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Magyar Agrár- és Élettudományi Egyetem (MATE), Kaposvári Campus, Kaposvár
Hungarian University of Agriculture and Life Sciences (MATE), Kaposvár Campus, Kaposvár

Article

Examination of the evapotranspiration dynamics of maize in Thornthwaite-Mather type compensation evapotranspirometer

Ariel TÓTH [1*], Gábor SOÓS [1], Szabina SIMON [1], Brigitta SIMON-GÁSPÁR [1]

[1] Hungarian University of Agriculture and Life Sciences (MATE), Georgikon Campus, 8360, Keszthely, Festetics György str.7.

ABSTRACT - According to the data provision of the National Meteorological Service, since the early 1980's an intense warming has begun and it is also reflected in domestic observations. In Hungary, just as in other Central European countries, the extremes of weather events are becoming more common. As a main crop, maize (sweet corn) has an outstanding national and global significance. Certainly, global warming and changes in water supply will harmfully affect the cultivability of maize too. Water stress reduces the leaf surface, therefore because of the less captured photosyntetically active radiation, biomass production and yields will be reduced. Weeds with a wider tolerance range than crops may also become increasingly dangerous competitors in field crop production because of their wide tolerance range, fertility and strong adaptability to changing climate- and precipitation conditions. In this research the effect of climate change on the evapotranspiration of maize was investigated at the Agrometeorological Research Station of MATE Georgikon Campus in Keszthely, between 21 May 2021 and 1 September 2021 in Thornthwaite-Mather type compensation evapotranspirometer. The aim of the study was to assess the main characteristics (like leaf area index, daily evapotranspiration, and yield) of sweetcorn under optimal water supply conditions. Furthermore it was also an aim to determine how weeding affects plant characteristics so half of the treatment (1 vessel of the evapotranspirometer) was kept weed-free, while the other half was exposed to natural weeding. In terms of results, positive relation between temperature and evapotranspiration was found and it has been established, that maximum temperature has a greater effect on evapotranspiration, than daily mean temperature. In case of yield indicators, the negative effect of weeding was statistically detectable and it was also pointed out, that the presence of weeds can negatively affect the quantity of crops. The results of the study was compared to a number of other researches on the subject, and it was concluded that the negative consequences of climate change, especially the increasing frequency of drought-hot periods could pose a major threat to successful maize production in the future.

Keywords: sweetcorn, evapotranspiration, weeding, leaf area index, climate change

INTRODUCTION

According to the data of the Central Statistical Office, in 2019 the sown area of corn was 1.03 million hectares in Hungary, which means a notable area compared to the complete 9.3 million hectares of the country. Corn is a widely used

*CORRESPONDING AUTHOR
Magyar Agrár- és Élettudományi Egyetem (MATE), Georgikon Campus
✉ *8360 Keszthely, Festetics György út 7.., ☎ 06 30 292 1270*
E-mail: tothariel96@gmail.com

crop. On the one hand it has an important role in human consumption (sweetcorn, popcorn, corn poridge, flour, beer base) and on the other hand, in livestock feeding (fodder, silage etc.), furthermore it is also suitable for industrial purposes (furfural, isosugar and starch production, corn oil), and it's stalks and cobs are also used for heating or recycling back into the soil. In addition an important way to use corn is the production of ethyl-alcohol, which is mainly used as gasoline biofuel additive (*Ranum et al.*, 2014).

Production needs

Corn is a heat-demanding plant, which is suitable to be cultivated in warmer areas. The minimum required soil temperature for germination is 10 ^{o}C but on 16-18 ^{o}C germination will be faster. 32 ^{o}C is the critical temperature, that can adversely affect yields at any stage of developement. Frost also threatens corn at any stage, especially the leaves of ripe plants (*Plessis*, 2003). The amount of heat during the growing season significantly affects the yields of corn. It is favorable if it is between 1250-1750 ^{o}C (*Dénes*, 2005).

