БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ . BULGARIAN ACADEMY OF SCIENCES

ИНЖЕНЕРНА ГЕОЛОГИЯ И ХИДРОГЕОЛОГИЯ, 29

ENGINEERING GEOLOGY AND HYDROGEOLOGY, 29

София, 2015. Sofia

New Hydro-physical Index and Technology for Managing the Water Status of Vadose Zone

Ilia Christov[1]

[1] - Institute for Soil Science, Agrotechnology and Plant Protection, Sofia 1080, Bulgaria
E-mail: idchristov@doctor.bg

Ил. Христов. 2015. Нов хидро-физически показател и технология за управление на водния статус на аерационната зона, *Инженерна геология и хидрогеология*, 29, стр. 85 - 96.

Резюме. Статията разглежда върхови научни постижения в областите физика на почвата и биофизика на растителни популации и приложението им в аграрната наука и практика на напояване.

Водният статус на аерационната зона непрекъснато и силно влияе върху формирането на биопродуктивността. Създадена е практическа възможност за научно управление на този статус във всяко земеделско поле не само в страните на Европейския съюз, но и в останалия свят. Това управление довежда до най-ефективно използване на енергията, водата и човешкия труд, т. е. до получаване на земеделска продукция с ниска себестойност.

Решени са редица кардинални екологични проблеми на управлението на водния статус на аерационната зона, който определя развитието на земеделските култури с оглед продуктивността им и защита на околната среда като повърхностни водоеми, подпочвени води и почви от замърсители, свързани със земеделска дейност.

Дългогодишни теоретични и експериментални научни изследвания върху водния статус на аерационната зона при отглеждане на различни земеделски култури в условията на карбонатен чернозем в Опитна станция Лом в Северозападна България, 10 агроекологични района в цялата страна и района на Солун, Гърция, са проведени в продължение на 30 години.

Въведен е нов универсален показател и класификация за количествена енергетична оценка на водния статус на аерационната зона. Разработена е компютъризирана технология (изследователска версия) за прецизен мониторинг на водния дефицит в коренообитаемия слой на аерационната зона през три денонощия и управление на водния й статус. Това се извършва чрез текущо съставяне и изпълнение на специфичен график за напояване с оглед реализиране на подходящо енергетично равнище на почвена влага в аерационната зона през целия вегетационен период. Естественият воден статус (без напояване) през редица години е оценен с помощта на новия показател и метод.

Въведен е показател за степента на засушаване, който отчита еталонната евапотранспирация, валежите и водния запас в коренообитаемия слой на аерационната зона. За първи път е въведено начало на засушаването. Това е денонощието, в което се реализира енергетичното равнище L =15 $J^{1/2}$ $kg^{-1/2}$ на влагата в аерационната зона.

Получените експериментални данни позволиха да се разработят модели за влиянието на водния статус на аерационната зона не само върху количеството, но и върху качеството на добива от земеделската култура. Установена е устойчива зависимост на биопродуктивността от водния статус на аерационната зона както за естествени (без напояване), така и за създадени чрез напояване водни режими на зоната, които бяха оценени чрез новия показател *L* на енергетични равнища.

Научната основа за оценка и управление на водния статус на аерационната зона и базираната върху нея технология за практическо приложение разкриват нови производствени резерви за развитието на устойчиво земеделие. Необходим е инвеститор за създаване на софтуерен продукт за масово практическо приложение у нас, Европейския съюз и останалите страни.

В сравнение с традиционната земеделска практика на напояване, многогодишните резултати за царевицата показаха, че приложението на тази технология:

● спестява вода средно 29.5% от напоителната норма, което намалява риска от ерозия, дълбочинна филтрация и замърсяване на подпочвените и повърхностните води;

● осигурява воден статус на аерационната зона, което е необходимо за действително получаване на определено количество и качество на добива;

● спомага за целесъобразно определяне на хранителния режим, съответстващ на водния статус на аерационната зона;

● намалява броя на поливки средно с 2.875 в сравнение с проектния поливен режим;

● повишава добива от царевично зърно средно от 7 до 12 t ha^{-1};

● минимизира изразходваната електрическата енергия и горива в агроекосистемите, което води до значително намаление на емисиите на CO_2 и замърсяване на атмосферата;

● намалява изразходването на ненужен земеделски труд и издига интелектуалното равнище на хората в земеделието.

Ключови думи: ненаситена зона, воден статус, енергетично равнище на почвена влага , система за подпомагане вземането на решения.

Abstract. The paper deals with a new universal estimation of water status of the unsaturated (vadose) zone, as well a technology for current computerized monitoring the water deficit in vadose zone and managing its water status.

