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JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2022.141551
2022, No. 54 (VII–IX): 21–25

The use of the phytomonitoring method to control the irrigation of tomato plantations: A case study

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RECEIVED 11.05.2021 ACCEPTED 05.11.2021 AVAILABLE ONLINE 28.09.2022

Abstract: The article is devoted to the current scientific and practical problems of planning irrigation with phytomonitoring methods. In particular, it focuses on the methodological approach to tomato irrigation planning. The field experiment was laid by the method of systematic placement of elementary plots in four replicates. The PM-11Z phytomonitor was used to determine changes in stem diameter, juice flow, leaf temperature, and fruit growth.

On the basis of the experimental studies, parameters are defined for the start of watering with the positive, negative and zero water balance of the plant. It has been proved that when vegetative irrigation is planned with a positive plant water balance, the daily amplitude of stem contraction (*DCA*) and the trend of the sap flow rate should be analysed. A fall in two consecutive morning stem diameter peaks (*MXSD*) indicates a negative plant water balance, which is the starting point for watering. To assign watering with a zero water balance, it is necessary to use information from the fruit growth sensor and the juice flow rate. A decrease in their indications marks the need for the next watering.

Keywords: fruit growth rate phytomonitoring, daily amplitude of stem contraction, maximum daily stem diameter, minimum daily stem diameter, sap flow, water balance of the plant

INTRODUCTION

The decision to conduct subsequent vegetative watering can be based on any date-marking approach (method). There are many methods for determining the timing of vegetative irrigation, which, due to their characteristics and design, are divided into four main groups: soil moisture, calculation, biological (physiological), and visual. The most reliable and accurate are the methods in the first group, the use of which is based on the monitoring of moisture in the soil root layer. One of the disadvantages of the methods from the first group is labor intensity, which in most cases makes it difficult to use them in agricultural production [Shatkovskyi, Zhuravlov 2016]. Planning of irrigation with phytomonitoring methods refers to the physiological methods used to determine irrigation [Ton *et al.* 2001].

Phytomonitoring is a continuous, long-term simultaneous monitoring of several plant characteristics and environmental parameters using sensors that do not damage the plant [Ton, Kopyt 2003]. It helps to determine the physiological status of plants and give recommendations on how to optimise their cultivation. Leading world scientists claim that a phytomonitoring system increases yields and lowers the cost of growing crops by providing timely and accurate information about the physiological state and identifying stressful conditions before they actually affect a plant or fruit [Gurovich, Alvarez 2007; Gurovich *et al.* 2006]. Phytomonitoring allows you to make timely decisions regarding: irrigation, fertilisation, chemical treatment, and other field work. It uses special sensors, data collection system, and computer data processing. There are two groups of basic parameters (recorded or calculated) that are used in phytomonitoring. The first one includes temperature, plant and air temperature difference, water flow in the stem, change in the shoot diameter, fruit growth, and others, whereas environmental parameters include solar radiation intensity, air temperature, relative humidity, water vapor pressure deficit (*VPD*), wind speed, rainfall, and soil temperature and moisture [Ton, Kopyt 2003]. According to scientists (Ton *et al.* [2001], Gurovich and Gratacos [2022], Gurovich and Alvarez [2007]), the most important advantage of the phytomonitoring methodology is the ability to build a convenient information channel that facilitates communication between humans and plants not only in research, but also in the accurate implementation of various cultivation technologies. In this case, the plant that is linked with the phytomonitor can be considered a biosensor. The most informative and representative are not absolute values of recorded parameters, but the forms of curves built on daily data recording and daily trends in phytomonitoring parameters.

Continuous monitoring of plant growth allows to detect time-related negative influence of external factors, in particular the lack of water in soil, long before they become visible [Gurovich, Alvarez 2007]. The use of phytomonitoring for irrigation management allows to optimise the process and helps the producer to make timely decisions about the next watering depending on the current needs of the plant [Gurovich, Gratacos 2002]. A study in Chile showed that irrigation planning based on phytomonitoring information increased the yield and size of avocados [Gurovich *et al.* 2006] and grapes [Gurovich, Saggé 2005; Quezada *et al.* 2020]. Research conducted on horticultural and ornamental crops confirmed the possibility of using the amplitude of daily contractions and changes in the maximum daily diameter of the trunk as an indicator of plant water stress and the possibility of prescribing watering based on these indicators [Ginestar, Castel 1998; Gurovich 2006; Kopyt *et al.* 2001; Kovalev *et al.* 2017; Selles *et al.* 2004; Silva-Contreras *et al.* 2012; Ton *et al.* 2004; Ton, Kopyt 2004].

