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Water saving based on moisture observations: scheduling drip irrigation regimes for tomatoes under greenhouse conditions in Tajikistan

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ABSTRACT

This study aimed to examine the efficiency of different drip irrigation regimes in spring film greenhouses for early tomato harvesting. The field (small-plot) experiment included designing and testing the watering technology suitable for rural Tajikistan. Irrigation, soil moisture, and tomato growth were followed for several seasons under four irrigation pilots. The experiments showed that the most effective drip irrigation regime for Elpida hybrid tomato was carrying it out while regulating soil moisture within 75-85%, with the irrigation demand of 4,978 m^3/ha and irrigation norm of 99.0 m3/ha, also contributing to better water efficiency. The volume of irrigation water for the production of one unit of tomato crop in the second experiment was 5.73 m^3/ha, i.e. 14.18% less than in the control plot. The study showed that the tomato evapotranspiration coefficient tends to increase as the threshold of soil mois-ture before and after irrigation grows. The maximum net yield amounted to 1,342 thou. Somoni/ha – 1.9 times or 52.7% higher compared to the control plot. The research findings can guide individual farmers and production facilities, as well as the overall development of agrarian economies like Tajikistan.

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1. Introduction

Drip irrigation has been used to improve tomato production, quality and yield (Yasonidi, 2001). It is also one of the most efficient and broadly investigated irrigation techniques (Battam et al., 2003), the benefits of which include increased yields with the simultaneous reduction of irrigation rates and prudent use of water per unit of production, as well as reduction of moistened zone (Yasonidi et al., 2012). Drip irrigation can deliver water and nutrients to desirable root zone and has hence become the dominant irrigation method in greenhouse production. Compared with traditional border and furrow irrigation, drip irrigation allows bringing down water loss from evapotranspiration and percolation, thereby saving water and fertilizers. Under certain circumstances, it can even minimize soil degradation and salinity (Hao Liu et al., 2019; Hanson & May, 2004; Mahajan & Singh, 2006). In the last two decades, the area under drip irrigation globally has grown by the factor of 6.5 and is approx. 10.3 mln ha currently (Grigorov & Fedoseeva, 2006). However, in Tajikistan this technique has not yet received wide application.

In recent decades, the expansion of irrigated areas with micro-irrigation systems has been especially significant in China and India, where drip irrigation application has grown 88 and 111 times, respectively. In the latter, the farmland area under drip irrigated currently amounts to approx. 2 mln ha. According to the data of the Yugopoliv Korolev Agro Company, as of 2011 in Russia drip irrigation systems serviced 35-40,000 ha of vegetable crops and 6.5-7,000 ha of orchards, vineyards, and berry fields.

Field tomato production has recently benefited from film shelters allowing year-round supply of crops to consumers. Tomato varieties and hybrids grown in film greenhouses are characterized by early maturity and high productivity. At present, most tomato varieties for protected soil have been replaced by first-generation (F1) heterotic hybrids with higher disease resistance (Pulatov & Aliev, 2009).

This research aimed to analyze the efficiency of drip irrigation for tomato fruit development and early harvesting in spring film greenhouses. The study used the (F1) Elpida early maturing determinant first-generation tomato hybrid. The seedlings were grown in polyethylene pots. Growing tomatoes from seedlings using film shelters in the conditions of Tajikistan's Hisor Valley has not been scientifically substantiated yet. In this regard, the research team has developed a technology for growing seedling tomatoes in film greenhouses based on optimized water and mineral nutrition ensuring the planned high-quality tomato crop.

2. Materials and methods

2.1. Experiment setup

The field experiments were carried out in small plots (280 m^2) in the spring film greenhouse of Taj-Cable OJSC heated with solar energy during 2018-2021 (Yasonidi et al., 2015). The irrigation was carried out following the active soil layer (50 cm) moisture content regime via drip emitters installed on the irrigation pipe (every 40 cm) with four repetitions as follows (Dospekhov, 1979):

1. Active soil layer irrigation with moisture regulation within 70-80%, lowest moisture capacity;
2. Active soil layer irrigation with moisture regulation within 75-85%, lowest moisture capacity;
3. Active soil layer irrigation with moisture regulation within 80-90%, lowest moisture capacity.
4. Active soil layer irrigation with moisture regulation within 85-95%, lowest moisture capacity;
5. Control: Irrigation with active soil layer humidity regulation. Watering of tomatoes was done with keeping pre- and post-irrigation moisture of the calculated soil layer within 70-95%.

