Metóda diagnostiky vodného režimu pôdy pre návrh závlah

Soil water regime diagnosis for irrigation purposes

Viliam Novák, Hana Hlaváčiková

Ústav hydrológie SAV, Račianska 75, 831 02 Bratislava 3, Slovensko

Abstrakt

Príspevok obsahuje návrh metódy diagnostiky vodného režimu pôdy (VRP). Základnou myšlienkou metódy je overený poznatok o priamej úmernosti medzi produkciou biomasy (úrodou) a sezónnym úhrnom potenciálnej transpirácie porastov. Pretože meteorologické charakteristiky, ktoré určujú potenciálnu evapotranspiráciu špecifického porastu a ovplyvňujú tiež transpiráciu majú stochastický charakter, je potrebné získať pre každú plodinu sezónne úhrny potenciálnej a aktuálnej transpirácie za vegetačné obdobia minimálne počas 20 rokov. Tieto informácie boli získané retrospektívnym matematickým modelovaním. Rozdiely medzi sezónnymi úhrnmi potenciálnej a aktuálnej transpirácie príslušných plodín, umožňujú posúdiť možné zvýšenie úrody optimalizáciou režimu vody v pôde a teda posúdiť vhodnosť zriadenia a prevádzky závlah v príslušnej lokalite a pre konkrétne plodiny.

Kľúčové slová: Vodný režim pôdy, transpirácia, produkcia biomasy, matematické modelovanie, závlahy

Abstract

A method to estimate biomass production as a function of the seasonal transpiration totals is presented. This approach is based on frequently published linear empirical relationships between seasonal transpiration rates of particular canopy and biomass production (yield). Novelty of this approach is the use of an empirical relationship between seasonal transpiration and yield, which leads to relatively simple method of yield evaluation with acceptable accuracy. Transpiration rates were calculated retrospectively with the HYDRUS-ET software package. The cumulative frequency distribution of seasonal transpiration was chosen as the basic characteristic of the soil water regime. This approach allows one to estimate cumulative frequency curves of actual and potential yields. The difference between these two curves allows to evaluate yield increase by soil water regimen optimisation and to perform cost-benefit analysis

Key words: soil water regime, transpiration, biomass production, mathematical modelling.

Introduction

Soil water is only one of many preconditions to influence biomass production. It is known, that irrigation as one of the methods of soil water regime optimization is contributing to the biomass production significantly. About 20 percent of irrigated soils of the world are producing more than 40 percent of plant production. Those soils are located mainly in arid or semiarid zones. A key step in design and implementation of irrigation or drainage system is to diagnose the existing (natural) soil water regime and possible influence of its optimization on biomass production increase.

Is not easy to relate directly the soil water content to biomass production, therefore it is necessary to look for another ways of expression the relation between biomass production and soil water influence on it. Plant production can be evaluated by so called "crop growth models", calculating assimilation rate as a complex function of environmental parameters, which is difficult to estimate; those models are usually canopy oriented: WOFOST [1], MACROS [2], DAISY [3]. The soil water influence on plant production is expressed roughly there and they are not suitable to evaluate soil water regime influence on yields. Because direct and unambiguous relationships soil water content (soil water potential) – growth rate (biomass production) were not found, researchers tried to find another ways of expressing quantitatively the role of soil water in biomass production. To evaluate the influence of soil water on plant production using transpiration as an integral part of production process was used.

Results of numerous measurement in vitro conditions demonstrated the low variability ratio of assimilation and transpiration intensity under given conditions [4]. From it follows linear relation between photosynthesis and biomass production rate. In reality, results of field measurements have shown linear relationship between plant production and transpiration total during vegetation period of particular plant.

A quantitative assesment of the influence of soil water in the soil root zone on biomass production can be made using well-known and widely accepted empirical relationships between biomass production (yield) and transpiration total during the growing season of a given crop [5], [6], [7], [8]. These relationships, are valid for a particular plant (canopy) and site subject to standard tillage and nutrition conditions. The only transient characteristic is the transpiration rate as influenced by local meteorological conditions and soil water. The relationship between biomass production (yield) and the seasonal transpiration rate can be expressed by the linear equation.

