Water-saving technologies for vegetables in the south of Russia

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Abstract. The article presents the results of studies, showing that to obtain the planned yield of table beets and carrots with drip irrigation 60-80 t/ha on the light brown soils in the south of Russia, water-saving technologies were applied. These technologies, combining the application of the developed irrigation regimes simultaneously with the introduction of calculated doses of mineral fertilizers, allow significantly reduce the total water consumption (Water Total Consumption Coefficient - WTCC) and Irrigation Water Expense (IWE) to produce 1 ton of harvest. It was established that maintaining a constant Soil Pre-Irrigation Moisture (SPIM) 80% of Full Moisture Capacity (FMC) and an increase of the mineral fertilizer doses to N210P100K260 allowed to obtain the highest yield of carrot in our field experience 81.6 t/ha. It happened simultaneously with the reduction of water total consumption coefficients to a minimum of 7.22 and the irrigation water expenses to 5.52 mm/ton. In variants with a differentiated wetting depth of 0.3-0.5 m the maintaining an optimal irrigation regime of 80% of FMC and increasing fertilizer doses to N230P180K100, the yield of table beet increased to 84.1 t/ha. It caused the maximum reduction of WTCC to 5.98 and IWE – to 4.51 mm/ton.

1. Introduction
Nowadays, growing vegetables, the deficit of fresh water increases every year. Thus it is necessary to develop measures for the rational use of water resources; the introduction of resource-saving technologies into irrigated agriculture; the irrigation methods that reduce water consumption to produce 1 ton of crop.

The climatic conditions of the Volgograd region allow it to be one of the main producers of vegetable crops in the South of Russia. Crops of beetroot and carrot under drip irrigation, occupy large areas in this region. Today, given the available resources (water, technical, labor, financial) and the possibilities of selling the grown crop, farmers are not faced with the task of obtaining the highest possible yields of vegetables. The main task is to obtain the planned yields of vegetables in any weather conditions while maintaining soil fertility and environmental safety.

In this regard, the main purpose of scientific research conducted by the Volgograd State Agrarian University in the Volgograd Region is to determine the optimal combination of drip irrigation regime and mineral nutrition of carrot and table beet to obtain the planned yield of 60, 70 and 80 t/ha.

The researches of carrot are conducted in various directions. In India [1], the effect of cadmium on the quality of carrots is being studied; in Brazil [2, 3] the time of sowing and total water consumption; in Turkey [4] soil loss during carrot harvesting; in Spain [5] the possibility of using groundwater for irrigation. Irrigation regimes are carefully studied in Tunisia, where there is an acute shortage of water.
In the Volgograd region, evaporation is 3 times more than precipitation, so the main task for us is the use of water-saving irrigation technologies. The big researches in our region were carried out by Martynova A.A. [7]. She studied irrigation regimes and fertilizer doses to obtain carrot yields up to 70 t/ha with drip irrigation in 2008-2009. Since 2013 [8, 9] she explored options for obtaining yields of up to 80 t/ha with sprinkler irrigation and drip irrigation, on options combining various irrigation regimes and agrotechnical operations (plowing, cultivation, milling, etc). So, in order to obtain the planned yield of up to 80 t/ha of carrots in our research, we looked for options combining irrigation regimes and fertilizer doses to reduce water consumption per 1 ton of crop.

The researches of beet are doing in many countries. They are held in Turkey [10, 11], Iran [12], Italy [13, 14], USA [15], Germany [16]. However, all of them are aimed at developing the technology of growing sugar beet. In Russia, sugar beets are grown on black earth without watering. In the south of Russia, one of the most important vegetable crops is table beet. Such studies were conducted by Stepanova N.E. in 2005-2007 [17]. She received the yield of beets up to 100 t/ha when irrigating was with sprinkler irrigation system, however, with very high quantity of fertilizers and high consumption of irrigation water.

So the central task of our researches were the development of water-saving technologies, combining the application of the developed drip irrigation regimes for carrots and vegetable crops simultaneously with the introduction of calculated doses of mineral fertilizers, which significantly reduce water consumption to obtain 1 ton of crop [18, 19].

2. Materials and methods
The field for research in 2015-2017 was located on the light brown heavy loamy soil of the Volgograd region. In the layer of the soil (0.0-0.5 m) the density of the soil was 1.31 t/m³, the humus content was 1.87-2.02%, the Full Moisture Capacity was 22.93% of the mass of dry soil. The soil of the site was not saline, pH = 7.0-8.3.

