VALIDATION OF AN AUTOMATED COMPENSATION EVAPOTRANSPIROMETER WITH CADMIUM POLLUTED MAIZE

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Abstract

There are only a few facilities to determine the evapotranspiration of a crop canopy. One of these possibilities is the use of evapotranspirometers. In spite of known shortcomings of the equipment they are widely applied in the everyday practice of crop water loss measurements. In our investigation the traditional compensation evapotranspirometer of Thornthwaite-Matter type was renovated at Keszthely Agrometeorological Research Station in 2011. The volume of the tanks (growing chambers) was 4 m^3 each with surface area of 4 m^2, and the depth of them 1 m. The tanks were layered with soil column characteristic of the surroundings of Keszthely area. The test plant was a short growing season maize hybrid Perlona.

Earlier traditional evapotranspirometers were able to measure the daily sum of lost water. Later on the mechanic construction of the equipment might be automated. The renewed instrument is able to collect the water use of the tank in second's interval. We represent our preliminary results showing diurnal variation of maize evapotranspiration in two different treatments. One of them contains the impact of cadmium on maize water loss. Detailed discussion on the influence of cadmium pollution on water loss of maize excluded from the study. Performing of polluted crops aimed only an independent treatment in our methodological experiment. Main goal of this investigation was an outline of functioning of converted evapotranspirometers.

Key-words: compensation evapotranspirometer, water loss, cadmium, maize, validation

Összefoglalás

A keszthelyi Agrometeorológiai Kutatóállomáson az 1970-es években telepítettek Thornthwaite-Matter típusú kompenzációs evapotranspirometereket. Ezek mechanikus konstrukcióban a napi párolgásösszeg meghatározására voltak alkalmasak. 2011-ben a műszereket automatizáltuk, mely eredményeként a növények vízfogyasztásának napi változását másodpercenként tudjuk követni. A bemutatásban óraátlagok alapján szemléltetjük a kukorica vízfogyasztásának napi változásait különböző időjárási feltételeknél. Az automatizálás eredményét a kadmium szennyezés evapotranszspirációra gyakorolt hatásának másodpercenként gyűjtött adatokból származtatott óraátlagainak felhasználásával is szemléltetjük. Nem volt célunk a kadmium kukoricára gyakorolt hatásának részletes elemzése, a szennyezett kezelés csak a felújított evapotranspirometer működésének reprezentálására szolgált. A kadmiummal szennyezett növények jelentették a második kezelést.

Introduction

Reference evapotranspiration (ET_o) is one of the most frequently cited processes of evaluating crop water use and irrigation necessity. The definition of ET_o was drawn by *Jensen et al.* (1990) as follows: "the rate at which water, if available, would be removed from the soil and plant surface of a specific crop, arbitrarily called a reference crop." Although any crop could be a reference crop, the 0.2 m tall clipped grass or 0.5m tall alfalfa is widely current.

Grismer (2002) rated 50 methods to evaluate reference evapotranspiration. He concluded that the assumptions, data demands, mainly meteorological ones, and results scatter on high extent in different methods. The FAO standard counting the ET_o is the well known Penman Monteith (*Allen et al. 1998*) equation:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma \ \Delta(1 + 0.34u_2)} \qquad (1)$$

where ET_o is the hypothetical reference crop evapotranspiration rate in mm d^{-1}, T is mean air temperature in °C, and u_2 is wind speed in m s^{-1} at 2 m above the ground. RH or dew point and air temperature, needed to get saturation deficit (e_s-e_a), are also measured at 2 m above the soil surface. The Rn is the net solar radiation, the G is the soil heat flux (W m^{-2}). The psichrometric constans is γ (0.5 g m^{-3} K^{-1}), the Δ denotes the slope of saturated vapour pressure-temperature relation (Pa °C^{-1}).

This worldwide applied assumption lies on well discussed physical and biological (physiological) basis.

There is other way in evapotranspiration evaluation, measuring the daily loss of a water body. The proper equipment to achieve this goal is the class “A” pan. Although the accuracy of class “A” pans in reference evapotranspiration measurement is controversial, its simplicity, practicality, wide availability and low cost make them widely applicable in irrigation management (*Medeiros et al.* 2001). On the other hand the FAO do not recommend any more the use of “A” pans in evaluation of reference evapotranspiration. At a push in estimation of ET_o FAO recommends a minimum 10-day or longer time period for irrigation purposes.