The characteristics of the drip lines utilized in the experiment are given in Table I. The nominal pipe diameter in the greenhouse was 14 mm, and the consumption of drippers was 3.0 l/h.

Table I. J-TurboLine drip lines used in the experiment

Nominal diameter, mm	Wall thickness, mm	d_H,mm	d_B, mm	Dripper consumption, l/h	Distance between drippers, Δt, cm	Maximum pressure, Pa	Coil length, m
12	0.65	11.8	10.5	3.0	20-100	2.0	500
13	0.90	12.3	10.5	3.0	20-100	3.5	400
14	1.10	12.7	10.5	3.0	20-100	3.5	400

The experiment sequence was as follows. First, the seeds were sown into soil with the moisture content maintained at 70-80%, i.e. lowest moisture capacity, and temperature of 25-30°C. The seedlings were planted along a stretched twine, with peat pots buried in the soil at 3/4 of their heights, so that the plant root neck did not suffer from water flowing down during irrigation and did not contact soil to prevent potential infection. The seedlings in plastic pots were planted in holes, so that the coma surface during planting was 1-2 cm above ground level. After planting, the plants were watered with warm water (24-26°C) for 2-3 min (Alpatiev, 1981).

The seedlings appeared after 5-7 days, and with preliminary germination after 1-2 days. After germination, the temperature was reduced to 12-16°C during the day and 8°C at night for 4-5 days. After that, the temperature was raised to 19-22°C during the day and 16°C at night. The experiments were arranged in four blocks (four replicates) and were conducted according to the following scheme (Fig. 1.).

2.2. Water balance assessment and irrigation scheduling

The water balance for each plot was assessed as the difference between inflow and outflow per unit area in the calculated soil layer for a certain period. Under these conditions, the water balance equation is as follows:

$$B = P - R \ m^3/ha \qquad (1)$$

,where

P is the inflow (the inflow included water supply to the field as irrigation (m^3/ha)),

R is the outflow,

and B is the water balance residual term.

The irrigation water demand was determined based on the actual measurements; and water consumption was estimated by assuming that the inflow and outflow of soil water to the calculated soil layer were equal. Hence, the following water balance equation for a period of time:

$$B = \Sigma V пв - \Sigma V pn \pm \Delta W, \ m^3/ha \qquad (2)$$

, where

$\Sigma V_{пв}$ is the sum of water supplied to the experimental plots for the estimated period (m^3/ha),

ΣV_{pn} is the total soil moisture consumption as evapotranspiration for the calculation period (m^3/ha),

and ΔW is the change in soil moisture reserves at the beginning and end of the growing season.

The water amount supplied under different options was determined based on the actual readings of water meters installed at the growing season's beginning. The total soil moisture consumption for evapotranspiration for the calculation period was determined by summing the difference between soil moisture reserves in the calculation layer after and before subsequent irrigation. The influx and consumption of water due to the difference in soil moisture reserves at the beginning and end of the growing season were determined based on the formula for actual soil moisture measurements.

