Original scientific paper

Preliminary research of soil water availability and heat stress

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Abstract
On the eastern part of Croatian 2012. year was characterized as extremely dry and major yield losses of spring crops, especially maize, were detected. After that conclusions have been drawn that if we want quality production it is necessary to build major irrigation systems. Drought was mentioned as the only cause of the decrease in yield and damage from heat stress was not considered in detail. Although high temperature stress is usually associated with drought, extremely high temperatures and low relative humidity can cause equal or even greater damage to the primary organic production. If the high temperature (above 35^{0}C) matches with pollination of maize, soybeans and sunflowers in our climate, it will result in poor pollen production and viability and significant decrease in yield. In order to reliably determine the indicators of a lack of water in the soil and to realistically understand the problem, we set the automatic measuring device Datalogger Decagon's 5TE, with two measuring probes to monitor humidity and temperature at two depths (30 and 60 cm). The results of measuring the humidity and temperature of soil under the maize in the Gat area are showing the long-term heat stress, but not the water stress, because the content of available water in soil (percentage by volume) was significantly above the point of permanent wilting.

Key words: heat stress, maize, availability of water, data logger

Introduction
After the fierce summer heat in the 2012th the major yield losses of spring crops, especially maize, were detected. After that, farmers intensively started to think about the major irrigation of agricultural land in Croatia, because drought was mentioned as the only cause of the decrease in yield. Therefore, as a solution to future damage they often propose more extensive irrigation of crops. Damage from heat stress was not considered in detail. Although high temperature stress is usually associated with drought, extremely high temperatures and low relative humidity can cause equal or even greater damage to the primary organic production. Since irrigation systems for crops are extremely expensive investments and unprofitable for spring crops, we believe that this preliminary study of water availability that we have started in Veliškovci-Gat significantly indicate that heat stress can cause severe yield losses of spring crops and that irrigation systems cannot fully solve the above problem.

High temperatures cause the denaturation, desiccation and increased respiration of the plant. Temperature around 50^{0}C causes coagulation of proteins, and even at 35-40^{0}C plant organs can denature because of physiological-biochemical processes in the direction of synthesis of toxic substances (Vukadinovic, 1999). Maize reacts with yield losses already when temperatures go above 32^{0}C and in the past 50 years the prevailing opinion is that the heat stress can cause equal or greater damage than those caused by drought (Hawkins et al., 2012).

If the high temperature (above 35^0C) matches with pollination of maize, soybeans and sunflowers in our climate, it will result in poor pollen production and viability and significant decrease in yield (Elmore and Taylor, 2011). Also, the conduction system of plants, due to high evapotranspiration, fails to compensate the loss of water from the leaves, although with adequate moisture in the soil turgor falls, which can cause high damage if such conditions persist for several days.

Material and methods

In order to reliably determine the indicators of a lack of water in the soil and to realistically understand the problem, Department of Chemistry, Biology and Soil Physics of the Faculty of Agriculture in Osijek, has set the automatic measuring device (Datalogger Decagon's 5TE, measurement error <3%) with two measuring probes to monitor humidity and temperature at two depths (30 and 60 cm). The automatic measuring device was placed in the Veliškovci-Gat area.

The automatic measuring device for measurement of humidity and temperature was set at one-hour interval and was dug in on June 15th 2012. The data from the device was collected on November 8th 2012 and measuring had been continued till the June 21st 2013. During the tests, the probe on 30 cm depth was damaged by basic soil tillage and fertilization after maize harvest, so the one-year cycle measurements were completed with only one probe put on the depth of 60 cm, so there were 8901 measurements on the depth to 60 cm and 3609 measurements on the depth to 30 cm. The results for temperature and humidity are shown in the Graphs 1 and 2. Estimation of soil suitability and fertilizer recommendations was calculated using the ALRxp calculator. (Vukadinović, 2001; Đurđević, 2010) Soil samples were grounded in a soil mill and analyzed in the laboratory to the following chemical properties of soil: the soil pH in water and KCl, humus, AL-P_2O_5, AL-K_2O (Vukadinović and Bertić, 1988).

The following agro-tehnics are applied:

a) basic fertilizer 100 kg/ha of uree and 100 kg/ha of MAP,
b) chiseling on 40 cm (heavy duty chisel),
c) spring furrow closing with heavy spike harrow,
d) seedbed preparation (spring-tooth harrow),
e) sowing of maize hybrid (FAO 300) on 24th April 2012. with pneumatic seeder (plant density 62,000 per hectare with grain spacing 23 cm,
f) top dressing with 200 kg/ha of KAN in stag of 6 leafs along with cultivation so that the total amount of added NPK was: 175:106:42 kg/ha,
g) harvested on 12th September 2012. when the grain contained 12% of moisture.