Cadmium is a toxic heavy metal that accumulates in all branches of the food chain. In plants it can be easily taken up. We chose the maize as test plant, because the sensitivity of maize to cadmium was extremely high (*Wojcik and Tukendorf* 1999). Earlier investigations showed depression of crop evapotranspiration due to Cd pollution (*Kirkham 2006*). Impact of Cd on other maize properties was summed among others by *Bi et al. (2009*).

The purpose of the study was the review of functioning of a renewed mechanic evapotranspirometer. We used two different water treatments in validation of the equipment. Of the two water treatments one was polluted with cadmium. Detailed investigation on the impact of cadmium on maize evapotranspiration excluded from our observation. The polluted crops represented an independent water treatment only. Reconstruction aimed the accommodation to the most up-to-date data acquisition system of the research area (*Berke* 2007).

Materials and Methods

Study on the measurement of maize evapotranspiration was carried out at Keszthely Agrometeorological Research Station in the growing season of 2011. The soil was Ramann’s brown forest soil with a mean bulk density of 1.46 Mg m^{-3} in the top 1 m of the profile and an available water capacity of 150 mm m^{-1}. Nutrients (180, 80 and 120 kg ha^{-1} N, P and K, respectively) were applied in spring, immediately prior to sowing. The usual agronomic measures (plant protection, weed control) recommended for the location by the staff of the University of Agricultural Sciences, Keszthely, were applied. The test plant was the short- season maize hybrid Sperlona.

Two treatments were applied at "ad libitum" watering in Thornthwaite type compensation evapotranspirometers. Half of the crops were polluted with cadmium. Characteristics of the instrument see also below. The actual evapotranspiration was calculated as a residual term of the water balance after *Antal* (1968).

The Cd concentration used for pollution was 10^{-5} M [$Cd(NO_3)_2 \times 4H_2O$]. A motorised sprayer (SP 415) was used to apply the pollutant in the field at weekly intervals.

Differences in seasonal mean evapotranspirations were compared using the LSD test at the P=0.05 significance level (STATA 5.0 program package). In diurnal variation of evapotranspiration and water uptake the influence of cadmium was analysed using paired t- test.

Results and Discussions

Conversion of traditional mechanic evapotranspirometers at Keszthely

The aim of installation of Agrometeorological Research Station at Keszthely was the foundation of an evaporation measurement system in Hungary including crop evapotranspiration. The beginning of observations started in the early 1970'-es. To gauge daily water loss of crops twenty four Thornthwaite-Matter type compensation evapotranspirometers were settled into two measuring units (two cellars). The instruments were self-made ones as in general worldwide, because ready installations were not available.

The evapotranspirometers contain two separate units (*Fig. 1*); the growing chamber or tank in the field (1) and the measuring cellar (2) below the soil surface at the edge of the field. A tube connects the two units of the evapotranspirometer.

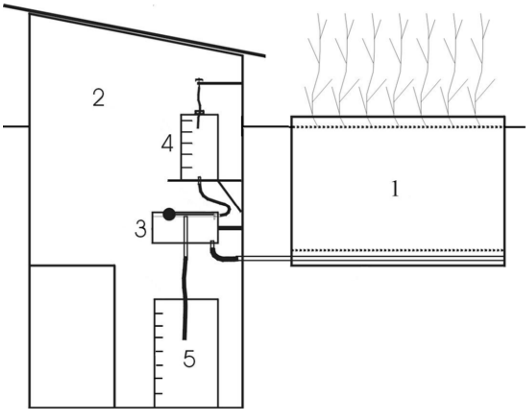


Figure 1. Schematic representation of the Thornthwaite-Matter type compensation evapotranspirometer

The tanks were settled in the middle of a field, where the irrigation facilities were also at our disposal. The irrigation and size of field guaranteed the existence of an irrigated canopy just surrounding of our growing chambers. The field layout, evapotranspirometers and crop fetch covered a total area of about 0.7 ha. In the tanks a constant water table level was kept at a depth of 0.90 m. The growing chambers were metal containers with a volume of 4 m^3 (2×2 m in area, 1 m in depth), filled with a monolith from the surrounding areas, layered as in the natural state. Each evapotranspirometer unit consisted of three measuring pots mounted into the cellar (see Fig. 1). The water level controlling pot (3) was placed in the middle. Above and below this central unit the compensation (4) and leakage (5) pots were placed, respectively. A mechanic float as water level controller was fixed in the controlling pot.

