Dependence of apple productivity and fruit quality on the method of drip irrigation terms appointment

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Abstract

Modern fruit growing involves the use of drip irrigation systems. The methodology for diagnosing of drip irrigation terms appointment and calculation of irrigation rates require continuous improvement on the basis of the introduction of measuring instruments. These issues are relevant for the commercial fruit growing of the world’s most common perennial crop – apple trees (Malus domestica Borkh). The purpose of the experiment was to optimise drip irrigation regimes and to analyse the evapotranspiration (ET) of an apple tree depending on the methods of drip irrigation terms appointment. For comparison, four methods were applied: 1) the digital iMetos ECO D2 soil moisture station, 2) the tensiometric method, 3) the Penman-Monteith calculation, and 4) the visual method. The control was irrigation-free treatment. The results of the experiment confirmed the effectiveness of the use of drip irrigation for the cultivation of an intensive apple orchard at the Steppe of Ukraine. According to the parameters of the drip irrigation regime and the yield of apple trees, the use of the iMetos ECO D2 soil moisture station was determined as the most effective method of drip irrigation terms appointment. In this treatment, the irrigation rate was 650 m³ ha⁻¹, the crop evapotranspiration (ETc) value 3.25 thousand m³ ha⁻¹, the water consumption coefficient 83.4 m³ t⁻¹, the irrigation efficiency 20.7 m³ t⁻¹, and the marketability of apples was 93%. It was found that the removal of fruit ripeness parameters: tissue density, sugar content, and degree of starch degradation, were within the sanitary norms of apple quality. This method is defined as the most water-saving, based on the experimental data on irrigation rate and crop productivity. Thus, it is recommended for the use in apple production in the South of Ukraine.

Keywords: drip irrigation, irrigation regime, yield, quality, soil moisture station, apple tree.

Introduction

Apple (Malus domestica Borkh) is the most common fruit culture in the world: according to the FAO official data for 2020, in the world, fruit production of apples occupies the second position with a share of 9.6%, second only to bananas (FAOSTAT, https://www.fao.org/faostat/en/#data). But over the last 10 years, apple consumption in Ukraine has only increased by 18.3–25.8 kg per year per person, while the medical norm is 50 kg per year (Matviets, Snihovy, 2014). Despite the fact that over the past 10 years the productivity of apple orchards in Ukraine has increased by 35–40%, the task of increasing the volumes while reducing the cost of apple production remains one of the priorities in the agricultural sector (Morozov, Kozlova, 2013). Commercial fruit growing with intensive cultivation technology is becoming more widespread in the world (Dzikiti et al., 2018). A mandatory condition for the application of this technology is drip irrigation (Douh, Boujelben, 2012; Romashchenko, Riabkov, 2012). In the cultivation of perennial plants, its use makes it possible to create intensive apple orchards with a yield of more than 50 t ha⁻¹ with a high quality of products (Veverka, Pavláčka, 2012). The maximum effect of irrigation depends on the actual mode of irrigation – timing, rates, and the amount of irrigation (Campbell, Campbell, 1982; Rai et al., 2017). In turn, the drip irrigation regime determines the method of determining the timing of watering. The use of different approaches and methods of diagnosing of irrigation in horticulture involves monitoring of meteorological parameters (Romashchenko et al., 2016; Robinson et al., 2017), determination of water and physical parameters of the soil (Chenaf et al., 2016) including moisture content in the root layer of the soil (Chen et al., 2018; Han et al., 2018), parameters of the physiological state of crops (Lo Bianco, 2019), and the crop evapotranspiration...
(Odi-Lara et al., 2016; Volschenk, 2017). The influence of the methods of setting the timing of watering for drip irrigation of apple on yield, biometric parameters, marketable and taste qualities, and basic biochemical indicators of production is insufficiently investigated (Pavelkivskyi, 2013; Riabkov, 2016). It is important to study the quality of agricultural products, their parameters, and ratios that shape its selling price, which can fluctuate within very wide limits (Shatkovskyi et al., 2017; Chen et al., 2018). The urgent issue for farmers and scientists remains to find and analyse factors that contribute to improving the quality characteristics of the fruit (Wright, 2015; Neilsen et al., 2016). Therefore, studies on optimising the methods of watering for drip irrigation and the impact on productivity and quality characteristics are relevant (Marsal et al., 2013; Jiang, He, 2021).

