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CROP WATER SUPPLY AND ITS RELATION TO YIELD OF SPRING WHEAT IN THE SOUTH OF RUSSIAN PLAIN

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The proposed method to estimate water supply of spring wheat crop is based on the ratio of the water amount extracted by plants under actual conditions of growth (transpiration) to cover needs for maximum (potential) yield (potential transpiration). Estimates of spatial, inter- and intra-annual water supply variability of the spring wheat crop in basic agricultural zones are given. Dependence of the spring wheat yield on water supply is presented.

KEY WORDS: Soil Water, Crop Yield, Transpiration, Southern Russian Plains.

Nadežda Šumová: ZÁSOBOVANIE PORASTU JARNEJ PŠENICE VODOU VO VZŤAHU K ÚRODÁM V PODMIENKACH JUHORUSKEJ NÍŽINY. J. Hydrol. Hydromech., *57*, 2009, 1; 20 lit., 6 obr., 1 tab.

Navrhnutá metóda určenia zásobovania porastu jarnej pšenice vodou je založená na určení pomeru množstva vody odobratého koreňmi rastlín (transpirácia) k potenciálnej transpirácii, ktorá je podmienkou maximálnej (potenciálnej) úrody. Práca obsahuje údaje o priestorovej, ročnej a medziročnej variabilite transpirácie jarnej pšenice v základných poľnohospodárskych oblastiach, ako aj závislosť úrod jarnej pšenice na zásobovaní porastu vodou (transpirácii).

KĽÚČOVÉ SLOVÁ: pôdna voda, úroda, transpirácia, Juhoruské nížiny.

Introduction

The combination of high level of radiation income with soil high content of organic matter was a factor of the Southern Russian Plains transformation to agricultural landscape. However, agricultural crops in these regions are subjected to regular droughts which makes it necessary to seek for ways to achieve more complete and economically efficient use of natural soil water storage. Noted rise of biomass production prices at present time is accenting the problem of rational utilization of soil water resources for the purpose of stable harvest production. Therefore, the estimation of the water supply of agricultural crops under natural conditions and its optimisation seems to be actual.

A large number of different methods of estimating water supply of agricultural crops are known. Estimation of water supply from precipitation reduces to comparing the precipitation amount with the precipitation normal for a given region. In estimation water supply from soil water storage, the water content of the soil is compared with the field capacity. It is commonly assumed that the optimal value of available soil water storage is somewhat between field capacity of soil and soil water content of limited availability (*Novák*, *Havrila*, 2006; *Gusev*, *Novák*, 2007).

In most cases estimating water supply by empirical methods is based on numerous meteorological characteristics. A biological method of the water demand of plants calculating, proposed by Alpatjev, is most commonly used (*Alpatjev*, 1954). The basic elements of this method are air humidity deficit and the biological evaporation coefficient that takes into account the ontogenesis stage of plant, variation in biomass accumulation, and qualitative changes in the plants, particularly in phytoclimate. A set of time-varying biological coefficients over the growing season for the same type of phytocenosis is called a biological curve. According to Alpatjev, the need of water supply of plant is calculated as a difference between the estimated water demand (potential transpiration) and actual evapotranspiration.

The estimation of plants water supply need is usually based on the use of coefficients or indices representing a ratio of the water resources (precipitation, soil moisture, etc.) to the water demand, calculated through potential evapotranspiration, or to its substitute. Among different indices Selyaninov`s hydrothermal coefficient (*Selyaninov*, 1958) and Shashko`s atmospheric index (*Shashko*, 1967) are most commonly used.

Methods of estimating water supply (or water needed to meet potential transpiration) have been developing extensively. *Budyko* (1971) identifies the water demand with potential evapotranspiration which, in turn, is proportional to air humidity deficit calculated from the temperature of an evaporating surface. The needed water supply of plants is defined as a difference between potential evapotranspiration and actual evapotranspiration. *Kharchenko* (1968) proposed a method for calculating water supply of plants based on water and heat balance equations with water supply being estimated by the ratio of the water balance of the root layer to the optimal water consumption. In Konstantinov`s method (*Konstantinov* et al., 1971) water supply of plants is defined as the difference between potential evapotranspiration and actual evapotranspiration. Actual evapotranspiration is calculated from the theory of turbulent exchange by using some empirical relationships with actual evapotranspiration and potential evapotranspiration is being calculated from air temperature and air humidity.

Experts from FAO (Food and Agricultural Organization of the United Nations) suggest the method of potential and actual evapotranspiration calculation from meteorological data and "crop" coefficient (*Allen* et al., 1998). Potential evapotranspiration is calculated from the combined Penman-Monteith method, which was devised for a universal hypothetical vegetative cover representing a dense and well-wathered green grass cover 0.12 m high. This method of estimating water consumption is essentially close to Alpatjev biological method of calculating water demand (*Alpatjev*, 1954), with the only difference that potential evapotranspiration is determined by Alpatjev using vapor pressure deficit of air.

The aim of this paper is to present methodology of crop canopy (spring wheat) water demand calculation, as well as its potential and actual water supply during different stages of plant development at 45 sites of the Southern Russian Planes, as well as to evaluate expected spring wheat yields as related to its relative transpiration.

Method

To estimate water supply of agricultural crops, a parameter is used here that can be called relative transpiration and represent a ratio of actual to potential transpiration (*Budagovskiy*, *Shumova*, 1976; *Shumova*, 2000). This approach takes into account natural regularities in the formation of soil hydrological conditions and their variability from year to year. Water supply parameter is

$$rET = ET/ETO, \tag{1}$$

where rET – water supply parameter, ET – actual transpiration, ETO – potential transpiration (the transpiration not limited by the soil water content).

Water supply parameter ET/ETO shows the extent to which soil water storage provides the unlimited supply and development of a vegetative cover. If ET/ETO is equal to 1, this implies that plants do not suffer from moisture deficit. If this ratio is less than 1, soil water storage constrain transpiration and thus the growth and development of plants, i.e., drought occurs (the less the ratio ET/ETO, the more severe the drought is). The value of ET/ETO depends substantially on the character of the vegetative cover, particularly on the length of the growing season.

The ratio ET/ETO is a relative indicator of water supply of the vegetative cover. The absolute values of soil water deficit can be derived through the transpiration deficit dET defined as a difference between potential and actual transpiration

$$dET = ETO - ET. \tag{2}$$

To estimate the water supply parameter ET/ETO and its deficit dET, the model of evapotranspiration is used (*Budagovskiy*, 1964). Various modification of this model are described in the literature by its author. Parameters of the model estimation are described by *Shumova* (2003), where the detailed description of the method could be found. The actual and potential transpiration is determined from the following relationships:

$$ET = \begin{cases} ETO & \text{at} \quad V \ge V_{cr} \\ \dfrac{V}{V_{cr}} ETO & \text{at} \quad V < V_{cr} \end{cases}, \tag{3}$$

$$ETO = b_1 D_{LAI} \Phi_1 d + \\ + b_2 \left[R\left(1 - \Phi_2 e^{-nLAI}\right) - \left(1 - \Phi_2\right) B \right] - \\ - \left(1 - \Phi_2\right) ES, \tag{4}$$

