calculated irrigation rates ranged from 533 to 666 m^3/ha. The actual irrigation rates, accounting for water losses for evaporation, filtration, and discharge, were within 611–778 m^3/ha. Water losses in filtration had a range of 14.7%–16.8%. By irrigating with a variable, a high uniformity of soil moisture along the length of the furrow and minimal discharges of irrigation water (up to 2%) were notable.

Table 1 provides irrigation norms for the experimental variants, based on the water cost for microclimate formation with sprinkling and combined irrigation during high air temperatures (25 °C). The table also showed water losses for filtration and discharge at the end of the furrows with surface irrigation by years of research. The apple fruit yield, weighed from all the trees, gave the data recorded on total (biological) fruit yield and the marketable yield. Furthermore, random selection of 10 fruits ensued on each plot of the studied variants of the experiment. Fruit net weight, external color, skin thickness, and pulp firmness measurement continued in the laboratory for various experimental variants. The firmness measuring used an FT 327 digital penetrometer with a 10-mm cylinder. Notably, with sprinkling and combined irrigation, the fruit weight was larger than with drip and surface irrigation methods. However, the weight of an individual fruit on the branches of the lower tier of trees with sprinkling and combined irrigation reached 179–184 g. In the area of drip irrigation, it did not exceed 149 g, and with surface irrigation, it was 120 g.

The apple fruits showed elongation, dry peel, slightly rough, and golden yellow with brown speckles. The fruits' pulp firmness in all experimental variants and average over the years ranged from 5.5 to 6.6 kg/cm^2 with slight differences among the variants. By assessing the quality of apple fruits, a refractometer according to degrees Brix (Brix scale, n.d.) determined the sugar content in apple juice. For fruit, sugars meant the total content of sucrose, fructose, vitamins, acids, amino acids, and other substances. The indicators of sugar content of apples according to the variants of the experiment appear in Figure 7. The higher sugar content was evident with drip irrigation (14.5%). On average, with sprinkling and combined irrigation, the sugar contents were at the level of 12.2% and 13.6%, respectively, while in surface irrigation, it decreased to 10.8%. With apples, the recommended Brix values are low (6 Brix), medium (10 Brix), good (14 Brix), and

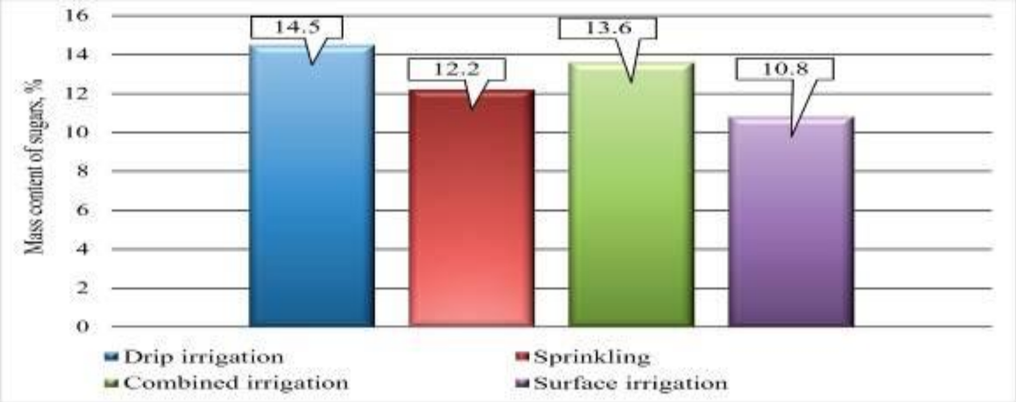

Figure 7. Mass content of sugars in apples by experiment options (average over the years of research).

excellent (16 Brix). Therefore, the drip, sprinkling, and combined irrigation variants rated as good, with the surface irrigation variant found to be close to medium.

