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Water-saving technology of subsurface irrigation of fruit crops seedlings

Nurlan Balgabaev*, Vyacheslav Zharkov, Yelena Angold and Kuanysh Dzhabaev

Kazakh Scientific Research Institute of Water Economy (Kaz SRIWE), Koigeldy Street, 12, Taraz, 080003, Kazakhstan Republic

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ABSTRACT

Subsurface irrigation is a promising resource-saving method of plant irrigation, which allows creating optimal water and nutrient regimes in the root layer of the soil, increasing the yield of crops, eliminating unproductive costs of irrigation water, and automating the irrigation process. Subsurface irrigation is associated with the development of conservation agriculture technologies. It is the refusal of plowing that gave rise to the development of this irrigation technology in agricultural production. The application of subsurface irrigation is especially promising for farms in areas with a shortage of irrigation water. The subsurface irrigation technology is based on the principle of continuous supply of water to plants according to their water absorption, taking into account the nature of soil moisture and the capabilities of technical means. The creation of highly productive gardens in Kazakhstan primarily depends on the performance of nursery gardens, as well as on the quantity and quality of planting material. Currently, there is an urgent need for the development and intensification of fruit production to create a sufficient amount of planting material to ensure the food security of the Republic of Kazakhstan. Using subsurface irrigation systems makes it possible to grow plant seedlings at a compacted spacing to form a high-quality root system of the trees. To increase the yield of plants per unit of area, it is recommended to use a compacted scheme for placing seedlings in container-type devices with subsurface irrigation elements comprised of porous tubes. It has been revealed that the root system of apple seedlings grown in baskets had more compacted configuration when using subsoil irrigation. In all fractions that differ in the total length and weight of the roots, the root system of apple seedlings grown in baskets has more compact shape and greater number of root hairs with the diameter of less than one mm than the root system of plants grown without baskets when watered using drip irrigation. Because of the predominance of water-conducting root-hairs, subsurface irrigation contributes to the active growth of the aboveground part that is confirmed by conducted research.

Key words: *Subsurface irrigation, Fruit crops seedlings, Research, Results.*

Introduction

The creation of highly productive gardens primarily depends on the performance of nursery gardens, i.e. on the quantity and quality of planting material. Fruit trees on dwarf (low-growing) rootstocks with the density of planting from 1,500-2,000 to 3,000 trees per ha should be widely distributed since they allow providing country's population with necessary fruit at an earlier time. One of the important means of fruit nurseries intensification is irrigation. Even in places where precipitation is sufficient, because of their uneven distribution over time, nurseries need additional irrigation.

To improve the quality of the material in nurseries, it is necessary to use a rational irrigation technology that provides optimal moisturization of the root layer of the soil during the entire growing season. The irrigation method must meet economic and technical requirements, as well as climatic, topographical, and soil conditions (Krivolapov *et al.*, 2019; Kudrin, 2019). Surface irrigation, sprinkling, and drip irrigation are mainly used in the practice of parent plant irrigation. Surface irrigation technology is based on the principle of periodic accumulation of moisture in the active layer of the soil. Furrow irrigation is the most promising type of surface irrigation since this method preserves the lumpy structure of the soil and does not form a solid crust. Thus, soil aeration deteriorates slightly, and irrigation can be performed at relatively small irrigation rates. It is advisable to use it at an irrigation rate higher than 500 m^3/ha on heavy and medium soils at small slope angles from 0.005 to 0.050. The length of the furrow depends on the slope angle of the soil surface towards the irrigation direction, and the type of soil. According to the research of many authors (Shtepa, 1979; Shulga and Dukmasov, 1980), the applicability of this method of irrigation is limited to the maximum allowable terrain slopes up to 0.01. The main disadvantage of surface irrigation is the uneven distribution of water along the length of furrows, and the unproductive water consumption (water discharge, filtration, etc.), which reduces the effectiveness of irrigation effect. Growing water scarcity is affecting the agricultural sector worldwide. Increasing the productivity of water use is an important means for increasing crop production (The International Commission on Irrigation and Drainage (ICID), 2012).