Under domestic conditions, a minimum amount of water is available for producing corn. The water demand of corn, grown under optimal conditions is 550-670 mm in Hungary, depending on climate conditions and agronomic factors. In seed stage and initial growth phase it does not require much water, so soil moisture is sufficient. Irrigation is not necessary in the vegetative phase either, but the water use of corn peaks in the early reproductative phase, so it is justified to avoid water stress during tasseling, flowering and pollination. Drought during flowering is the most dangerous as dehydration of pistils and pollens can result in poor fertilization (*Kranz et al.*, 2008). The depth of rooting is greatly influenced by the amount of water stored in the soil from the previous year and the amount of rainfall, during the growing season. The main water use period of corn is from mid-June to mid-August. Drought during ripening speeds up the ripening process, preventing the grains from reaching their potential size and weight (*Lamm et al.*, 2009).

Taking the agro-ecological properties of Hungary and the water demand of corn into account, it would be justified to irrigate crops. Experiences also show that irrigation in appropirate time, according to the needs of plants increases the yield (*Smith et al.*, 1992). In Hungary only about 2% of corn fields are irrigated due to small farm sizes and the lack of integrated water management systems (*Gaál et al.*, 2014). Expanding the irrigation network and optimizing irrigation systems would be one of the most effective adaptation measures to mitigate the effects of drought in maize production (*Hanquing et al.*, 2019). In addition, drought tolerance of maize hybrids would also be an important component of successful cultivation in the future, especially in areas prone to drought (*Cooper et al*., 2014).

Soils with extreme conditions or poor water management such as sandy or saline soils are not suitable for growing corn (*Udvardy*, 2010). It is desirable if soil has a deep fertile layer, favorable morphological characteristics, optimal moisture content, suitable chemical properties (pH: 6.5-7.5) and sufficient amount of accessible plant nutrients (*Plessis*, 2003). The most favorable soils for corn are humus- and nutrient-rich, easily warming chernozem, brown forest, chernozem brown, meadow chernozem and meadow soils.

The expected effects of climate change in Hungary

In 2021, the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change drew attention to the fact that, if current emission trends continue, global warming will be exceeded by 1.5 °C, thereby warm seasons will be prolonged, while cold seasons will be shortened, and the frequency of extreme warm weather events will be increased and they will increasingly exceed the upper tolerance limit of agriculture (*IPCC*, 2021).

In their study, *Ciscar et al*., (2011) predicted a global temperature rise of 2.3-3.1 °C, which is worse than the number, specified by the IPCC. The majority of studies on the subject agree that Europe (including Hungary) will be more affected by the negative effects of climate change than the world average. As a result of the intensification of the greenhouse effect, domestic climate may become warmer, dryer and richer in sunlight (*Mika*, 2002). The IPCC report also points out, that as a result of climate change, the water cycle may become more intense, so that while rainfall would increase sharply in some areas, droughts would worsen elsewhere. Agriculture is the most directly affected economic sector by global warming. Farming needs to adapt to changed environmental and biological conditions so some desertified and eroded areas should even be completely excluded from agricultural production (*Farsang et al*., 2015).

In their research *Pásztor et al*., (2010) tried to assess the agroecological potential of Hungary and its future during climate change, using a 4M simulation model. In terms of their results, the negative effects of climate change will prevail in Hungary, so according to the forecast, the average yield of maize will also decrease. The reason of maize yield loss is the rising temperature and extremes in the precipitation phenomena, especially during the generative period (*Széles et al*., 2018).

In their study *Meza et al.*, (2018) concluded, that the yield loss of maize, due to climate change will be 10-30%, depending on the climate change scenario and the applied hybrid.

Aware of these informations, irrigation of maize may have a great importance in the future.

Evapotranspiration of maize under drought and warm conditions

Evaporation of the water content of soil and transpiration of plants take place in parallel, forming the evapotranspiration complex. The extent of current evapotranspiration is influenced by a number of factors, such as soil cover, soil structure, moisture content, crop type and growth phase, and weather factors, like radiation, temperature, relative drought and wind speed (*Lich et al.*, 2017). Water requirements of maize grown with adequate water supply is equal to the sum of the daily evapotranspirations measured during the growing season (*Basso et al.*, 2018).

Plants release about 95-98% of their water intake in form of water vapor (*Loch et al.*, 2004). A corn plant evaporates about 200 litres of water during the growing season, which if cannot be replaced from the soil, needs to be returned by irrigation.