The phytomonitoring method is also successfully used to manage irrigation of vegetable crops on open and protected soils [Nikolaou *et al.* 2019]. Studies conducted in Israel [Itiel *et al.* 2002] on the management of irrigation of peppers using a phytomonitoring system revealed significant nocturnal plant transpiration. Decisions based on these data contributed to an increase in productivity. The use of phytomonitoring to study the growth dynamics of greenhouse tomatoes [Sleptsov *et al.* 2020] and the control of the plant production process [Usoltsev, Nestyak 2018] allows you to quickly identify the factor that reduces the rate of fruit growth and plant productivity. The application of the phytomonitoring method in practice requires a highly qualified agronomist [Sleptsov *et al.* 2020]. Therefore, it is important to develop criteria for the rapid interpretation of information. Little attention has been paid to managing irrigation of field crops, and no such studies have been conducted in Ukraine.

MATERIALS AND METHODS

The research was carried out in 2018–2020 under production conditions on land operated by "Organic Systems" Sp. over 7.5 thous. ha along with the subsequent processing in our own plants. The experimental production plant is located in the Chaplinsk Oblast in the Kherson Oblast in Ukraine (Sucha Steppe subzone, Google Maps location 46°40' N, 33°35' E). The climate of the study area is moderately hot and very dry. Aggregate temperatures above 10°C range from 3300 to 3400°C, the amount of rainfall in this period is 200–220 mm, the hydrothermal coefficient according to G.T. Sielaninov is 0.6 [Ukrainian Hydrometeorological Center 2021]. The automatic internet meteorological station iMetos®, located directly on the test stand, was used to monitor weather conditions during the research.

The soil of the experimental plot is dark chestnut, low-humus (1.7–1.9%). MMHC for a soil layer of 0–50 cm is 25.8% of absolutely dry soil (101 mm), and its bulk density is 1.35 g·cm^{-3}. Water intake for irrigation was carried out from the Chaplinsky canal (Chaplinsky irrigation system, feeding from the North Crimean canal, water from the Dnieper River). For the main irrigation indicators, according to DSTU 2730, 7286 and 7591, irrigation water corresponds to the 1st quality class and is suitable for drip and subsurface drip irrigation of tomato seedlings.

The field experiment was based on the method of systematic placement of elementary plots in four replicates [Ushkarenko *et al.* 2014]. The plot area is 20 m^2. The experiment used an early-maturing hybrid of Melman F1 tomato (H 9997 F1) Organic for combine harvesting, which was grown in the system of organic farming. The planting scheme is 1.50 × 0.25 m. Ground drip irrigation was used for irrigation with irrigation pipelines at the depth of 0.25 m.

To plan tomato irrigation by phytomonitoring, a PM-11Z phytomonitor was used, which was equipped with a sensor to detect micro-changes in the stem diameter SD-5z, sap flow SF-4z, leaf temperature LT-1z, and plant fruit growth FI-Mz. Sensors for measuring environmental factors and plant life processes were installed in accordance with the guidelines [Ilnitskiy *et al.* 2012]. Parameters that characterise various plant life processes were measured synchronously with meteorological parameters and soil moisture. All measurements were performed every 20 min.

RESULTS AND DISCUSSION

The following parameters have been used to control tomato watering using the SD-5z micro-stem diameter sensor: daily reduction amplitude (*DCA*), minimum (*MNSD*) and maximum (*MXSD*) daily stem diameter. A decrease in the diameter of the stem indicates a negative water balance, an increase in diameter – positive, a constant value – zero. A decrease in two consecutive morning maxima (*MXSD*) is an indicator of insufficient moisture supply (plant does not have time to compensate for daytime water loss during night), which is one of the criteria for starting watering or increasing the watering rate [Blanco-Cipollone *et al.* 2017; Gurovich, Saggé 2005; Selles *et al.* 2004; Silva-Contreras *et al.* 2012].