Sprinkler irrigation and drip irrigation are the most advanced methods of irrigation. Such technologies are aimed at continuously supplying plants with water in line with their water absorption. The effectiveness of sprinkling and drip irrigation technologies is evidenced by data on their applicability in countries around the world (Nosenko, 1973; Sezen *et al.*, 2011; Angold *et al.*, 2016). When watering crops, including fruit seedlings, it is possible to use modern sprinkler apparatus such as T-L with a central drive, wide-coverage, front-face, wide-coverage with a hippodrome irrigation system, and drum machines with a turning platform, as well as stationary sprinkler systems.

Currently, drip irrigation of fruit crops seedlings is effective technology in terms of water consumption, which is relevant in the context of irrigation water scarcity. Using drip irrigation provides a dosed supply of water to the root system and fertilization along with water. This method allows using irrigation in windy weather and does not require plot planning. The most common irrigation systems for crops are drip irrigation systems produced by Netafim, Naan Dan Jain Irrigation (Israel); T-Systems (USA); EOLOS (Greece); and several firms in Turkey and China. The flow rate of droppers ranges from 1 to 12 l/h at operating pressures from 0.05 to 0.4 MPa. At that, the coefficient of variation (CV) is less than 4%. The main advantage of drip irrigation is to create optimal water and nutrient regime directly in the root system of plants and reduce the consumption of water and fertilizers. In comparison with other irrigation systems, drip irrigation has disadvantages that must be taken into account when using this technology. This is the possibility of clogging droppers, mechanical damage, and short-lived drip tapes, as well as the probability of uneven watering. Typical systems also have certain limitations on applicability.

A promising resource-saving method of plant irrigation is subsurface irrigation, which allows creating optimal water and nutrient regimes in the root layer of the soil, increasing the yield of crops, eliminating unproductive costs of irrigation water, and automating the irrigation process. Using subsurface irrigation is particularly promising for farms in areas with a shortage of irrigation water (Chenafi, 2016; Irmak *et al.*, 2016; Mo *et al.*, 2017; Montazar *et al.*, 2017). The subsurface irrigation technology is based on the principle of continuous supply of water to plants following their water absorption, taking into account the nature of soil humidification and the capabilities of technical means. Using subsurface irrigation systems in nursery gardens with apple seedlings planted in baskets with humidifiers makes it possible to grow plants at a compacted spacing to increase the number of seedlings with a high-quality root system. A distinctive feature of the considered subsurface irrigation system is the use of subsurface irrigation pipes as humidifiers, manufactured by Kaz Kauchuk LLP using innovative technology. The operation principle of such pipes is that at low pressure (less than 0.06 MPa), hoses filled with water ooze into the ground, and because of the suction properties of the roots and the capillarity nature of the soil, water flows directly to the roots and, as a result, is consumed for its intended purpose.

Methods

Field experiments were laid at the experimental production site of the Kazakh Scientific Research Institute of Water Economy (KazSRIWE) (Kazakhstan, Taraz).

For growing annual apple seedlings placed in container-type devices, the subsurface irrigation technology was used.

Irrigation of plants by such systems has several advantages, of which the main are the following ones:

- Significant water savings, since during surface irrigation and sprinkling, up to 50% of water is lost due to evaporation, surface runoff, and weathering;
- Reducing the water consumption for irrigation reduces the cost of the irrigation system because of the use of lower capacity pumps, as well as pipelines of smaller diameter;
- Water and nutrients are delivered directly to the root zone (irrigation efficiency reaches 90%), ensuring healthy plant growth and increasing its productivity;
- Safe and efficient delivery of fertilizers to plant roots that reduces chemical contamination of the soil;
- Increased soil aeration – small soil particles are not washed out, the surface remains loose decreasing soil compaction which improves root system growth and development;
- Keeping the soil surface dry makes it difficult for weed seeds to germinate, so fewer herbicides and surface treatments are needed;
- Possibility of compacted planting of seedlings when using the irrigation system in container-type devices to ensure optimal water and nutrient regimes in the root zone during its formation;
- Possibility of transferring containers with plants with developed root system to the open ground, using subsurface or drip irrigation, or sprinkling systems following the agro-technological planting scheme;
- Avoidance of damage to underground irrigation pipes by people, animals, and birds;
- Reducing the risk of infecting plants with fungal diseases, because the soil surface, stems, and leaves remain dry, which dramatically reduces the risk of spreading diseases;

The proposed system of subsurface irrigation requires compacted spacing of seedlings arrangement in devices that ensures optimal water and nutrient regimes, as well as contributes to the formation of a high-quality root system of seedlings, and increases the yield of plants per unit area.

