Determination of optimal irrigation rates of agricultural crops under consideration of soil properties and climatic conditions

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Abstract
In conditions of increasing water shortage, further development of irrigated agriculture production is impossible without improving the methods of cultivation of agricultural crops, primarily irrigation technology. In 2015 the experiment have been conducted on the territory of irrigation farming area of village Tamarisi (Marneuli Municipality), according to which comprehensive study of local climatic and soil conditions were conducted. Received data were used for computation crop water requirements for tomato and melon under the different irrigation treatments. Obtained results have shown the possibility of water use efficiency and obtaining sufficiently high yields of crops that participated in the experiment that became possible in a case of usage of drip irrigation technology in combination with plastic mulch.

Introduction
According to the soil and climatic conditions, the territory of Georgia is specific, hence it is divided into 22 agricultural zones. This explains the different character of agriculture and, accordingly, necessity for considering an appropriate land reclamation (ameliorative) measures.

Optimal management of water resources in agriculture, which mainly considers selection of optimal parameters of irrigation regime in order to get the regular and sustainable yield, while maintaining of the ecological balance, stays as one of the actual problem nowadays.

Errors while selection of irrigation regime is mainly stipulated in the models describing the soil moisture dynamics due to the negligence of some physical or mechanical properties of soil, water and air modes data, evapotranspiration, agro-climatic indicators, etc.

Therefore in irrigation farming, development of existing or new areas for some of specific hydrogeological, rheological landscape and other conditions, require scientific methods of cultivation. The main aim of the article is to determine an optimal irrigation regimes of agricultural crops, including proper irrigation scheduling, especially during the period of plant growth through consideration of soil properties and evapotranspiration (ET).

Experimental section
In 2015 the experiment was conducted at Tamarisi village experimental site in the Marneuli Municipality, which is an

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integral part of the administrative borders of Kvemo Kartli Region (44°47′58″ East longitude and 41°29′24″ North latitude, elevation — 420 m above sea level).

Situated in fertile alluvial plains of Khrami Rivers, and with availability of appropriate irrigation facilities, from agricultural point of view Marneuli Municipality is pretty prosperous area. A cattle breeding is also predominant. This region is said to have been producing half of the total Georgia’s production of vegetables, meat and milk products.

Marneuli Municipality is located in the accumulative depression of Kvemo-Kartli Region in Southern Georgia. Topography is predominantly undulating and dotted with low range hills. Topography in the south, towards River Khrami is predominantly plain.

Comparatively, Marneuli city is located on the higher elevation than its surroundings. Town mostly drains into River Alageti.

Marneuli Municipality can be best described as having moderately humid subtropical climate, and is characterized with climate zones, as determined by the relief. In general, the territory has a moderately warm stepppe climate, with hot summers. Experimental area (Tamarisi village) is located in the lower part of Marneuli Municipality, where the climate is subtropical and dry. There is almost no snow in winter. Stable snow cover is formed only in the mountains and forests. According to the Marneuli weather station (which is located at 432 m above sea level) the average air temperature in January (the coldest month) is 0(−)0.7 °C and in July (the hottest month) — (+)23.9 °C. Absolute value of minimum air temperature is (−)25 °C and maximum temperature is (+)40 °C. The vegetation period lasts for 7 months.

In Marneuli the annual precipitation is 444 mm, among which 121 mm falls in cold seasons (XI—III months). The long sunny days are typical for this climate.

It should be noted, that municipality is characterized with optimum climate for agricultural production. Due to the suitable climate conditions it is possible to harvest 2—3 times a year (see Figs. 1—6).

Marneuli Municipality is in the Madneuli-Poladauri sub-zone of Bolnisi zone. This sub-zone is characterized by Eocene volcanic and sediment strata; Oligocene and Oligocene Miocene terrigenic, and in small areas Pliocene and Upper Cretaceous carbonate-volcanic formations. According to seismic zoning map, Georgia is classified into Zone 6 to Zone 9 (in increasing order of seismic intensity) and Marneuli falls under Zone 7 (strong seismic intensity zone). However, there is no recent history of earthquakes in Marneuli.
Located in the alluvial plains of Khamri River, area possesses fertile agricultural lands. Samples of the soil were taken during the project implementation period (2015y.) at the experimental plot in village Tamarisi (Marneuli Municipality) at different depths and from the laboratory analysis the area where experimental plot is located belongs to the Forest-steppe (arid sparse forest) zone and soil was classified as clay loamy. The soil cover of the zone is represented mainly by Grey-Cinnamonic and Cinnamonic soils.

