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RESEARCH ARTICLE

Measurement of the cell sap concentration of plant's leaves for irrigation's scheduling

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Abstract

The results of the investigations of the relationship between the Cell Sap Concentration (CSC) of leaves of tilled crops and their moisture availability are presented. The relationships between the CSC of leaves and the time of day, as well as patterns of changes in the CSC's index in different parts of the leaf: in the handle, middle and tip, were investigated. Field experiments during 2010-2012 were carried out on the sugar beet, tomato and potato crops, which were grown under drip irrigation. The CSCs of leaves were determined by the digital refractometer Atago PAL-Alpha in 10 replications. It is established that between leaf's CSC and soil moisture, there are reliable inverse correlation dependencies in all phases of plants growth, in particular, CSC of leaf tends to increase with decreasing of soil moisture. The correlation coefficients (r) and the error of the correlation coefficient (m_r) are calculated.

The dynamics of CSC's changes during the day depended on the temperature and humidity of the surface air layers and did not depend on the type of culture and the phase of its development. The highest correlation between CSC and soil moisture was recorded in the morning hours: from 07:00 to 09:00, and then, during the day, it tended to decrease. The definition of CSC in different parts of the leaf showed that the minimum indices are typical for the petiole, and the highest was in samples taken from the leaf apex. This dependence was typical for all cultures regardless of the phase of their development. The change in the size of the CSC of the leaf, depending on the canopy level, had no regularities. For a more reliable determination of the CSC, samples must be taken from the middle of a leaf of one layer in the morning at one time; the replication of the determination is at least 5 samples.

Keywords: Cell sap concentration, soil moisture, irrigation diagnosing, refractometer

Introduction

The maximum effect of irrigation depends on the timing of the irrigation's start. The design irrigation regime approximately determines the timing of vegetation irrigation. Actually, the time of irrigation is appointed in the process of plants vegetation (Rai 2017). In the practice of irrigated agriculture, various methods of vegetative irrigation's terms appointment are used. By the scientists (Jones 2004; 2008) the methods are divided into three groups by their constructive features and characteristics: by soil moisture measurements, by soil water balance calculations, by plants physiological responses. Among the most commonly used today are the methods of the first (Campbell G.S. & Campbell M.D. 1982; Yemelyanov 1983) and the second (Allen et al. 1998; Romashchenko et al. 2018) groups. At the same time, we state that soil moisture is only one of the abiotic ecological factors of the earth, which affects the water exchange of plants. Therefore, one of the pain points of these methods is the lack of connection with the plants themselves, that is, they don't take into account the physiological state of plants (Jones 1990; Ton 2004).

One of the first developers of the method of appointment of the terms of irrigation by the parameter CSC of leaves was M.F. Lobov (1949), who proved the effectiveness of the CSC's method on vegetable crops (Lobov 1957). Further research and testing of this method was carried out on peach (Sellés & Berger 1990), sorghum (Gnanasiri 1992), grapes (Girona et al. 2006; Pilar et al. 2007), olive (Moriana et al. 2008), wheat (Alghory & Yazar 2019), and nut crops (Fulton et al. 2001). However, most studies have been conducted for the conditions of sprinkler and surface irrigation of fruit and grain crops.

Therefore, conduction of the researches aimed at the diagnosing of irrigation by the parameter CSC of the leaves of tilled crops on drip irrigation is relevant.

Materials and Methods

In order to determine the dependencies between soil moisture and CSC of leaves, in 2010-2014, on the areas of the Kamiansk-Dnyprovska Experimental Research Station IWPaLR NAAS, Kamyanka-Dniprovska, Zaporozhye region, Ukraine (47°46' N, 34°42' E), the researches on the cultures of beet sugar and potatoes were conducted.

