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B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Features of application of the Penman–Monteith method for conditions of a drip irrigation of the steppe of Ukraine (on example of grain corn)

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Abstract

In the article presented the features of application and adaptation of the calculation method for determination of evapotranspiration Penman–Monteith. With the purpose of effective use of this method in the practice of a drip irrigation in the steppe zone of Ukraine, on the base of the field's experiments results were conducted correlation of K_c with a taking into account deviations from standard conditions (on the example of grain corn).

Key words: *coefficient of culture, drip irrigation, evapotranspiration, grain corn, rate of irrigation*

INTRODUCTION

The biological basis of irrigation's mode is a total water consumption of plants or actual evapotranspiration (*ETc*). Under the *ETc* we understand the total volume of water that evaporates during the vegetative period by plants and soil surface (physical evaporation – *Ke*) infiltrate into the lower soil's horizons and spends by plants on transpiration (*Kcb*).

Determining factors that influence the value of the *ETc* are the climate of zone and weather conditions of current or calculated growing season of their cultivation.

Determination of agricultural crops' water consumption is a key issue from the solution of which depends the values of irrigation's rates, efficiency and ecological consequences of irrigation.

In the practice of irrigated agriculture water consumption is calculated using different methods: by the data of special experiments, by the coefficients of transpiration and water consumption, on the base of water balance's equations and so on.

At present there are many methods by which evapotranspiration has determined on the basis of meteorological parameters and biological characteristics of agricultural crops. At the irrigated conditions of the steppe zone of Ukraine at different times practically applicated the following methods: bioclimatic method of A.M. Alpatyev [ALPATYEV 1954], and later it was improved by S.M. Alpatyev [ALPATYEV 1965] and by V.P. Ostapchik [OSTAPCHIK 1989], biophysical method of D.A. Shtoyko [SHTOYKO *et al.* 1977] and of M.M. Ivanov [IVANOV 1954] and others.

In the world for a long time been widespread methods of Penman [PENMAN 1956] and Blaney–Criddle [BLANEY, CRIDDL 1950]. Taking into account a certain inexactness of these methods in the 1990 council of experts in FAO had recommended approving of the combined method of Penman–Monteith as the standard for calculation of an etalon total evapotranspiration (*ETo*).

The method predicts determination of *ETo* of a hypothetical culture with a height of 0.12 m, the surface resistance of 70 cm^{-1} and albedo of 0.23, similar to the a lawn grass with the same height in a phase of active vegetation and sufficiently moistured. Design equation of Penman–Monteith was determined from the equation of energy balance of soil surface, and the dependence of *ETc* to *ETo* displays a coefficient of a culture *Kc*, which describes the differences between a typical crop and standard lawn grass [ALLEN 2010; ALLEN *et al.* 1998; BLAINE 2008].

The values of *Kc* are typical values, expected for average *Kc* in standard climatic conditions that are defined as sub-humid climate (kind of steppe climate, most provided with precipitations) with the average daily minimal air humidity $RH_{min} \approx 45\%$ and an average wind speed of 2 $m \cdot s^{-1}$. Arid climate and higher wind speed causing an increase of *Kc*'s values [ALLEN 2010; FARG *et al.* 2012; SUMNERA *et al.* 1998]. The climatic conditions of dry steppe of Ukraine ($RH_{min} \approx 30\%$, $v \approx 3$ $m \cdot s^{-1}$) differs from the typical FAO, so for the practical application of the Penman–Monteith method, is necessary to adjustment *Kc*, taking into the account deviations from standard conditions [KOKOVIHIN 2010].

MATERIAL AND METHODS

Field experiments were conducted on lands of SE "HH" Brylivske' Institute of Water Problems and Land Reclamation NAAS (dry steppe subzone – the climate is lukewarm, very dry) – 46°40′ of north latitude, 33°12′ of east longitude, altitude – 17 m. Soil – dark brown residual alkaline light-loamy.

Experiments were conducted in the 2013–2015 years on a culture of a grain corn (hybrid DKC 5276 DEKALB®, FAO 460. For the recording of meteorological parameters used online weather station iMetos®, which was located directly on the experimental plot. *ETo* determined using CropWat 8.0. The actual evapotranspiration *ETc* determined using the internet station of soil moisture monitoring iMetos®SM/ECHO/TNS/ECOD2, which was equipped with soil moisture sensors Watermark 200SS type on different depths of soil profile and distances from the point of water supply.