The rate of evapotranspiration can also be reduced with proper nutrient supply. The value of transpiration is the lowest with satisfying nutrient supply (*Loch et al.*, 2004). An optimal dose of phosphorus and potassium reduces water consumption by about 25-30%.

The effects of weeding in maize fields

Maize, as a large-scale crop (70-75 cm row spacing) cannot compete with weeds without systematic human weed control (*Bozsik et al.*, 1997). In their study, *Varanasi et al.*, (2016) stated that weeds are likely to show greater resistance and adaptability to changes in CO_2 concentration and rising temperature than cultivated plants, due to their diverse gene pool and plasticity. Next to the variety of environmental conditions, weeding is one of the main reasons of the decrease in maize yields (*Rajcan et al.*, 2001).

Former domestic studies have attempted to detect a correlation between weediness and crop depression in maize and have concluded that the average yield of maize grown without weed control was only 23.5% compared to the weed-free control treatment (*Bozsik et al.*, 1997). Nevertheless, this value cannot be considered constant because the weed composition of maize may vary considerably depending on the ecological and agrotechnical characteristics of the specific area.

The multiplication of weeds may lead to a large loss of nutrients, which slows down the developement of maize. In addition, next to the loss of nutrients, competition for space, water and light between industrial plants and weeds are also cannot be neglected (*Zimdahl,* 2004).

The purpose of the research

For the better understanding of the effects of climate change on maize production, the aim of the study was to assess the evapotranspiration dynamics of maize under optimal water supply conditions, using Thornthwaite-Mather type compensation evapotranspirometer in the quite arid and warm growing season of 2021 which was suitable to model the expected future conditions related to global warming. An other aim was to determine, how weeding affect yields and other performances of maize.

MATERIAL AND METHODS

The study took place at the Agrometeorological Research Station of the Hungarian University of Agricultural and Life Sciences, Georgikon Campus, Keszthely (N: 46°, 44', 7.93", E: 17°, 14', 16.65", altitude: 114.2 m).

The research was set up in a Thornthwaite-Mather type compensation evapotranspirometer (*Figure 1.*), which consists of a variable number of 4 m^2 surface, 100 cm deep culture vessels and a measuring cellar, which are connected to each other via a pipeline. Soil is placed in culture vessels according to natural stratification (*Simon et al.*, 2020). The Thornthwaite-Mather type compensation evapotranspirometer is commonly used to measure the potential evapotranspiration of plant populations. The culture vessel is connected to a compensation tank via a pipeline, so the water level below the crop can be kept at a constant depth, which is equal to the water level of the compensation tanks. It is controlled by a float and an overflow pipe, so if the water level drops due to the co-evaporation of the plants and the soil, the float will open a tap and the water from the dosing tank (tank 1.) will be replenished. If the water movement is in the opposite direction (due to precipitation), the water flows into a water collection tank (tank 2.), through an overflow. Potential evapotranspiration can be determined by knowing the daily values of depletion from tank 1. and the values of backflow to tank 2. (*Gombos*, 2011).

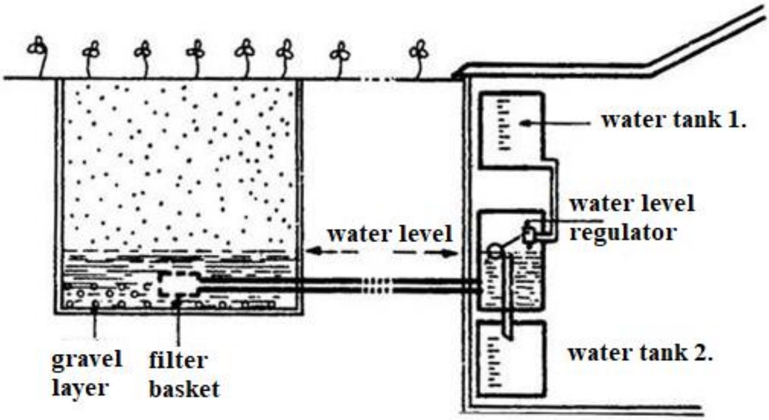

Figure 1: The structure of the Thornthwaite-Mather type compensation evapotranspirometer (*Gombos,* 2011)