The soil of the experimental plot-typical chernozem, low-humic, medium loamy, the minimum moisture-holding capacity (MMHC) of 0-60 cm soil's layer is 18.8%, the bulk density is 1.35 g/cm³. From 2016 to 2018, the researches were carried out on the culture of tomato seedlings on the lands of the Experimental Farm "Brilyvske" IWPLM NAAN, Oleshkivsky district, Kherson region, Ukraine (46°40' N, 33°12' E). The field trials were held on at the dark chestnut, light-loamy soil, the minimum moisture-holding capacity (MMHC) of 0-70 cm soil's layer is 17.4%, the bulk density is 1.5 g/cm³.

By the research, the method was specified the layer-by-layer determination of soil moisture by the thermostat-weight method (Reynolds 1970) and the parallel determination of CSC of leaves. With this aim, a mature leaf was taken from the second canopy level of the plant. Changes in the CSC index were also determined depending on the time of day and in different parts of the leaf: in the handle, middle and tip. Placement of the experimental plots is systematic, replication is fourfold. The area of cultivated plots-40 m², registration plots-25 m². For accounting and observation, commonly used techniques were used (Ushkarenko et al. 2010). The digital refractometer Atago PAL-Alpha was used for the CSCs of leaves determination (Fig. 1). The number of replications is 10-fold.

Figure 1. The digital refractometer Atago PAL-Alpha.

Results and Discussion

Statistical processing of experimental data revealed the existence of significant inverse correlation dependences between CSC of leaves and soil moisture for the main phases of the plant's development (Fig. 2, 3 and 4). Thus, it has been found that the CSC of plant leaves increases with a decreasing in the moisture content of the root layer of the soil. According to averaged data, for volumetric moisture capacity 15.6% (60% of MMHC of soil) CSC of leaves of sugar beet plants by 4.85%, and potatoes–1.90% higher than under the soil moisture content 23.4% (or 90% from MMHC of soil).

In the conditions of soil's volumetric moisture capacity

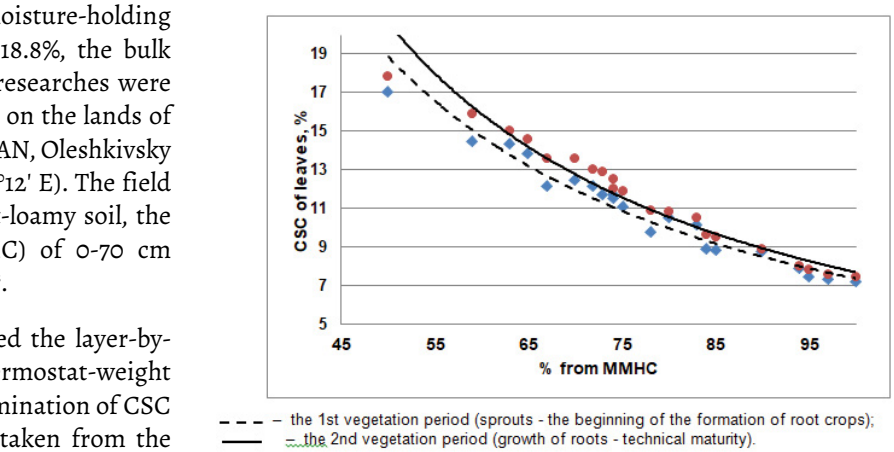

Figure 2. Dependencies "CSC of leaves-soil moisture" for the main phases of sugar beet development (soil layer-0-60 cm).

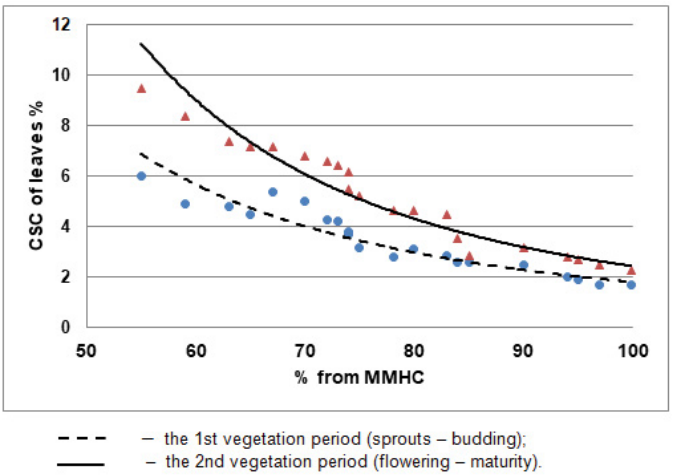

Figure 3. Dependencies "CSC of leaves-soil moisture" for the main phases of potato development (soil layer-0-40 cm).