Results

In 2015, tests were started on the experimental production site to study the subsurface irrigation technology used for apple seedlings grown in container-type devices with the subsurface irrigation system in comparison with apple trees grown in baskets with surface irrigation along furrows (Fig. 1).

Fig. 1. Container-type devices

The compacted spacing of seedlings in container-type devices was used with subsurface irrigation elements made of porous tubes placed in containers to form a high-quality root system of seedlings to increase the yield of plants per unit area. In this case, the inlet and outlet ends of the porous tubes were connected to the irrigation pipeline of the system comprised of pipe segments with the length corresponding to the compacted spacing scheme of seedlings. After completing the formation of the root system, the seedlings, along with container-type devices and subsurface irrigation pipes were planted in the open ground following the recommended planting scheme. At that, subsurface irrigation pipes used for watering seedlings, located in container-type devices, were later used as irrigation elements and were connected to the irrigation network comprised of pipeline segments.

Pits were prepared and container-type devices were placed with elements of subsurface irrigation, seedlings, and soil. The entire distribution network of the subsurface irrigation system was placed on the ground (Fig. 2).

After planting trees, the site was watered manually until the seedlings gained full ability to adapt, then the soil near the trees was compacted, and row spacing was cultivated.

After the appearance of five-centimeter shoots, organic fertilizers were introduced in the circles around the tree trunks, i.e. the area developed by the root system of trees.

Fig. 2. Planting of apple trees into the baskets for testing subsurface irrigation technology

The average doses of N, P_2O_5, and K_2O mineral fertilizers in the newly planted garden amounted to 60-90 kg/ha. Ammonium nitrate was applied in dry form as a top dressing at the beginning of the season when planting the trees on a one-off basis, and later, two or three times during the summer in the form of a solution applied under the root, as well as through the subsurface irrigation system in a proportion of 25-30 g per 10 liters of water. During the expected budding, Novalon was applied at a rate of 500-1,000 l/ha. Besides, the Baikal EM-1 preparation was repeatedly applied with irrigation water. The nursery garden was sprayed against diseases and pests during the entire growing season.

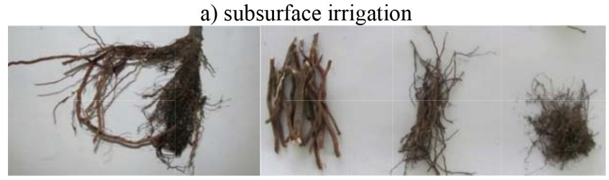
Subsurface irrigation was carried out in a way to maintain soil moisture within the range of 70-80% MMHC (Minimum moisture-holding capacity). Water consumption was recorded by the water flow meter and amounted to 3,800 m^3/ha during the growing season. Ten irrigations were carried out on the surface irrigation area of apple seedlings. The irrigation rate amounted to 4,650 m^3/ha. Comparing with surface irrigation, the decrease in water consumption during vegetation was 850 m^3/ha.

To assess the quality of seedlings at the end of growth processes (before leaf fall), the measurements and observations were made at the site of subsurface irrigation and the site of furrow irrigation. It was revealed that the best conditions for the growth and development of both plants and their root systems were observed during the growing season at subsurface irrigation.