Data were obtained under field and laboratory conditions over 30 year research period. Fundamental physical laws and recent Bulgarian and foreign top scientific achievements were aggregated and applied to be created the new scientific basis of the technology.

The obtained results showed the successful applications of: (a) the hydro-physical index and the method for its determination for water status of root layer (part of vadose zone) under both irrigation and non-irrigation conditions, and (b) the Technology for Monitoring, Estimating and Managing (TMEM) of the water status of this layer in irrigation rural activities, taking into account the European ecological requirements. The technology is applied as Decision Support System (DSS) in irrigation agriculture. Dependence of the maize yield on the introduced universal estimate of vadose water status is established for the first time in agricultural sciences and practices. The application of DSS (research version) showed higher efficiency compared to the traditional irrigation regime. The maize grain yield increased on average more than 70%, implementing the DSS schedules to maintain the energy level $L = 15\ J^{1/2}\ kg^{-1/2}$ of water status of vadose zone, which took into account the meteorological features of each year and saved on average (over eight years) 29.5% of irrigation water in comparison with the traditional project irrigation regime for considered crop and region.

Keywords: unsaturated zone, soil moisture status, energy level.

Introduction

Water status of vadose zone is one of the most important factors with strong influence on the amount and the quality of plant production. Up to now, there was no universal quantitative estimate of this status for all porous mediums (Kozlowski, 1978). In irrigation practice, the widely used assumption of relationship between total water flow through the unsaturated zone and crop productivity is not reasonable. It was proved that the bioproductivity is not proportional to the total water flow through the vadose zone. It could be considered as a very rough approximation, which is not appropriate for irrigation scheduling (Alpatiev, 1963).

The local (point) methods for measuring soil moisture in vadose zone cannot be applied for current monitoring and managing in the dozens fields of municipality, the hundreds fields of district and thousands ones in a country with the needed periodicity of 3 days. To obtain representative values of water supply in vadose root zone for one field of 50 ha during one maize growing season in three days, on average 25000 single soil moisture measurements are necessary. It is obvious that the point soil moisture measuring methods are not applicable for the wide irrigation practice (Kincaid et al., 1973).

Filippova (1964) concluded that we need soil moisture sampling over the depth at 160 soil profiles in the vadose zone in 50 ha field to obtain representative data with an error of measurements to be equal to ±10 mm (or 100 m3 ha-1) water supply in 1 m soil depth at probability of 80-85%.

Leonov et al. (1972) established that the average water supply in 1 m soil layer of vadose zone is determined with an error of 8.4% when the soil moisture distribution is measured at two points in an area of 0.5 ha. This error reaches up to 79.6% for an area of 50 ha. To decrease the error up to 7.0% for the area of 50 ha, it is necessary to analyze 50 soil moisture profiles (50 points on the soil surface), each of which includes 10 measurements in depth. The local measurements of soil moisture and other soil physical indices of vadose zone can be very accurate for a small area around the measured points. However, their representativeness is a serious problem, when trying to extrapolate them for larger areas. This problem requires other approaches, methods and additional efforts to be solved. The local (point) methods are applicable in experimental fields and also for precise calibration of other devices and methods.

The distribution of the resultant water through the vadose zone during the growing season greatly affects the plant growth. The second strongly acting factor is the changing susceptibility at different stages of plant to decrease its yield under various water deficits in vadose zone (Christov, 1989 and 2004). The irreversible processes in plant, which are caused by water shortage in vadose root zone, are the third factor heavily and constantly decreasing the bioproductivity (Christov, 2012).

The paper is aimed at establishing the great role of water status of the unsaturated zone through the introduced hydro-physical index of energy levels for estimating the vadose zone water status and the possibility of its successful management in solving geological and agricultural problems of practical importance.

Material and methods

Over a period of thirty years, at experimental fields of the Poushkarov Institute for Soil Science and fields located in 10 agroecological regions in Bulgaria and at the field of Land Reclamation Institute, Sindos, Thessaloniki, Greece, we created different water statuses of the vadose root zone, measuring the soil moisture distribution with both the sample-weighing method and the neutron moisture-meter in the frames of international and national projects.

The crop yield and its quality were precisely measured. Regularities of the formation of water supply in vadose zone during the infiltration processes originated from rainfalls and irrigation by us using closed furrow and sprinkling methods at different slopes were established under field conditions.

In the laboratory of University of California, Davis, we successfully applied the Phillips theory. Using soil columns and water applicators, we established the regularities of movement of wetting front and soil moisture in Columbia silt loam and later, in Calcareous Chernozems and other Bulgarian soils.