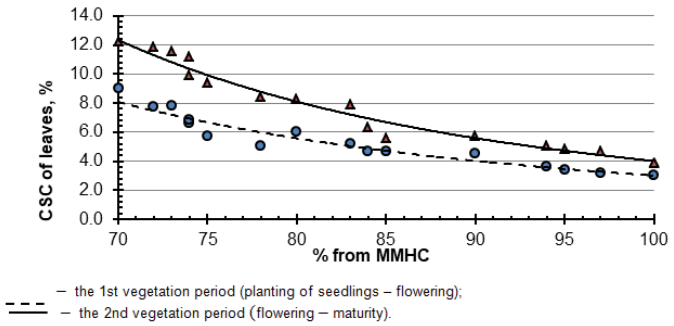

Figure 4. Dependencies "CSC of leaves-soil moisture" for the main phases of transplanted tomato's development (soil layer-0-40 cm).

18.3% (70% of MMHC of soil) the CSC of leaves of tomato plants is 6.15% higher than under the soil's moisture content of 23.5% (90% of MMHC of soil).

According to the data obtained, the correlation coefficients r and the error of the correlation coefficient (m_r) were calculated (Tab. 1).

The result indicated in Tab. 1. shows that the qualitative evaluation of the epidermal section of *Spigelia anthelmia* leaves on the microscopic slide using a microscope shows that a very clear and large cell, straight and rectangular to polygonal cell shape on both abaxial and adaxial epidermis is present. Presence of Anomocytic stomata, the epidermal walls have straight anticlinal walls. The abaxial epidermis as a non-glandular trichome, while trichome is absent on the adaxial epidermis. There is the presence of crystals on the abaxial epidermis and absent on the adaxial.

Table 1. Correlation dependencies between CSC of leaves and soil moisture under drip irrigation of tilled crops.

Value of r and m_r	Pre-irrigation level of soil's moisture, %MMHC						
	60	**65**	**70**	**75**	**80**	**85**	**90**
Sugar beet (soil layer 0-60 cm)							
r	-0.86	-0.87	-0.90	-0.90	-0.92	-0.90	-0.80
m_r	± 0.06	± 0.05	± 0.08	± 0.09	± 0.05	± 0.02	± 0.04
Potato (soil level 0-40 cm)							
r	-0.82	-0.80	-0.85	-0.87	-0.85	-0.80	-0.77
m_r	± 0.07	± 0.06	± 0.05	± 0.01	± 0.03	± 0.10	± 0.11
Tomato transplanted (soil level 0-40 cm)							
r	-0.77	-0.72	-0.83	-0.85	-0.83	-0.80	-0.78
m_r	± 0.05	± 0.05	± 0.04	± 0.04	± 0.06	± 0.09	± 0.10

The coefficient k was calculated by the methods of mathematical statistics, by introducing the obtained coefficient into the parabola equation (y=k/x) we obtain the corresponding value of the CSC of the leaves of the plants at different levels of pre-irrigation moisture of soil (Tab. 2).

To establish the associations between the CSC of the leaves of the plants and the time of day, measurements were performed hourly from 07:00 to 21:00. Observations showed that the lowest values of CSC noted at 7:00 am, and the highest between 13:00 and 15:00. The determined dynamics depended on the temperature and humidity of the surface air layers and did not depend on the type of culture and the phase of its development (Tab. 3).