The average height of apple saplings at subsurface irrigation was 164 cm. When irrigating along furrows, their height did not exceed 151 cm. It should be noted that with the same leaf surface area (0.8-0.88 m^2), apple-tree leaves on the plot of subsurface irrigation had larger surface area (up to 30.6 cm^2), while their number was less (171 pcs.) compared to the number of apple-tree leaves from the plot of furrow irrigation (288 pcs.). Apple trees from container-type devices grown on the site of subsurface irrigation and those from the site of surface irrigation were excavated to assess their root systems.

After washing, the roots were sorted into fractions to determine the length and weight of the roots (Figs. 3 a, b) (Table 1) (Alekseyev and Gershunov 1972).

a) subsurface irrigation



b) furrow irrigation

Fig. 3. The root system of apple seedlings

It was revealed that in all fractions that differed in the total length and weight of the roots, the root system of apple seedlings grown in baskets had more compact shape and greater number of root hairs with the diameter of less than one mm than the root system of plants grown at the furrow irrigation site. The predominance of water-conducting hairs contributed to the active growth of the seedlings' aboveground part, which was confirmed by conducted research.

The subsurface irrigation technology with the application of a porous tube and dripper line as humidifiers for fruit plantations was studied in comparison with the surface irrigation with droppers at the sites of Kaz SRIWE in the Zhambyl Region in the orchard's territory laid out in 2016.

The diagram of the pilot production site is shown in Fig. 4.

The subsurface irrigation system (Fig. 5a) included a water supply source *1*, a pumping station *2*, supply *3*, distribution *4*, and irrigation *5* pipelines, and container-type devices *6* for subsurface irriga-

Table 1. Characteristics of root systems of apple seedlings at subsurface irrigation and furrow irrigation sites

Roots diameter	Subsurface irrigation		Furrow irrigation	
	Fractions	%	Fractions	%
	Roots length, cm			
More than 3 mm	150.2	7.5	250.8	8.4
From 2.9 to 1 mm	283.0	14.1	706	23.5
Less than 1 mm	1,570	78.4	2,045	68.1
Total	2,003.2	100.0	3,001.8	100.0
	Roots weight, g (without primary root)			
More than 3 mm	31.2	62.4	72.0	73.2
From 2.9 to 1 mm	13.2	26.4	16.8	17.1
Less than 1 mm	5.6	11.2	9.6	9.7
Total	50.0	100.0	98.4	100.0

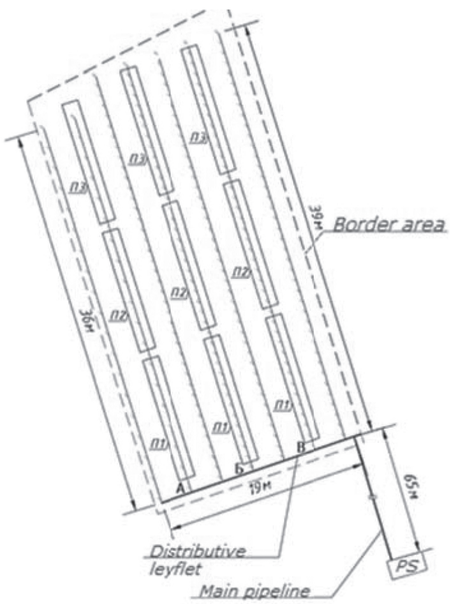


Fig. 4. Diagram of the experimental production site of the Kaz SRIWE orchard.
Growing apple seedlings in the baskets at: A – subsurface irrigation with a porous tube of KazKauchuk; B – subsurface irrigation with a dripping line; C – surface drip irrigation; P1, P2, P3 – test plots

tion of seedlings. The length of irrigation pipelines corresponded to the seedling's layout scheme.

The container-type device of subsurface irrigation (Fig. 5b) consisted of a basket *7*, a subsurface irrigation tube *8* with an inlet *9* and an outlet *10*. The soil *11* and seedling *12* were placed in the basket. The outlet of the subsurface irrigation tube at the end sections was closed with a plug *13*.