The basic principle of evapotranspirometers functioning is the communicating vessels. If additional liquid is added to one vessel (controlling pot), the liquid will again find a new equal level in all the connected vessels (tank in the field) (en.wikipedia.org/wiki/Communicating_vessels). In our everyday work the components of the water balance were registered each day of the season, expressing evapotranspiration as the residual term. The inputs were the daily rainfall amount (P), the additional watering added by compensation pot (C) and in case of drought the irrigation water (I). When the precipitation exceeded the water holding capacity of the soil column of tanks, the leakage water (L) was an output in addition to evapotranspiration (ET_o):

$$P+C+I = ET_o+L \tag{2}$$

The traditional evapotranspirometers were renewed in 2011. The control system was changed from mechanical to electronic. Two pots, the compensation and leakage ones were omitted. The compensation pot was replaced by an electronic switch connected to the water supplier tap (*Fig. 2*).

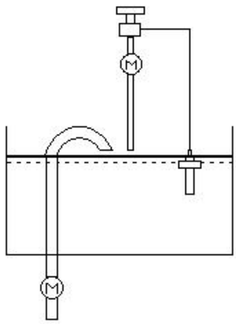


Figure 2. The reconstructed compensation system of the evapotranspirometer with float ring on the right and siphon (inverted U shape tube). M denotes flow meters

The electronic switch was controlled by a reed switch and a magnet built into a float ring. Finally the water level was adjusted by the float ring. At declining water level (in case of crop water use) the float ring's magnetic field opens the electric tap. When the water level reaches the adjusted level the float ring closes the water supply. When the amount of precipitation is higher than the water holding capacity of the soil column, the surplus water flows into the controlling vessel and the additional water is siphoned off. The picture of the renewed system is presented on the Photo 1.

Photo 1. One unit of water supplier with the data logger of the evapotranspirometer (Photo: G. Soós)

A meteorological data logger of HYGACQ V1.3 type was connected to each cellar. The frequency of data sampling is 1 second. The logger calculates hourly sums and memorizes them. The collected hourly data can be loaded by PC using the WHYGACQ computer program. The program has a graphical surface providing a quick view about temporal variation of water supply.

Weather of the studied season

Seasonal air temperature was 1.2°C higher in 2011 than the climatic norm (*Fig. 3*). Extremely low precipitation sum amounting to about half the average figure (54%) was observed. The season of 2011 was the driest from the beginning of meteorological observations (1871) in Keszthely. In the course of monthly meteorological data there was only one exceptional months, the month July, when both climate means (air temperature and precipitation sum) were in good correspondence with the long-term average. All in one, the other periods were warm and dry in 2011.

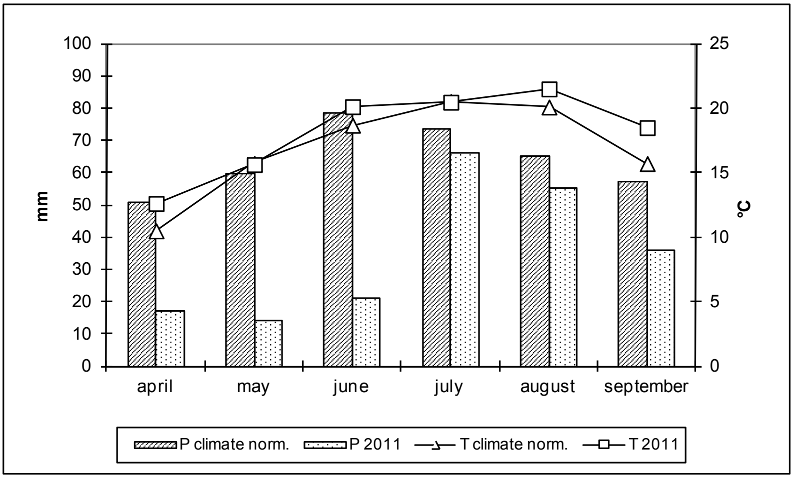


Figure 3. The weather of the season of 2011 at Keszthely.
The climate norms were calculated for 1971-2000.

Actual evapotranspiration of maize

At non limited watering the size of actual evapotranspiration follows the changes in transpiration surface (leaf-area -index) and radiation intensity. In the early stage and in the end of the season less water loss is observed than in the middle of the vegetation period. Arid season of 2011 resulted in extremely high total water losses in maize. Yearly evapotranspiration sums in control and polluted maize totaled in 463.9 mm and 428.9 mm, respectively (*Fig. 4*). The seasonal evapotranspiration sums differed significantly at the 5% probability level. The greatest value of daily water loss was measured during flowering in 9th July 2011 (7.1 and 6.7 mm in control and polluted crops). Cadmium pollution did not modify the date at which peak daily evapotranspiration loss was observed.

