Assignment of Irrigation Norms for Available Water Reserves Taking Into Account Soil Heterogeneity as a Water Saving Approach to Crop Irrigation

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Abstract. Water-saving irrigation regimes for crops include reducing irrigation costs by reducing water supply. However, it also affects obtaining maximum crop yields, and increasing the fertility of the land, and avoiding negative environmental consequences. Creating the optimal, most favorable, comfortable level of soil moisture is a difficult task, which is influenced by many factors. One of the approaches to the appointment of irrigation norms is to take into account the heterogeneity of the soil profile and available moisture reserves. Formulas for calculating irrigation rates for available moisture reserves allow rational use of irrigation water, minimizing losses. The calculation was carried out according to two formulas - according to A.N. Kostyakova both for available moisture reserves for the 0-60 cm layer as a whole and layers every 10 cm. The choice of the estimated year was based on the availability of a water balance deficit, defined as the difference between the water consumption E and precipitation Pe for the calculation period. As a result of calculations, the following results were obtained: taking into account the heterogeneity of the soil profile, it is possible to save from 100 to 400 m³ / ha during the growing season without loss of crop yield.

1. Introduction

Resource-conservation methods of watering are understood as reducing the cost of land irrigation by saving water, modernizing machines and mechanisms, choosing the optimal method of watering, and conducting complex land reclamation [1, 2].

A water-conservation irrigation regime of agricultural crops includes a reduction in the cost of irrigation by reducing water supply. However, it also affects obtaining maximum crop yields, increasing land fertility, and avoiding negative effects on the environment. Creating the optimal, most favorable, comfortable level of soil moisture is a difficult task, which is influenced by many factors. In the current situation of water deficit, a sharp increase in the cost of 1 m³ of water, the issue of water-conservation irrigation regimes of agricultural crops is most acute [3, 8, 9, 11, 12, 14, 18]. The subjects of the study are different approaches to the appointment of irrigation norms. The objective of the study was to find the most rational water-saving method of assigning an irrigation rate that would take into account environmental factors as much as possible.

The purpose of the experiment was to determine the timing and norms of irrigation using available moisture reserves (taking into account the heterogeneity of the soil).

2. Methods of Research
The conducted research has shown that the humidification of a specific soil layer in a certain range of humidity gives significant results in saving irrigation water and a maximum increase in the yield of cultivated crops [4, 5, 10, 13, 17].

The research plot is located on the second over-floodplain terrace of the Volga River. The second over-floodplain terrace of the Volga (Kholmskaya or Srednekhvalinskaya) occupies an area from 27 to 35 meters of absolute height, 2 – 7 km wide, deeply extending to the East along the banks of the Saratovka River. Its surface is flat, in the Volga strip there are old trees-channels and closed depressions. Sometimes the microrelief expressed in the form of hollows.

On the predominant part of the terrace area, the slopes are small from 0.002 to 0.005, directed mainly towards the Volga river and the Saratovka river. The processes of plane erosion are poorly developed [2, 3].

![Figure 1. - Surface relief of the research plot. Height from a randomly selected zero. The original scale is 1: 1000. Vertical cross-section through 10 sm](image)

The modern surface relief of the research plot has an anthropogenic character (Fig. 1). The scope of repeated height measurements at one point most often varies from 0 to 2.5 cm (maximum 4.5 cm), due to measurement errors and the available nanorelief of the field surface. The plot was repeatedly subjected to planning using long-range planners.

During the growing season, the contours of the drying zones are modified. The layer of maximum moisture consumption is gradually shifted, moving from the upper 0-10 cm in the initial phase of vegetation to the underlying layers of soil. The main consumption of soil moisture is due to the root system. Depending on the rate of growth and distribution of the main mass of roots, a drying front of the soil profile is formed [6, 7] (Fig. 2).
The purpose of the experiment was to determine the timing and norms of watering using available moisture reserves (taking into account the heterogeneity of soils). As a comparison, we used the traditional approach in assigning irrigation regimes using the Kostyakov’s A. N. method.