The aim of this work was to evaluate the possible increase three important crops yield (maize, winter wheat, spring barley) and their variability by optimizing soil water regime in South Slovakia environment.

Method

Thirty one seasonal totals of potential and actual transpiration were calculated, as a sum of daily values, assuming stable properties of soil and plants. Real daily meteorological characteristics were used measured at meteorological stations near experimental site.

Simulation model HYDRUS – ET - version 1- [9] was used. It is modification of well – known one dimensional model HYDRUS (version 6.1) and HYDRUS-1D with interactive graphical interface. This programme is based on governing Richards equation describing transport of water in variably saturated porous media and convective – dispersion equation for transport of solute and heat as well. Richards equation involves the term to calculate, water extraction by roots. Subroutine describing rain and irrigation water interception as well as evapotranspiration and its components calculation is a part of the model HYDRUS – ET. Modified version of the Penman – Monteith and Budagovskij method for calculation of evapotranspiration was incorporated in the model used [10].

Soil

Table 1. Soil characteristics used in simulation procedure. Sandy loam (Haplic Chernozem) at Most pri Bratislave, South Slovakia (Experimental field of Hydromeliorácie, s.e., Bratislava).

θ_v	θ_{la}	θ_{fc}	θ_s	K	α	n
0.18	0.28	0.35	0.4	5.6×10^{-7}	0.0577	1.299

θ_v – volumetric soil water content corresponding to the wilting point [$cm^3\,cm^{-3}$], θ_{fc} – soil water content corresponding to the „field capacity“[$cm^3\,cm^{-3}$], θ_s – water content of the saturated soil [$cm^3\,cm^{-3}$], θ_{la} - volumetric soil water content corresponding to the “limited availability” of soil water by plants [$cm^3\,cm^{-3}$], K_s – hydraulic conductivity of the soil saturated with water (saturated hydraulic conductivity) [$m\,s^{-1}$], α [cm^{-1}] and n [–] – van Genuchten’s equation coefficients [11].

Canopies

Three types of plants (canopies) were chosen for analysis: maize, winter wheat and spring barley. The only source of water were precipitation, no irrigation was used. Duration of growth seasons of particular plants (Tab.2) was different; different were seasonal transpiration totals too. Actual growth period of winter wheat is longer than it is noted in the table, which does not include autumn and winter period of growth. It is assumed transpiration during winter period and plant production is not significant, the most influential is „hot“ period.

Table 2. Seasons of crops duration.

Plant	Growth period	Number of days
Maize	May 5 – September 16	134
Winter wheat	April 1 – June 25	86
Spring barley	April 7 – June 25	79

Results and discussion

Transpiration totals E_t of maize, winter wheat and spring barley were calculated retrospectively for 31 seasons (Fig.1). They are presented as empirical curves of exceedance for years 1971–2000 and 2003, the last was extraordinary hot. Length of vegetation periods of winter wheat and spring barley are close, but transpiration totals are quite different (Tab.3). Reasons are natural; meteorological conditions during their vegetation periods are different. Precipitation totals and air temperature are the most important factors. Winter wheat stage of ontogenesis during early part of spring vegetation period allowed quite different –higher - transpiration and growth rate.

The average characteristics of seasonal transpiration of the three canopies under study in seasons of years 1971–2000 and 2003 are in Tab.3. Minimum transpiration totals were calculated for all the three canopies in year 1988, maximum transpiration totals were calculated for cereals in 1996, but yield of maize was the lowest (as well as transpiration total) in the season 1985. The reason of it was high precipitation total during the second part of the year 1996. It confirms quantitatively well known empirical information: particular vegetation period is of different suitability for different canopies.