In the apple orchard, the water-consumption components (such as precipitation and moisture reserves in the soil) were identical over the years of research on experimental variants. The water productivity assessment depended on the fruit yield and irrigation norms, as expressed in kg/m^3. This indicator details the benefits derived from actual water consumption, which can be used to assess the impact of on-farm strategies in water-scarce conditions. It also provides an indication of the water that can be saved by using different irrigation methods while increasing crop yields.

The apple trees' fruit yield, on average, for three years with drip, sprinkling, and combined irrigation, exceeded the surface irrigation by 22.4%, 30.4%, and 39.9%, respectively. Over a three-year average, the higher productivity of irrigation water emerged by assessing its costs per unit of production in the combined irrigation area (4.57 m^3/c). Here, the highest apple fruit yield (19.74 t/ha) was also remarkable, ensured by the improvement of microclimatic indicators for plant growth and development. High water productivity was also noteworthy with drip irrigation (4.93 m^3/c), with a fruit yield of 17.27 t/ha. Notably, the drip irrigation taken separately does guarantee a high fruit yield in regions with high air temperature and low air humidity.

Under such conditions, and to improve plant development, microclimate has a positive effect on the water regime and growth and development of plants; it was necessary to additionally use sprinkling. Thus, the combined irrigation increased the apple fruit yield in the regions of arid agriculture. A high fruit yield in apple trees was also evident during sprinkling (18.4 t/ha), with the water productivity enhanced (5.6 m^3/c) over three years. The lowest productivity of apple trees (14.11 t/ha) with the lowest water productivity (42.0 m^3/c) resulted in surface irrigation in apple trees.

DISCUSSION

Evaluation of drip, sprinkling, combined, and surface irrigation showed clear differences in effectiveness and limitations. Daytime sprinkling and combined irrigation improved the microclimate as compared with surface irrigation and sprinkling that reduced maximum air temperature by up to 5.2 °C and increased air humidity up to 21%. However, the differences between drip and combined irrigation systems were smaller (≤ 2.5 °C and ≤ 11%). Relative to sprinkling, drip irrigation was hotter and drier (up to +3.6 °C and −15% humidity), while combined irrigation was close to sprinkling (up to +1 °C and −4% humidity).

These results were consistent with past reports that sprinkling improves soil water regime and microclimate by lowering temperature and increasing humidity (Sezen *et al*., 2011; Finger *et al*., 2015; Regnum, 2021). The micro-sprinklers can reduce heat/drought stress (-1 °C– -3 °C; +11%–17% RH) and enhance the leaf-level physiology in arid conditions (Kalashnikov *et al*., 2017).

In this study, sprinkling and added sprinkling under combined irrigation improved the apple tree's water-regime indicators (leaf water content, transpiration, relative turgidity deficit, and water absorption) as compared with drip and surface irrigation. Drip irrigation saved water (17.37%) less than sprinkling and 5.23% less than combined, with similar water-saving patterns reported for drip irrigation systems in apple studies (Zhong *et al*., 2019). Evidence from other regions also showed drip and sprinkling irrigation methods can improve plant growth and development and fruit yield and quality (Han *et al*., 2018).

Compared with surface irrigation, the apple fruit yield increased by 22.4% (drip), 30.4% (sprinkling), and 39.9% (combined). The fruits' sugar content was the highest under drip (14.5%), followed by combined (13.6%) and sprinkling (12.2%); and the surface irrigation showed the lowest (10.8%). The highest water productivity occurred under combined irrigation (4.57 m^3/c; 19.74 t/ha), followed by drip (4.93 m^3/c; 17.27 t/ha) and sprinkling (5.6 m^3/c; 18.4 t/ha), while surface irrigation was the worst one (42.0 m^3/c; 14.11 t/ha). Past studies likewise support the drip irrigation and sprinkling benefits under water scarcity conditions (Uçgun *et al*., 2018) and emphasize sprinkling for microclimate improvement (Regnum, 2021) and its highest appraisal in orchards and vineyard irrigation (Boman *et al*., 2012).