$$ES = ESO\left(\gamma V e^{-H/ESO} + 1 - e^{-H/ESO}\right), \tag{5}$$

$$ESO = b_1 \Phi_s D_s d + b_2 \left(\mathrm{R} e^{-nLAI} - B\right), \tag{6}$$

$$V_{cr} = 60 + 4.2EO, \tag{7}$$

$$EO = b_1 D_{LAI} \Phi_1 d + b_2 \left(R - B\right), \tag{8}$$

$$b_1 = \frac{0.7}{1 + 1.56\varphi}, \quad b_2 = \frac{0.026\varphi}{1 + 1.56\varphi}, \tag{9}$$

$$\varphi = \frac{24513}{\left(235 + T\right)^2} e^{\frac{17.1T}{235+T}}, \tag{10}$$

$$D_s = \frac{0.8u}{u^{1/2} + 0.7}, D_{LAI} = \frac{c_1 \tilde{u}}{c_2 \tilde{u}^{1/2} + 1}, \\ \tilde{u} = u + 0.4, \tag{11}$$

$$\Phi_s = e^{-1.1LAI}, \\ \Phi_1 = \left(1 - e^{-LAI}\right), \\ \Phi_2 = e^{-0.25LAI}, \tag{12}$$

where ET and ETO – actual and potential transpiration respectively [mm day^{-1}], ES and ESO – actual and potential soil evaporation respectively [mm day^{-1}], EO – potential evapotranspiration [mm day^{-1}], V and V_{cr} – available and critical soil water storage respectively [mm], H – precipitation [mm day^{-1}], LAI – leaf area index [cm^2 cm^{-2}], T – air temperature at 2 m [^{o}C], d – air humidity deficit at 2 m [mb], u – wind speed at 2 m [m s^{-1}], R – net radiation [cal cm^{-2} day^{-1}], B – heat flux in the soil [cal cm^{-2} day^{-1}], b_1 and b_2 – function of air temperature, φ – derivative of the saturated water vapor pressure function according to air temperature [mb ^{o}C^{-1}], D_s, D_{LAI} and $\tilde{u}$ – wind speed function, Φ_s, Φ_1 and Φ_2 – functions of the leaf area index, γ – empirical parameter dependent on hydro-physical properties of soil (equals to 0.0025 mm^{-1} for the forest-steppe and steppe zones), n – coefficient dependent on the geographical latitude and season of year (*Budagovskiy*, 1964), $c_1 = 2.4$, $c_2 = 4$ m$^{1/2}$ s$^{-1/2}$ – coefficients determined from field experiments. (Calories are sometimes used, which are units used in tables to calculate transpiration).

The calculation is carried out on the basis of agrometeorological and actinometric station data, on air temperature, air humidity deficit, wind speed, net radiation, precipitation, and initial available soil water storage. To determine the leaf area index, data on the height and density of plants in the main phases of their development are used (*Shumova*, 1994). Data on the annual amplitude of air temperature, the latitude of the station, and wind-vane elevation are also necessary. The calculation is convenient to do for ten-day intervals.

Results

Using the above relationships, mean long-term values of actual and potential transpiration for spring wheat crops for ten day time intervals in the growing season have been obtained for 45 agrometeorological stations in the Southern Russia Plains (Fig. 1). For six stations representing a diverse set of natural conditions of this region ten-day values of actual and potential transpiration have been calculated for individual years. The series covering the seasond of 24 years 1952–1975 (for Kamennaya Step it covers 22 years (1954–1975)). It should be noted that the 30-year series for 1951–1980 gives the most representative estimates of inter-annual variability (*Carter* et al., 1994). This series includes moist, dry, warm, and cold periods. However, as shown by analysis, the use of the series as long as 24 and 22 years did not produce unacceptable errors in the estimates derived.

Fig. 2 shows mean long-term values of water supply of spring wheat crops for the sprouts-full ripeness and for the main phases of plant development. From Fig. 2 it follows that the mean long-term values of ET/ETO for the growing season as a whole do not reach unity over the entire area of forest-steppe and steppe zones, varying between 0.8 and 0.3. This indicates occurrence of drought across the territory under consideration, it differs only in intensity. In the very initial phases of plant development, i.e., sprouts and third leaf, the ratio ET/ETO fails to attain unity only outside a steppe

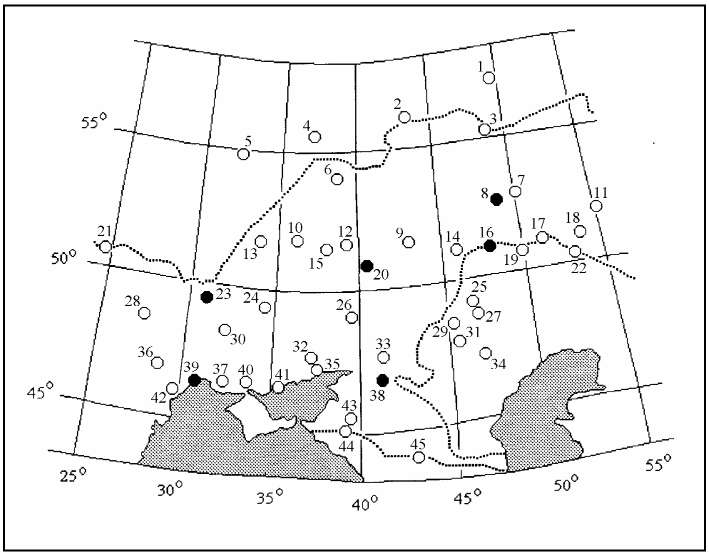

Fig. 1. Location of agrometeorological stations. 1 – Nolinsk, 2 – Roika, 3 – Kazan, 4 – Nemchinovka, 5 – Shokino, 6 – Mikhailov, 7 – Samara, 8 – Bezenchuk, 9 – Rostoshi, 10 – Ushakovo, 11 – Orenburg, 12 – Voronezh, 13 – Glukhov, 14 – Saratov, 15 – Nizhnedevitsk, 16 – Ershov, 17 – Uralsk, 18 – Chingirlau, 19 – Kamenka, 20 – Kamennaya Step, 21 – Vladimir-Volynskii, 22 – Belogorka, 23 – Mironovka, 24 – Poltava, 25 – Dzhanybek, 26 – Belovodsk, 27 – Elton, 28 – Novaya Ushitsa, 29 – Kapustin Yar, 30 – Kirovograd, 31 – Chernyi Yar, 32 – Volnovakha, 33 – Konstantinovskii, 34 – Kharabaly, 35 – Mariupol, 36 – Kishinev, 37 – Kherson, 38 – Gigant, 39 – Odessa, 40 – Askania-Nova, 41 – Kirillovka, 42 – Sarata, 43 – Korenovsk, 44 – Krasnodar, 45 – Zolotushka. Empty circles – stations used average long-term data, full circles – data for particular subsequent years. Here and in the following dotted lines are the boundaries of the forest-steppe and steppe zones.
Obr. 1. Rozmiestnenie agrometeorologických staníc. 1 – Nolinsk, 2 – Rojka, 3 – Kazaň, 4 – Nemčinovka, 5 – Šokino, 6 – Michajlov, 7 – Samara, 8 – Bezenčuk, 9 – Rostoči, 10 – Ušakovo, 11 – Orenburg, 12 – Voronež, 13 – Gluchov, 14 – Saratov, 15 – Nižnedevick, 16 – Jeršov, 17 – Uralsk, 18 – Čingirlav, 19 – Kamenka, 20 – Kamennaja Step, 21 – Vladimir-Volynskij, 22 – Belogorka, 23 – Mironovka, 24 – Poltava, 25 – Džanybek, 26 – Belovodsk, 27 – Elton, 28 – Novaja Ušica, 29 – Kapustin Jar, 30 – Kirovograd, 31 – Černyj Jar, 32 – Volnovacha, 33 – Konstantinovskij, 34 – Charabaly, 35 – Mariupol, 36 – Kišinev, 37 – Cherson, 38 – Gigant, 39 – Odesa, 40 – Askania-Nova, 41 – Kirilovka, 42 – Sarata, 43 – Korenovsk, 44 – Krasnodar, 45 – Zolotuška. Prázdne krúžky – stanice využívajúce priemerné dlhodobé údaje, plné krúžky – údaje pre niektoré po sebe idúce roky. Na tomto a na ďalších obrázkoch sú čiarkovanými čiarami znázornené hranice medzi lesostepnou a stepnou zónou.