Tab. 3: The average transpiration characteristics of three canopies during their vegetation period. Average values were calculated for 31 seasons. (E_t is seasonal average transpiration total, E_{tp} seasonal average potential transpiration total, $E_{t,d}$ daily average transpiration total, $E_{t,max}$, $E_{t,min}$ are daily averages transpiration total in season with maximum and minimum seasonal transpiration totals).

Canopy	**E_t mm/year**	**E_{tp} mm/year**	**E_t /E_{tp}**	**$E_{t,d}$ mm/year**	**$E_{t,max}$ mm/day**	**$E_{t,min}$ mm/day**
Maize	144	161	0.88	1.07	1.27	0.64
Winter wheat	113	148	0.78	1.13	1.68	0.85
Spring barley	68.9	82	0.83	0.87	1.1	0.55

Empirical curve of exceedance of dry grain yields *Y* of maize canopy (1), winter wheat (2) and spring barley (3) during the seasons in years 1971–2000 and 2003, Most pri Bratislave site is shown in Fig.2. Curves of exceedance in Fig. 2. were calculated using relationship presented in Fig. 3. This empirical relationship is relating weight of dry maize grains yield *Y* and seasonal transpiration totals of maize, during its vegetation period E_t. This empirical relationship represents 5 seasons within the time interval 1971–2000 and 2003. Such type of relationship was estimated using field data even for other two canopies (not shown here).

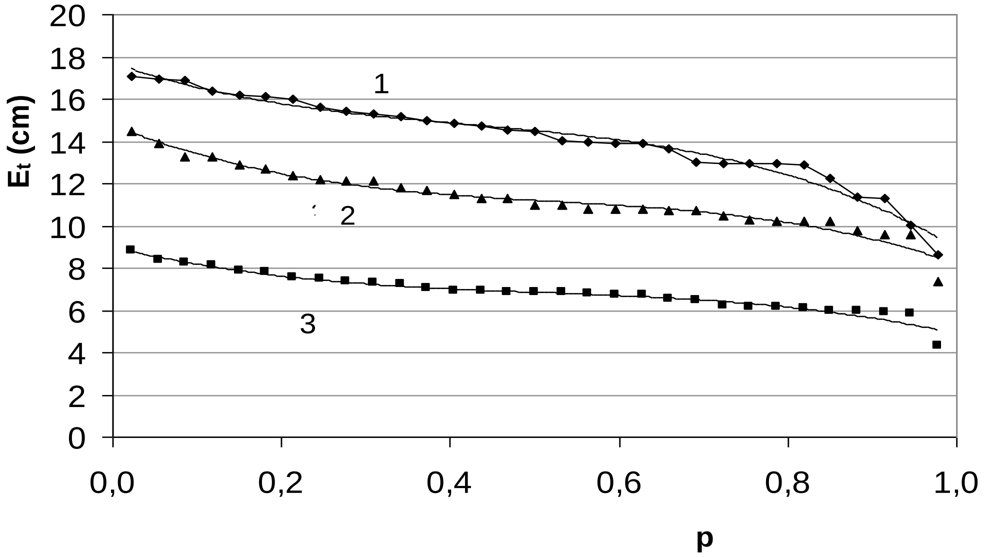

Fig. 1. Exceedance curve of seasonal transpiration totals (E_t) of maize (1), winter wheat (2) and spring barley (3) canopy in years 1971–2000 and 2003, Most pri Bratislave site, South Slovakia.