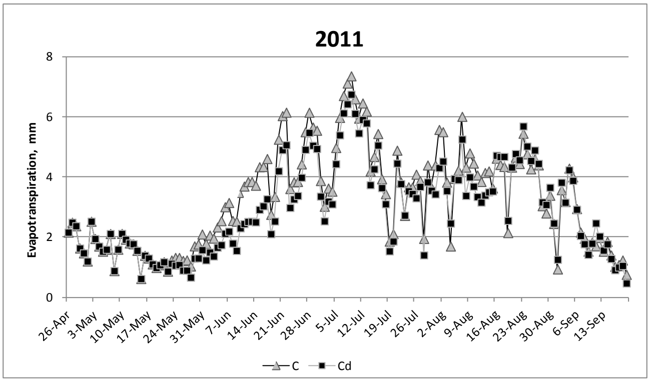


Figure 4. Seasonal variation of actual evapotranspiration in maize at Keszthely

The sum of yearly evapotranspiration of Cd polluted maize significantly lowered with 13% during 2011. Decline was the most pronounced in the second half of June and on some extremely hot days. The monthly mean temperature of June exceeded the climate norm of Keszthely with 1.5°C. In the beginning and in the end of the vegetation period the impact of Cd was more moderate on maize water loss.

Impact of atmospheric cadmium pollution on the daily dynamic of system's water uptake

The renewed evapotranspirometer permitted the hourly imitation of growing chamber's water compensation, by presenting the member C in Eq. 1. This is the amount of additional water offered to soil and crops grown in the growing chamber. We demonstrated hourly distribution of compensation water for different radiation regimes; for overcast and completely clear days separately. On cloudy days, both radiation and water replenishment were low and consolidated (*Fig. 5*). Radiation intensity was expressed by total incoming radiation (global one, W/m^2). The impact of Cd was also moderate. Decreased water use of cadmium polluted maize was in accordance to earlier investigations (*Fodor* 2003).

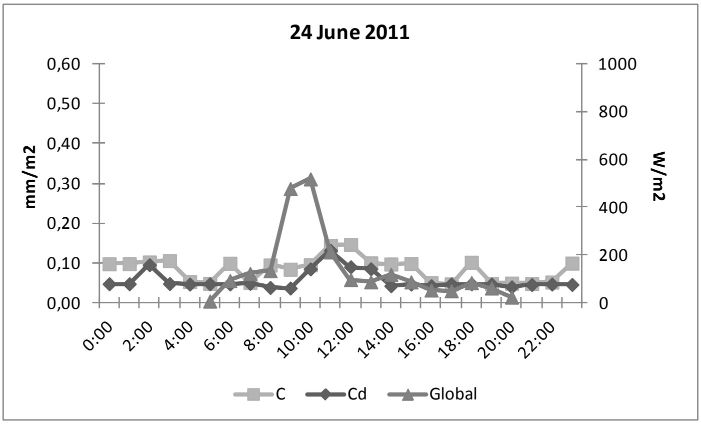
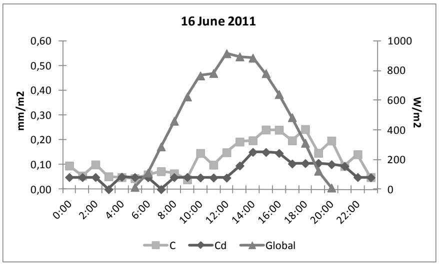


Figure 5. Daily variation in water uptake during overcast day

At the beginning and in the end of the season (low solar angles and small leaf size) the daily water compensation (*Fig. 6)* is only a few mm (1-2 mm/m^2). The time of highest irradiation using DST (daylight saving time) is at 13:00 in Hungary (about 10 minutes earlier at Keszthely). In our case it means Central European Time +1:00, or UTC+2:00. The time of largest system's water demand did not coincide with the highest solar angle; the peak water uptake was late about two to three hours. It means that the water demand follows better the air temperature curves then radiation changes.