Soil samples for agrochemical analysis were taken at the experimental-demonstration fields at different depths: 0–20 cm and 20–40 cm and for hydro-physical analysis – at depth 0–16, 16–32, 32–48, 48–64, 0–64 at 10 sites along double-diagonal transects. Eight volume-equivalent cores were taken with an aluminum auger within an area of 4 × 4 m at each site. The fine earth (<2 mm) of the air-dried samples, ground in a porcelain mortar, was investigated in the laboratory of Agricultural University of Georgia [1].

According to the soil testing it is revealed that pH value at 0–20 cm soil depth is equal to 8.3, and at the low depth 20–40 cm this value slightly increases up to 8.4. This soil is characterized with medium carbonate content, which quantity reaches 6,0%.

Cinnamonic soils are characterized with high clay content and low humus composition fluctuates between 3 and 10%. Geochemical potential of these soils is acid in reaction, which weakens with the depth and changes into neutral. In brown carbonate soils, carbonate material presence is significant. Lithological information indicates that the depth of soil along the experimental territory extends to over 10–20 m, with top thin layer characterized by clayey soil, followed by sand and gravel layer.

The grey-cinnamonic soils are characterized by undifferentiated, clayed, carbonate, low-humus profile. The soil profile has the following structure: 

\[ A_{1}^{4} \rightarrow A^{1} \rightarrow \text{AB}(\text{Ca}) \rightarrow \text{B(Ca)} \rightarrow \text{Ca} \rightarrow \text{C} \rightarrow \text{A} \]  

The main diagnostic indicators are relatively long stretch of humus and carbonate profile, well-marked claying in the middle of the profile and carbonates from the surface.

The grey-cinnamonic soils are characterized by medium and increased humus content (its content in the upper layer of soil 0–20 cm reaches 3,8% and in the lower layer 20–40 – 2,24%) and strong coherency of humus substances, high claying of the whole soil profile and maximum content of sedimentary fractions in the middle, weak alkali and alkali reactions, carbonation of the whole profile and quite strong, well-marked carbonate-alluvial horizon.

The grey-cinnamonic soil is potentially quite fertile but agricultural production is impeded by lack of water. Without irrigation most crop yields are low. The soil is poor with nutrients. The grey-cinnamonic soils, especially light grey-cinnamonic soils there have increased quantity of total and absorbable phosphorous (4,8 mg in 100 g soil sample). In addition, the content of total and absorbable phosphorous is higher in the lower layer of soil at a depth of 20–40 cm. Given grey-cinnamonic soils are prone to erosion and desalinization. According to the recommendations presented during soil testing, in order to enhance the fertility of these soils, we have used mineral fertilizers including phosphate fertilizers, regulated soil moisture strictly following the irrigation regimes.

The cinnamonic soils are characterized by well-defined profiles with color differentiation and distinct claying process of the soil depth in the regime of flushing water absence. The soil profile has the following structure: 

\[ A-B_{(\text{Ca})}-\text{BC(B(Ca))}-\text{Bm}-\text{C} \]  

The main diagnostic indicators are metamorphic clayed Bm horizon and carbonation of the profile.

The cinnamonic soils are characterized by dark brown and brown color of the humus horizon, grained structure, weak alkali, medium content of humus, deep humification, humate type of humus, carbonation, claying, high absorption rate, stability of chemical composition of soil and sedimentary fraction, abundance of montmorillonite and illite in clay minerals.