Using the regression method, we processed the data on current water status of vadose zone and the obtained crop yield. Aggregating different physical, hydro-geological and biological knowledge and experience, we introduced the estimation index of energy levels *L* of the vadose water status and applied in a new technology developed for managing this status through creating special schedules for irrigation in agriculture.

Classification of these energy levels is based on the dependence of plant photosynthesis on the soil moisture potential of vadose zone, which governs 90% of the intensity of this productive process (Idso, 1986).

To be created an energy level of vadose water status in field, the technology has to be adapted for the geographical region. Information about the irrigation technical possibilities, kinds of crops and soils, communication facilities, and current meteorological data in the region, is necessary.

The technology application takes into account the current meteorological, soil-physical, crop biological and agrochemical data, and the fundamental laws governing the main processes in the vadose zone. This technology allows developing a special irrigation schedule in chronological sequence during the growing season for any crop. For this irrigation scheduling that is specific for each field and vadose zone, it is necessary to establish an adequate energy level L of the soil moisture, which enables to obtain the planned amount of the crop yield.

Results and discussion

The developed scientific basis is the main result that is based on the theoretical framework –both physical and biological relationships, laws and specific regularities, which govern the processes forming the water status of vadose zone. It was created from "the point of view of plants". Complete set of seven current meteorological indices, soil-physical characteristics, phenological information and biological functions of crops are the input data.

The aggregated scientific basis consists of different components. These are the main models for calculating: (a) the current actual and maximum allowed soil moisture deficits in soil root layer; (b) the reference and actual evapotranspiration; (c) the dew point each day-and-night; (d) the daily solar radiation; (e) the reduced wind speed; (f) the crop biological functions; (g) the daily thickness of soil root layer for different crops grown on the soil profile considered; (h) the daily rate of evapotranspiration from groundwater; (i) the monitored expected rate and date for watering; (j) the actual rate and date for watering to be implemented for creating the chosen energy level of soil moisture, which ensures the soil water status needed to be obtained the planned amount and quality of yield; (k) the effectiveness of watering process under the field features and suitable irrigation technique; (l) net and total (gross) watering rates (Christov, 2004 and 2012).

Water deficit

Each amount of water from rainfall and irrigation, which enters the soil root layer immediately after the moment of reaching the maximum soil moisture supply, drains away. This amount of water cannot increase the moisture supply because the maximum is reached (the soil moisture deficit is zero). This amount of water has no impact on the irrigation schedule, except for the cases of embarrassed or fully stopped deep filtration, surface run-off and interflow. The offered basis quantitatively takes into account this significant effect each day N (24 h) during the growing season (Christov, 1989 and 1991).

In the agricultural practices up to now, this effect was left unattended. It leads to significant inaccuracy in the agroecosystem water balance and in the irrigation schedule. The rainfall efficiency of moisture supply formation calculated for the whole growing season (even for month and decade of days) is a very rough approximation, which leads to incorrect determination of the irrigation schedule. The solution of this problem for each twenty-four hours is one of the advantages of the offered scientific basis for managing the irrigation practices.

Based on the hydro-physical law of water mass conservation, we can obtain the equation for calculating the current soil moisture deficit in the root layer of soil on the Nth day, which is applied for each agricultural field, crop and kind of soil. The equation of Kincaid et al. (1973) does not take into account the amount (mm) of water that enters into the soil root layer from near groundwater on the same day.

Maximum allowed soil moisture deficit is also a function of time during the growing season. It corresponds to the chosen energy level (L, $J^{1/2}$ $kg^{-1/2}$) of water status in vadose layer. It depends on the norm of maximum allowed deficit and thickness of the soil root layer.

The norm depends on both the soil moisture retention properties and the crop biological features related to water in soils. It is directly linked to the chosen energy level L of soil moisture (Christov, 2004). On each third day during the growing season, we calculate and compare both the current and maximum allowed moisture deficit in the soil root layer. The days for watering the field are identified when the values of current and maximum allowed soil moisture deficits are equal. To maintain the chosen energy level L of moisture in field, we have to keep the current deficit less than the maximum allowed one for this level (Christov, 2008a).

Reference and actual evapotranspiration

The actual evapotranspiration is a complex of processes including movement of water in liquid and gaseous states in the soil, plant population and ground layer of atmosphere. These processes are described on the basis of physical and biological laws, and using: soil-physical and crop-biological information and a complete daily set (maximum, average and minimum air temperature; mean air humidity; mean wind speed; precipitation; and sun shine duration) of current meteorological data available in the National Meteorological Network of each country. The complex model of actual evapotranspiration on the Nth day (24 h) is proposed by Kincaid et al. (1973).