Globally, the combined irrigation is still underused; technical approaches proposed in Russia aim to reduce temperature stress and stabilize yields (Han *et al*., 2018), and field results in Volgograd Oblast showed benefits for multiple crops, including yield increases versus drip alone (Melikhova, 2019). Overall, sprinkling, and especially the combined irrigation, best improved microclimate and plant water status and enhanced the apple fruit yield and quality. Meanwhile, drip irrigation minimized the seasonal water use, and surface irrigation had the highest water use per unit output with the lowest fruit yield.

At the same time, these findings' interpretation should proceed with some caution because the experiment only assessed a single cultivar (Golden Delicious) grafted on MM106 rootstock at one site in Southern Kazakhstan over three growing seasons. Under high air temperature and low relative humidity, drip irrigation alone was insufficient to improve microclimatic conditions, whereas sprinkling and combined irrigation reduced temperature stress and improved plant water-regime indicators. Combined irrigation produced the highest fruit yield and favorable water productivity, while drip irrigation required the least amount of water and resulted in the optimum fruit sugar content. Surface irrigation showed the lowest overall efficiency because it required the most water input and produced the lowest yield and quality indicators.

CONCLUSIONS

The evaluated irrigation methods differed substantially in their effects on water use, fruit yield, and fruit quality. Drip irrigation showed the highest water-use efficiency during the growing season, and combined irrigation appeared to be the most suitable option for arid environments with high temperatures and low relative humidity. Sprinkling was also beneficial but requires greater water input, while surface irrigation was the least efficient treatment overall. Since the conduct of the experiment was on a single cultivar at one site over three growing seasons, further research is necessary to confirm these findings across other cultivars, rootstocks, and agroecological conditions.

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REFERENCES

Angold YeV, Zharkov VA (2014). Special features of drip-sprinkler irrigation technology. *Water Suppl.* 14(5): 841-849. https://doi.org/10.2166/ws.2014.041.

Balgabev NN, Kalashnikov AA, Zharkov VA, Angold EV, Dzhumabekov AA, Grichanaya TS (2018). Combined drip-sprinkler irrigation system. Utility model patent of the Republic of Kazakhstan No. 2770. *Industrial property. Official bulletin. Inventions. Useful models* 17.

Boman B, Sanden B, Peters T, Parsons L (2012). Current status of micro sprinkler irrigation in the United States. *Appl. Eng. Agric.* 28(3): 359-366. https://doi.org/10.13031/2013.41495.

Brix scale or how to choose the perfect fruit and vegetables? (n.d.). Available: https://veoan.ru/company/blog/shkala-briksa-ili-kak-vybrat-idealnye-frukty-i-ovoshchi/ (accessed on November 29, 2021).

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 Agric. Res.* 10(7): 54-68. https://doi.org/10.22004/AG.ECON.281258.

Dospekhov BA (1985). Metodika polevogo opyta (s osnovami statisticheskoy obrabotki rezul'tatov issledovaniy) [Methods of field experience (with the basics of statistical processing of research results)]. Agropromizdat, Moscow.

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

Han SG, Selvakumar G, Yi PH, Lee SE (2018). Effect of sprinkler, surface drip and subsurface drip irrigation methods on ‘fuji’/m9 and ‘fuji’/m26 apple orchards growth, soil properties, and water consumption. *Korean J. Soil Sci. Fert.* 51(4): 608-615. https://doi.org/10.7745/KJSSF.2018.51.4.608.

Kalashnikov AA, Kurtebaev BM, Baizakova AE, Kalashnikov PA (2017). Specific features of the mist sprinkling technology. *J. Pharm. Sci. Res.* 9(9): 1498-1504.

Khasan M, Almatar A, Kuznetsov EV, Khajidi AE (2020). Investigation of sprinkler characteristics for efficient operation of irrigation systems. In: Materials of the International scientific-practical conference of specialists, scientists and graduate students dedicated to the 75th anniversary of the Victory in the Great Patriotic War. I.T. Trubilin Kuban State Agrarian University, Krasnodar, pp. 166-173.