Based on the above, research on the impact of methods for setting watering dates on yield and quality characteristics is relevant. The novelty lies in the experimental substantiation of the technology of drip irrigation based on automated instrumental measurement, calculation, and other methods of irrigation management.

Thus, the main purpose of the study was a comprehensive assessment of methods for determining the timing of watering apple trees.

**Material and methods**

**Experimental site description.** The basis of the research was the field experiment method. Characteristics of the experiment were the following: one-factor, short-term (2015–2017 years), conducted in the production conditions of JSC Enograi, Sofievka village (46.612396, 32.230880), Bilozerskyi district, Kherson region, Ukraine (Romashchenko et al., 2014). The soil of the experimental area was Haplic Kastanozem according to WRB (2015), and the texture was silty loam. In the soil 0–100 cm layer, the density of the structure was 1.35 g cm⁻³, the lowest moisture content 24.6% by weight of dry soil, and the humidity of stable wilting 12.2%. The content of humus in the 0–50 cm layer was 1.25%, lightly hydrolysed nitrogen 5.74 mg 100 g⁻¹ of soil, mobile phosphorus 19.75 mg 100 g⁻¹, and mobile potassium 6.35 mg 100 g⁻¹.

According to the data of Kherson Meteorological Station, the average long-term precipitation was 434 mm, during the apple growing season it does not exceed 273 mm, and the average long-term air temperature was +10.2°C including +11.1°C for the last 20 years. The years of experiment differed in the conditions of natural moisture: during the growing season, 193.0 mm of productive precipitation fell (70.4% of the climatic norm) in 2015, 306 mm (111.7%) in 2016, and 267 mm (97.4%) in 2017. The apple (Malus domestica Borkh) orchard was planted in the spring of 2010 according to the scheme 4 × 1 m on the rootstock M-9, cultivar ‘Renet Symyrenka’.

**Experiment scheme.** The assessment of the methods for setting the timing of drip irrigation was carried out by conducting a one-factor field experiment according to the scheme: (1) using the digital iMetos ECO D2 soil moisture station with Echo Probe EC-5 type sensors (iMetos-ECO-D2, 2011; Shatkovskyi et al., 2016); (2) the tensiometric method (Romashchenko et al., 2012) using sensors with a mechanical vacuum gauge; (3) the Penman-Monteith (FAO crop coefficients) calculation method for the determination of evapotranspiration (EC) using the weather station iMetos, IRRMET application and computer program CROPWAT, version 8.0 (Allen et al., 1998; Robinson et al., 2017); (4) the visual method when the drip irrigation regime was actually adopted in the farm: by external signs of plants, their condition, changes in leaf colour, reduction of tissue flooding, and other available visual signs of water stress of plants; (5) the conditional control (without irrigation – natural moisture). In treatment 1, the Echo Probe EC-5 sensor detects the volumetric water content (VWC) in the soil and works on the principle of frequency domain reflectometry (FDR).

The humidity range of the root soil layer was maintained from 80% to 100% of the lowest soil water capacity (DSTU 7594:2014) (Romashchenko, Riabkov, 2012; Shatkovskyi, Chabanov, 2012). The WC (m³·ha⁻¹) factor of apple trees was calculated as the ratio of the evapotranspiration under standard conditions (ETc) to the yield (Y) of plants (Ushkarenko, 1995):

\[
WC = \frac{ETc}{Y}
\]

The coefficient of irrigation efficiency (C.) was determined by the dependency (Ushkarenko, 1995):

\[
C_r = \frac{IR}{Y_w - Y} - 1
\]

where IR is irrigation rate, m³·ha⁻¹; Y – yield with irrigation, t·ha⁻¹; Y_w – yield without irrigation, t·ha⁻¹.