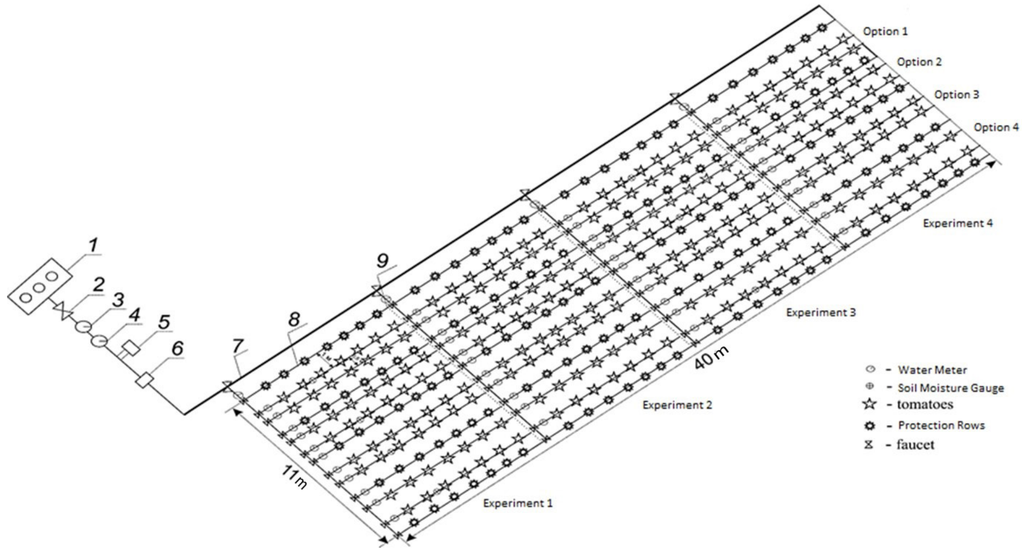

Figure 1. Scheme of experimental plots and protective strips in the spring film greenhouse: 1) water storage tower; 2) valve faucet 1; 3) pressure gauge; 4) water meter; 5) fertilizer mixer; 6) filter; 7) local pipeline; 8) irrigation pipelines with drippers; 9) valve faucet 2.

2.3. Soil properties

The main physical and water-holding properties of soils were determined annually at the beginning of field research (Table II). On average, over the three years of research, planting of seedlings according to the experiments was carried out during March 18-25. The growing season continued until September 15.

Table II. Water-physical properties of dark old irrigated grey soil

Depth, cm	Volumetric weight, t/m^3	Porosity (% of soil volume)	Lowest moisture capacity, % dry weight soil	Wilting moisture, % dry mass of soil	Irrigation rate at humidity fluctuation by 10%, m^3/ha
0-5	1.18	55.7	24.6	6.2	14.51
5-20	1.15	58.3	24.3	6.6	41.92
20-35	1.09	59.8	23.5	6.8	38.42
35-60	1.22	61.6	24.4	6.8	74.42
60-80	1.17	59.4	24.5	6.9	57.33
80-100	1.19	60.3	24.8	7.0	59.02

According to humus content in the 0-30 cm arable layer (3.31-3.37%), the soil of the experimental plot was characterized by average soil fertility. The content of total nitrogen in the arable layer was 0.31%, phosphorus – 0.30%, and potassium – 1.9%. The soil nitrate content amounted to 51.3 mg/kg, mobile phosphorus – 453 mg/kg, and exchangeable potassium – 312 mg/kg. The soil solution was neutral or slightly alkaline. The soil's granulometric composition was medium loam with the physical clay content of 28-46% and physical sand content of 46-60%, i.e. favourable for tomato cultivation using drip irrigation.

The soil at the experimental site was supplemented with organic fertilizers before planting the seedlings. During the growing season, complex mineral fertilizers were applied to all options using the same method. The CombiFert drug (1 kg per 500 liters of water) was mixed and distributed via droppers.

3. Results

3.1. Influence of drip irrigation on tomato yields

In the irrigation experiment, the optimal yield was 143.54 t/ha for moisture content of 75-85% (Table III, Fig. 2.). The yield grew by 35.04 t/ha compared to the control plot during 3 years of observation. The increased and lowered moisture content of 70-80% and 80-90%, respectively, likewise led to higher yield. The observed yield growth became statistically significant at 5% significance level (HCP0.95=1.35 t/ha).

Table III. Influence of different drip irrigation regime moisture contents on the yield of Elpida tomato hybrid in spring film greenhouses for 2018-2020 compared to the control plot

Irrigation method	Moisture content	Yield, t/ha	Yield increase, t/ha
Drip irrigation with cable lines under each row, with drippers every 0.4 m	70-80%	132.71	24.21
	75-85%	143.54	35.04
	80-90%	115.54	7.04
	85-95%	105.40	-3.1
	Control	108.50	0

3.2. Reduced water consumption with drip irrigation

The optimal tomato yield (143.54 t/ha) was observed for Experiment 2 with the average irrigation rate of 99 m^3/ha (Table IV). The average duration of irrigation during the experiments was 877 – 1,378 h (on average 1,128.2), i.e. 12% more compared to the control plot. The duration of inter-irrigation periods was 2-4 days in Experiment 4, and 3-6 days in Experiment 2 (Table IV).