The equation for calculating the soil physical factor well describes the experimental data obtained for the basic soils in Bulgaria. We applied the physical law of energy equivalent for the water transformation from liquid state into gaseous one. We take into account whole complex of meteorological factors under reference conditions. Heat flux to/from soil for each 24 h and the radiation balance are calculated too.

Analysis of experimental data showed that the value of heat flux usually varies from 10 to 30% of the radiation balance value.

Dew point

The dew point is calculated through the measured air humidity and temperature at a moment. It is very important index in the scientific basis. At the temperature of dew point, the evaporation processes from soil surface and plants stop. The opposite direction processes of water vapour condensation from the ground layer of atmosphere to soil surface and plant cover as dew appear. Applying the iteration method with accelerated congruence, we calculated the dew point.

Daily solar radiation

The daily sums of solar radiation are directly measured only in some stations of the National Meteorological Network in Bulgaria. In most stations, there is available and routinely measured the duration of sun shine using heliographs. This physical index can be used for calculating the solar radiation. Lingova (1981) showed that the optimal interpolation of month sums of sun shine duration is allowed up to 100 km in winter, 200 km in summer and more than 400 km in spring and autumn.

Daily sum of solar radiation is calculated as part of the solar radiation received on the ground surface under cloudless sky for the region considered. It depends on the geographic latitude and the date of year. This part of solar radiation depends on the ratio between the duration of sun shine and the duration of day N. Special model converts the date (day, month) into the date number N.

Wind speed at 2 m height

Air mass movement over the ground surface significantly exerts influence on the reference and actual evapotranspiration. The measured wind speed depends on the height above the soil surface. The heights of anemometer in the National Meteorological Network are different not only in the individual stations, but also for various periods of observation in the same station. In the Climatic Reference Book of Bulgaria, volume 4 entitled Wind, the wind speed is referred to the height of 10 m. The wind speed dependence on the height of measuring in field is calculated using the logarithm law (Hipps, 1985).

Crop biological function

The crop biological function (CBF) serves to transform the reference evapotranspiration (RE), corresponding to field capacity (FC), into the value of actual one for a fixed crop. RE takes into account the complex influence of the meteorological factors under conditions of reference crop (alfalfa) at typical phase of its development. CBF represents the part of RE, which characterizes the total evaporation for fixed crop by both development phases and days during growing season. Moreover, the crop biological function depends on the planting date and the full cover date, which are specific for each crop and field.

Daily thickness of soil root layer for different crops and soils

The increase of soil root layer leads to direct change in both the moisture supply available for plants and the time interval for its consumption under the same meteorological and soil conditions. This increase inserts significant influences on both the soil moisture status and the productivity. This increase must be taken into account when calculating the rate and date of watering (irrigation schedule).

Under fixed soil conditions, the maximal effective thickness of the water-supplying root layer should be established for each crop. The thickness reaches its maximal value on the full cover day for the most annual plants. From the planting date to the full cover date, the effective thickness of soil root layer is precisely calculated.

Establishing the real effective thickness of moisture-supplying soil layer significantly specifies the water status management, which leads to effective use of: water resources, energy needed for different agricultural activities, human labour and time, saving significant part of them.

Rate of underground water participation in evapotranspiration process

Unsaturated zone is a complicated porous medium, where the water movement runs in different soil genetic horizons. The rising and the descending flows in soil are the basic processes characterizing the water exchange between this zone and both the ground layer of air and the deeper underground water layers.

Using experimental data averaged over month and 10 days, Harchenko (1985) gave an exponential approximation of the ground water participation in the evapotranspiration.

Our model for calculating the daily rate of ground water participation in evapotranspiration is based on one day (24 h) interval and includes precise dependence through a complex coefficient consisted of three physical quantities: (*i*) reference evapotranspiration; (*ii*) crop biological function; and (*iii*) soil physical factor.

The experimental data showed that our model more precisely takes into account the real evapotranspiration, the soil-physical and plant biological factors than those of Harchenko (1985).

Predicting and monitoring expected rate and date for watering

The complete set of input current meteorological data during growing season is necessary for managing the water status of vadose zone. This management is implemented through applying a precise model for predicting and monitoring the expected rate and date for watering. The computerized monitoring is carried out for each field and crop in a period of three days. Special model transforms the date (day, month) into the day of year N (Christov, 2012).