zone in the lower reach of the Volga River. But beginning with the tillering phase, the drought crosses the southeastern boundary of the steppe zone and begins to extend farther to the north. By the heading phase the drought covers nearly the entire area except the northwest of the forest-steppe zone and a region near the southern boundary. This space distribution of drought is traced until the phase of milk ripeness, and only its intensity increases. By the full ripeness phase drought covers the entire territory of forest-steppe and steppe zones. It should be noted that there is a rather close relationship between water supply in the whole growing season and water supply in individual phases of plant development (Fig. 3).

To determine the missing water amount that is necessary for the plants to develop optimaly (regarding to water supply), the relationship between the water supply parameter ET/ETO and the transpiration deficit dET can be used (Fig. 4).

The probability curves shown in Fig. 5 give the idea of inter-annual variability of the water supply parameter ET/ETO in the growing season as a whole and at the main phases of spring wheat development for six agrometeorological stations. The probability was determined from

$$P = \frac{m - 0.4}{n + 0.2} 100\%, \qquad (13)$$

where P – probability, m – the number of the term in the series arranged in descending order, n – the number of terms in the series.

Fig. 5 shows that ET/ETO reaches unity for the whole growing season only in 5 out of 24 years even in the most favorable Mironovka, 3 out of 22 years in Kamennaya Step, and 1 out 24 years in Gigant. The ratio ET/ETO never attains unity in Bezenchuk, Ershov, and Odessa. In other words, drought occurs in Bezenchuk, Ershov, and Odessa every year, differing only in intensity.

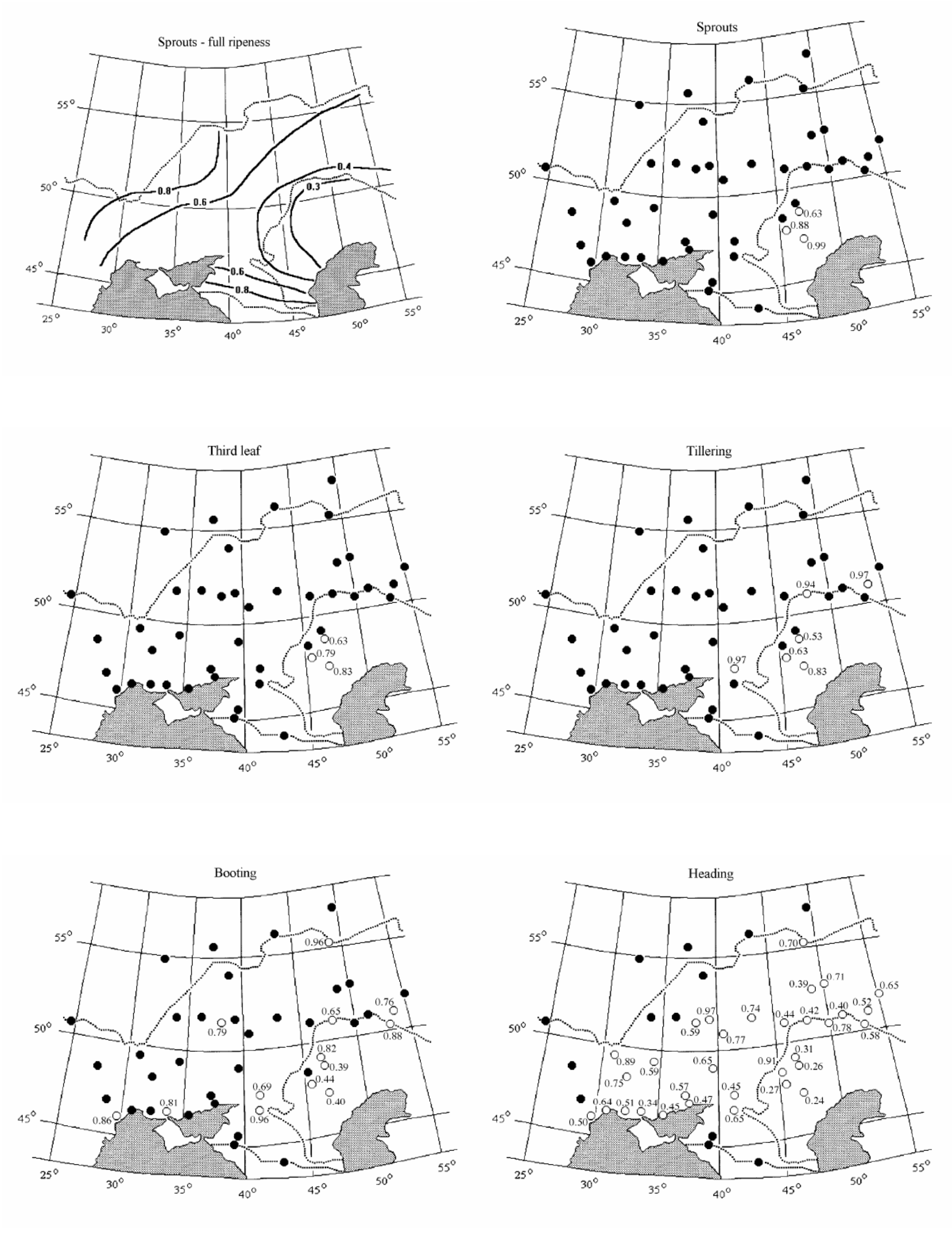
Sprouts - full ripeness
Sprouts
Third leaf
Tillering
Booting
Heading

Fig. 2.