The hybrid of carrot "Major F1" and a table beet variety "Bordeaux" were grown under drip irrigation.

In order to achieve this goal, in the process of scientific research on carrots, 2 factors were studied: factor A - soil water regime, factor B - doses of mineral fertilizers.

The soil water regime (factor A) was investigated in 3 variants. For carrots, two options were considered with differentiated SPIM 70-80-70 and 70-90-80% of FMC, in 3 interphase periods ("seeding - beginning of the root fruit formation", "root fruit formation – technical ripeness", “technical ripeness - harvest.”), and one option with a constant SPIM 80-80-80% of FMC. For beetroot, 3 options were developed with constant SPIM 70, 80 and 90% of FMC.

Factor B was also investigated in 3 variants. For carrots, quantity of mineral fertilizers N150P60K180, N180P80K220, N210P100K260, and for beets - N130P80K20, N180P130K60, N230P180K100 (kg/ha), respectively for yields of 60, 70 and 80 t/ha, were studied.

For the beet was also laid the third factor studied (factor C). This is a different depth of moisture in the soil, where the main mass of root crops are located: 0.5 and 0.3-0.5 m.

Weather conditions in terms of the ratio of precipitation to the sum of temperatures for two years of research were characterized as extremely arid and for one year – as a little arid.

3. Results and Discussion
The elements of the irrigation regime, the Irrigation Quantity (during the growing season) and the Total Water Consumption of carrots are shown in the Table 1.

The calculations showed that with an increase SPIM in the interfacial periods from 70 to 80 and further to 90% of FMC the Irrigation Rates for carrots with drip irrigation dropped from 30.0 to 25.0 and then to 20.8 mm/ha.

With an increase of the soil moisture before irrigation from 70-80-70 to 70-90-80% of FMC, the Number of Irrigations during the growing season increased on average from 15 to 20, and the Irrigation
Quantity increased from 405.0 to 478.0 mm/ha. The highest Total Water Consumption of 589.0 mm/ha was obtained on the variant with a permanent irrigation regime of 80-80-80% of FMC.

**Table 1.** Elements of the Irrigation Regime, the Irrigation Quantity and the Total Water Consumption of carrots with drip irrigation, on average for 2015-2017.

| SPIM, % FMC | Interphase periods | Total number of irrigations | Irrigation quantity | Total water consumption |
|-------------|--------------------|-----------------------------|---------------------|-------------------------|
|             | seeding - beginning of the rootfruit formation | rootfruit formation | technical ripeness - harvest | pieces | (mm/ha) | (mm/ha) |
| 70-80-70    | 4*30.0             | 9*25.0                     | 2*30.0              | 15        | 405.0   | 567.8   |
| 80-80-80    | 6*25.0             | 9*25.0                     | 3*25.0              | 18        | 450.0   | 589.0   |
| 70-90-80    | 4*30.0             | 10*20.8                    | 6*25.0              | 20        | 478.0   | 578.1   |

In irrigation research, two key indicators are commonly used to compare options. These are Water Total Consumption Coefficients (WTCC) and Irrigation Water Expenses (IWE), showing respectively the efficiency of using the total amount of water (irrigation water, rain, water in the soil, ground water) and only irrigation water to produce 1 ton of harvest.

To determine WTCC, it is necessary to divide the Total Water Consumption by yield, and for IWE should be divided the Irrigation Quantity by the yield of vegetables.

The yield of carrots, WTCC and IWE according to the variants of our field experiments are shown in the Table 2.

The results showed that the yield of carrots with drip irrigation significantly increased with improved irrigation regime and the level of mineral fertilizers.

The highest yield experience of 71.5 ... 81.6 t/ha a was obtained in variants with a constant irrigation regime of 80-80-80% of FMC. It was accompanied by an increase in the productivity of the use of moisture, reducing to a minimum the Water Total Consumption Coefficients 7.22 ... 8.24 and Irrigation Water Expenses 5.52 ... 6.29 mm / ton.

With increasing the quantity of fertilizers to N210P100K260, the yield of carrots increased from 57.9 ... 71.5 to 68.2 ... 81.6 t/ha. This contributed to reducing the WTCC and IWE respectively to 7.22 ... 8.33 and 5.52 ... 6.58 mm/ton.