We implement two interrelated procedures. The first one results in a periodical predicting of the rate and date for watering in chronological consequence during growing season, using each time new actual meteorological data of the past three days. The second one consists of a periodical updating of these rate and date and establishing the actual necessary rate and date.

Net and total (gross) watering rates

The net watering rate is equal to the current moisture deficit in the soil root layer on the day, when it reaches the maximum allowed value, corresponding to the chosen energy level *L* of soil moisture. The net irrigation norm for the whole growing season is equal to the sum of all net watering events (Christov, 2012).

The total (gross) rate of watering takes into account the coefficient of effectiveness for watering process, which accounts for the water losses during watering. The total (gross) irrigation norm is equal to the sum of all gross rates of watering during the growing season.

Effectiveness of watering process

The coefficient of effectiveness for watering process varies from 0 to 100%. It is a measure for determining the degree of both the moisture supply formation in the soil root layer and the compensation of maximum allowed moisture deficit $D_{max}(N_i)$ in the same layer after accomplishing the watering process (Christov, 2012).

Classification for estimating the water status of vadose zone

The impact of water status of vadose zone on bioproductivity is determined through the new index L of realized energy level of soil moisture. Christov (1992) introduced the hydro-physical index *L* of energy level of vadose zone for the first time, which is proportional to the low boundary of interval of the change of water potential ψ by absolute value raised to the 1/2 power. Method for determining the universal index L (for all soils with different texture) was developed (Christov, 2004) and technology for creating a scientifically chosen energy level L of vadose water status in field was developed and successfully verified (Christov, 2012).

Table 1 presents the nine classes of energy levels *L* of soil moisture in vadose zone. The classes are determined based on the degree of photosynthesis reduction caused by decrease in the soil water potential of root layer, which is part of the vadose zone.

These energy levels are quantitatively linked with the soil moisture potential ψ, which corresponds to the volumetric soil moisture θ through the equation of Gardner. We found analytical equations to determine the Gardner's coefficients applying the routinely measured soil characteristics (field capacity FC; wilting point WP; and the corresponding values of soil moisture potential ψ, J kg^{-1}) (Christov, 2008d).

Decision Support System (DSS)

The developed and verified technology for creating a scientifically chosen energy level *L* of vadose water status in field is a practical tool to be easily used by scientists and farmers for precise decision-making in engineering geology and agricultural sciences and practices. The application of this tool was organized in details (Christov, 2008b).

The adequacy of this Decision Support System (DSS) was thoroughly examined (Christov, 2008c).

Estimation of water status of vadose zone

Table 1 shows the developed classification of energy levels (*L*, $J^{1/2}$ $kg^{-1/2}$) for estimating the water status of vadose zone, which is universal for kind of soil and subsoil layers, as well for all crops.

The new top achievements in hydro-geology and soil physics on the water status of vadose zone introduced a quantitative universal *L* measure of water status of agroecosystems for the first time in world agricultural sciences and practices. Moreover, they offer innovative technology to create specified water status of vadose root zone with minimum amount of water and obtain planned amount and quality of crop yield.

Figure 1 shows the dependence of yield Y of maize grain (H-708 hybrid) on the vadose water statuses (Calcareous Chernozems, Lom region, Bulgaria), which were estimated with the new universal index *L* and created in fields during a period of 30 years.

Table 1.Classification of the soil moisture energy levels (L, $J^{1/2}\ kg^{-1/2}$) in vadose zone based on the minimum allowed values of the lower limit of the soil water potential range (ψ_{min}, $J\ kg^{-1}$) at each stage of crop growth
Таблица 1. Класификация на енергетични равнища (L, $J^{1/2}\ kg^{-1/2}$) на аерационната зона, която е базирана на минималните стойности на долната граница на диапазона на изменение на водния потенциал на почвата (ψ_{min}, $J\ kg^{-1}$) във всеки етап на развитие на земеделската култура

Class number	Class name and diapason of minimum value ψ_{min} of potential	L, $J^{1/2}\ kg^{-1/2}$	ψ_{min} $J\ kg^{-1}$
1	Class of biological optimum (more than –53)	1 2 3 4 5	–10 –20 –30 –40 –50
2	Class of middle levels (–109, –53)	6 7 8 9 10	–55 –60 –65 –80 –100
3	Class of slightly lowered levels (–236, –110)	11 12 13 14 15	–120 –140 –160 –190 –225
4	Class of moderately lowered levels (–419, –237)	16 17 18 19 20	–250 –290 –320 –360 –400
5	Class of strongly lowered levels (–649, –420)	21 22 23 24 25	–440 –480 –520 –570 –625
6	Class of transitionally low levels (–929, –650)	26 27 28 29 30	–675 –730 –780 –840 –900
7	Class of moderately low levels (–1261, –930)	31 32 33 34 35	–960 –1020 –1090 –1150 –1225
8	Class of very low levels (–1649, –1262)	36 37 38 39 40	–1300 –1370 –1450 –1520 –1600
9	Class of extremely low levels (less than –1650)	41 42 43 44 45	–1700 –2000 –2500 –5000 –10000