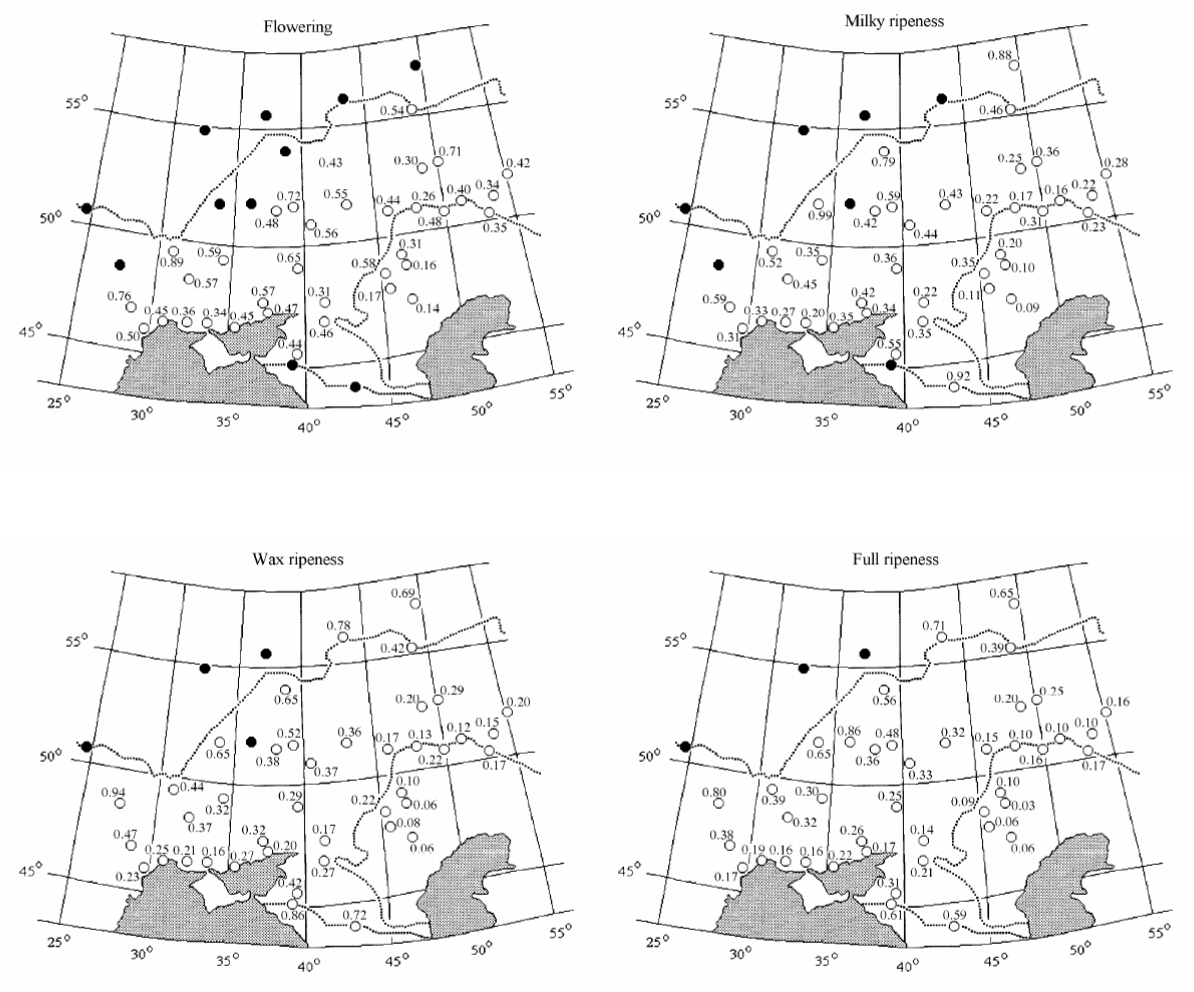

Fig. 2. Mean long-term water supply ET/ETO of spring wheat crops for the whole growing season (sprouts – full ripeness) and for the main development phases. Full circles – $ET/ETO = 1$, empty circles – $ET/ETO < 1$.

Obr. 2. Priemerné mnohoročné hodnoty parametra ET/ETO pre jarnú pšenicu za celé vegetačné obdobie (vzchádzanie – plná zrelosť) a pre hlavné vývojové fázy. Plné krúžky – $ET/ETO = 1$, prázdne krúžky – $ET/ETO < 1$.

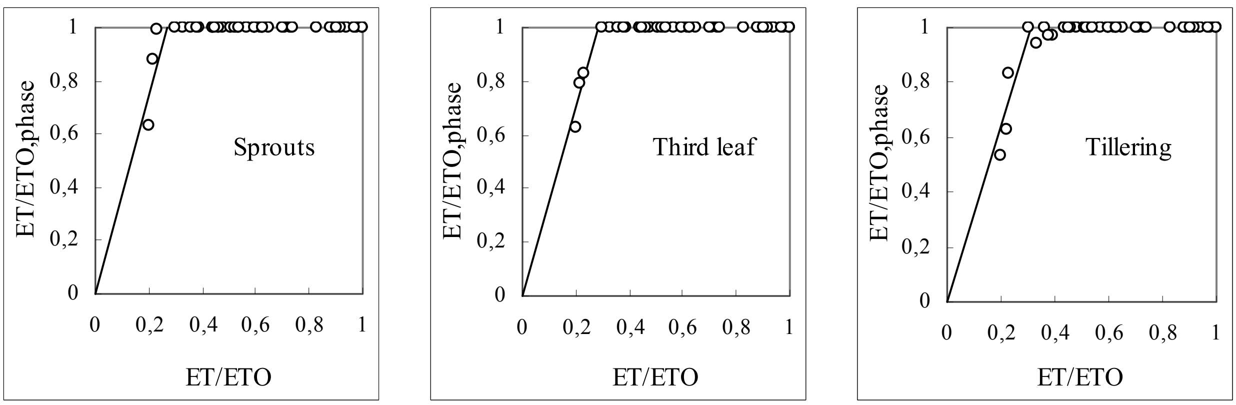

Fig. 3.