**Table 2.** Yield of carrots, Water Total Consumption Coefficients (WTCC) and Irrigation Water Expenses (IWE), on average for 2015-2017.

| yield of carrots, t/ha | variants of field experiments | WTCC mm/ton | IWE mm/ton |
|------------------------|------------------------------|-------------|------------|
| real                   | planned                      | quantity of fertilizers, kg/ha | SPIM, % of FMC | SPIM, % of FMC | SPIM, % of FMC |
| 57.9                   | 60                           | N_{150}P_{60}K_{180}         | 70-80-70        | 9.81       | 7.01 |
| 62.8                   |                              |                           | 70-90-80        | 9.21       | 7.61 |
| 71.5                   | 80                           | N_{180}P_{80}K_{220}       | 80-80-80        | 8.24       | 6.29 |
| 66.3                   | 70                           |                           | 70-80-70        | 8.56       | 6.11 |
| 72.0                   | 80                           | N_{180}P_{80}K_{220}       | 70-90-80        | 8.03       | 6.64 |
| 73.6                   |                              |                           | 80-80-80        | 8.01       | 6.11 |
| 68.2                   | 80                           | N_{210}P_{100}K_{260}      | 70-80-70        | 8.33       | 5.94 |
| 72.7                   |                              |                           | 70-90-80        | 7.95       | 6.58 |
| 81.6                   | 80                           |                           | 80-80-80        | 7.22       | 5.52 |
In this regard, the maximum yield of carrots in our experience of 81.6 t/ha was obtained while maintaining soil moisture not lower than 80-80-80 % of FMC, together with maximum quantity of fertilizers N210P100K260. In this variant, water was used most efficiently, because since for three years of research the Water Total Consumption Coefficient and the Irrigation Water Expenses reached their minimum values on average equal to 7.22 and 5.52 mm/ton.

In experiments with beetroot with an increase SPIM from 70 to 90% of FMC, the number of irrigations increased (Table 3) from 9 to 32 for soil moisture depth 0.5 m and from 7-5 to 21-19 for soil moisture depth of 0, 3-0.5 m. The Irrigation Quantity also increased from 324.0 to 384.0 for soil moisture depth of 0.5 m and from 334.0 to 385.5 mm/ha for soil moisture depth of 0.3-0.5 m. However, the value of Irrigation Rate decreased from 36.0 to 12.0 mm/ha for soil moisture depth 0.5 m and from 22.0-36.0 to 7.5-12.0 mm/ha for soil moisture depth of 0.3-0.5 m.

Table 3. Elements of the Irrigation Regime and the Irrigation Quantity of beetroot with drip irrigation, on average for 2015-2017.

| SPIM, % FMC | irrigation rate, mm/ha | total number of irrigations, pieces | irrigation quantity (mm/ha) |
|-------------|-------------------------|----------------------------------|--------------------------|
|             | soil moisture depth of 0.5 m |                                  |                          |
| 70          | 36.0                    | 9                                | 324.0                    |
| 80          | 24.0                    | 15                               | 360.0                    |
| 90          | 12.0                    | 32                               | 384.0                    |
|              | soil moisture depth of 0.3-0.5 m |                                |                          |
| 70          | 22.0-36.0               | 7-5                              | 334.0                    |
| 80          | 14.8-24.0               | 11-9                             | 378.8                    |
| 90          | 7.5-12.0                | 21-19                            | 385.5                    |

Our research showed that the productivity of table beet under drip irrigation increased while maintaining a differentiated soil moisture depth of 0.3-0.5 m, optimizing the irrigation regime and increasing the level of mineral nutrition (Table 4).

On the variants with a differentiated soil moisture depth of 0.3-0.5 m, as compared with a constant 0.5 m, the yield of beets increased from 49.7-76.3 to 54.9-84.1 t/ha.

On variants with a dose of fertilizer N130P80K20, the lowest yield of beet 49.7-54.9 t/ha was observed while maintaining the soil moisture before irrigation during the whole growing season not less than 70% of FMC. With an increase SPIM to 80% of FMC, the yield of beets increased to 59.7-63.7 t/ha. A further increase SPIM up to 90% of FMC led to an over-wetting of the soil and a decrease in yield to 56.4-58.9 t/ha.

The same pattern was observed on variants with other levels of mineral nutrition N180P130K60 and N230P180K100. Therefore, maintaining the soil moisture not lower than 80% of FMC throughout the growing season is the optimal irrigation regime for growing beetroot with drip irrigation.

The rise of the fertilizer doses from N130P80K20 to N230P180K100 also contributed to increase the yield of beets from 49.7-59.7 to 68.3-76.3 t/ha in variants with a constant soil moisture depth of 0.5 m and from 54.9-63.7 to 72.0-84.1 t/ha - with a differentiated wetting depth of 0.3-0.5 m.