Results and discussion

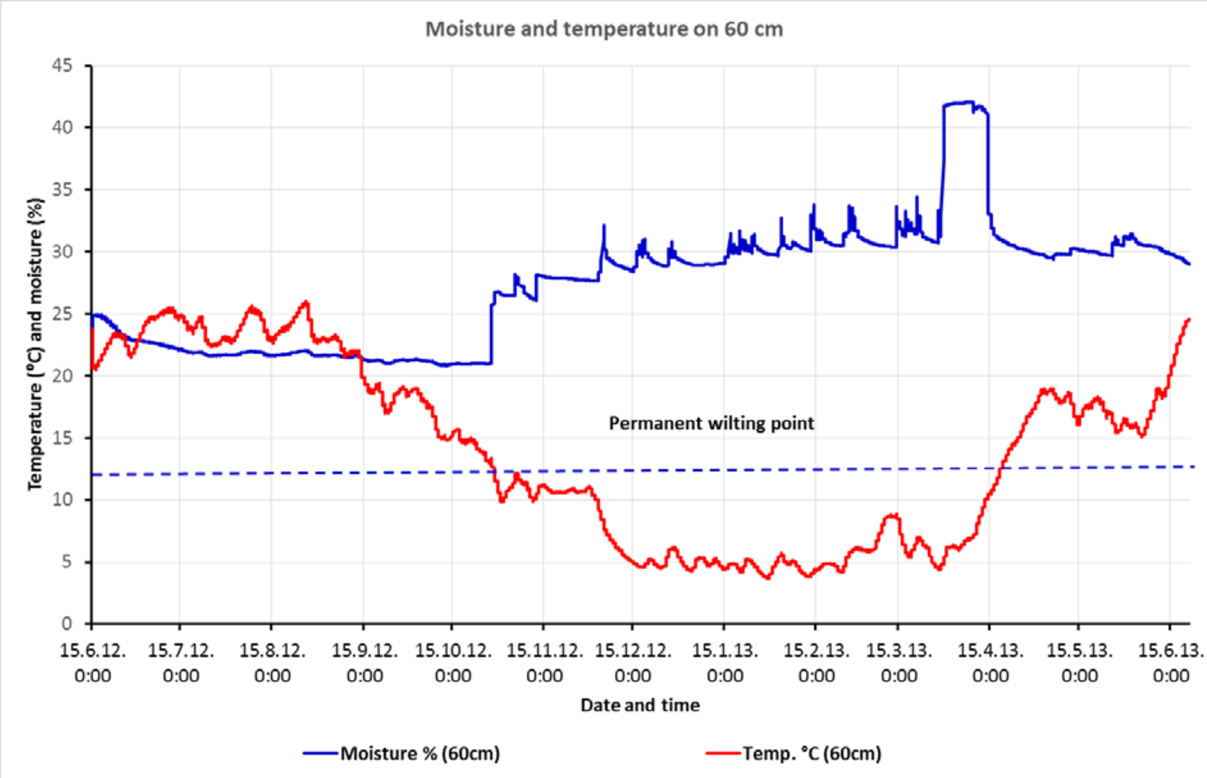
To reliably determine the level of high temperature stress on maize and to assess the damage from the heat it is necessary to analyze soil moisture, plant density and age (critical phase of the silking / pollination and grain filling), the duration of high temperature and hybrid tolerance (genetic and physiological adaptability). Production field was well supplied with available phosphorus and potassium, with silt texture and slightly acidic soil pH reactions, low on humus, with good relative soil suitability for crops from 60-80% (P2) (Table 1).

When Soil fertility control was conducted and relative suitability of soil for crops was calculated on research plot the expected yield of corn was 9.6 t ha^{-1} of dry grain. Therefore, the fertilization was targeted to yield of 10 t ha^{-1} of dry grain, and using ALRxp calculator fertilizer recommendations were calculated (NPK 175:106:42 in kg/ha).

Table 1. Chemical properties of soil

Chemical analysis of soil	0 – 30 cm
pH_{KCl}	5,76
pH_{HOH}	6,70
AL-P_2O_5 mg 100 g^{-1}	20,10
AL-K_2O mg 100 g^{-1}	27,27
Humus %	1,41

Moisture and soil temperature were measured at soil depth of 30 and 60 cm (Graph 1 and 2), and the percentage of moisture was never below the permanent wilting point (~ 12%), so drought was not as fierce as it was expected, and was not the cause of the low yield of maize which was significantly below the expected 10 t/ha of dry grain. In fact, the yield of five maize hybrids in the studied field was between 4 and 5 t ha^{-1} of dry corn.