To test the subsurface irrigation technology, the soil and M9 apple seedlings were placed in baskets, while the inlet and outlet holes of the subsurface ir-

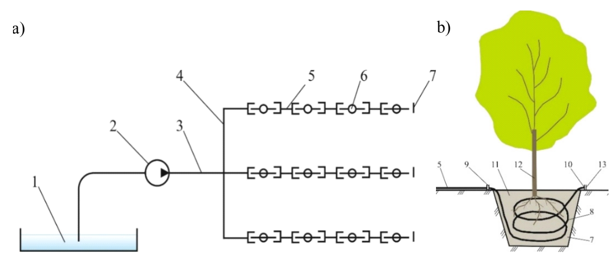


Fig. 5. System (a) and container-type device (b) for subsurface irrigation

rigation pipes after planting were connected to a single irrigation system (Fig. 6).

Subsurface irrigation was carried out in a way to maintain soil moisture within the range of 70-80% MMHC.

(a) Arrangement of seedlings in baskets (b) Control

Fig. 6. Planting apple seedlings in baskets for testing the subsurface irrigation technology

During the growing season, measurements of the height of seedlings, the diameter of stems, the growth of annual shoots, and other necessary observations were carried out on the site (Budagovsky, 1976; Popov, 1976; Karimov, 1983).

Irrigation was carried out on plots of subsurface irrigation with an irrigation network comprised of porous hoses and dripping tubes arranged in baskets. Because there was no closing of the humidification contours on the irrigated areas after irrigation, irrigation norms were applied using a humidification coefficient K_{vpo}=0.67. During the growing season, taking into account the initial water-charging irrigation, the irrigation rate was 4,100 m^3/ha.

After the growth process was completed (before leaf fall), the measurements and observations of plant growth and development were made to assess the quality of apple seedlings grown in areas of subsurface irrigation in baskets with porous hoses and dripping tubes.

The following was revealed concerning the plots of subsurface irrigation in baskets. When watering seedlings using a porous Kaz Kauchuk tube, the greatest increment in all indicators was noted for baskets with a soil mixture comprising 50% of the natural soil (medium-textured loam) and 50% of peat. Seedlings height was, on average, 134.3 cm, shoots increment amounted to 50.6 cm, while trunk diameter was 3.4 cm. At the seedlings growing site with a soil mixture comprising 75% of organic soil and 25% of peat, the height of seedlings was 128.3 cm, shoots increment – 49.2 cm, and the trunk diameter – 3.26 cm. When growing seedlings in baskets with natural soil (100%), the height of seedlings was 124 cm, the shoots increment – 35.6 cm, and the trunk diameter – 3.23 cm.

In areas of subsurface irrigation of seedlings in baskets irrigated by dripping pipes, the largest increment in all indicators was also observed in baskets with a soil mixture comprising 50% of the natural soil of the site (medium-textured loam) and 50% of peat. The height of seedlings averaged 142.7 cm, shoots increment amounted to 61.9 cm, and trunk diameter – to 2.17 cm. In the baskets with soil mixture comprising 75% of organic soil and 25% of peat, seedlings height was 142 cm, shoots increment – 54.3 cm, and trunk diameter – 2.13 cm. When growing seedlings in baskets with natural soil (100%), the height of seedlings was 126.7 cm, the shoots increment – 43.1 cm, and the trunk diameter – 1.97 cm.

At the drip irrigation of apple seedlings grown without containers in the natural ground, plant height averaged 129 cm, shoots increment – 47.4 cm, and trunk diameter – 1.8 cm. Leaf area, their shape index, and the total number were determined for each test variant.

Quantitative indicators of vegetative organs of seedlings grown on the experimental production site are shown below in Table 2.

To assess the root system of apple trees, baskets with seedlings were excavated at the sites of subsurface irrigation and from the site of drip irrigation. After washing, the roots were sorted into fractions to determine their total length and weight (Table 3).