In this regard, on average for 3 years of research, the highest beet yield 84.1 t/ha was obtained on variants with a differentiated wetting depth of 0.3-0.5 m while maintaining an optimal irrigation regime of 80% of FMC combined with quantity of fertilizers N230P180K100.

Our research has shown that increasing of the beet yield has contributed to reduce the Total Water Consumption and Irrigation Water Expense to produce 1 ton of harvest.

On options with a differentiated moisture content of 0.3-0.5 m, compared with a constant depth of 0.5 m, WTCC decreased from 6.33-9.11 to 5.98-8.67, and IWE – from 4.72-6.81 to 4.51-6.54 mm/ton.
While maintaining an optimal irrigation regime of 80% of FMC, the Water Total Consumption Coefficient and Irrigation Water Expenses for beet reached minimum values of 6.33-8.09 and 4.72-6.03 mm/ton, respectively, for a depth of 0.5 m and 5.98-7.89 and 4.51-5.95 – for a different it of 0.3-0.5 m.

While improving the soil food regime by increasing fertilizer dosage from N130P80K20 to N230P180K100, WTCC decreased from 8.09-9.01 to 6.33-6.85 and IWE - from 6.03-6.81 to 4.72-5.18 mm/ton for a layer of 0.5 m and respectively from 7.89-8.67 to 5.98-6.53 and from 5.95-6.54 to 4.51-4.93 mm/ton – for a depth of 0.3-0.5 m.

### 4. Conclusion
The results of studies showed that to obtain the planned yield of table beets and carrots with drip irrigation 60-80 t / ha on the light brown soils in the south of Russia, water-saving technologies were applied. These technologies, combining the application of the developed irrigation regimes simultaneously with the introduction of calculated doses of mineral fertilizers, allow significantly reduce the Total Water Consumption and Irrigation Water Expenses to produce 1 ton of harvest.

In the field experiments with carrots it was found that maintaining a constant SPIM 80% of FMC and an increase of the mineral fertilizer doses to N210P100K260 allowed to obtain the highest yield 81.6 t/ha. It happened simultaneously with the reduction of water total consumption coefficients to a minimum of 7.22 and the irrigation water expenses to 5.52 mm/ton.

In the field experiments with table beets it was established that in the variants with a differentiated wetting depth of 0.3-0.5 m the maintaining an optimal irrigation regime of 80% of FMC and increasing fertilizer doses to N230P180K100, the yield increased to 84.1 t/ha. It caused the maximum reduction of WTCC to 5.98 and IWE – to 4.51 mm/ton.

| Yield of table beet, t/ha | variants of field experiments | WTCC mm/ton | soil moisture depth of 0.5 m | soil moisture depth of 0.3-0.5 m |
|---------------------------|-------------------------------|-------------|-----------------------------|---------------------------------|
| real                      | planned                       | quantity of fertilizers, kg/ha | SPIM, % of FMC | WTCC mm/ton | IWE mm/ton |
| 49.7                      | 60                            | N₁³₀P₈₀K₂₀  | 70                          | 8.89                          | 6.52                          |
| 59.7                      | 80                            | N₁₈₀P₁₃₀K₆₀ | 70                          | 8.09                          | 6.03                          |
| 56.4                      | 90                            | N₁₈₀P₁₃₀K₆₀ | 90                          | 9.01                          | 6.81                          |
| 59.4                      | 70                            | N₁₈₀P₁₃₀K₆₀ | 70                          | 7.44                          | 5.46                          |
| 67.3                      | 80                            | N₂₃₀P₁₈₀K₁₀₀ | 80                          | 7.18                          | 5.35                          |
| 62.7                      | 90                            | N₂₃₀P₁₈₀K₁₀₀ | 90                          | 8.09                          | 6.12                          |
| 68.3                      | 80                            | N₂₃₀P₁₈₀K₁₀₀ | 70                          | 6.47                          | 4.74                          |
| 76.3                      | 80                            | N₂₃₀P₁₈₀K₁₀₀ | 80                          | 6.33                          | 4.72                          |
| 74.1                      | 90                            | N₂₃₀P₁₈₀K₁₀₀ | 90                          | 6.85                          | 5.18                          |

Table 4. Yield of table beet, Water Total Consumption Coefficients (WTCC) and Irrigation Water Expenses (IWE), on average for 2015-2017.
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