Data from the 38-year series were used to determine the calculated irrigation regime. The calculation was performed using two formulas — for A. N. Kostyakov’s method and for available moisture reserves, for a layer of 0-60 cm the whole and layers every 10 cm. The calculation year was selected based on the availability of the water balance deficit, which is defined as the difference between water consumption $E$ and precipitation $P_e$ for the calculation period (for the calculation period from the spring tillering phase to full ripeness). Water consumption was calculated on the basis of meteorological data for the considered period of time. Weather station data from the town Marks were used. Water consumption was calculated using A. S. and S. M. Alpatyevs’ method.

3. Results and Discussion

Using mathematical statistics formulas, we determined the main characteristics of the variability of the series [15, 16, 19, 20]. The coefficient of variation is 0.22; the coefficient of asymmetry is 0.43. The standard deviation is 65, 93.

After calculating the statistical parameters of the series, we made a theoretical security curve for the water balance deficit. On the security curve, we showed the average values of the water balance deficit over the period in descending order.
Figure 3. a) The water balance deficit security curve and b) the water balance deficit security curve with an overlay of the average water balance deficit values for the period in descending order.

To determine the years of the corresponding estimated security (25, 50, 75, and 95% security), we use the water balance deficit security curve with an overlay of real years [1].

Calculated irrigation regimes and water savings for years of varying security are presented using two approaches in table 1:

Table 1. Values of watering and irrigation norms for years of estimated security (25, 50, 75, 95%) water balance deficit, m³/ha

| Vegetation period | Vegetation phases | By A.N. Kostyakov | Available moisture reserves |
|-------------------|-------------------|-------------------|-----------------------------|
|                   |                   | By layers | Layer 0-60 cm | By layers | Layer 0-60 cm | Water balance deficit security | Irrigation water saving |
| 10.04-20.04       | tillering         | 0         | 0             | 0         | 0             | 0                               | 0                        |
| 20.04-30.04       | piping            | 0         | 0             | 0         | 0             | 0                               | 0                        |
| 1.05-10.05        | piping            | 0         | 0             | 0         | 0             | 0                               | 0                        |

*Note: The table provides values for different vegetation periods and phases, including layers of moisture reserves and irrigation water savings for various water balance deficit security levels.*
| Date         | Operation    | Value 1 | Value 2 | Value 3 | Value 4 |
|--------------|--------------|---------|---------|---------|---------|
| 10.05-20.05  | earing       | 515     | 414     | 364     | 403     |
| 20.05-31.05  | earing       | 0       | 0       | 0       | 0       |
| 1.06-10.06   | earing       | 515     | 414     | 364     | 403     |
| 10.06-20.06  | flowering    | 0       | 0       | 0       | 0       |
| 20.06-30.06  | ripening     | 0       | 0       | 473     | 504     |
| 1.07-10.07   | ripening     | 636     | 518     | 0       | 0       |
| 10.07-20.07  | ripening     | 0       | 0       |         |         |

Irrigation norm, m³/ha

| Date         | Operation    | Value 1 | Value 2 | Value 3 | Value 4 |
|--------------|--------------|---------|---------|---------|---------|
| 10.04-20.04  | tillering    | 0       | 0       | 0       | 0       |
| 20.04-30.04  | piping       | 0       | 0       | 0       | 0       |
| 1.05-10.05   | piping       | 0       | 414     | 364     | 403     |
| 10.05-20.05  | earing       | 515     | 414     | 0       | 403     |
| 20.05-31.05  | earing       | 515     | 414     | 364     | 403     |
| 1.06-10.06   | earing       | 515     | 414     | 364     | 403     |
| 10.06-20.06  | flowering    | 0       | 0       | 0       | 0       |
| 20.06-30.06  | ripening     | 0       | 518     | 473     | 504     |
| 1.07-10.07   | ripening     | 636     | 0       | 0       | 0       |
| 10.07-20.07  | ripening     | 0       |         |         |         |

Irrigation norm, m³/ha

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| 10.06-20.06  | flowering    | 515     | 414     | 364     | 403     |
| 20.06-30.06  | ripening     | 0       | 518     | 473     | 504     |

Heterogeneity of the soil profile 27%
4. Conclusion

From the data given in the table, it can be concluded that if we calculate watering norms taking into account the heterogeneity of soils, the A. N. Kostyakov’s formula gives an overestimation of the results on average by 11-27%. Therefore, using the formula for calculating watering norms for available moisture reserves is more rational. When taking into account the heterogeneity of the soil profile, it is possible to save from 100 to 400 m³/ha during the growing season without losing crop yield.

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