As observed, the diameter of the tomato stem decreased (Fig. 1). Thus, the maximum (*MXSGR*) and minimum (*MNSGR*) daily stem growth rate on July 1 were –0.023 and –0.032 mm, respectively. The daily amplitude of the reduction on June 30 was 0.043 mm, and on July 1 it increased by 0.009 mm. This denoted the onset of water stress in the plant. The decrease in *MXSD* and *MNSD* on July 1 indicated the need for irrigation, which was also confirmed by the increase in *DCA*.

According to the results, it was found that the morning maximum change in the diameter of the *MXSD* stem was observed at 6–7 o'clock in the morning. Thus, on June 11, the morning maximum was 2.609 mm. This was 0.083 mm more than the morning maximum on June 10. Such changes in the diameter of a stalk denoted a positive water balance of a plant (Fig. 2). A more detailed examination of the dynamics of changes in the diameter of the stem with a positive water balance helped to observe the reaction of the plant to watering. Before watering, the increase in stem diameter was 0.0037 mm·h^{-1}. After the start of watering on June 11 at 12 o'clock at the rate of 60 m^3·ha^{-1}, the

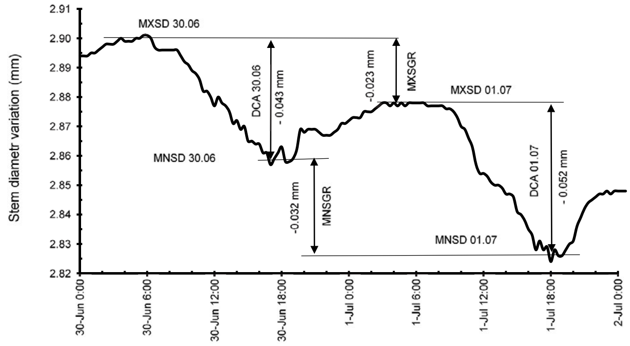

Fig. 1. Criteria for determining of the start of watering; *MXSD* = maximum daily stem diameter, *MNSD* = minimum daily stem diameter, *DCA* = daily contraction amplitude, *MXSGR* = maximum daily stem growth rate, *MNSGR* = minimum daily stem growth rate; source: own study

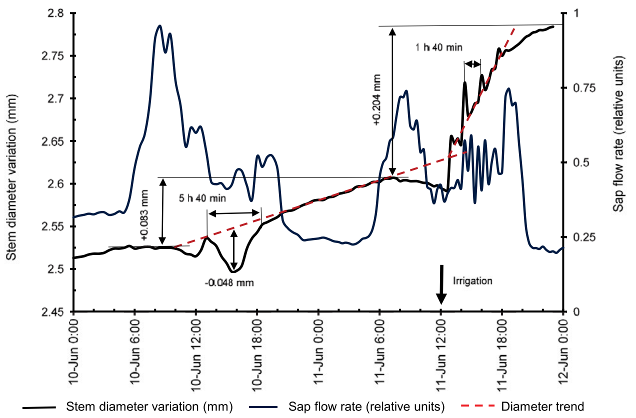

Fig. 2. Appointment of watering with a positive water balance of the plant; source: own study

stem diameter increased seven times and amounted to 0.0263 mm·h^{-1}, and the daily increase was 0.204 mm. Moreover, after watering, the diurnal depression of stem reduction decreased by 4 h, and the daily amplitude of stem reduction at the maximum value of water vapor pressure deficit in the air (3.89 kPa) decreased by 0.01 mm and was 0.038 mm. According to the data from the sap flow sensor, the expediency of the irrigation carried out on June 11 was confirmed. Thus, the morning maximum of the rate of sap flow along the xylem on June 10 was 0.22 relative units higher than the morning maximum on June 11. Before irrigation on June 10, the rate of sap flow along the xylem had a negative trend and decreased from 8 to 17 h, and the evening maximum of the rate of sap flow along the xylem was 0.52 relative units, which was 1.8 times less than the morning one. On June 11, before watering, the speed of sap flow also decreased, but from 2 p.m. there was an increase, and the evening maximum speed of sap flow reached the value of the morning and was 0.74 relative units.

