Water balance in the aeration zone at the irrigation of red beets in the Russian Non-Chernozem area

Abstract. Obtaining soils spread over 85% of this territory, 30% of which are podzolic soils in watersheds. Therefore, the studies of the change patterns of soil moisture at the conditions of sod podzolic soils is relevant. In Russia, the studies on the research results they conducted the relation between the water consumption of red beets and the moisture content in the watershed elements of the water balance. The correlation coefficient of the considered values is 0.9. We provided a research on experimental plots and in lysimeters. The water balances for the months of the growing season 2010–2011 (97, 195 mm) and the sum of average daily air humidity deficits (12.1, 9.6 mb) influence water consumption (510, 498 mm) and the total amount of precipitation for the growing season, which is achieved with modern irrigation systems. The irrigation system design of the Central Russian province of the Non-Chernozem area occupies 9 million hectares. A relation between the water consumption of red beets and the moisture content in the watershed podzolic soils was obtained. The correlation coefficient of the considered values is 91. However, it should be noted that there is no data on the relation between irrigation norms and water consumption of red beets.

1. Introduction

We stated the relation between the irrigation of red beets and the moisture content in the aeration zone during the growing season, which is achieved with modern irrigation systems. The irrigation system design of the Central Russian province of the Non-Chernozem area occupies 9 million hectares. A relation between the water consumption of red beets and the moisture content in the watershed podzolic soils was obtained. The correlation coefficient of the considered values is 91. However, it should be noted that there is no data on the relation between irrigation norms and water consumption of red beets.

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2. Materials and Methods
2.1. Climate and soils

The Central Russian province belongs to the temperate mid-continental zone with mild winters in the west and moderately cool summers in the east. The sum of biologically active air temperatures ranges from 180°C to 220°C, and the growing season lasts 110–140 days. The precipitation amount over a year is 525–650 mm. During the sunniest and the hottest summer periods when the air temperature rises to more than +30°C, some dry periods occur, which can be 4–6 to 10–30 days long, resulting in sharp soil moisture reduction. This negatively affects the plant growth and development.

The average air temperature during the growing season (May–August) was 20.2°C in 2010, and 18.2°C in 2011, and the precipitation amount during the red beet growing season was 97.195 mm. According to the air temperature May–August in 2010, 2011 were considered very hot. The years 2010 and 2011 were severely dry according to the precipitation amount.

A map of the Central Russian province of the Non-Chernozem zone is presented in Figure 1.

Fig. 1. Map of the Central part of the Russian Non-Chernozem zone.
2.2 The characteristics to conduct field research

The studies were carried out at a stationary experimental base located on a watershed area with sod-podzols in Moscow Oblast, Sergiev Posad district. Geographic coordinates of the experimental base are 56°34' north latitude, 38°09' east longitude.

Scientific research was carried out on plots of 80 square meters, each in triplicate. Options: 1 – soil moisture was studied within the range (0.6–0.7) from the total moisture capacity (TMC); 2 – also in the range (0.7–0.8) of TMC; 3 – also in the range (0.8–0.9) of TMC; 4 (control) – without irrigation.

During the research, the following doses of fertilizer N70P75K150 were applied to red beets.

The watering was carried out with the Rain Bird system using pull-out sprayers (model 1812), the sprayer flow rate is 0.84 m³/h, the watering radius is 4.5 m. The depth of 0.5 m was taken to determine soil moisture on the experimental plots. The total depth was divided into layers of 10 cm (5 layers in total), where measurements were taken with an electric moisture meter TRIME–FM with a tubular sensor – T3. The moisture meter was verified with the thermostat–weight method. The graphs, the equations of regression and determination coefficients were obtained with the Microsoft Office Excel 2007 program.

To determine the total water consumption of the studied crops one used round metal lysimeters with a tray and infiltration and compensation pipes. The height of the lysimeter cylinders without tray is assumed to be 1.8 meters, and the circle diameter is 1.6 m. The lysimeters were installed with soil monoliths without disrupting its structure.

The lysimeter design diagram is given in Figure 2. The agrochemical and water-physical indicators were determined in a specialized laboratory.

2.3 Water consumption calculation

The total water consumption for red beets was obtained with round metal lysimeters with a tray and pipes to measure both the aeration zone recharge from groundwater and infiltration. Lysimeters have the following parameters: height without tray – 1.8 m, cross-sectional area – 2 sq. m. The equation for the water balance of the lysimeter aeration zone and for the calculated horizon of the plots has the following form (in mm):

\[ E = O_c + m \pm q - \Delta W, \]

where

\[ E \] – the total water consumption of red beets;
\[ O_c \] – precipitation;
\[ m \] – watering norm;
\[ q \] – water exchange between the root soil layer and the underlying layers;
\[ +q \] – moisture infiltration in the soil;
\[-q\] – aeration zone recharge from groundwater;
\[ \Delta W = W_k - W_n \] – final and initial soil moisture reserves.