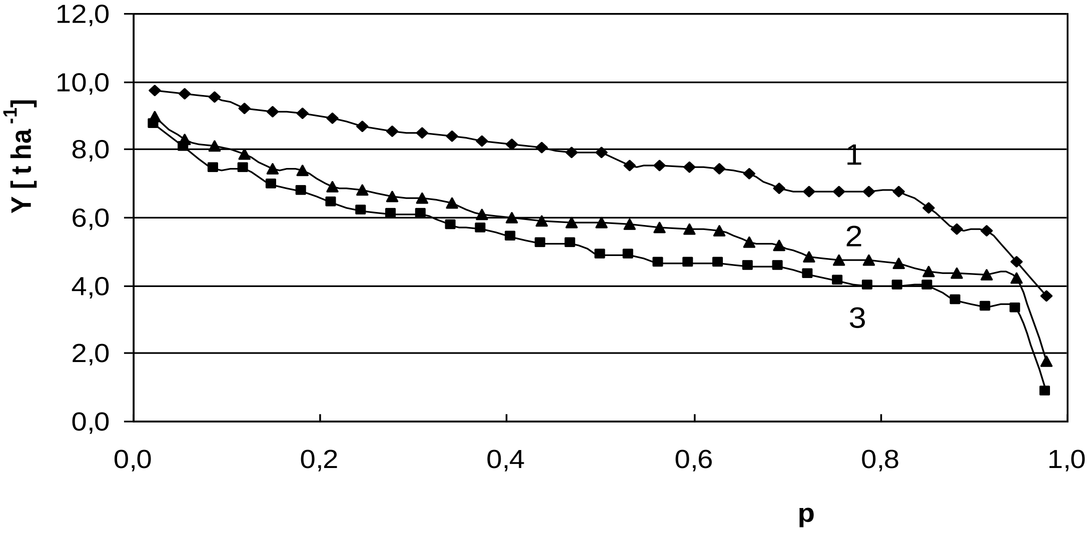

Fig.2. Exceedance curve of dry grain yields (*Y*), of maize (1), winter wheat (2) and spring barley (3) during the seasons in years 1971–2000 and 2003, Most pri Bratislave site, Slovakia.

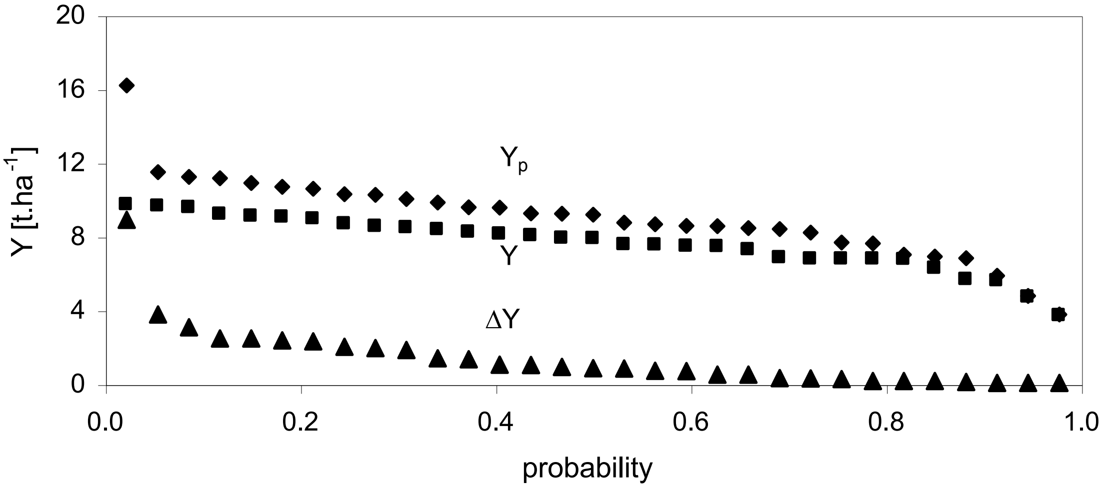

Fig.3. Dry grain yield (*Y*) and seasonal transpiration totals of maize canopy (E_t). Empirical relationship represents 5 seasons within the time interval 1971–2000 and 2003. Most pri Bratislave site, South Slovakia.