As *Kc* actually depends on the phase of culture's development, corn growing season was divided into three parts: an initial, middle and final phase.

RESULTS AND DISCUSSION

Determined that in a 2013 actual average daily evapotranspiration *ETc* differs from evapotranspiration *ETc* (FAO) calculated with a using of the cultures coefficient *Kc* (FAO) (Fig. 1). Thus, during the period "emergence of seedlings – headling of panicles" (I decade of May – III of June) and from the milk ripeness before harvesting (II decade of July – I of September) *ETc* (FAO) exceeds the actual average daily evaporation *ETc* respectively on 2.0 and 2.8 mm.

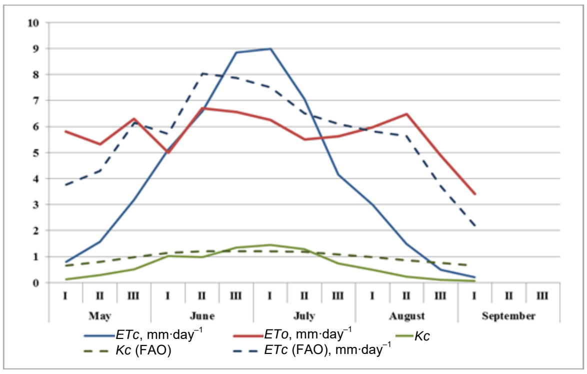

Fig. 1. Daily evapotranspiration and *Kc* of corn – 2013 year; source: own study

From the headling of panicles to milky ripeness (III decade of June – II of July) *ETc* (FAO) is less than the actual evaporation at average on 10 $m^3 \cdot ha^{-1}$. At time of corn's emergence seedling *Kc* (FAO) was 0.65, that in conditions of 2013 was at 4.7 times higher than actual *Kc*.

Within a May and I–II decades of June *Kc* (FAO) correspondently was in 3/1 and 1.2 times higher than actual value of *Kc*. From venting of panicles to milky ripeness (crucial period as for water consumption) *Kc* (FAO) was on 10% lower than the actual *Kc*. During maturation (from milk to full ripeness) *Kc* (FAO) once again exceeds the actual value at 1.5 times and at the first week of September – in 11 times.

During corn's growing season (May–September) in 2013 precipitations were equal to 138 mm (middle dry). By the appointment of irrigations by instrumental method were conducted 30 vegetation watering's with an irrigation rate 450 mm, total water consumption was equal to 594.9 mm. Lower *ETc* (actual) in 2013 (in comparison with 2014–2015) was associated with low temperature mode and rainy weather in July, when *ETo* = 5.79 $mm \cdot day^{-1}$ (in the 2014–2015 – 7.37–7.35 $mm \cdot day^{-1}$).

Appointment of irrigations by the method of Penman–Monteith required holding of 5 additional vegetation watering's, which, increased irrigation rate and total water consumption at 75.0 and 71.2 mm correspondently. The productivity of dry grains (14% humidity) by the different methods of irrigation appointment was within 16.8–17.1 $t \cdot ha^{-1}$ (by $LSD_{0.5}$ = 0.7 $t \cdot ha^{-1}$).

By the method of Penman–Monteith in 2014 from germination to the I[st] decade of June and from I[st] decade of August to harvesting the total average daily evaporation exceeded actual accordingly on 2 and 3 mm (Fig. 2). At the same time from the second decade of June to the third decade of July, on the contrary – the average daily evaporation reduced on 2 mm. *Kc* (FAO) at the initial and final phases of the culture's development exceeded actual respectively at the 65 and 85%, and in the middle of the season, on the contrary – was lower on 20%. Over the vegetation period of 2014 dropped out 145.6 mm of precipitations (middle dry year). By the appointment of irrigation by instrumental method were conducted 38 vegetation irrigations with an irrigation rate 570 mm, total water consumption was equal to 736.9 mm. Appointment of watering's by the method of Penman–Monteith required 4 additional vegetation watering's, which, respectively, has increased the irrigation rate and total water consumption on 60.0 and 54.4 mm. Grain's yield by the different methods of irrigation's terms appointment was within 17.1–17.5 t·ha^{-1} ($LSD_{0.5}$ = 0.6 t·ha^{-1}).