Graph 1. Moisture and temperature on 60 cm (15.06.2012.-21.06.2013. 8901 measures)

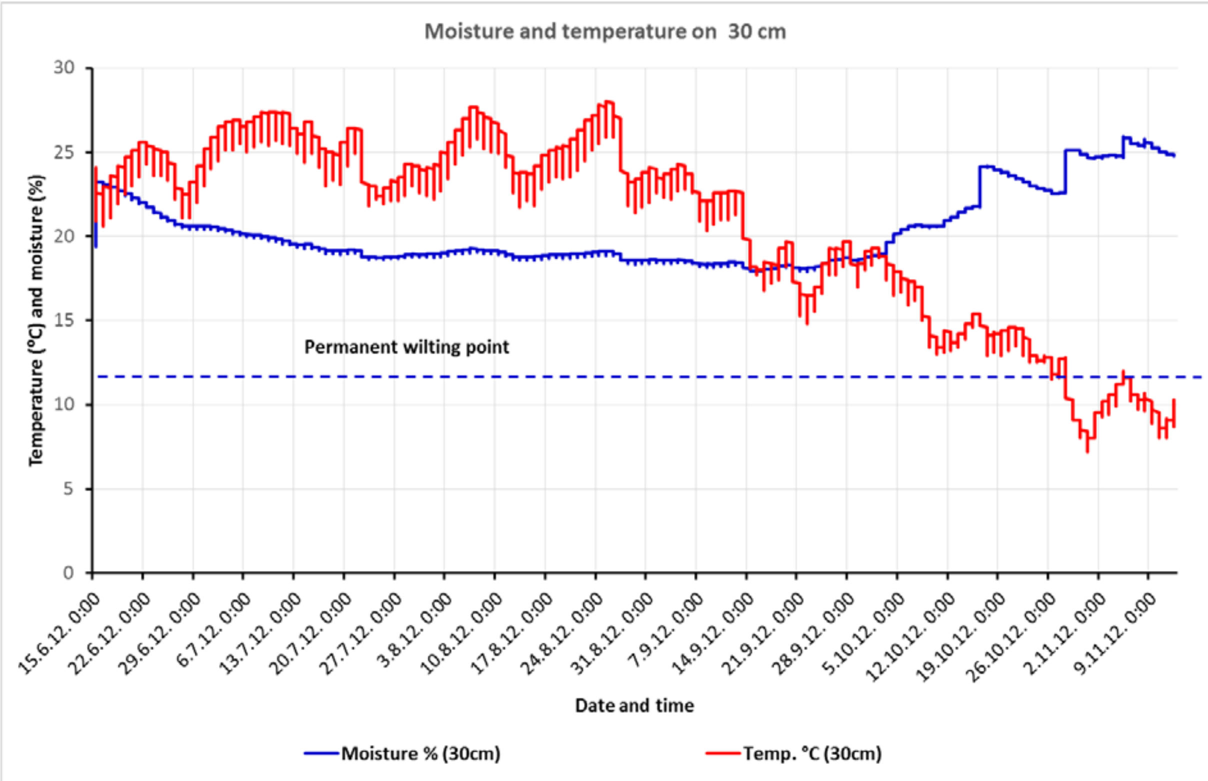
Table 2. Average monthly temperature and precipitation in Osijek

Trend	April	May	June	July	August	September	November
Air temperature							
Average [°C]	11.5	16.5	19.8	21.6	20.8	16.7	11.2
Aps. Max [°C]	30.9	36.0	39.6	40.3	38.9	37.1	30.5
Precipitation							
Precipitation [mm]	58.8	69.1	83.0	60.9	59.4	55.2	58.8