The highest correlation between CSC and soil moisture was recorded in the morning hours: from 07:00 to 09:00, and then, during the day, it tended to decrease. Therefore, taking this into account, measurements of CSC's indices should be carried out in the morning, at the same time.

The definition of CSC in different parts of the leaf showed that the minimum indices are typical for the petiole, and the highest was in samples taken from the leaf apex. This dependence was typical for all tilled crops regardless of the phase of their development. The change in the value of CSC of leaves depending on the tier of the leaves' location did not have clear regularities. So, for the most reliable determination of CSC, it is necessary to take a sample from the middle part of the leaf of the same canopy level.

Table 2. The values of CSC of leaves of tilled crops depending on volumetric soil moisture of medium loamy soil and level of pre-irrigation soil moisture (LPISM).

Phase of development	K	CSC of leaves depending on LPISM						
		60%	**65%**	**70%**	**75%**	**80%**	**85%**	**90%**
		Sugar beet (soil layer 0-60 cm)						
sprouts-the beginning of the formation of root crops	219	14.0	12.9	12.0	11.2	10.5	9.9	9.4
root growth-technical maturity	235	15.1	13.9	12.9	12.1	11.3	10.6	10.0
the average values	227	14.55	13.40	12.45	11.65	10.90	10.25	9.70
Potato (soil layer 0-40 cm)								
sprouts-budding	72	4.6	4.3	4.0	3.7	3.5	3.3	3.1
flowering-maturity	105	6.7	6.2	5.7	5.4	5.0	4.7	4.4
the average values	89	5.65	5.25	4.85	4.55	4.25	4.00	3.75
Transplanted tomato (soil layer 0-40 cm)								
planting of seedlings-flowering	69	-	-	9.0	6.3	5.8	4.5	4.0
flowering-maturity	95	-	-	12.2	10.0	8.1	6.4	5.8
the average values	83	-	-	10.60	8.15	6.95	5.45	4.90

Table 3. The dynamics of CSC of the leaves of tilled crops during daylight hours (variant with LPISM 80% of MMHC)*.

Crop	Hour of a day, hrs./CSC of leaves, %							
	07:00	**09:00**	**11:00**	**13:00**	**15:00**	**17:00**	**19:00**	**21:00**
Sugar beet	11.2	11.6	12.0	12.8	13.0	12.5	12.1	11.9
Potato	3.5	3.7	3.8	4.2	4.6	4.2	4.1	3.8
Transplanted tomato	5.6	5.9	6.1	6.7	7.4	6.7	6.6	6.1

*Notice. CSC's parameters were adjusted to the temperature of +18°C.

Discussion

Comparison of the results of our research with the results of other scientists has shown both the same and different conclusions. We have only confirmed the general pattern of growth of CSC of leaves against the background of soil moisture reduction, as established earlier (Lobov 1957; Garin 1957; Bolotskyh 1971; Nadezhdina 1990). However, the CSC's parameters of sugar beet, potato, and tomato leaves directly determined by us differ from obtained earlier (Gorbatenko 1965; Gromova 1978). These differences are related to the different soil, climatic conditions, as well as the varietal characteristics of crops.

The obtained results regarding the appointment of irrigation terms according to the parameters of the CSC are recommended for approbation and implementation in the zonal conditions of research areas.

Conclusion

Thus, we have experimentally established the general patterns of changes in the CSC of leaves of tilled crops depending on the soil moisture.

The appointment of the irrigation of sugar beet at CSC of its leaves 10.5% in the first half of the growing season, in the second half-11.3%, potatoes at 3.5% and 5.0%, and tomato seedling 5.8%-8.1%, respectively, ensures the maintenance of water regime of the soil at the level of 80%-85% of soil's MMHC. For a reliable determination of the CSC, samples must be taken from the middle of the leaf of one canopy layer in the morning at one time; the replication of the determination is at least 5 samples.

The prospect of further researches is in the determination of the water deficit and water content in the leaves, depending on the water availability of plants.

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