The data on amounts Y of maize-grain yield, which is obtained under different vadose water statuses (estimated through the universal index L) and appropriate plant nutrition during the period of many years are described by the equation:

$$Y = 19.214 - 0.516\,L \qquad (1)$$

The coefficient of correlation is equal to 0.973.

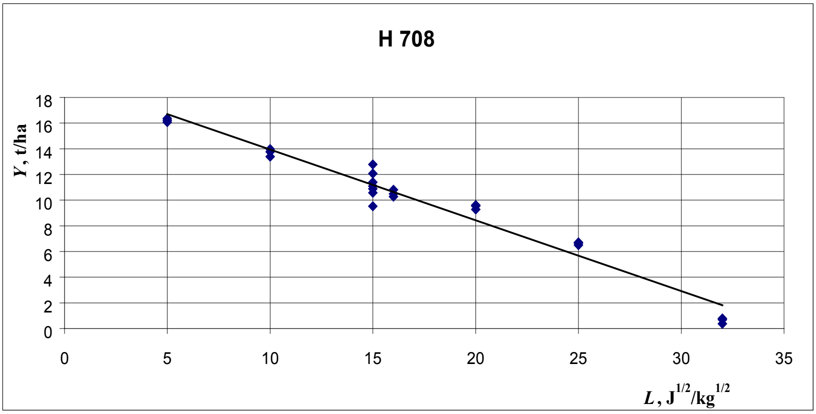

Fig. 1.Yield Y (t ha^{-1}) of maize grain in dependence on the vadose water statuses (Calcareous Chernozems, Lom, Bulgaria), which were estimated with the index (L, J$^{1/2}$ kg$^{-1/2}$) of energy levels of soil moisture and created in field
Фиг. 1. Добив Y (t ha^{-1}) от H 708 царевично зърно в зависимост от водния статус на аерационния кореноoбитаем слой (Карбонатен чернозем, Лом, България), оценен с помощта на показателя (L, J$^{1/2}$ kg$^{-1/2}$) на енергетични равнища на почвена влага, който е създаден в полето

Profits of applying the DSS in agricultural practice

The prerequisites for profitable farming are: estimating the vadose water status; establishing appropriate irrigation scheduling (watering rate and date of application), currently applying DSS; and applying of the necessary universal energy level L = 15 J$^{1/2}$ kg$^{-1/2}$ of soil moisture. This level is recommended by us for all soils and crops in the agricultural practices. Moreover, the farmer can create different vadose water statuses and actually obtain the planned amount of yield (Table 2).

The energy level L = 5 J$^{1/2}$ kg$^{-1/2}$ belongs to the Biological Optimum of plant soil water status. It can be created in field vadose zone, using the DSS to obtain the crop yield, which is genetically possible for new sorts and hybrids.

The risk coming from the influence of the most important water factor of vadose zone on bioproductivity can be completely removed applying DSS under conditions of ecologically-acceptable irrigation technical facilities and available water resources. The minimum total needed amount of water and its precise distribution to obtain a planned crop yield can be reached using DSS.

Traditional irrigation schedule based on average climatic data over many years for the maize crop grown on Calcareous Chernozems soil in north-western Bulgaria (Zahariev et al., 1986) includes 6 times of watering during the growing season each year with total irrigation norm equal to 3600 m^3 ha^{-1} (1 mm water layer = 1 m^3 da^{-1} = 10 m^3 ha^{-1}). The grain yield based on using climatic methods of evaluating vadose water status on average reaches 7 t ha^{-1}.

Applying the DSS (research version), the precise schedules include 3.125 times of watering on average for 8 years with total irrigation norm equal to 2780 m^3 ha^{-1} or 29.5% less amount of water. When we created the energy level L = 15 J$^{1/2}$ kg$^{-1/2}$, we obtained on average 12 ± 0.05 t ha^{-1} of maize grain each year under appropriate plant nutrition (Table 3).