Table IV. Summary of irrigation regimes for 2018-2020

Indicator	Experiment 1	Experiment 2	Experiment 3	Experiment 4	Control
Number of irrigations	42	49	54	63	44
Average duration of watering for the period, h	877	1073	1184	1378	995
Inter-irrigation period (min/max), days	3/5	3/6	2/5	2/4	3/5
Water supply, m^3/ha	4245.9	4978.0	5495.5	5916.1	4385.0
Actual average irrigation rate, m^3/ha	96.0	99.0	93.5	95.6	132.7
Yield, t/ha	132.71	143.54	115.54	105.40	108.50

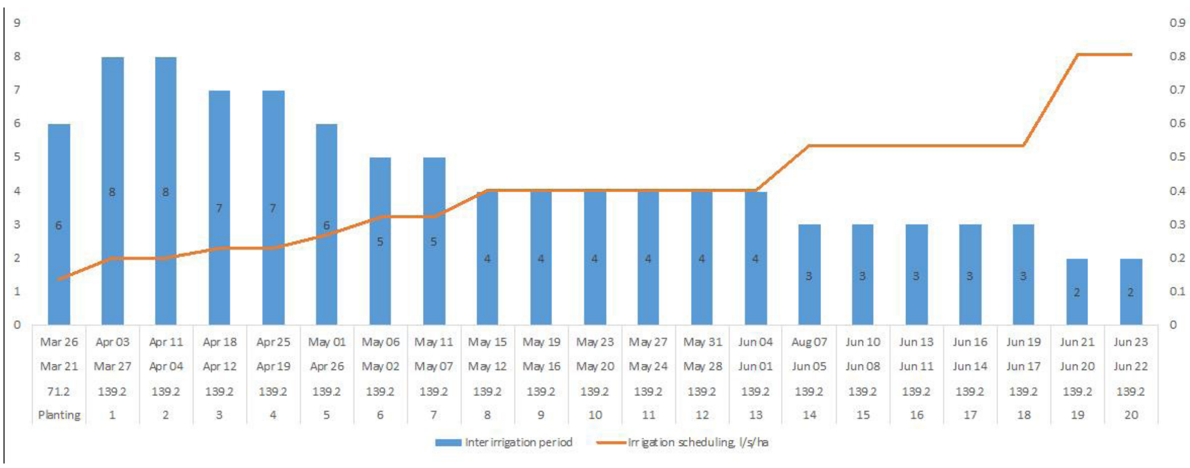

Figure 2. Recommended irrigation regime for early Elpida tomato harvesting in spring film greenhouses.

The average amount of applied water changed from 4,245.9 in Experiment 1 to 5,916.1 m^3/ha in Experiment 4; and the average irrigation rate changed from 93.5

m³/ha in Experiment 3 to 99.0 m³/ha in Experiment 2. The mean irrigation rate in all four experiments turned out 38.23% less compared to the control plot.

The three-year long observations showed that the number of irrigation rounds – depending on the increase in pre-irrigation soil moisture content of the calculated layer (from 70 to 85% of the lowest moisture capacity) – increased from 42 in the Experiment 1 to 63 in Experiment 4. The number of irrigation rounds in the Control Experiment was 44.

3.3. Soil moisture regime under drip irrigation

The evapotranspiration of the tomato field was determined by measuring soil moisture and calculating the moisture content of the calculated layer before and after each irrigation (Table V).