Kyzylorda-News.Kz (2021). Yablonevyye sady budut vozrozhdat' v Kazakhstane [Apple orchards will be revived in Kazakhstan]. Available: https://kyzylorda-news.kz/ru/obshestvo/jablonevye-sady-bwdwt-vozrozhdat-v-kazahstane-101624/ (accessed on November 29, 2021).

Liu Zh, Jiao X, Zhu Ch, Katul GG, Ma J, Guo W (2021). Micro-climatic and crop responses to micro-sprinkler irrigation. *Agric. Water Manag.* 243: 106498. https://doi.org/10.1016/j.agwat.2020.106498.

Mayer AV, Zakharov YuI, Krivolutskaya NV (2015). Universal'naya mnogofunktsional'naya sistema orosheniya dlya kombinirovannykh sposobov poliva [Universal multifunctional irrigation system for combined irrigation methods]. *Proc. Lower Volga Agro-Univ. Compl. Sci. Higher Edu.* 1(37): 206-210.

Mekonnen MM, Hoekstra AY **(**2011). National water footprint accounts: The green, blue and grey water footprint of production and consumption*.* Value of Water Research Report Series 50. UNESCO-IHE, Delft.

Melikhova EV (2019). Technology of combined irrigation of vegetable crops. *Veget. Crops of Russia* 2: 84-87. https://doi.org/10.18619/2072-9146-2019-2-84-87

Miller MS (1973). Letniye prakticheskiye zanyatiya po fiziologii rasteniy: polevaya praktika: posobiye dlya studentov ped. vuzov [Summer practical classes in plant physiology: Field practice: a manual for University students]. Prosveshcheniye, Moscow.

Ovchinnikov AS, Borodychev VV, Khrabrov MYu, Gurenko VM, Mayer AV (2015). Kombinirovannoye orosheniye sel'skokhozyaystvennykh kul'tur [Combined irrigation of agricultural crops]. *Proc. Lower Volga Agro-Univ. Compl. Sci. Higher Edu*. 2(38): 6-13.

Pulatov YaE (2017). Water-saving irrigation technologies and water use efficiency in agriculture. *Ekologiya & stroitelstvo* 4: 21-26.

Regnum (2021). Kitay rasprostranil vodosberegayushcheye orosheniye na 37,8 mln ga zemel’ [China has extended water-saving irrigation to 37.8 mil. ha of land]. Available: https://regnum.ru/news/society/

3313769.html (accessed on November 29, 2021).

Rich composition of apples with health and longevity benefits (n.d.). Available: http://vitaminodin.ru/produkty/vitaminy-v-yablokax.html (accessed on December 20, 2021).

Sezen SM, Yazar A, Kapur B, Tekin S (2011). Comparison of drip and sprinkling irrigation strategies on sunflower seed and oil yield and quality in the Mediterranean climatic conditions. *Agric. Water Manag.* 98(7): 1153-1161. https://doi.org/10.1016/j.agwat.2011.02.005.

Suleimanov PS (2019). Progressive irrigation methods application in the orchards and their positive and negative properties. *Bull. Sci. Pract.* 5(4): 222-226. https://doi.org/10.33619/2414-2948/41/28.

Uçgun K, Küçükyumuk C, Bayav A (2018). Effects of transition from flood irrigation to drip irrigation on leaf nutrient concentrations of apple cv. Starcrimson Delicious. *J. Plant Nutr.* 41(16): 2085-2090. https://doi.org/10.1080/01904167.2018.1485935.

Zharkov VA, Abduramanov NA, Angold EV, Dzhabaev KE (2021). Technical means of drip-sprinkler irrigation systems. *Herald Sci. S. Seifullin Kazakh Agrotech. Univ.: Multidiscipl*. 3(110): 40-46. https://doi.org/10.51452/kazatu.2021.3(110).763.

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. *Agric. Water Manag.* 222: 221-230. https://doi.org/10.1016/j.agwat.2019.05.03.