The optimal soil water regime for plant growth allows potential transpiration, soil water content is not limiting transpiration. Exceedance curves of the corn grain yield (*Y*) and the calculated potential yield (Y_p), and the difference (ΔY), for the 1971–2000 and 2003 growing seasons at Most pri Bratislave calculated from corresponding exceedance curve of potential transpiration totals E_{tp}, (Fig.4.) demonstrates relatively low capacity of soil water regime optimization for the corn grain yield increase. The average corn grain yield (*Y*) was estimated to be 7.64 t ha^{-1}, and the average potential yield (Y_p) 9.03 t ha^{-1}. This means that the difference was ΔY =1.4 t ha^{-1}, which represents 18% of the average yield. The question now arises whether or not it would be reasonable (cost-effective) to design and operate an irrigation or drainage system to optimize the soil water regime to increase dry grain yield by 1.4 t ha^{-1}.

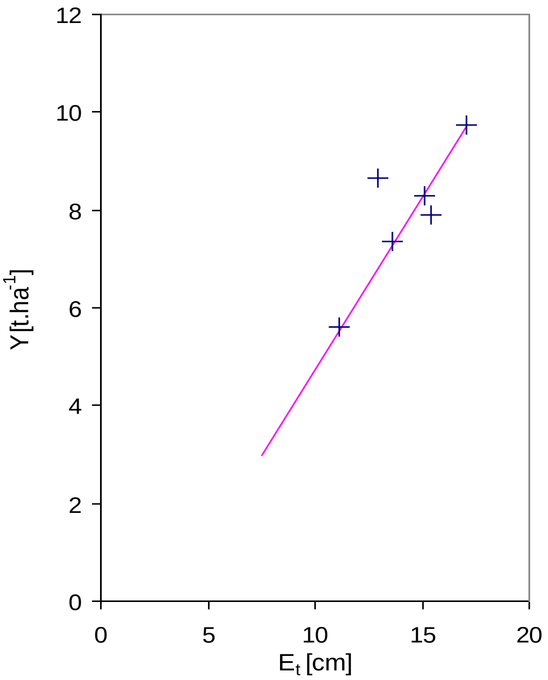

Fig. 4. Exceedance curves of the maize grain yield (*Y*), the calculated potential yield (Y_p), and their difference (ΔY), for the 1971–2000 and 2003 growing seasons, Most pri Bratislave site, Slovakia.

The described relationships are valid when extreme drought, heat and nutrition stresses are avoided and basic plant physiological functions are preserved [12].

Conclusions

1. Mathematical model HYDRUS – ET with incorporated method of evapotranspiration and its components calculation using Penman– Monteith method modified by Budagovskij and Novák, was applied to calculate seasonal transpiration totals of three canopies (maize, spring barley and winter wheat) for 31 seasons in Southern Slovakia site.

2. Empirical curves of exceedance of dry grain yields of the three canopies (maize, spring barley and winter wheat) were estimated, using empirical relationship between grain yield (*Y*) and seasonal transpiration totals (E_t) - Fig.3. Relatively homogeneous field of grain yields (as an exception is the season 2003) demonstrates favourable conditions of South Slovakia for growth of cereals without irrigation.

3. Exceedance curves of the maize grain yield (*Y*), calculated potential yield (Y_p), and their difference (ΔY), for the 1971–2000 and 2003 growing seasons at Most pri Bratislave calculated from corresponding exceedance curve of potential transpiration totals E_{tp}, (Fig.4) demonstrates relatively low capacity of soil water regime optimization for the maize grain yield increase. The average maize grain yield (Y) was estimated to be 7.64 t ha^{-1}, and the average potential yield (Y_p) 9.03 t ha^{-1}. This means that the difference was $\Delta Y = 1.4$ t ha^{-1}, which represents 18% of the average yield. The question now arises whether or not it would be cost-effective to design and operate an irrigation or drainage system that will optimize the soil water regime to increase the dry grain yield in average by the 1.4 t ha^{-1}.

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Kontakt:

Ing. Viliam Novák, DrSc.
Ústav hydrológie SAV
Račianska 75
831 02 Bratislava 3
Slovenská republika
Tel.: ++421 2 49 268 279
E-mail: novak@uh.savba.sk