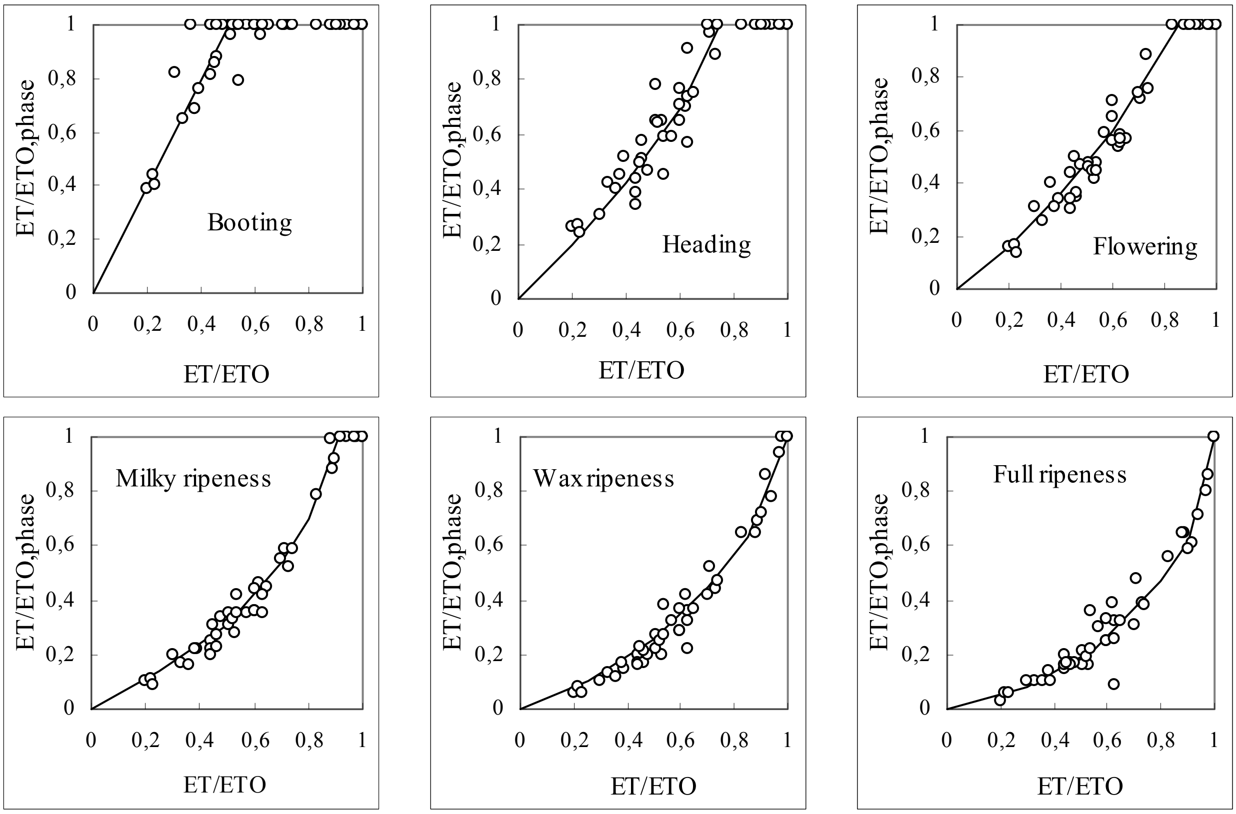

Fig. 3. Dependence of water supply of spring wheat in the main development phases ET/ETO_{phase} on water supply for the whole growing season ET/ETO.

Obr. 3. Pomerná hodnota parametra zásobenia jarnej pšenice vodou (relatívna transpirácia) počas hlavných fáz ontogenézy ET/ETO_{phase} v závislosti na tejto hodnote pre celé vegetačné obdobie ET/ETO.

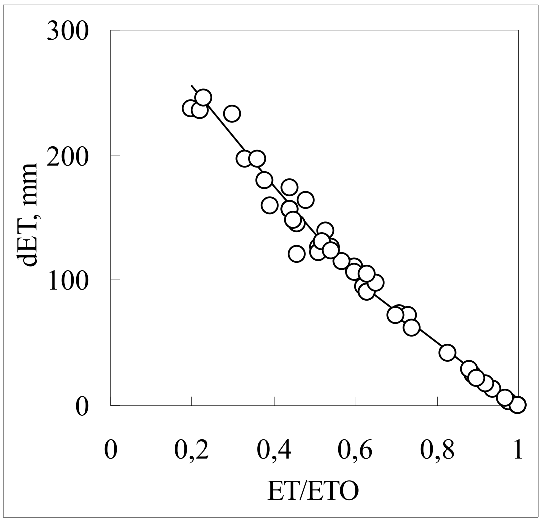

Fig. 4. Water supply paremeter ET/ETO and transpiration deficit dET.

Obr. 4. Pomerná hodnota parametra zásobenia jarnej pšenice vodou ET/ETO a transpiračný deficit dET.

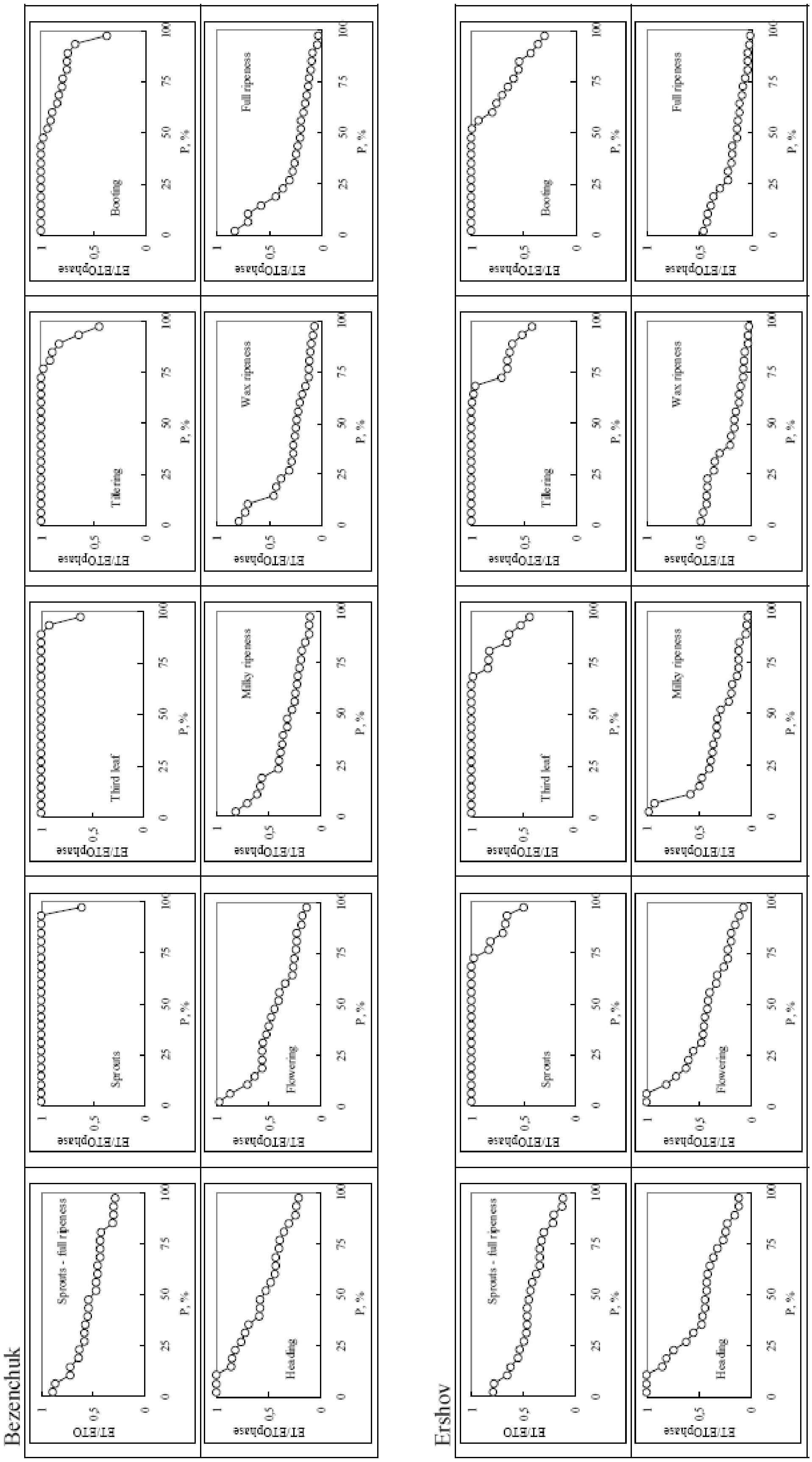
Bezenchuk
Ershov
Sprouts - full ripeness
Sprouts
Third leaf
Tillering
Booting
Heading
Flowering
Milky ripeness
Wax ripeness
Full ripeness
ET/ETO
ET/ETOphase
P, %