Fruitage from each survey site was weighed and sorted.

**Determination of product quality.** The quality of apple fruits was determined by several biometric parameters. Biometric indicators of apple trees were determined according to the generally accepted methodology (Horoshiko et al., 2004). So, studies of compliance with the medical and biological requirements and the sanitary quality standards for apples were carried out in the regional laboratory of the Ministry of Health of Ukraine, which has the necessary calibration certificate. According to the results of analytical studies, the conclusions of a sanitary doctor were provided on the compliance of product samples with the current regulatory documents (JCaHuIIH 8.8.1.2.3.4-000-2001, https://zakon.rada.gov.ua/rada/show/v0137588-01?lang=en#Text).

To assess the quality of the fruit, degree of starch degradation (by iodine-starch test method), tissue density (by penetrometer), and sugar content (refractometrically) were determined. Product quality was also analysed by the size of the fruit and the calibre: weight and maximum cross-sectional diameter. For this purpose, 200 fruits were selected from each of the five experimental sites. These fruits were weighed, and the average apple weight was determined in the experimental treatments. After that, the fruit calibration kit was used to determine the weight and average diameter of the fruit for each treatment of the experiment.

**Statistical analysis** of the results of experiment was performed by variance, correlation, and regression methods using the software Statistica, version 6.0 (TIBCO Software Inc.).

**Results and discussion**

The averaged data over the years of the experiment on the parameters of drip irrigation regimes depending on the methods used are shown in Figure 1. For the experimental period, the minimum values of the irrigation rate and the number of irrigations during the apple growing season were obtained in the treatment using the iMetos ECO D2 soil moisture station – 650 m³·ha⁻¹ and 9.7, respectively. In turn, the maximum values of irrigation rate and number of irrigations were obtained in the treatment using the tensiometer: 703 m³·ha⁻¹ and 10, respectively. The difference between the maximum and
minimum values of irrigation rate was 53.3 m³ ha⁻¹, or 8.2%, and between the number of irrigations it was 0.3 (number of waterings), or 3.5%.

The factors that formed the ET were meteorological parameters, water-physical properties of soils, and biological features of apple culture (Odi-Lara et al., 2016; Robinson et al., 2017).

Table 1 shows the parameters of evapotranspiration of apple trees depending on the methods of assigning irrigation periods. The average value of ET under the conditions of drip irrigation regularly exceeded the similar indicator in rainfed conditions by 579 m³ ha⁻¹, or by 21.5%. The highest value of ET under the conditions of drip irrigation was obtained in the treatment using the tensiometer – 3305 m³ ha⁻¹. Correspondingly, the lowest ET value was in the treatment using the iMetos ECO D2 soil moisture station – 3252 m³ ha⁻¹. The difference between the maximum and minimum average ET values was 53.4 m³ ha⁻¹, or 1.6%. On the basis of experimental results, the influence of the method for diagnosing the timing of irrigations during the growing season on the yield of apple trees was determined. Also, on the basis of ET parameters, irrigation rates, and yield levels, water consumption coefficients and apple irrigation efficiency coefficients were calculated.

Table 1. Evapotranspiration under standard conditions (ETc), apple fruit yield, coefficients of water consumption, and irrigation efficiency depending on the methods of drip irrigation terms appointment