According to Penman–Monteith's method at 2015 from germination till I decade of June and from the II decade of August to harvesting the total average daily evaporation had exceeded the actual on 2 mm. While, as from the II decade of June till I decade of July, on the contrary – the average daily evaporation had reduced on 1 mm. *Kc* (FAO) at the initial and final phases of the culture's development exceeded the actual on 75 and 80% accordingly, and in the middle of the season, on the contrary – was lower on 10% (Fig. 3).

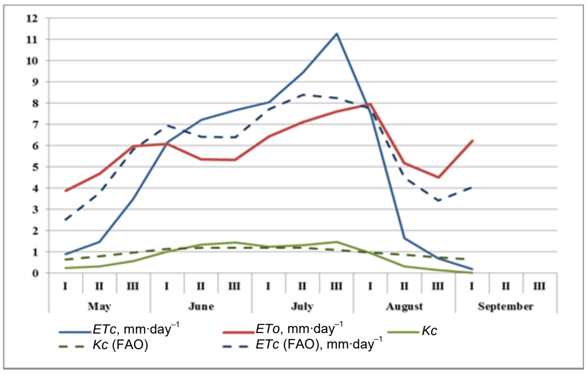

Fig. 2. Daily evapotranspiration and *Kc* of corn – 2014 year; source: own study

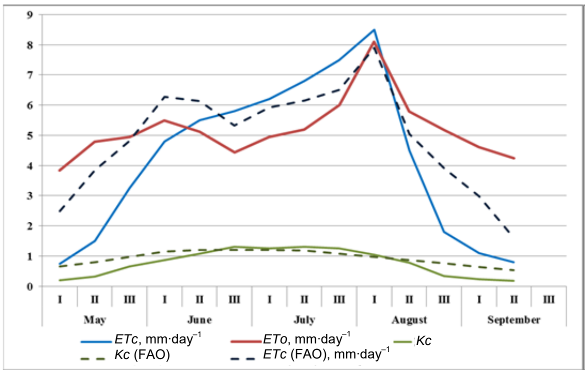

Fig. 3. Daily evapotranspiration and *Kc* of corn – 2015 year; source: own study

In 2015 dropped out 335.2 mm of precipitations (medium humid), which led to increasing of corn's vegetation period on a one decade, compared to the 2013–2014 years. According to appointment of irrigations by the instrumental method were conducted 25 waterings with an irrigation rate of 375.0 mm, total water consumption was equal to 784.1 mm. Appointment of waterings by the method of Penman–Monteith required 7 additional waterings, which, respectively, increased the irrigation rate and total water consumption on 105.0 and 103.5 mm. The yield of dry grains (14%) by the different methods irrigation's terms appointment was within 16.8–17.0 t·ha^{-1} (by $LSD_{0.5}$ = 0.8 t·ha^{-1}).

Thus, for a three years of investigations *Kc*-actual although it was slightly different, but its relationship to the *Kc* (FAO) is clearly correlated in time, that gives us possibility for further calculations of the average daily evaporation by the method of Penman–Monteith, adopt the average value of *Kc*-accepted (*Kc*(actual.)) (Fig. 4). Can state that the value of *Kc*(ac.) for the culture of corn in the conditions of steppe differs from typical *Kc* (FAO). Thus, at the initial stage of development of corn *Kc* (FAO) was higher than *Kc*-ac. from 225 to 20%, what, as calculations show, is a consequence of excessive irrigation during this period approximately 100 mm. Within the season (II decade of June – III decade of July), when observed the critical period as for corn's water consumption, *Kc* (FAO) on the contrary – at 10–15% lower than the *Kc*(ac.) which, in turn, already causes moisture deficit within 40–50 mm. From the beginning of the final phase up to harvesting of grain, *Kc* (FAO) again exceeds *Kc*(ac.) at 20–215%, causing over watering at 50–60 mm.