Fig. 5

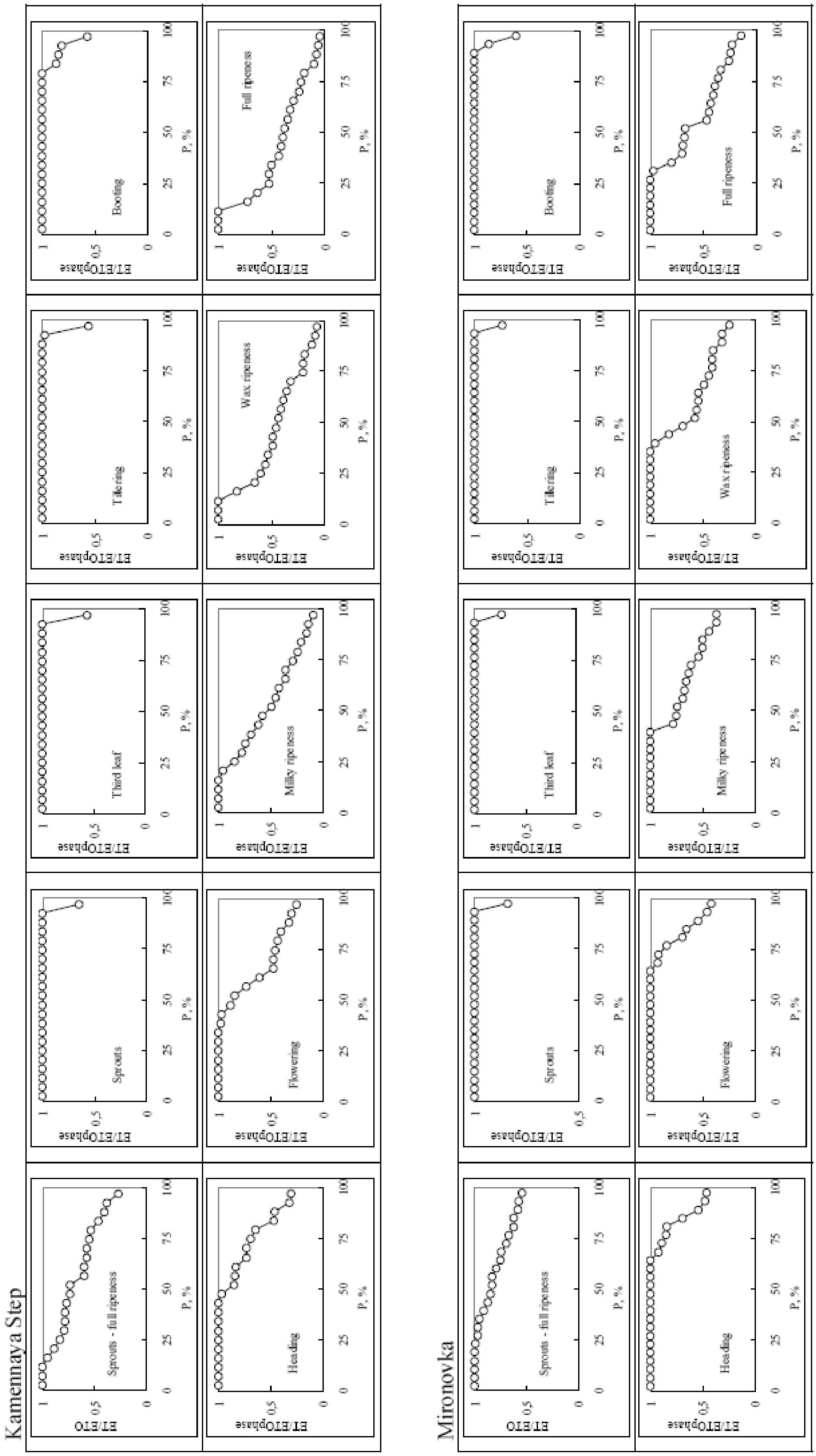

Fig. 5, continued.
Obr. 5, pokračovanie.

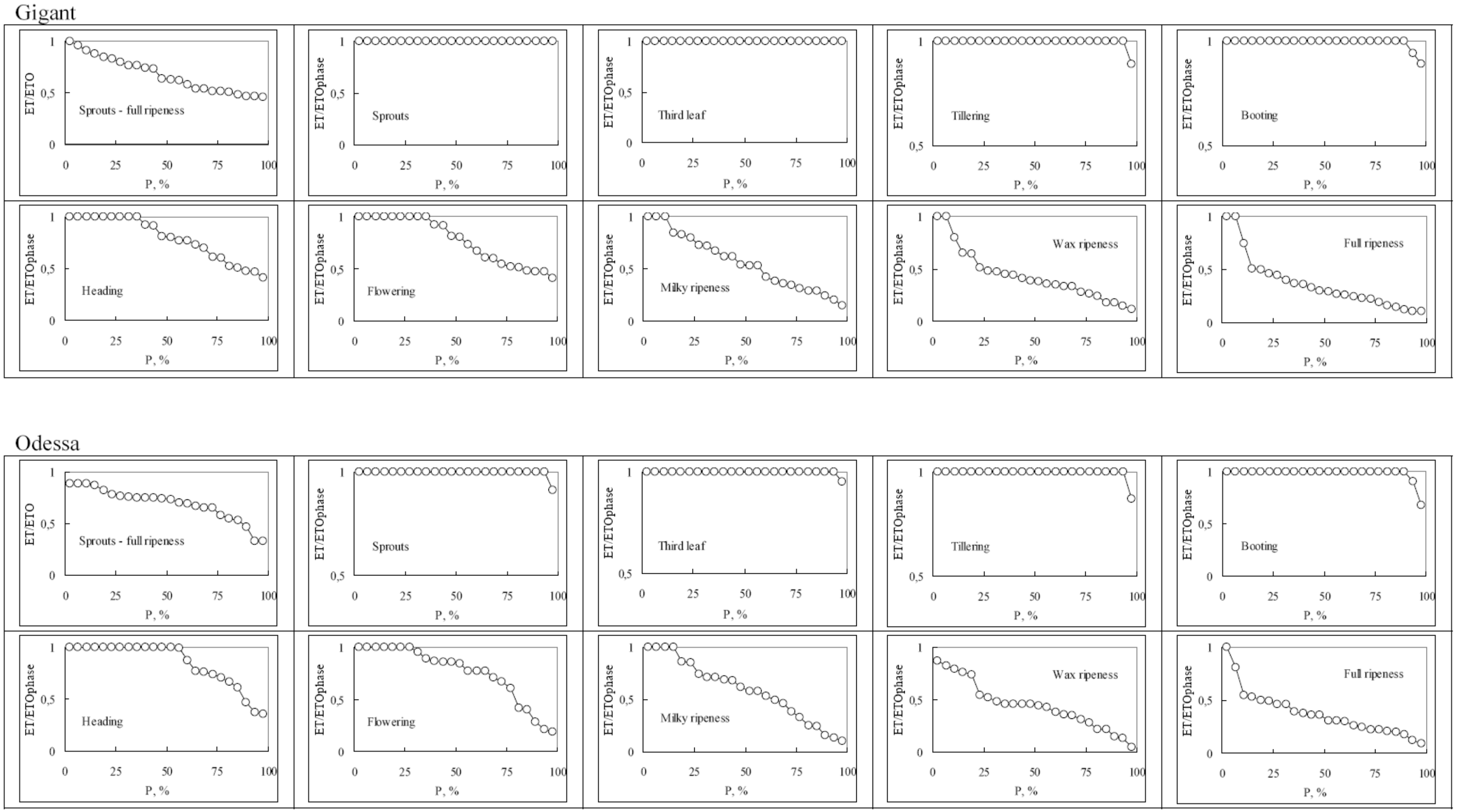

Fig. 5. Curves of exceedance of the spring wheat water supply parameter for growing season (sprouts-full ripeness) ET/ETO and in the main development phases ET/ETO_{phase}.