<table>
<thead>
<tr>
<th>Method</th>
<th>ETc m³ ha⁻¹</th>
<th>Yield t ha⁻¹</th>
<th>Water consumption coefficient m³ t⁻¹</th>
<th>Coefficient of efficiency of irrigation m³ t⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>iMetos ECO D2 soil moisture station</td>
<td>3252 ± 276</td>
<td>43.1 ± 3.0</td>
<td>83.4 ± 5.4</td>
<td>20.6 ± 1.4</td>
</tr>
<tr>
<td>Tensiometric</td>
<td>3305 ± 316</td>
<td>40.0 ± 2.8</td>
<td>94.4 ± 6.1</td>
<td>24.7 ± 1.8</td>
</tr>
<tr>
<td>Penman-Monteith calculation</td>
<td>3270 ± 278</td>
<td>32.9 ± 2.3</td>
<td>110.6 ± 7.2</td>
<td>31.5 ± 2.2</td>
</tr>
<tr>
<td>Visual</td>
<td>3294 ± 348</td>
<td>29.5 ± 2.1</td>
<td>122.2 ± 7.9</td>
<td>38.7 ± 2.8</td>
</tr>
<tr>
<td>Control (without irrigation)</td>
<td>2701 ± 332</td>
<td>11.6 ± 0.9</td>
<td>856.1 ± 55.6</td>
<td>x</td>
</tr>
<tr>
<td>LSD₁₀₅</td>
<td>274.1</td>
<td>5.52</td>
<td>11.5</td>
<td>3.32</td>
</tr>
</tbody>
</table>

Average value ± SD; x – it is impossible to calculate the irrigation efficiency coefficient for this option

The analysis of the results showed that the highest fruit yield was obtained in the treatment using the iMetos ECO D2 soil moisture station – 43.1 t ha⁻¹, which was 6.7 t ha⁻¹ more than the average for irrigated conditions. In the irrigation treatments, the lowest crop productivity was obtained in the treatment using the visual method – 29.5 t ha⁻¹, which was 6.9 t ha⁻¹ lower than the average. The difference between the maximum and minimum values of yield was 13.6 t ha⁻¹, or 31.6%. It is expected that in the control (without irrigation) treatment a minimum fruit yield was 11.6 t ha⁻¹, which was only 31.8% of the average yield for irrigated experimental treatments. The optimum value of the water consumption coefficient was obtained in the treatment using the iMetos ECO D2 soil moisture station – 83.4 m³ t⁻¹, which was 19.3 m³ t⁻¹ lower than the average value of the irrigation. Instead, the highest coefficient of water consumption was obtained in the treatment using the visual method – 122.2 m³ t⁻¹, which was 19.5 m³ t⁻¹ above the average value of the irrigation. The difference between the maximum and minimum values was 38.8 m³ t⁻¹, or 31.8%. The water consumption coefficient of apple trees in the control treatment was 856.1 m³ t⁻¹, i.e., 2.47 times higher than the average value of the irrigation. The optimum value of the coefficient of irrigation efficiency was obtained in the version with the diagnosis of irrigation time using the iMetos ECO D2 soil moisture station – 20.6 m³ t⁻¹, which was 8.3 m³ t⁻¹ lower than the average value of the irrigation. The maximum coefficient of irrigation efficiency was defined in the treatment using the visual method – 38.7 m³ t⁻¹, which exceeded the average value by 8.9 m³ t⁻¹. The difference between the minimum and maximum values of the irrigation efficiency was 18.1 m³ t⁻¹, or 87.9%.

The analysis of fruit yield and ET parameters showed the effectiveness of the method using the iMetos ECO D2 soil moisture station.

In addition to the statistics on fruit yield, the number of fruits per one tree was additionally calculated depending on the factor being investigated (Figure 2).

The maximum number of fruits from one tree was in the treatment using the iMetos ECO D2 soil moisture station – 17.2 kg, while using the visual method it was only 11.8 kg.

Based on the analysis of fruit yield levels and plant biometric parameters in the experimental treatments, an appropriate relationship was determined: with the growth of fruit yield, biometric parameters of tree (height, crown diameter, shoot length, and number of

![Figure 1. Modes of drip irrigation of apple trees, depending on the methods of drip irrigation terms appointment.](image-url)
Dependence of apple productivity and fruit quality on the method of drip irrigation terms appointment

Thus, to increase the productivity of the apple tree, it is necessary to maintain an optimal balance between the growth processes of the tree, the development of its biometric indicators and fruiting. At the same time, in the control (without irrigation) treatment, an increase in the parameters of the circumference and height of the tree was recorded against the background of a decrease in the growth processes of the above-ground tree system including the leaf surface area, shoot length, and fruit parameters, which confirms the non-alternative use of drip irrigation. The range of parameters of removable ripeness of apple fruits in the experimental treatments is shown in Table 2.