Table V. Water balance of tomato irrigation regime (mean for 2018-2020)

Observation period	Irrigation, m^3/ha	Evapotranspiration, m^3/ha	Balance, m^3/ha
Experiment 1			
March 31	69.9	146.15	-76.25
April 30	417.6	452.9	-35.3
May 31	591.6	583.85	7.75
June 30	904.8	905.45	-0.65
July 31	1,113.6	1,087.05	26.55
August 31	800.4	817.2	-16.8
September 30	348.0	403.95	-55.95
During irrigation period, total	4,245.9	4,396.5	-150.6
Experiment 2			
March 31	71.2	134.5	-63.3
April 30	313.2	354.5	-41.3
May 31	696.0	686.2	9.8
June 30	1,044.0	1,023.75	20.25
July 31	1,252.8	1,251.95	0.85
August 31	1,078.8	1,090.85	-12.05
September 30	522.0	519.25	2.75
During the irrigation period, total	4978	5061	-83
Experiment 3			
March 31	66.7	181.3	-114.6
April 30	522.0	532.7	-10.7
May 31	730.8	778.9	-48.1
June 30	1,218.0	1,177.8	40.2
July 31	1,322.4	1,314.25	8.15

Table V. Cont.

August 31	1,148.4	1,123.85	24.55
September 30	487.2	5639	-76.7
During the irrigation period, total	5,495.5	5,672.7	-177.2
Experiment 4			
March 31	69.7	170.5	-100.8
April 30	626.4	639.95	-13.55
May 31	835.2	853.45	-18.25
June 30	1,183.2	1,175.7	7.5
July 31	1,600.8	1,600.1	0.7
August 31	1,183.2	1,237.95	-54.75
September 30	417.6	456.05	-38.45
During the irrigation period, total	5,916.1	6,133.7	-217.6
Control			
March 31	69.8	40.95	28.85
April 30	382.8	425.75	-42.95
May 31	696.0	683.8	12.2
Jun 30	870.0	863.65	6.35
July 31	1,148.4	1,173.6	-25.2
August 31	904.8	939.4	-34.6
September 30	313.2	402.35	-89.15
During the irrigation period, total	4,385.0	4,529.5	-144.5

Depending on the pre- and post-irrigation moisture content, the incoming part of the water balance (irrigation) item changed from 4,246 m^3/ha to 5,916 m^3/ha in Experiment 1 (Table V). The expenditure part of the water balance item ranged from 4,396.5 m3/ha in Experiment 1 to 6,133.7 m^3/ha in the fourth experiment. An increase in the pre-irrigation moisture content of the calculated soil layer from 70 to 85% of the lowest moisture capacity and after irrigation from 85 to 95% of the lowest moisture capacity contributed to higher expenditure part of the water balance item by 1,738 m^3/ha or 39.54%. The maximum value of the water balance expenditure part in all experiments was observed in July. Monthly water consumption for evapotranspiration, except for March and September, varied from 354.5 m^3/ha in the Option 2 to 1,600.1 in Option 4. The water balance for the irrigation period according to the experiments changed from 83 m^3/ha to 217.6 m^3/ha in Experiment 2.

Taking account of the fact that the soil moisture stock formed due to pre- and post-planting irrigations was insignificantly involved in the water balance, then irrigation water was the only source of water supply for tomatoes in greenhouses. The final result experiment statistics are presented in Table VI below.

Table VI. Early tomato harvest, 2018-2020

Experiment	Yield, t/ha	Difference with standard		Group
		t/ha	%	
Control	108.50	-	-	St.
1	132.71	24.21	22.31	2
2	143.54	35.04	32.29	1
3	115.54	7.04	6.48	3
4	105.40	-3.1	-2.85	4
Smallest significant difference 0,5	-	1.63	1.35	-

Compared to the Control Experiment, the difference between the options was significant at 5% significance level (smallest significant difference 0.95=1.35 t/ha), i.e. all yield differences were statistically significant.

4. Discussion

Greenhouse farming of valuable crops like tomatoes and other vegetables represents one of the ways to ensure food security for the growing population of Tajikistan. Film greenhouses are twice as cheap as conventional stationary ones. In addition, spring-summer-autumn crop rotation allows making them 4-5 times less energy intensive compared to existing analogues, as well as guarantees high yields of vegetable crops and, consequently, high farmer incomes (Yasonidi et al., 2012). This study demonstrated the advantages of using drip irrigation in film greenhouses.