Obr. 5. Čiary prekročenia parametra zásobovania jarnej pšenice vodou počas vegetačného obdobia (vzchádzanie – plná zrelosť) ET/ETO a počas hlavných fáz ontogenézy ET/ETO_{phase}.

The plants were fully supplied with water in the initial development phases (sprouts and third leaf) only at Gigant site. At the other five stations in the sprouts phase, drought was recorded once in Bezenchuk, Kamennaya Step, Mironovka, and Odessa, and 7 times in Ershov. During the whole period under study the drought was recorded in Bezenchuk beginning with wheat flowering, in Ershov beginning with milk ripeness, and in Odessa beginning with wax ripeness. A critical period for spring wheat in dry regions is the period from booting phase to heading. But as seem from Fig. 5, in these phases of plant development their water supply is reduced sharply. In the booting phase, drought was recorded in 13 out of 24 cases in Bezenchuk and Ershov, 4 out of 22 cases in Kamennaya Step, and 2 out of 24 cases in Mironovka, Gigant, and Odessa. In the heading phase, there was drought in 21 out of 24 years in Bezenchuk and Ershov, 12 out of 22 years in Kamennaya Step, 8 out of 24 years in Mironovka, 15 out of 24 years in Gigant, and 11 out of 24 years in Odessa.

The average values and statistical characteristics of ET/ETO for the whole growing season and the main phases of spring wheat development for six agrometeorological stations are presented in Tab. 1.

Relationship between yield and transpiration

The linear relationship between yield and seasonal canopy transpiration was published by *Hanks* and *Hill* (1980), *Vidovič* and *Novák* (1987), based on empirical data. This relationship is valid for particular plant and environmental conditions. Utilising this approach, *Novák* and *van Genuchten* (2008) proposed the method soil water regime evaluation with respect to plant production. Similar type of relationship was published previoously by *Mechaninova* (1971), which was used later by *Shumova* (2000). This relationship expresses grain yield of spring wheat and growing season consumptive use:

$$Y = 0.09E - 6.8\,, \tag{14}$$

where Y – grain yield [10^2 kg ha^{-1}], E – growing season water consumptive use [mm].

The term "water consumptive use" is deeply embedded in the land reclamation literature. In the context of the present paper this term is nothing more nor less than evapotranspiration. A somewhat different approach to estimate spring wheat grain yield has been suggested by *Kirilicheva* (1967)

$$Y = 0.22K - 0.90\,, \tag{15}$$

where K – plant water supply parameter during sowing-heading time interval.

Plant water supply parameter K is determined (*Protserov*, 1955)

$$K = \frac{V_s - V_h + H_{s-h}}{0.6\sum d}100\%\,, \tag{16}$$

where V_s and V_h – available soil water storage at the beginning and at the end of the sowing-heading time interval respectively [mm], H_{s-h} – precipitation over the sowing-heading time interval [mm], $\sum d$ – average daily air humidity deficit sum over the sowing-heading time interval [mm].

Another way of plant water supply parameter estimation K is the ratio of the actual sowing-heading time interval evapotranspiration (determined by a water balance method) to the potential evapotranspiration (determined from air humidity deficit) over the same period. Then Eqs. (14) and (15) can be written as

$$Y = 0.09ETS_{gs} - 6.8\,, \tag{17}$$

$$Y = 22\frac{ETS_{s-h}}{EO_{s-h}} - 0.90\,, \tag{18}$$

where ETS_{gs} – growing season evapotranspiration [mm], ETS_{s-h} – sowing-heading time interval evapotranspiration [mm], EO_{s-h} – potential evapotranspiration over the sowing-heading time interval [mm].

Using Eqs. (17) and (18) and model-calculated data of growing season evapotranspiration ETS_{gs}, sowing-heading time interval evapotranspiration ETS_{s-h} and sowing-heading time interval potential evapotranspiration EO_{s-h}, spring wheat grain yield estimation has been carried out. Fig. 6 presents relationship between spring wheat water supply parameter ET/ETO and grain yield obtained by Meshchaninova equation (empty circles) and Kirilicheva equation (full circles). A smaller spread of the points derived from Kirilicheva equation can be explained by the fact that this equation takes into account all meteorological parameters available.

T a b l e 1. The average values and statistical characteristics of ET/ETO for the whole growing season and the main development phases of spring wheat for six agrometeorological stations; ($\overline{ET/ETO}$ – average value, $\sigma_{ET/ETO}$ – mean square error, $C_{V\ ET/ETO}$ – variation coefficient).

T a b u ľ k a 1. Priemerné hodnoty štatistických charakteristík parametra (relatívnej transpirácie) ET/ETO pre vegetačné obdobie a hlavné vývojové fázy jarnej pšenice pre šesť agrometeorologických staníc; ($\overline{ET/ETO}$ – priemerná hodnota, $\sigma_{ET/ETO}$ – priemerná kvadratická odchýlka, $C_{V\ ET/ETO}$ – koeficient variácie).

Development phase	Parameter	Bezenchuk	Ershov	Kamennaya Step	Mironovka	Gigant	Odessa
Sprouts - full ripeness	$\overline{ET/ETO}$	0.52	0.42	0.69	0.82	0.68	0.69
	$\sigma_{ET/ETO}$	0.16	0.18	0.21	0.16	0.17	0.16
	$C_{V\ ET/ETO}$	0.31	0.43	0.30	0.20	0.25	0.23
Sprouts	$\overline{ET/ETO}$	0.98	0.92	0.98	0.99	1	1
	$\sigma_{ET/ETO}$	0.08	0.14	0.08	0.03	0	0.02
	$C_{V\ ET/ETO}$	0.08	0.15	0.08	0.03	0	0.02
Third leaf	$\overline{ET/ETO}$	0.98	0.90	0.98	0.99	1	1
	$\sigma_{ET/ETO}$	0.08	0.17	0.09	0.06	0	0.01
	$C_{V\ ET/ETO}$	0.08	0.19	0.09	0.06	0	0.01
Tillering	$\overline{ET/ETO}$	0.94	0.88	0.98	0.99	1	1
	$\sigma_{ET/ETO}$	0.14	0.19	0.09	0.06	0.02	0.03
	$C_{V\ ET/ETO}$	0.15	0.22	0.09	0.06	0.02	0.03
Booting	$\overline{ET/ETO}$	0.89	0.82	0.96	0.98	0.99	0.98
	$\sigma_{ET/ETO}$	0.15	0.24	0.10	0.08	0.02	0.07
	$C_{V\ ET/ETO}$	0.17	0.29	0.10	0.08	0.02	0.07
Heading	$\overline{ET/ETO}$	0.58	0.49	0.81	0.90	0.79	0.85
	$\sigma_{ET/ETO}$	0.25	0.28	0.24	0.18	0.21	0.22
	$C_{V\ ET/ETO}$	0.43	0.57	0.30	0.20	0.27	0.26
Flowering	$\overline{ET/ETO}$	0.43	0.44	0.73	0.89	0.77	0.75
	$\sigma_{ET/ETO}$	0.22	0.26	0.29	0.19	0.22	0.27
	$C_{V\ ET/ETO}$	0.51	0.59	0.40	0.21	0.29	0.36
Milky ripeness	$\overline{ET/ETO}$	0.34	0.31	0.56	0.76	0.56	0.59
	$\sigma_{ET/ETO}$	0.19	0.25	0.31	0.23	0.26	0.29
	$C_{V\ ET/ETO}$	0.56	0.81	0.55	0.30	0.46	0.49
Wax ripeness	$\overline{ET/ETO}$	0.28	0.22	0.46	0.70	0.43	0.44
	$\sigma_{ET/ETO}$	0.20	0.16	0.29	0.28	0.24	0.22
	$C_{V\ ET/ETO}$	0.71	0.73	0.63	0.40	0.56	0.50
Full ripeness	$\overline{ET/ETO}$	0.28	0.19	0.43	0.64	0.37	0.37
	$\sigma_{ET/ETO}$	0.22	0.14	0.29	0.31	0.25	0.21
	$C_{V\ ET/ETO}$	0.79	0.74	0.67	0.48	0.68	0.57