Thus, the parameters of the optimal removable ripeness of the cultivar ‘Renet Symyrenka’ apple fruits were in the necessary ranges (Babuk et al., 2013). According to the results of analytical studies, the conclusions of the sanitary doctor regarding the conformity of the product samples with the current regulatory documents were provided (ДСанПіН 8.8.1.2.3.4-000-2001). The results of measurements of fruits according to the treatments of the field experiment are given in Table 3.

The analysis of the data of Table 3 shows that the fruit parameters of irrigated treatments fluctuate slightly: by weight ± 5 g and by diameter ± 6 mm. Therefore, smaller parameters of the size of the fruit were in the treatment using the visual method. In general, the average value of the apple mass at various drip irrigation regimes and the average diameter of the apples corresponded to the pomological characteristics of the cultivar (Babuk et al., 2013; Kondratenko, 2013). According to the unified qualification adopted in European countries (Kondratenko, 2013), apples in irrigated research areas belong to the 5th group “over average size” (151–200 g) of fruit weight. Fruit parameters were significantly less in the control (without irrigation) treatment – in comparison with irrigated treatments, the fruit weight was 98.8 g, or 2.2 times less, and the diameter 30.7 mm, or 1.7 times smaller.

### Figure 2. Quantity of fruits of removable ripeness from one apple tree depending on the method of appointment of watering time

### Table 2. Parameters of removable ripeness of apple fruits depending on the methods of drip irrigation terms appointment

<table>
<thead>
<tr>
<th>Method</th>
<th>Tissue density kg cm⁻²</th>
<th>Sugar content %</th>
<th>Degree of starch degradation, points</th>
</tr>
</thead>
<tbody>
<tr>
<td>iMetos ECO D2 soil moisture station</td>
<td>8.2–8.8</td>
<td>11.0–13.1</td>
<td>2–7</td>
</tr>
<tr>
<td>Tensiometric</td>
<td>8.7–9.3</td>
<td>10.1–12.9</td>
<td>1–6</td>
</tr>
<tr>
<td>Penman-Monteith calculation</td>
<td>8.4–8.8</td>
<td>11.8–13.3</td>
<td>2–7</td>
</tr>
<tr>
<td>Visual</td>
<td>7.4–8.1</td>
<td>11.6–12.4</td>
<td>3–5</td>
</tr>
<tr>
<td>Control (without irrigation)</td>
<td>8.8–9.4</td>
<td>11.9–12.7</td>
<td>4–6</td>
</tr>
</tbody>
</table>

### Table 3. Parameters of apple fruits depending on the method of drip irrigation terms appointment

<table>
<thead>
<tr>
<th>Method</th>
<th>Average mass of apples g</th>
<th>Average diameter of apples mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>iMetos ECO D2 soil moisture station</td>
<td>183 ± 9</td>
<td>75 ± 4</td>
</tr>
<tr>
<td>Tensiometric</td>
<td>182 ± 8</td>
<td>73 ± 5</td>
</tr>
<tr>
<td>Penman-Monteith calculation</td>
<td>184 ± 8</td>
<td>74 ± 5</td>
</tr>
<tr>
<td>Visual</td>
<td>180 ± 9</td>
<td>70 ± ab</td>
</tr>
<tr>
<td>Control (without irrigation)</td>
<td>84 ± b</td>
<td>42 ± b</td>
</tr>
<tr>
<td>Average value for the irrigation</td>
<td>163 ± 7</td>
<td>67 ± 4</td>
</tr>
<tr>
<td>Including average value for the irrigation</td>
<td>183 ± 8</td>
<td>73 ± 4</td>
</tr>
</tbody>
</table>

Note. The difference between the averages (for each parameter) under the different methods of drip irrigation terms appointment marked by not the same letter (a, b) are significant (p < 0.05); average value ± SD.