It was revealed that at subsurface irrigation, the root system of apple seedlings grown in baskets had more compact shape. In all fractions that differed in

Table 2. Quantitative indicators of vegetative organs of seedlings

Type of the plot	Test variant	The average height of the seedlings, cm	Average increment of annual shoots, cm	Trunk diameter, cm	The average number of leaves per one tree, pcs.	Average leaf area, m^2	Leaf shape index (average)
1	2	3	4	5	6	7	8
Growing seedlings in baskets with subsurface irrigation using a porous tube	1st variant	124.0	35.6	3.23	160	0.413	1.83
	2nd variant	128.3	49.2	3.26	189	0.584	1.92
	3rd variant	134.3	50.6	3.4	185	0.566	1.9
Growing seedlings in baskets with subsurface irrigation using a dripper line	1st variant	126.7	43.1	1.97	145	0.439	1.83
	2nd variant	142	54.3	2.13	170	0.442	1.9
	3rd variant	142.7	61.9	2.17	178	0.454	1.92
Growing seedlings without baskets at drip irrigation using a dripper line	Control	129.0	47.4	2.01	117	0.269	1.86

Table 3. Characteristics of root systems of fruit crops in the plots at subsurface and drip irrigation

Roots diameter	Subsurface irrigation						Drip irrigation	
	Variant-1		Variant -2		Variant -3		by fractions	%
	By fractions	%	By fractions	%	By fractions	%		
Roots length, cm								
More than 3 mm	140.2	7.0	138.3	6.8	136.5	6.1	135.2	7.3
From 2.9 to 1 mm	283.0	14.1	300.1	14.8	290.5	13.1	301.6	16.2
Less than 1 mm	1,580	78.9	1,592	78.4	1,801	80.8	1,420	76.5
Total	2,003.2	100.0	2,030.4	100	2,228	100	1,856.8	100
Roots weight, g (without primary root)								
More than 3 mm	30.1	61.4	28.5	58.4	28.3	56.1	31.5	62.5
From 2.9 to 1 mm	13.2	26.9	13.9	28.5	15.0	29.8	13.8	27.4
Less than 1 mm	5.72	11.7	6.4	13.1	7.1	14.1	5.12	10.1
Total	49.02	100.0	48.8	100	50.4	100	50.42	100

the total length and weight of the roots, the root system of apple seedlings grown in baskets had more compact shape and greater number of root hairs with the diameter of less than one mm than the root system of plants grown without baskets when watered using drip irrigation. Because of the predominance of water-conducting root-hairs, subsurface irrigation contributed to the active growth of the aboveground part that was confirmed by conducted research.

According to the observations on the growth and development of seedlings grown on the experimental production site in baskets with subsurface irrigation carried out using a porous tube and a dripper line, as well as grown without baskets with drip irrigation using a dripper line, the following should be noted. Good development indicators of the vegetative organs of all trees were observed in the root system of trees during the growing season provided optimal values of soil moisture. At that, in the variants where seedlings were grown in baskets, the largest increment in all indicators was observed in baskets with a soil mixture comprising 50% of natural soil (medium-textured loam) and 50% of peat. Such mixed soil can be recommended for using in the plots where apple seedlings are grown in baskets with subsoil irrigation.

The developed system and subsurface irrigation device allow increasing the yield of seedlings per unit area at the compact spacing of baskets filled with planting material, as well as improving their quality. The amount of necessary fertile mixed soils in the nursery gardens is reduced because of placing them only in baskets, which also reduces labor costs, and improves labor conditions.

Conclusion

1. The conducted research has proved the effectiveness of the subsurface irrigation technology in the orchard with apple seedlings cultivated in special basket-type devices with the installed subsurface irrigation pipes and mixed soil comprising 50% of natural soil (medium-textured loam) and 50% of peat.
2. In all fractions that differ in the total length and weight of the roots, the root system of apple seedlings grown in baskets has more compact shape and greater number of root hairs with the diameter of less than one mm than the root system of plants grown without baskets when watered using drip irrigation.
3. The developed system of subsurface irrigation allows increasing the yield of seedlings per unit area at a compact spacing of baskets with planting material in the nursery gardens and improving the quality of root systems of fruit seedlings. The amount of necessary fertile mixed soils in the nursery garden is reduced because of placing them only in baskets, which also reduces labor costs and improves labor conditions.
4. It is possible to transfer containers with plants having developed root systems to the open ground, using subsurface or drip irrigation, or sprinkling systems following the agro-technological planting scheme.

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