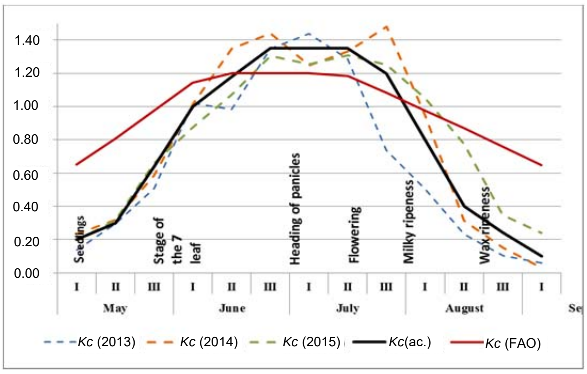

Fig. 4. Dynamics of changes during the growing season of corn and the ratio of *Kc* (FAO) and *Kc*(ac.); source: own study

For determination of *ETc* of corn for grain should have *ETo* calculated by the method of Penman–Monteith (in the program "*ETo* Calculator" or other) for a certain period of time (day or decade) multiplied on the corresponding average decade value of the crops coefficient (Tab. 1).

Table 1. Average decade values of corn's coefficient *Kc*

May			June			July			August			September
I	II	III	I	II	III	I	II	III	I	II	III	I
0.20	0.30	0.64	1.00	1.18	1.35	1.35	1.35	1.20	0.80	0.40	0.24	0.10

Source: own study.

Using software CropWat [FARG *et al.* 2012; KOKOVIHIN 2010], iMetos (application "Irrimet") is convenient to use the data of Table 2.

Table 2. Coefficient *Kc* for corn by conventional phases of development

Conventional phase of plants development	Data	*Kc*
Initial	05 of May	0.20
Early middle	25 of June	1.35
Termination of the middle	25 of July	1.35
Almost final phase	05 of September	0.10

Source: own study.

CONCLUSIONS

1. By results of researches established that the value of the actual cultures coefficient *Kc* for grain corn in the conditions of steppe of Ukraine differs from the typical *Kc* (FAO).

2. At the initial and final stages of development of corn *Kc* (FAO) is higher than the actual value on 20 to 225%, and in the middle of the season, on the contrary – is lower on 10–15%. This leads to an excessive irrigation at the beginning and end of the growing season of corn and to the moisture's content deficit at the critical period of plants development.

3. Considering the clear correlation of *Kc* (FAO) and *Kc*(ac.) for determination of the actual evapotranspiration (*ETc*) of grain corn plants in the conditions of a drip irrigation in the steppe of Ukraine recommended using of the corrected values of *Kc* (Tab. 1, 2).

REFERENCES

ALLEN R.G. 2010. Penman-Monteith evapotranspiration calculations: Reference *ET* and crop coefficients [online]. Colorado Evapotranspiration Workshop March 12, 2010 pp. 124. [Access 06.06.2016]. Available at: http://ccc.atmos.colostate.edu/ET_Workshop/pdf/2_Allen.pd.

ALLEN R.G., PEREIRA L.S., RAES D., SMITH M. 1998. Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper. No. 56. Rome. FAO pp. 300.

ALPAT'EV A.M. 1954. Vlagooboroty v prirode i ikh preobrazovaniya [The hydrological cycles in nature and their transformation]. Leningrad. Gidrometeoizdat pp. 322.

ALPAT'EV S.M. 1965. O polivnykh rezhimakh sel'skokhozyajstvennykh kul'tur. V: Oroshaemoe zemledelie v evropejskoj chasti SSSR [About the irrigation modes of agricultural crops. In: Irrigated agriculture in the European part of the USSR] Moskva. UROZHAY p. 185–190.

BLAINE H. 2008. Crop coefficients [online]. Davis. University of California pp. 52. [Access 06.06.2016]. Available at: http://ucanr.edu/sites/irrigation_and_soils_/files/93370.pdf

BLANEY H.F., CRIDDLE W.D. 1950. Determining water requirements in irrigated areas from climatologically and irrigation data. Washington. US Soil Cons. Serv. SCS-TR-96 pp. 48.