Table 2. Yield (t ha^{-1}) of the H-708 maize grain obtained at different energy levels L of vadose water status (Calcareous Chernozems, Lom, Bulgaria). The yield values marked with asterisk (*) show that the plants are depressed by water deficit in vadose zone (Christov, 2012)
Таблица 2. Добив (t ha^{-1}) от H-708 царевично зърно, получен при различни енергетични равнища L на водния статус на аерационния коренообитаем слой на почвата (Карбонатен чернозем, Лом, България). Стойностите на добива, означени със звездичка (*), показват, че растенията са били депресирани от воден дефицит в аерационната зона (Christov, 2012)

Year	Created energy levels ($J^{1/2}$ $kg^{-1/2}$) of vadose water status				
	$L = 5$	$L = 10$	$L = 15$	$L = 22$	$L = 26$
	Fertilization rates $N_{340}P_{450}(3)K_{160}$				
1986	16.36	14.24	13.72	9.90	–
1987	16.22	14.70	12.48	–	5.58*
1988	16.07	14.91	12.68	–	6.17*
Mean	16.21	14.61	12.96	9.90	5.87*
	Fertilization rates $N_{280}P_{320}(3)K_{120}$				
1986	15.85	13.39	12.96	9.71	–
1987	16.09	13.77	11.07	–	5.44*
1988	14.95	13.98	11.71	–	5.76*
Mean	15.63	13.71	11.91	9.71	5.60*
	Fertilization rates $N_{220}P_{230}(3)K_{80}$				
1986	15.54	13.12	12.79	8.70	–
1987	14.55	10.86	9.52	–	7.34
1988	14.93	13.71	12.07	–	6.21
Mean	15.00	12.56	11.46	8.70	6.77
	No fertilization $N_0P_0(3)K_0$				
1986	12.95	10.25	9.81	7.54	–
1987	12.14	10.38	9.62	–	6.52
1988	11.15	9.48	8.95	–	5.42
Mean	12.08	10.03	9.46	7.54	5.97

Table 3. Irrigation schedules established by the ecotechnology for H-708 maize, through which we realized the energy level L = 15 $J^{1/2}$ $kg^{-1/2}$ in field (Lom, Bulgaria) in 1981-1988. Equivalent energy levels L_e for vadose water statuses of years (no irrigation) are shown in brackets. We compare the traditional schedule shown down (Zahariev et al., 1986) with precisely determined irrigation schedules needed to obtain 12 t ha^{-1} of grain for each specific year
Таблица 3. Графици за напояване, установени с помощта на екотехнологията (DSS) за царевичен хибрид H-708, чрез които ние реализирахме енергетичното равнище L = 15 $J^{1/2}$ $kg^{-1/2}$ в полето през 1981-1988 г. Показателите на еквивалентните енергетични равнища L_e на водния статус (без напояване) са означени в скоби. Ние сравняваме традиционния график, показан долу (Zahariev et al., 1986) с прецизно установените графици за напояване, които са необходими за получаване на 12 t ha^{-1} зърно през всяка година с различни метеорологични условия

Table 3 is on the next page ☞

Year and L_e, $J^{1/2}$ $kg^{-1/2}$	DSS-Irrigation schedules (dates and gross watering rates), m^3 ha^{-1}			Total number of watering	Total irrigation norm, m^3 ha^{-1}
	June	July	August		
1981 (19)	16.06 750	10.07 1100	3.08 1200	3	3050 (+18%)
1982 (16)	24.06 790	24.07 1140	–	2	1930 (+87%)
1983 (20)	2.06 600	–	2.08 17.08 1180 410	3	2190 (+64%)
1984 (25)	27.06 780	15.07 1000	4.08 1220	3	3000 (+20%)
1985 (32)	10.06 28.06 650 850	14.07 30.07 1030 1200	13.08 1200	5	4930 (-27%)
1986 (22)	–	–	6.08 27.08 1230 300	2	1530 (+135%)
1987 (26)	24.06 820	27.07 1190	25.08 420	3	2430 (+48%)
1988 (26)	16.06 700	15.07 31.07 970 1120	18.08 380	4	3170 (+14%)
Mean over 8 years	1	1	1.125	3.125	2780 (29.5%)
Tradition for each year	2 times of watering in decades 1st and 3rd	3 times of watering in decades 1st, 2nd, 3rd	1 watering in decade 2nd	6 times of watering each year	3600 each year

Conclusion

The validated scientific basis combines all models and sub-models, hydro-physical regularities and actual requirements in order to describe the real processes and the special conditions, which form the water status in vadose zone.

We present very brief description of the complete scientific basis that is included in a computerized technology for making decisions to estimate and create an appropriate energy level of soil moisture in vadose zone. New energetic estimate, computerized Decision Support System (DSS) and classification of water status in vadose zone were recently developed and verified.