As of today, the surface furrow method is the most wide-spread irrigation technique used in tomato cultivation in Tajikistan. The method's main disadvantages include uneven field moistening (moisture uniformity coefficient below 0.6-0.7), and large irrigation water losses reaching 40-60% of intake. In its turn, the latter leads to significant irrigation soil erosion reaching values up to 150 t/ha during the irrigation season. Despite certain additional ex-penditure, early production in greenhouses is costs-effective and offers a number of advantages. However, the limiting factor in early tomato production based on existing drip irrigation systems is the lack of technology for growing tomatoes in film greenhouses, corresponding to the possibilities of drip irrigation.

Currently, the Government of Tajikistan is taking steps to promote water-efficient technologies, which – in addition to saving water – have been scientifically proven to be economically effective. Unfortunately, implementing water-saving techniques such as drip irrigation is difficult due to high capital investment costs and lack of domestic expertise. Therefore, sufficient material resources are necessary. There is a need to engage governmental agencies and private companies in implementing water-saving technologies in the country.

To improve drip irrigation regimes with the simultaneous introduction of recommended organic mineral doses when growing tomatoes in spring film greenhouses, this research aimed to investigate the possibilities for obtaining early tomato harvest.

This study was carried out to enhance the drip irrigation regime for tomatoes in spring film greenhouses to ensure proper plant growth and development, as well as heavy yield of high-quality tomatoes. The study has managed to design an effective technology for growing seedling tomatoes of the Elpida determinant early-ripening hybrid (F1) in film greenhouses by optimizing plant water and mineral nutrition.

Under the different regimes of pre- and post-irrigation moisture in the calculated soil layer, the total evapotranspiration index increased from 4,246 to 5,916.1 m^3/ha. The lowest indicator was registered in Experiment 1 (soil moisture of 70-80% of the lowest moisture capacity), and the highest was obtained in Experiment 4 (85-95% of the lowest moisture capacity). An increase in soil moisture before irrigation up to 85% of the lowest moisture capacity delayed flowering, fruit formation, and the start of the first harvest by 6-8 days compared to the Control Experiment. Experiment 2 turned out to demonstrate the most efficient irrigation regime (soil moisture of 75-85% of the lowest moisture capacity), with tomato yield amounting to 143.54 t/ha, i.e. 35.04 t/ha higher compared to the control plot.

The study has shown that growing the determinant Elpida tomato hybrid in film greenhouses with the help of irrigation and soil moisture regulation within 75-85% (lowest moisture capacity) allows boosting the net income 1.9 times compared to the Control Experiment.

In general, the results obtained correspond to the reality of tomato cultivation in spring film greenhouses in the target area (Hisor Valley). According to the research findings, obtaining heavy yields of high-quality tomatoes depends on the effective implementation of drip irrigation regimes.

5. Conclusions

This study focused on developing drip irrigation regimes in spring film greenhouses for early tomato harvesting. The field (small-plot) experiment was designed to test and develop the technology in rural Tajikistan. During the three years of research, across one control and four experimental plots on average 49 vegetation irrigation rounds were required to maintain the required moisture content of 0.5 m soil layer within 75-85% of the lowest moisture capacity with drip irrigation. With the mean irrigation rate of 99 m^3/ha, the actual irrigation rate was 4,978 m^3/ha.

The study has demonstrated that the best option for irrigating the Elpida hybrid was drip irrigation with regulated active soil layer moisture content within 75-85% of the lowest moisture capacity (Experiment 2). The actual tomato yield in this experiment averaged 143.54 t/ha over the three years. The yield growth compared to the Control Experiment amounted to 35.04 t/ha, and 24.21 t/ha compared to Experiment 1.

Whereas the maximum cost of production of Elpida hybrid fruits using irrigation with soil moisture regulation within 75-85% of the lowest moisture capacity was 1,342.1 thou. Somoni/ha, in the Control Experiment it was 707.4 thou. Somoni/ha. The profit from the sale of tomatoes in Experiment 2 compared to the Control Experiment was higher by 634.7 thou. Somoni/ha or 52.7%. The research outputs can be helpful to farmers and production facilities, as well as valuable for developing agrarian economies like Tajikistan.

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