FARG E., ARAFAT S.M., ABD EL-WAHED M.S., EL-GINDY A.M. 2012. Estimation of evapotranspiration *ETc* and crop coefficient *Kc* of wheat, in south Nile Delta of Egypt using integrated FAO-56 approach and remote sensing data. The Egyptian Journal of Remote Sensing and Space Sciences. No. 15 p. 83–89.

IVANOV N.N. 1954. Ob opredelinii velichin isparyaemosti [On the determination of the evaporability value's]. Izvestiya VGO. No 2. T. 6 p. 189–196.

KOKOVIKHIN S.V. 2010. Perspektivi vikoristannya metodu Penmana-Montejta dlya vstanovlennya evapotranspiracii v umovax zroshennya Pivdnya Ukraini [Prospects of using of the Penman-Monteith method for establishing of evapotranspiration in the conditions of irrigation on the South of Ukraine]. Zroshuvane zemlerobstvo. Vip. 54 p. 280–286.

KOKOVIKHIN S.V. 2011. Prognozuvannya vodopotrebi sil's'kogospodars'kikh kul'tur ta formuvannya grafikiv poliviv z vikoristannyam programi «CROPWAT» [Prediction of water needs of agricultural crops and formation of irrigation schedules using the program «CROPWAT»]. Zroshuvane zemlerobstvo. Vip. 55 p. 298–303.

OSTAPCHIK V.P. 1989. Informacionno-sovetuyushchaya sistema upravleniya orosheniem [Information and advising system of irrigation's management]. Kiev. Urozhaj pp. 248.

PENMAN H.L. 1956. Evaporation. An introductory survey. Netherlands Journal of Agricultural Science. Vol. 4 p. 9–29.

SHTOYKO D.A., PYSARENKO V.A., BYCHKO O.S., YELAZHENKO L.I., 1977. Rozrakhunkovi metodi viznachennya sumarnogo viparovuvannya i strokiv polivu sil's'kogospodars'kikh kul'tur [Calculated methods for determining of total evaporation and terms of crops's irrigation]. Zroshuvane zemlerobstvo. Vol. 22. p. 3–11.

SUMNER D. M., JACOBS J.M. 2005. Utility of Penman–Monteith, Priestley–Taylor, reference evapotranspiration, and pan evaporation methods to estimate pasture evapotranspiration. Journal of Hydrology. Vol. 308. Iss. 1–4 p. 81–104.

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Dostosowanie metody Penmana-Monteitha do obliczania ewapotranspiracji kukurydzy uprawianej na ziarno w warunkach nawadniania na stepach Ukrainy

Celem badań prezentowanych w pracy była analiza specyfiki ewapotranspiracji i adaptacja obliczeniowej metody Penmana-Monteitha do określania tego parametru w warunkach stepu Ukrainy. Prowadzono krótkotrwałe doświadczenia polowe, wykorzystując ogólnie stosowane analizy statystyczne: dyspersji, korelacji, regresji i wariancji. W pracy określono wartość ewapotranspiracji obliczeniowej *ETo* i rzeczywistej *ETc*, wykorzystując do tego nowoczesne narzędzia (internetowa stacja meteo iMetos® i stacja pomiaru wilgotności gruntu iMetos® SM/ECHO/TNS/ECOD2). Na podstawie eksperymentu polowego skorygowano współczynnik roślinny *Kc* w zależności od fazy rozwoju roślin kukurydzy. Ustalono, że wartości rzeczywistego współczynnika roślinnego *Kc* kukurydzy uprawianej na ziarno w warunkach nawadniania kroplowego na stepach Ukrainy różnią się od *Kc* podawanego przez FAO. W początkowych i końcowych fazach rozwoju kukurydzy wartość *Kc* (FAO) zawyża wartość ewapotranspiracji rzeczywistej od 20 do 225%, a w połowie sezonu – zaniża o 10–15%. Ze względu na wyraźną korelację *Kc* (FAO) i *Kc*(ac.) do wyznaczenia ewapotranspiracji rzeczywistej (*ETc*) kukurydzy autorzy rekomendują stosowanie skorygowanej wartości *Kc*.

Słowa kluczowe: *dawki nawodnieniowe, ewapotranspiracja, kukurydza na ziarno, nawadnianie kroplowe, współczynnik roślinny*