At the next stage, fruits were sorted to determine marketability according to the state standards of Ukraine (DSTU EEEK OON FFV-50:2007; EKE OON FFV-50:2003. IDT; DSTU 8133:2015). The results are given in percent and shown in Figure 4.
The analysis of these data shows that the marketability indicators for apples under irrigated conditions were almost identical: the maximum differences between the treatments were 3.5%. During the experiment, the marketability of apples was higher in 2017 – 94% and slightly lower in 2016 – 92%. The marketability of fruits was significantly lower in the control (without irrigation) treatment – 49.6–51.0%.

**Conclusions**

1. Irrigation based on different methods had effect on the processes of evapotranspiration, crop productivity, and fruit quality of apple trees in the conditions of the Steppe of Ukraine.

2. The optimal water regime of the soil for growth and fruit yield formation was determined by scheduling of drip irrigation terms using the iMetos ECO D2 soil moisture station. When implementing this treatment of the experiment, the irrigation rate was 650 m³ ha⁻¹, the evaporation rate 3.25 thousand m³ ha⁻¹, the water consumption coefficient 83.4 m³ t⁻¹, and the irrigation efficiency coefficient was 20.7 m³ ha⁻¹, which ensured fruit yield at the level of 43.1 t ha⁻¹.

3. It was found that the parameters of removable fruit maturity: tissue density, sugar content, and degree of starch degradation, were within the sanitary norms of fruit maturity: tissue density, sugar content, and degree of starch degradation, were within the sanitary norms.

4. In the future, it is recommended to use the method of drip irrigation terms appointment for apple trees using the iMetos ECO D2 soil moisture station as the most effective for the formation of fruit yield and saving of irrigation water.

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Obelų produktyvumas ir vaisių kokybė priklauso nuo laistymo terminų nustatymo metodo

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Santrauka
Šiuolaikinėje sodininkystėje naudojamos lašelinės drėkinimo sistemos. Drėkinimo laiko nustatymas ir išlaistomo vandens kiekio apskaičiavimas reikalauja tobulinimo, atsižvelgiant į taikomas metodikas. Tai yra svarbu pasaulio pramoniniu būdu plačiausiai auginamai daugiamečių augalų rūšių – obelms. Tyrimo tikslas – optimizuoti lašelinio drėkinimo režimą ir nustatyti obelų sumini garavimą (ET), priklausomai nuo laistymo būdo. Buvo taikytų 4 metodai: 1) skaitmeninė dirvožemio drėgmės matavimo stotis iMetos ECO D2, 2) tensiometrinis, 3) Penmano-Monteitho ir 4) vizualinis; kontrolinis variantas – be drėkinimo. Tyrimas patvirtino lašelinio drėkinimo efektyvumą obelų sodus intensyviai auginant Ukrainos stepėse. Pagal drėkinimo režimo ir obelų derlingumo rodiklius buvo nustatytas efektyviausias laistymo datų parinkimo būdas – naudojant skaitmeninį dirvožemio garavimą režimą matavimo stotis iMetos ECO D2. Taikant šį metodą, obelų lašelinio drėkinimo norma buvo 650 m3 ha–1, augalų suminis garavimas (ETc) – 3,25 tūkst. m3 t–1, vandens sunaudojimo koeficientas – 83,4 m3 t–1, drėkinimo efektyvumas – 20,7 m3 t–1, obuolių prekinė vertė – 93 %. Remiantis eksperimentiniais lašelinio drėkinimo normų ir augalų derliaus duomenimis, šis metodas apibūdinamas kaip labiausiai taupantis vandenį, taigi, jį rekomenduojama taikyti Ukrainos žemės ūkio.

Reikšminiai žodžiai: lašelinis drėkinimas, drėkinimo režimas, produktyvumas, kokybė, dirvožemio drėgmės matavimo stotis, obelis.