This reaction of the stem and the speed of sap flow on the xylem to watering and external factors indicate that even with an upward trend in the stem diameter growth, the plant may experience a lack of water. Therefore, when planning irrigation with a positive water balance of the plant, it is necessary to analyse the daily amplitude of stem contraction (*DCA*) and the trend in the rate of sap flow. If the value of *DCA* for the next day increases or exceeds 0.043 mm, and the speed of sap flow decreases, it is necessary to apply watering.

With a water deficit in the plant, a decrease in the diameter of the stem is observed. Thus, from 28 to 29 June, the diameter of the stem decreased by 0.065 mm (Fig. 3). After watering on June 28 and 29 with a rate of 90 m^3·ha^{-1}, the rate of stem diameter decrease dropped. This can be seen from the change in the direction of the trend line, but the trend itself remains negative. By the time of irrigation on June 28, the rate of stem diameter decrease was 0.0155 mm·h^{-1}, and after irrigation it decreased 2.2 times and amounted to 0.0070 mm·h^{-1}. On June 29, the rate of decrease in the stem diameter was 0.0093 and 0.0013 mm·h^{-1}, respectively. On June 28, the daily amplitude of stem contraction was 0.084 mm, which is 2 times greater than the *DCA* on June 29, which was 0.039 mm. The analysis of the data shows that the water stress of the plant on June 28 was greater than on June 29. This is also confirmed by the xylem sap flow rate sensor. After watering, the rate of sap flow increased on June 28 and 29. An excess of the evening maximum speed over the morning one on June 28 and 29 was recorded, respectively, by 0.26 and 0.45 relative units. Morning maximums of the rate of sap flow along the xylem did not change and amounted to 0.74 relative units.

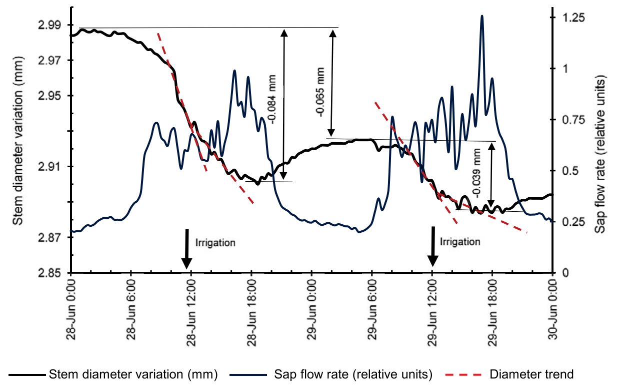

Fig. 3. Appointment of watering with a negative water balance of the plant; source: own study

The rate of stem diameter changes shows that even with insufficient daily irrigation, there is a water deficit in the plant. Therefore, if after several waterings there is no increase in the stem diameter, it is necessary to apply additional watering or to increase the watering rate.

The analysis of fruit growth rate data confirmed the need for changes in the irrigation planning strategy. Thus, by 12 o'clock on June 28, the growth rate was 0.043 mm·h^{-1}, then, despite watering, it decreased to 0.023 mm·h^{-1}, and remained at this level until 5 o'clock on June 29. From 5 to 12:00 on June 29, there was an increase in the growth rate of the fruit, which was 0.054 mm·h^{-1}, and then it again began to gradually decrease despite the watering (Fig. 4). Such a response of the growth rate to the irrigation demonstrated a reaction to an insufficient amount of moisture available for the plant.