From the Fig. 6 it follows that to provide minimum spring wheat grain yield for territory under investigation water supply parameter ET/ETO of the vegetation period must be no less than 0.2. Under optimal natural water supply conditions ($ET/ETO=1$) spring wheat grain yield is 2.5 t ha^{-1}. The use of the empirical relation between grain yield and the crop water supply (Fig. 6) is of acceptable accuracy for this arid region. It allows to estimate the spring wheat grain yield for different values of the water supply.

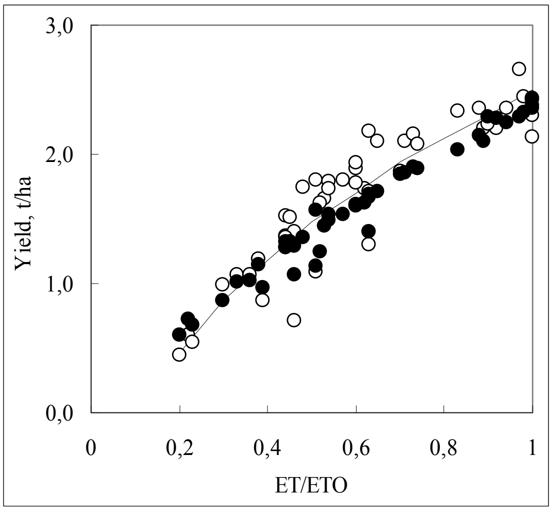

Fig. 6. Spring wheat grain yield and the water supply parameter ET/ETO; (empty circles – yield estimated by Meshchaninova equation, full circles – by Kirilicheva equation).
Obr. 6. Úroda zrna jarnej pšenice a parameter zásobenia porastu vodou ET/ETO; (prázdne krúžky – úrody určené pomocou rovnice Mešaninova, plné krúžky – rovnicou Kiriličeva).

Conclusion

The proposed method to estimate spring wheat grain yields was applied for Southern Russian Plain area using data of 45 agrometeorological stations. The relative seasonal evapotranspiration (ratio of evapotranspiration and potential evapotranspiration) for different sites and stages of ontogenesis are distributed in the range $0.2 \leq ET/ETO \leq 1$, which means high variability of yields. Exceedance curves of relative evapotranspiration for different stage of crop ontogenesis (Fig. 5) allows to estimate probability of relative evapotranspiration decrease below ET/ETO = 1. Curves of exceedance of relative evapotranspiration values below ET/ETO = 1 for particular ontogenesis stage and site can be used as a basic information to optimise crop water supply.

Agricultural crops in the Southern Russian Plain are subject to regular droughts which differ only in intensity and recurrence and sometimes have a catastrophic character. A radical way of improving crop water supply is to irrigate. But large-scale expansion of irrigation can lead to negative environmental effects. The application of “dryland farming system” methods namely retention of snow and meltwater in the fields, reduction soil water evaporation by mulching can be used.

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ZÁSOBOVANIE PORASTU JARNEJ PŠENICE VODOU VO VZŤAHU K ÚRODÁM V PODMIENKACH JUHORUSKEJ NÍŽINY

Nadežda Šumová

Navrhnutá metóda určenia úrody zrna jarnej pšenice bola aplikovaná na Juhoruskú nížinu s využitím údajov 45 agrometeorologických staníc. Pomerná sezónna transpirácia (pomer transpirácie k potenciálnej transpirácii) pre rozdielne lokality a fázy ontogenézy porastu bola v rozmedzí 0.2 ≤ ET/ETO ≤ 1, čo znamená, že variabilita úrod bola vysoká. Čiary prekročenia relatívnej transpirácie pre rozdielne štádiá ontogenézy porastu (obr. 5) umožňujú vypočítať pravdepodobnosť poklesu relatívnej transpirácie pod hodnotu ET/ETO = 1. Čiary prekročenia relatívnej transpirácie pod hodnotou ET/ETO = 1 pre konkrétnu fázu ontogenézy rastlín môžu byť využité ako základná informácia o potrebe optimalizácie zásobovania porastu vodou.

Poľnohospodárske porasty v Juhoruskej nížine pravidelne trpia suchom rôznej intenzity, niekedy má až katastrofický charakter. Radikálny spôsob zlepšenia zásobovania porastov vodou je využitie závlah, avšak ich masívne využitie môže viesť k negatívnym vplyvom na životné prostredie. Najvhodnejším sa javí použitie systému “dryland farming system”, ktorý využíva retenciu snehu a vodu z topiaceho sa snehu na poliach, a tiež redukciu výparu z povrchu pôdy mulčovaním.

Zoznam symbolov

ET, ETO	– aktuálna a potenciálna transpirácia [mm deň$^{-1}$],
ET, ES a ESO	– aktuálny a potenciálny výpar z pôdy [mm deň$^{-1}$],
EO	– potencálna evapotranspirácia [mm deň$^{-1}$],
V, V_{cr}	– dostupný a kritický obsah vody v pôde [mm],
H	– denný úhrn zrážok [mm deň$^{-1}$],
LAI	– index listovej pokryvnosti [cm^2 cm^{-2}],
T	– teplota vzduchu vo výške 2 m nad povrchom pôdy [^{o}C],
d	– vlhkostný deficit vo výške 2 m [mb],
u	– rýchlosť vetra vo výške 2 m [m s^{-1}],
R	– radiačná bilancia vyparujúceho povrchu [cal cm^{-2} deň$^{-1}$],
B	– tok tepla v pôde [cal cm^{-2} deň$^{-1}$],
b_1, b_2	– funkcie teploty vzduchu,
φ	– derivácia nasýteného tlaku vodných pár podľa teploty [mb ^{o}C^{-1}],
D_s, D_{LAI} a $\tilde{u}$	– funkcie rýchlosti vetra,
Φ_s, Φ_1 a Φ_2	– funkcie LAI,
γ	– empirický parameter závislý na hydrofyzikálnych vlastnostiach pôdy (0.0025 mm^{-1} pre lesostepnú a stepnú oblasť),
n	– koeficient závislý na geografickej šírke a ročnom období (*Budagovskij*, 1964),
$c_1 = 2.4$, $c_2 = 4$ m$^{1/2}$ s$^{-1/2}$	– koefficieny boli určené z poľných meraní.

(Ako jednotky sú niekedy použité kalórie; je to dôsledkom použitia tabuliek, ktoré ešte obsahujú tieto jednotky).