**Table 1 – Duration of crop development stages under the different irrigation treatments.**

<table>
<thead>
<tr>
<th>Crop name</th>
<th>Irrigation technology</th>
<th>Initial</th>
<th>Development</th>
<th>Mid</th>
<th>Late</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>Traditional</td>
<td>0–30</td>
<td>30–70</td>
<td>70–115</td>
<td>115–145</td>
</tr>
<tr>
<td>Melon</td>
<td>Traditional</td>
<td>0–30</td>
<td>30–70</td>
<td>70–115</td>
<td>115–145</td>
</tr>
<tr>
<td>Tomato</td>
<td>Drip</td>
<td>0–25</td>
<td>25–60</td>
<td>60–100</td>
<td>100–120</td>
</tr>
<tr>
<td>Melon</td>
<td>Drip</td>
<td>0–25</td>
<td>25–60</td>
<td>60–100</td>
<td>100–120</td>
</tr>
<tr>
<td>Tomato</td>
<td>Traditional</td>
<td>0–30</td>
<td>30–70</td>
<td>70–115</td>
<td>115–145</td>
</tr>
<tr>
<td>Melon</td>
<td>Drip + Mulch</td>
<td>0–26</td>
<td>26–59</td>
<td>59–109</td>
<td>109–149</td>
</tr>
<tr>
<td>Melon</td>
<td>Drip</td>
<td>0–25</td>
<td>25–60</td>
<td>60–100</td>
<td>100–120</td>
</tr>
<tr>
<td>Melon</td>
<td>Drip + Mulch</td>
<td>0–25</td>
<td>25–55</td>
<td>55–100</td>
<td>100–125</td>
</tr>
</tbody>
</table>
Table 2 – The parameters of the clay loam soil for the determination of the FAO-56 PM crop coefficient.

<table>
<thead>
<tr>
<th>Soil parameters (Clay Loam)</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field capacity</td>
<td>38.69%</td>
</tr>
<tr>
<td>Wilting point</td>
<td>22%</td>
</tr>
<tr>
<td>Effective rooting depth (m)</td>
<td>0.8</td>
</tr>
<tr>
<td>Total evaporable water, T EW (mm)</td>
<td>22</td>
</tr>
<tr>
<td>Readily evaporable water, REW (mm)</td>
<td>8</td>
</tr>
<tr>
<td>Total available water, TA W (mm)</td>
<td>160</td>
</tr>
<tr>
<td>Wetting fraction, f w (fraction)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

In order to increase the fertility of the cinnamonic soils, according to the recommendations made after soil testing, we have properly cultivated them, rationally used mineral and organic fertilizers, and carried out erosion control measures during introduction of traditional furrow irrigation. Proper cultivation of soils taking into consideration biological characteristics of tomato and melons participated in the experiments. These crops require cultivation maximum at the depth of 1 m and there is no danger of overturning alluvial-carbonate surface layer of the soil that may cause chlorosis.

According to their agronomic characteristics, the cinnamonic soils are one of the good soils and they are suitable for vegetables participated in the experiment. In order to get high yields and maintain positive humus balance fertilization is required in addition to biological measures. In irrigation these soils are often crusty and cracked and gleyed in the depth. Grass sowing and flood irrigation reduce soil density and characteristics of soils in orchards [2]. Different irrigation types and other characteristics. Sanding improves physical characteristics of soils in orchards [2]. Different irrigation treatments gave very interesting conclusions [3–16].

The objective of irrigation is to apply the required quantity of water as per crop requirement at the right time. Applied irrigation was scheduled on the basis of soil-water balance. Crop daily (ET C) was estimated according to the “two steps approach” [17]:

\[\text{ET}_C = \text{ET}_0 \times K_c.\]

The growing season is divided into four main development stages including initial, development, mid, and late-stages (see Table 1).

Reference evapotranspiration (ET 0) values was calculated by a modified Penman–Monteith’s equation from hourly weather data; as it is mentioned above, the Weather Station of the research plot, positioned 50 m apart from the experimental field, provided necessary hourly and daily meteorological data (including: air temperature, precipitation, humidity, wind velocity, sun hours, solar radiation). The crop coefficients (K C) for each crop development stage calculated according basal (K CB) and soil evaporation (K e) coefficients (K C = K CB + K e).

Watering was performed each time when the depletion of the available water reached the threshold value of 40%. Required irrigation amounts were calculated as:

\[V = \text{ET}_C \times A,\]

where

- \(V\) is volume of irrigation water (in liters);
- \(A\) – plot area (m²);
- \(\text{ET}_C\) – crop evapotranspiration (mm).

The soil parameters that were used in the FAO-56 procedure for calculating crop evapotranspiration and crop and stress coefficients are presented in Table 2.

For calculating crop water requirement (ET C), crop coefficient (K C) and irrigation schedule, we used FAO56 Spreadsheet, which is updated by Kimberly R7E Center in 2003.

For all crops participated in the experiments, the crop hydro-physical parameters for different irrigation treatments and crop development stages are presented in the Table 3.

Table 3 – Crop basic average hydro-physical parameters during crop development stages under traditional and drip irrigation (2015 y. experiment).