During the ripening of tomatoes, the diameter of the stem almost does not change, so its change is less informative about the plant water status. In this case, it is better to use information from other indicators, for example fruit growth and sap flow rate. Thus, watering carried out on July 24 and 25 at the rate of 70 m^3·ha^{-1} differently affected the diameter of the stem (Fig. 5). After watering on July 24, a slight increase in the stem diameter (0.004 mm) was observed and the daily amplitude of stem

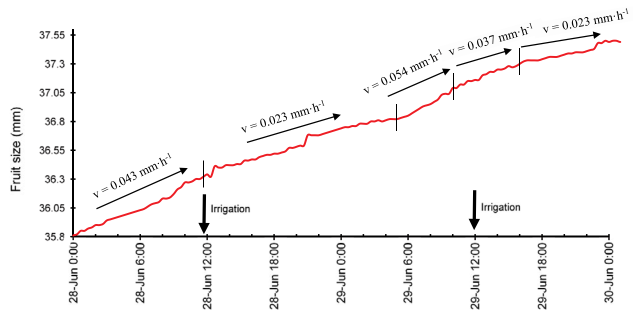

Fig. 4. The effect of watering on the growth rate of the fruit (irrigation on 28 and 29 June); source: own study

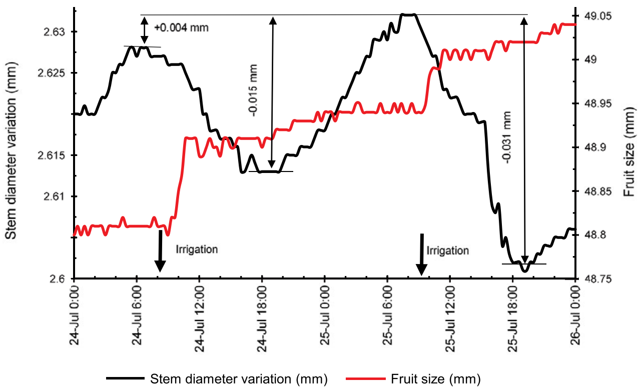

Fig. 5. Appointment of watering at the zero water balance of the plant, using a fruit growth sensor; source: own study

contraction was 0.015 mm. After watering on July 25, on the contrary, there was a decrease in the stem diameter by 0.019 mm and an increase in *DCA* by 0.031 mm. With such information from the stem diameter change sensor, we may conclude that the increase in the irrigation rate may be needed. However, the analysis of data from the fruit growth sensor showed a free irrigation management strategy. There was a response of the fruit to the irrigation. The average daily fetal growth rate did not change and on July 24 and 25, it was 0.030 mm·day^{-1}.

This was also confirmed by the xylem juice speed sensor. After watering, there was no decrease in the speed of sap flow. On July 25, the maximum speed value was 0.724 relative units, which was 0.066 relative units more than the maximum of July 24 (Fig. 6).

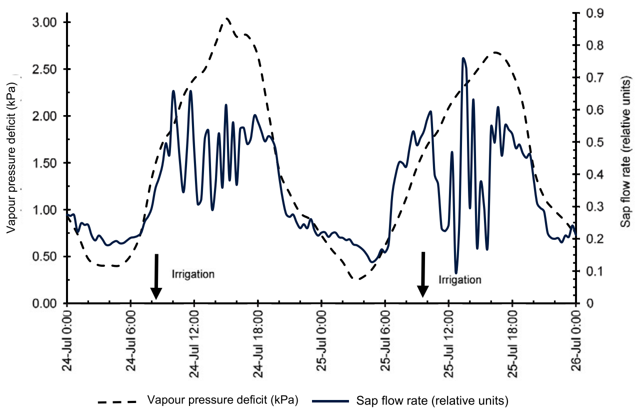

Fig. 6. Appointment of watering at the zero water balance of the plant, using the sap flow rate sensor; source: own study

CONCLUSIONS

The scientific and methodological approaches to the planning of tomato irrigation with the use of phytomonitoring methods in production conditions have been substantiated. It was found that when planning irrigation with a positive water balance of the plant, it was necessary to analyse the daily amplitude of stem contraction (*DCA*) and the trend in the rate of sap flow. If the value of *DCA* for the next day increases or exceeds 0.043 mm, and the speed of sap flow decreases, it is necessary to appoint watering. A decrease in two consecutive morning maxima (*MXSD*) indicates a negative water balance of the plant and the need to start watering. If, after several daily waterings, no increase in the diameter of the stem is observed, then it is necessary to decide to carry out additional daily watering or to increase the watering rate. At the zero water balance of the plant for watering purposes, it is necessary to use information from sensors detecting fruit growth and sap flow rate. A decrease recorded indicates the need for watering.

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