Fig. 2. Lysimeter design scheme: 1 – soil monolith with intact structure; 2 – metal cylinder; 3 – drainage inside the tray; 4 – tray body; 5 – connecting pipe; 6 – pipe for measuring the aeration zone recharge from groundwater; 7 – pipe for measuring infiltration; 8 – pipe for moisture meter probe.
The soil moisture level has a significant impact on both the irrigation rate and the water consumption. With the average precipitation 

\[ E_p = a \sum_{i=1}^{nd} ds_i \]

The experiments in lysimeters were carried out at a groundwater depth of 20 cm and with a coefficient of 0.5. The potential water consumption of cabbage during the growing season (2010-2011) amounted to 510 and 513 mm, respectively, on plot No. 1. The table below presents the water balance elements for this period:

<table>
<thead>
<tr>
<th>Year</th>
<th>Component</th>
<th>Value (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>( W_1 )</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>( W_2 )</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>( \Delta W )</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>( O_c )</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>( M )</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>( E_p )</td>
<td>510</td>
</tr>
<tr>
<td>2011</td>
<td>( W_1 )</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>( W_2 )</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>( \Delta W )</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>( O_c )</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>( M )</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>( E_p )</td>
<td>498</td>
</tr>
</tbody>
</table>

The water deficit of air humidity decreased during the beet growing season and slowed down during the onion period. The total water consumption for vegetation during the growing season in 2010 and 2011 amounted to 510 and 498 mm, respectively.
Irrigation norms were 423 and 336 mm and the water consumption was 492 and 465 mm. On plot No. 2 with the average moisture of 0.73 TMC and 0.71 TMC, the irrigation norms were 404 and 309 mm and the water consumption was 490 and 485 mm. On plot No. 3 with the average moisture of 0.62 TMC (over 2 years), these values were respectively 316, 258 mm; and 422, 426 mm. On the control without watering at the average moisture of 0.49 TMC and 0.48 TMC, the water consumption was 224, 244 mm.

The analysis shows that with a decrease in the moisture content of sod-podzols the irrigation rate decreases, the water consumption decreases with a decrease in soil moisture from 0.7 TMC and below. The differences in the irrigation norms between 2010 and 2011 are caused by different precipitation amounts.

Table 2. Water balances (mm) of the calculated soil layer depending on its moisture content during the red beet growing season in 2010...2011.

<table>
<thead>
<tr>
<th>Year</th>
<th>Plot 1</th>
<th>W/T</th>
<th>MC</th>
<th>∆W (mm)</th>
<th>P (mm)</th>
<th>M (mm)</th>
<th>q (mm)</th>
<th>E (mm)</th>
<th>ph</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0.8</td>
<td>+15</td>
<td>97</td>
<td>423</td>
<td>-13</td>
<td>492</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>0.78</td>
<td>+11</td>
<td>195</td>
<td>336</td>
<td>-53</td>
<td>465</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

We can observe a stabilization of irrigation norms and total water consumption at the soil moisture of 0.7-0.8 TMC. There is a decrease in irrigation norms and total water consumption at the soil moisture of more than 0.8 TMC, which is associated with a decrease in the red beet yield.

Water consumption is a main expenditure item in the water balance. In addition, deep groundwater, typical for watershed areas, forms infiltration from the calculated layer into the underlying horizons. Not taking infiltration into account can lead to an increase in irrigation norms and, as a result, to an increase in infiltration discharges. According to the experimental studies, an increase in soil moisture in the calculated layer leads to an increase in irrigation norms. Figure 3.

The correlation between irrigation norms (Mi/Mmax) of red beets and the moisture content of the calculated layer of sod-podzols is confirmed by the correlation coefficient of the relation graph, which is equal to 0.997 + 0.032.

The graph of the relation between the red beet water consumption and the soil moisture is presented in Figure 4. The correlation coefficient of this relation is 0.992 + 0.052.

According to the graph analysis, an increase in the soil moisture up to 0.70 TMC leads to an increase in water consumption of red beets. With a further increase in soil moisture, the water consumption decreases.

\[ y = -12.659x^2 + 19.349x - 6.3983 \]

\[ R^2 = 0.9943 \]


4. Conclusions

In order to obtain a stable red beet harvest to supply the population of the Central part of the Non-Chernozem zone in Russia the lands need irrigation. The irrigation method is sprinkling. The conducted scientific research is unique because on the sod-podzols of watersheds in the studied zone we obtained a relation between irrigation norms and the total water consumption of red beets with the moisture content of the calculated soil layer. The correlation coefficient between irrigation norms and soil moisture is 0.997±0.032, and the total water consumption with soil moisture is 0.992±0.052. Wherein, we obtained the coefficients that consider the decrease in soil moisture below optimal values. In the case of soil moisture decrease below optimal limits, it is necessary to use the coefficients which consider the level of soil moisture decrease when irrigating red beets. As a result of the study the scientists revealed, under experimental conditions, a relation between irrigation norms and the total water consumption of red beets with the moisture content of the calculated soil layer. Design firms are recommended to use coefficients that take into account a decrease in soil moisture. Farmers are encouraged to use the results of scientific research when operating irrigation systems. In the future, it is planned to expand scientific research with other crops and other irrigation methods.

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