Source: Meteorological and hydrological service, http://meteo.hr/

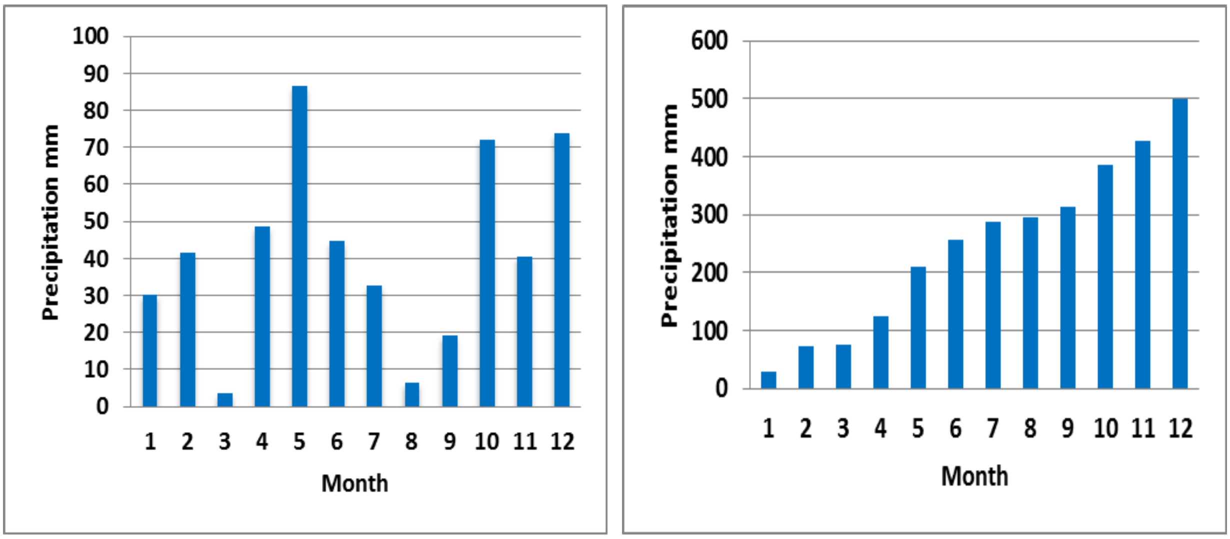
Deviation from the average monthly precipitation for Osijek is shown in Graph 2 (Monthly and cumulative). Since there were very small amounts of precipitation in March and August

(Graph 3a) compering to the average, the lack of water occurred only from August until the end of the year (Graph 3b).



Graph 2. Moisture and temperature on 30 cm (15.06.2012.-12.11.2013. 3609 measures)

However, as opposed to the relatively small lack of moisture in the soil, in the critical stages of the formation of corn yield (two weeks before and four after pollination), soil temperature was very high at both measuring depths (30 and 60 cm) until mid-September, with more expressed daily amplitude (~ 3^0C) at 60 cm (Graph 1).



Graph 3. Precipitation values for Osijek (Source: http://freemeteo.com)

Maize is a photosynthesis C4 type of plant that efficiently use CO_2 and grows from tropical to mild climate (up to 58 °N. Latitude). Studies are showing that the optimal daily temperatures for maize are between 20 and 23°C, and night temperatures from 18 to 22°C. Maize can endure short-term high temperature up to 44^{0}C, but noticeable damage to the leaves can be reported already at 37 ^{0}C (Johnson and Herrero, 1981). When there is enough moisture in the soil, temperatures below 36.5^{0}C will not significantly affect the yield, but when air temperature is higher than 34.5^{0}C, especially when the relative humidity is low, the reduction of pollen viability (ability pollination) and poor pollination may occur. Also with timely silking, heat alone can desiccate silks so that they become non-receptive to pollen (Bean and Kenny, 2011; Elmore and Taylor, 2011). It is important to highlight that high night temperatures (above 22.0^{0}C) increase plant respiration which can significantly reduce the yield due to accelerated maturation of maize with weak intensity of grain filling (Outlook Report, 2012).

In conclusion, exposure to high temperatures (with a maximum temperature of 34^{0}C or above) can result in yield loss. It was measured that on the fifth day there is a loss of approximately 2 percent; and on the sixth day an additional 4 percent loss. After the sixth day firing of leaves becomes likely and very extensive yield losses are incurred (Elmore and Taylor, 2011).

Conclusions

The results of measuring the humidity and temperature of soil under the maize during the period between June 15th 2012 and June 15th 2013 on the depths of 30 and 60 cm in the Gat area are showing the long-term heat stress, but not the water stress, because the content of available water in soil (percentage by volume) was significantly above the point of permanent wilting point.

Since the air temperature and its relative humidity were not measured at the given parcel, data from the Meteorological and Hydrological Service of Croatia for the city of Osijek indicate a very hot summer in 2012 (15 straight days with temperatures above 34^{0}C in July), so we believe that the heat stress, enhanced by "atmospheric" drought, had resulted in very low maize fertilization which in the end lead to low yield. This paper is a contribution to a better understanding of the damage to crop production as a result of high temperatures during long period of time and does not go in favor of mass application of irrigation, at least not for crops. Specifically, the hypothesis that the larger irrigation solves the problem of low crop yields is made questionable within this study, because it was determined that there had been sufficient supply of available water in the root zone, but at the same time the air temperatures were extremely high, so the shortfall in crop yield should be largely attributed to heat stress in the year 2012.

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