<table>
<thead>
<tr>
<th>Crop</th>
<th>Development stages</th>
<th>Dates</th>
<th>ET 0</th>
<th>K c</th>
<th>ET C (100%)</th>
<th>ET C (60%)</th>
<th>ET C (80%)</th>
<th>ET C (120%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tomato</td>
<td>L ini = 30</td>
<td>28.04–27.05</td>
<td>5.0</td>
<td>0.6</td>
<td>3.0</td>
<td>1.8</td>
<td>2.4</td>
<td>3.6</td>
</tr>
<tr>
<td>L dev = 40</td>
<td>28.05–06.07</td>
<td>6.3</td>
<td>0.87</td>
<td>5.5</td>
<td>3.3</td>
<td>4.4</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>L mid = 45</td>
<td>07.07–20.08</td>
<td>6.6</td>
<td>1.15</td>
<td>7.5</td>
<td>4.5</td>
<td>6.0</td>
<td>9.1</td>
<td></td>
</tr>
<tr>
<td>L late = 30</td>
<td>21.08–19.09</td>
<td>5.1</td>
<td>0.8</td>
<td>4.1</td>
<td>2.4</td>
<td>3.2</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>145</td>
<td>23.0</td>
<td>20.1</td>
<td>12.1</td>
<td>16.1</td>
<td>24.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melon</td>
<td>L ini = 25</td>
<td>10.05–03.06</td>
<td>5.4</td>
<td>0.5</td>
<td>2.7</td>
<td>1.6</td>
<td>2.2</td>
<td>3.2</td>
</tr>
<tr>
<td>L dev = 35</td>
<td>04.06–08.07</td>
<td>6.4</td>
<td>1.0</td>
<td>6.4</td>
<td>3.9</td>
<td>5.1</td>
<td>7.7</td>
<td></td>
</tr>
<tr>
<td>L mid = 40</td>
<td>09.07–17.08</td>
<td>6.6</td>
<td>1.05</td>
<td>6.9</td>
<td>4.1</td>
<td>5.5</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>L late = 20</td>
<td>18.08–06.09</td>
<td>5.4</td>
<td>0.75</td>
<td>4.1</td>
<td>2.4</td>
<td>3.3</td>
<td>4.9</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>120</td>
<td>23.8</td>
<td>20.1</td>
<td>12.0</td>
<td>16.1</td>
<td>24.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusion

Crop Yield with respect to the irrigation treatments – Table 3 shows that this superiority was confirmed with respect to all irrigation treatments. Crop yields significantly decreased with a decreasing water supply. Received results from this experiment allow us to determine connection between degree of water filling of soil pores and crop yield. Using the local natural-climatic data the relationship between evapotranspiration and crop yield at the different stages of crop development has been determined. It is determined that it is possible to receive high agricultural yield when drip irrigation in combination with mulching technology is used according to the crop water requirements. Particularly, in a case of drip irrigation application, the maximum yield was obtained when we applied the amount of irrigation water which was...
equivalent to the daily $ET_c$, but in a case of drip irrigation and mulching technology the maximum yield was corresponded to 0.75–0.8 $ET_c$, which actually provide the economic and sufficient supply of irrigation water by 20–25%.

Water use efficiency in drip irrigation and mulching technology was 2.5 times higher that of for surface furrow irrigation. The highest crop yields from three technologies were obtained at full irrigation treatments (received 100% of irrigation water requirement). Bigger fruits were obtained with optimum irrigation amounts for all three irrigation systems. Therefore, the best irrigation system was drip irrigation and drip irrigation in combination with mulching technology due to yield precocity, decreasing the water consumption and increasing the water productivity. Higher yield and better crop growth was observed in the mulched plots, due to conservation of soil moisture. Application of black plastic mulched significantly increased the crops fruit yields precocity, available soil moisture and decreased irrigation times particularly in yearly growth season and greatly controlled the weeds. Significantly higher water use efficiency was recorded in the mulched plots compared to the non-mulched plots under the same irrigation treatments.

The study indicated that 100% of irrigation water requirement met through drip irrigation along with black plastic mulch resulted in 72% increase in yield as compared to traditional furrow irrigation.

This result shows that, applying drip irrigation system, irrigation management and black plastic mulch can optimize the water consumption. Therefore, drip irrigation system and mulching were recommended for growing vegetables in the eastern regions of Georgia under limited water availability.

REFERENCES