Ramann brown forest soil was available in the culture vessels of the evapotranspirometer, on which the necessary soil preparation works were carried out, in the autumn of 2020. The soil preparation tasks, such as soil rotation, soil dusting, leveling and keeping the area weed free were done with manual tools. In addition to the establishment of appropirate soil condition, satisfying supply of nutrients was also provided. Nitrogen (225 kg/ha) was applied in 3 portions: 50% on the 14. day after sowing, 25% immediately before reaching the five-leaf stage and a further 25% immediately before flowering. 150 kg/ha of superphosphate and 100 kg/ha of 60% potassium salt granules were also applied on the experimental plots. Sowing took place on May 21, 2021, during which GSS 8529 supersweet maize hybrid was sown in 2 growing vessels, 3-3 rows per vessel with 75 cm row spacing, 12-13 cm plant distance and about 4-5 cm deep. To ensure the stock effect, the culture pots were sorrounded on all sides with maize to prevent border effect. Border effect means that certain parameters (like wind speed, temperature, or the mass of certain (weed) species) at the edge of the population change, compared to the internal section (*Margóczy*, 1998). The purpose of avoiding border effect was to get an uniform population without lower plants at the edges (which may could have modified our results) and to protect plants at the edges of the vessels from greater physical pressure to transpirate.

In this study 2 different treatments were set up. The 2 vessels were connected to the evapotranspirometer, which provided them a continuous optimal water supply. One of the vessels was exposed to weeding, while the other one was kept weed-free throughout the experiment. Weeds were not planted into the culture vessels. They were settled in a natural way therefore the area specific species were able to settle.

Measurement of leaf area

To determine leaf area, LI-3000C portable leaf area meter was used which has the advantage of working in fine resolution (1 mm^2), additionally it is suitable for non-destructive field measurements and ideal for long-term samplings due to its battery capacity.

The first leaf area measurement was performed on June 29, 2021 and from then on, repeated leaf area measurements were performed weekly until tasseling, in order to determine the leaf area of 5-5 representative sample plants. During the measurements always newly completely developed leaves were measured, then their surface was added to the results of previous measurements. By averaging the area of each leaf of 5 sample plants per vessel, the leaf area of the average plant per vessel was obtained.

Determination of leaf area index

The following formula was used to estimate leaf area index: $LAI_0 = (LA_0 \times LN \times PN) / T$, where LAI_0 is the leaf area index of the given species, LA_0 is the area of the average leaf size of the given species, LN is the average number of leaves per plant, PN is the number of plants in the study area and T is the size of the study area (*Richter*, 2009).

The highest productivity of maize can be achieved at LAI values ranging from 4 to 5 (*Lykhovyd et al*., 2019).

Monitoring of weather elements

Evapotranspiration data were compared with air temperature and precipitation data from the QLC-50 device located at the Agrometeorological Research Station. The QLC-50 measuring device, which is available for ten-minute sampling has been operating in the area of the Research Station since 1996 (*Kocsis*, 2008). The meteorological elements measured by the QLC-50 measuring machine are: wind speed, wind direction, air temperature, humidity, precipitation, soil surface temperature and soil temperature (at a depth of 5, 10, 20, 50 cm).

Determination of reference evapotranspiration

The concept of reference evapotranspiration provides comparability according to internationally accepted standards for the determination of evapotranspiration (*Irmak et al.*, 2011). The equation can be described as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_a + 273} u(e_s - e_a)}{\Delta + \gamma(1 + 0.34u)}$$

In the equation ET_0 is the reference evapotranspiration [mm day^{-1}], Rn is the radiation balance [MJ m^{-2} day^{-1}], G is the thermal flux of the soil [MJ m^{-2} day^{-1}], T_a is the daily mean temperature [^oC], u is wind speed at 2 m altitude [m s^{-1}], e_s is the saturation water vapor pressure [kPa], e_a is the actual water vapor pressure [kPa] and e_s-e_a is the saturation deficit [kPa], Δ is the slope of the temperature-saturation vapor pressure function [kPa $^oC^{-1}$] and γ is the psychrometric constant [kPa $^oC^{-1}$] (*Allen et al.*, 1998).