Some examples of application of the DSS research version in irrigation agriculture are presented. Dependence of the maize yield on the introduced universal estimate of vadose water status is shown for the first time in agricultural sciences and practices.

The new Scientific Basis (SB), as well the developed innovative technology for its application is recommended as a course in Bulgarian and English languages, offering top scientific attainments to students in the Geological Faculty of Sofia University, the Hydro-technical Faculty of University for Architecture, Building and Geodesy, Agricultural University of Plovdiv, etc.

The research version of the Technology for Monitoring, Estimating and Managing (TMEM) the water status of vadose zone can be developed into the Decision Support System to be friendly and easy applicable by scientists in complex research in different areas of geology and by farmers in biological agriculture for wide application in the European Union.

References

Alpatiev, A. M. 1963. *Crop Irrigation Regime*. Moscow, Kolos Publ., 248 p. (in Russian).

Christov, I. D. 1989.Theoretical Basis for Crop Water Management. - *International Agricultural Physics*, 5, 3-4, 261-268.

Christov, I. D. 1991. Soil Water Status Estimation and Current Management Concerning Crop Productivity. D. Sc. (Doctor of Biological Sciences) Dissertation, Faculty of Soil Science, Moscow University, 300 p. (in Bulgarian).
Christov, I. D. 1992. Energy Levels of Soil Moisture and Bioproductivity. - *International Agricultural Physics*, 6, 1-2, 89-94.
Christov, I. D. 2004. *Estimation of Agroecosystem Water Status and Formation of Plant Water Supply in Soils*. Monograph, Series Ecology, PublishScieSet-Eco Publ., Sofia, p. 216 (in Bulgarian).
Christov, I. D. 2008a. Management of Agroecosystem Water Status. Part 1. New Complex Scientific Base. - *Journal of Balkan Ecology,* 11, 1, 5-22.
Christov, I. D. 2008b. Management of Agroecosystem Water Status. Part 2. Organization of Decision Support System (DSS) Application and Advantages. - *Journal of Balkan Ecology*, 11, 2, 137-148.
Christov, I. D. 2008c. Management of Agroecosystem Water Status. Part 3. Adequacy of Decision Support System (DSS). - *Journal of Balkan Ecology*, 11, 3, 229-240.
Christov, I. D. 2008d. Management of Agroecosystem Water Status. Part 4. Relationships among Soil Moisture Energy Level, Soil Water Properties and Biological Features of Crop. - *Journal of Balkan Ecology*, 11, 4, 341-350.
Christov, I. D. 2012. *Monitoring and Management of Agroecosystem Water Status for Protecting Environment and Establishing Sustainable Agriculture*. Sofia, PublishScieSet-Eco Publ., p. 262 (in Bulgarian).
Filippova, A. K. 1964. Results on Soil Moisture in Catchment-basins. - *Scientific Papers of GGI*, 92, 104-118.
Harchenko, S. I. 1985. *Hydrology of Irrigated Lands*. St. Petersburg, GIDROMETEOIZDAT, 342 p. (in Russian).
Hipps, L. E. 1985. Study of the Atmospheric Layer, Which Supplies Heat Energy to Enhance Crop Evapotranspiration under Conditions of Sensible Heat Advection. - In: *Crop Water Requirements*, Versailles, INRA, 167-176.
Idso, S. V. 1986. Atmospheric- and Soil-induced Water Stress in Plants and Their Effects on Transpiration and Photosynthesis. - *J. Theor. Biol*., 21, 1-12.
Kincaid, D. C., D. F. Heermann. 1973. Scheduling Irrigation Using a Programmable Calculation. - *Agric. Res. Service*, USDA.
Kozlowski, T. T. 1978. Water Deficits and Plant Growth. New York. Acad. Press, 323 p.
Leonov, E. A., N. E. Leonova. 1972. Results from Study of Soil Water Regime and Small Reservoirs in Catchment-basin of Don River. - *Scientific Papers of GGI*, 194, 133-154.
Lingova, S. H. 1981. *Radiation and Light Regime in Bulgaria*. Sofia, Bulgarian Academy of Sciences, 228 p. (in Bulgarian).
Zahariev, T., L. Lazarov, S. Koleva, S. Gaydarova, Z. Koychev. 1986. *Crop Irrigation Regimes for Different Regions in Bulgaria*. Sofia, ZEMIZDAT, 646 p. (in Bulgarian).

Постъпила: 06.10.2015
Приета: 07.12.2015

Received: 06 October 2015
Accepted: 07 December 2015