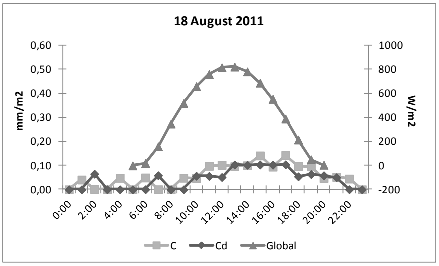


Figure 6. Hourly water consumptions during the time of canopy closure (16 June) and wax ripe (18 August)

The top water demand was observed at the time of tasseling (*Fig. 7*). Daily compensation water amounts totaled 5.99 and 4.45 mm/m^2 in control and polluted treatment, respectively. These observations are in accordance to earlier studies for maize (*Steduto and Hsiao 1998*), where peak rates of water losses were reached during the most active stage of growth, at tasseling independently on water supply. The impact of cadmium on clear days was significant ($P > 0.0000$) and high. In our clear sky sample day decline in water use of polluted treatment reached the 30%. In spite of undisturbed radiation (cloudiness) and "ad libitum" watering, the water consumption was more variable than the radiation curve calling the attention to other influencing environmental factors (air moisture, wind etc.). This small "noises" appeared parallel in the two treatments suggesting impact of non living environment more than influence of biological origin.

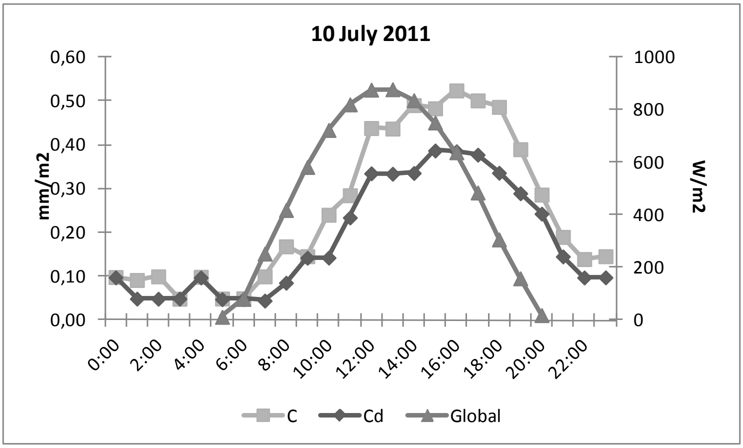


Figure 7. Peak water uptake of maize in tasseling
on completely clear sky conditions

Hourly actual evapotranspiration of maize was also calculated (*Fig.8*). Our sample day was in tasseling, at the same time as discussing amounts of compensation water. The impact of cadmium on maize evapotranspiration was significant ($P > 0.0000$).

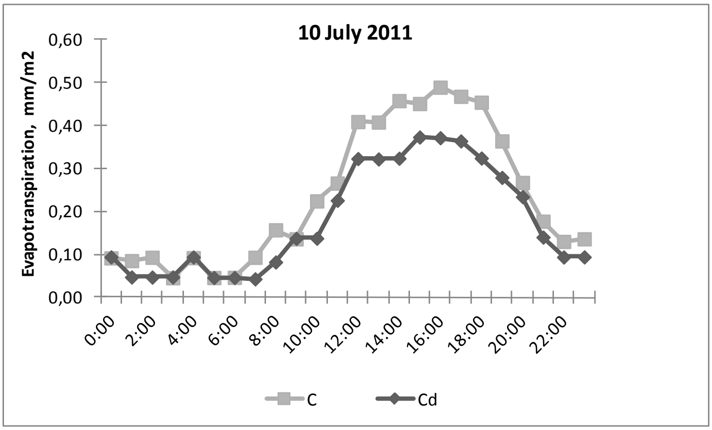


Figure 8. Diurnal variation of maize evapotranspiration
during tasseling

Water capacity of the tank's soil, mainly in the upper layers, might be low due to drought; the potential evapotranspiration was extremely high (7.7 mm). This was the reason why the amounts of compensation water and the counted evapotranspiration were close to each other. Almost the whole amount of additional water was turned into evapotranspiration, their rations were 93% (5.6 mm) and 96% (4.3 mm) in control and polluted crops, respectively. Only the remaining part of water enhanced the soil water capacity in daytime hours. Peak maize water losses were measured at 16:00 DST, at the time of warmest air temperatures.

Conclusion

Reconstruction of mechanic evapotranspirometer fulfilled our expectations. We could follow the dynamic of crop water uptake and reference evapotranspiration. In our sample the cadmium pollution declined with 13% the yearly sum of maize evapotranspiration. Our results were in accordance to earlier investigation of *Greger and Johansson* (1992) for beans. The impact of cadmium was the most pronounced in clear sky conditions.

With one exception, our observation covered an overview of diurnal variation of addition water, the compensation water. Discussion of hourly variation in maize evapotranspiration needs deeper consideration later.

Acknowledgement

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