To determine the evapotranspiration of a plant under favorable conditions, the plant coefficient Kc (also known as the plant constant) need to be obtained by comparing the measured evapotranspiration (ETc) of the plant to the reference evapotranspiration (ET_0) (Kc = ETc / ET_0). In knowledge of reference evapotranspiration, the evapotranspiration of a given plant can be calculated (*Allen et al.*, 1998). (ETc = Kc x ET_0) The plant coefficient of maize varies widely, usually between 0.15 and 1.2 depending on the phenophase, but its value is influenced by several factors (*Rácz*, 2014).

Extraction of crop data

Representative sampling of the experimental maize crop took place on 27 August 2021. For each treatment, the length and weight of the collected cobs (unfolded from their husks) were measured, then averaged, in order to compare the results of the treatments.

The experimental maize was let to dry until constant weight (11-12 % moisture content). The seeds were crushed from the tubes, and thousand-seed weight [g] was calculated by working with 5-5 repetitions per treatment. 50-50 randomly selected seeds per treatment were counted, measured by digital analytical scales, multiplied by 20, then averaged to get the most accurate result regarding to thousand-seed weight.

Statistical methods used

Two-way analysis of variance (ANOVA) tests were performed on the averages of the samples in IBM SPSS program, furthermore T-tests were also performed in Excel to confirm any significant differences.

RESULTS AND DISCUSSION

Weather conditions of the growing season

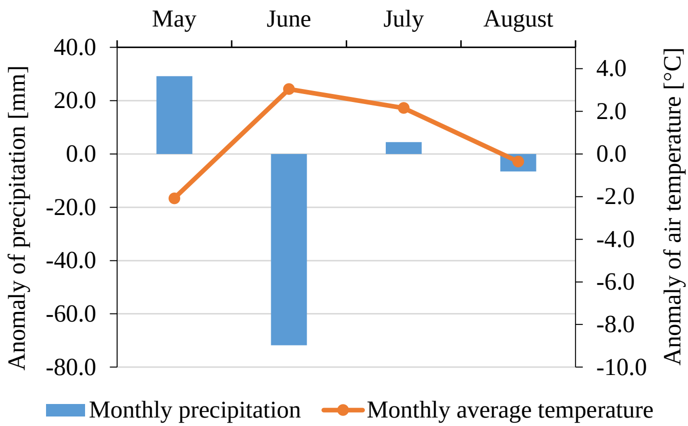

Figure 2. Deviation of the monthly precipitation amounts and the average monthly temperature of the 2021 growing season from the climate standard (1981-2010)

Due to the cold and rainy May, our experimental maize could only be sowed late, on the 21st of May (*Figure 2.*). June was quite arid and warm – a total of 3 mm precipitation fell on 2 rainy days. July and August did not show a significant difference from the 30 year average. In July, 69.2 mm of rain fell on 8 rainy days and in August 66.8 mm on 13 days. These months included days with larger amounts of precipitation (e.g.: July 17: 18.4 mm, July 30: 27.9 mm, August 1: 18.5 mm, August 26: 19.6 mm). Due to the drought year, it was not necessary to install a rain protection system.

The average temperature in May was 14.0 °C, which showed a notable deviation from the climate standard in a negative direction. Compared to that, June with an average temperature of 22.1 °C also showed a remarkable difference, but in a positive direction. In July, the average monthly temperature was

23.2 °C, which also deviates positively from the climate standard. With an average temperature of 20.1 °C, August did not show a significant deviation from the 30-year average.

In terms of temperature, it is important to examine not only the average but the maximum temperatures as well.

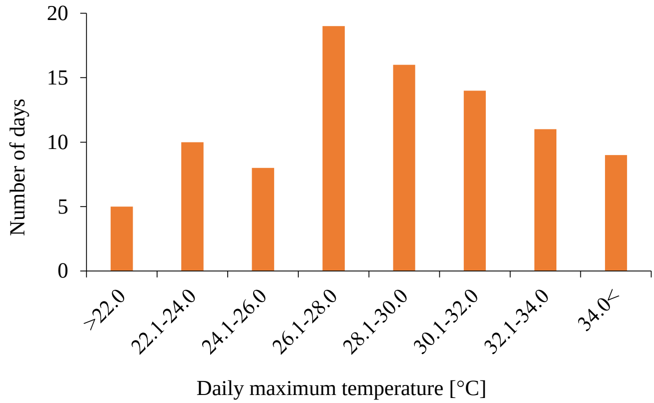

Figure 3. Distribution of daily maximum temperatures during the growing season

There were a total of 20 days in the growing season when the maximum temperature exceeded 32 °C, which is considered critical for maize in every growing phase. There were 9 days where it exceeded 34 °C too (*Figure 3.*).

Developement of leaf area during the growing season

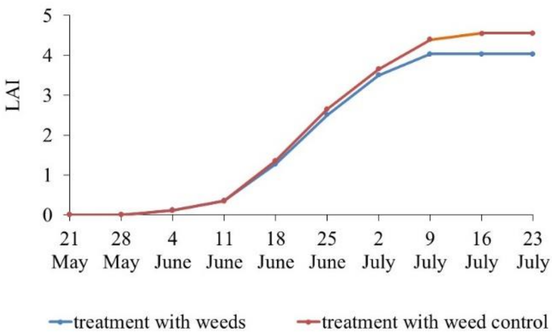

Figure 4. Developement of LAI (Leaf Area Index) of different treatments

In the treatment with weeds, the restraining effect of weeds on the leaf area began to become more pronounced from July 2 (*Figure 4.*). The presence of weeds reduced LAI by 11.5%. Based on the results of the two-way ANOVA, the presence or absence of weeds had a significant effect ($p = 0.003$) on the leaf area of maize. In connection with weeding, *Ngome et al*. (2012) described a significantly negative correlation ($p < 0.01$, $R^2 = 0.31$-0.51) between the LAI of maize and weed biomass.

Dependence of evapotranspiration on meteorological elements

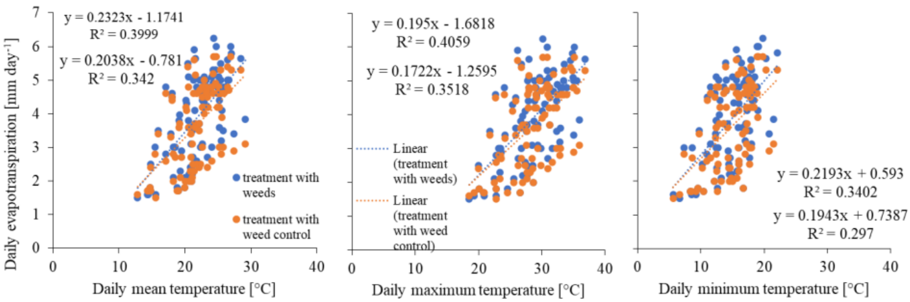

Figure 5. Relations between daily mean, maximum and minimum air temperature [°C] and daily evapotranspiration of maize [mm day^{-1}]

On *Figure 5*., a dot band, sharply separated from the linear line can be observed, where relatively low evapotranspiration values are associated with high temperature values. A reason for this is due to the fact that after germination, in late May – early June, the experimental plants did not have a large leaf area, so their transpiration was much lower, than in their fully developed state. Furthermore, during this initial period, the temperature was unusually high compared to the average. The reason for the upper jumps may be other effects that were not examined, e.g. the wind. Based on the results, a positive relationship was found between temperature and evapotranspiration: the higher the temperature, the higher the evapotranspiration is. The relationship is positive, but based on R^2 the maximum temperature (treatment with weeds: $R^2 = 0.4059$, treatment with weed control: $R^2 = 0.3518$) had a greater effect on evapotranspiration than the daily mean temperature (treatment with weeds: $R^2 = 0.3999$, treatment with weed control: $R^2 = 0.342$). The least close connection was detected in case of minimum temperature (treatment with weeds: $R^2 = 0.3402$, treatment with weed control: $R^2 = 0.297$).

Comparison of daily evapotranspiration and daily reference evapotranspiration

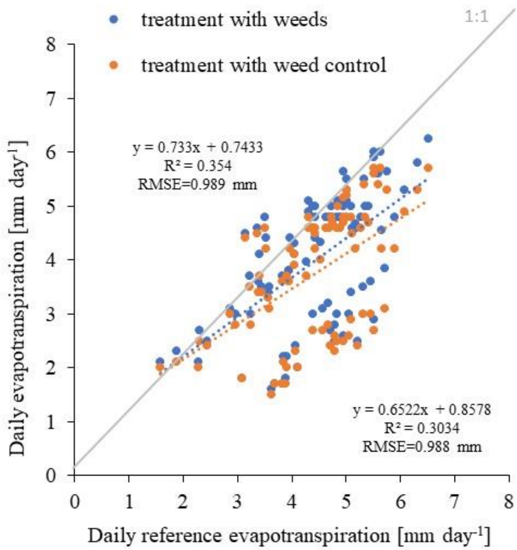

Figure 6. Relationship between daily reference evapotranspiration and daily evapotranspiration of maize

The small leaf area at the beginning of the growing season can also be observed on *Figure 6*. During this period, the reference evapotranspiration was much higher than the measured evapotranspiration values. Until the development of the first leaves, almost only the evaporation of the soil surface was observed. Based on the data measured during the growing season, the Penman-Monteith equation slightly underestimates our data. The reasons for the variability in daily evapotranspiration may have been due to both variabilities in meteorological elements and biological characteristics. During the growing season, the treatment with weeds transpirated a total of 350.2 mm of water, while the treatment with weed control transpirated a total of 328.9 mm. Comparing the evapotranspiration of the two treatments by T-tests, no significant difference ($p = 0.1744$) was observed. The cumulative Penman value was 388.5 mm. The daily mean evapotranspiration was 3.9 ± 1.2 mm for the treatment with weeds and 3.6 ± 1.2 for the treatment with weed control. The daily mean value of the reference evapotranspiration calculated by the Penman Monteith equation was 4.4 ± 1.0 mm. Comparing the individual treatments and reference evapotranspiration by T-tests, a significant difference was found for both treatments (treatment with weeds – reference evapotranspiration: $p = 0.0137$, treatment with weed control – reference evapotranspiration: $p < 0.001$).

In their research, *Tyagi et al*. (2003) examinated the evapotranspiration of maize under optimal water supply, in India. In their results they reported a cumulative evapotranspiration of 354 mm in the growing season.

Examination of the effect of weeds on crop

Based on the results of the two-way analysis of variance, the presence and absence of weeds had a significant effect ($p < 0.001$) on the development of the cob weights.

According to the data of the measured cob length, the average length was 10.86 ± 4.01 cm in the treatment with weeds and 16.97 ± 5.84 cm in the treatment with weed control. The expected value of cob length of GSS 8529 maize hybrid (20-22 cm), specified by the distributor was approached only with regular weed control. In connection with weeding, *Iderawumi et al*. (2018) pointed out, that in treatments where weed control does not happen within 4 weeks after sowing, corn yield drastically fall back, especially where there is no weed control at all.

Based on the results of the ANOVA and T-tests, weeds had also a significant effect ($p < 0.001$) on thousand-seed weights.

In agricultural industry, the decrease of cob weight, cob length and thousand-seed weight can also cause large losses of income.

CONCLUSIONS

The weather during the 2021 growing season was suitable for modelling the expected adverse effects of climate change. The research shows that the competition with weeds may cause significant changes in indicators, such as LAI, cob weight and cob length, which may lead to remarkable economical losses. The accelerated evapotranspiration which lead to insufficient water supply may also cause losses in yield, especially if weed control is unsatisfactory. The results of the study were compared with a number of other studies on the subject. Based on the results, the study also prove that the negative consequences of climate change, especially the acceleration of evapotranspiration, caused by the increase of drought, hot periods and the accelerated spread of weeds may pose a major threat to successful maize cultivation in the future. Therefore, it would be expedient to urge the preparation of agriculture for changing circumstances and to carry out further studies to assess the expected impacts of climate change on crop production.

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