Dynamics of the Available Water in Cinnamonic Forest Soil at Two Kinds of Grain Crops

Milena MOTEVA [1(✉)]
Zhivko ZHIVKOV [2]

Summary

According to many investigations in Bulgaria and abroad irrigation with reduced irrigation depths causes no proportional decrease in crop yield. The water-use efficiency from rainfalls and water applications is greater at smaller depths than at the optimum ones, especially in soils with great water-holding and good capillary properties. This information is worth for farmers from regions with insufficient and variable rainfalls and from countries under hard economic conditions. The main problem is how to obtain maximum production of good quality and of high probability rate to meet the food demand of the population.

The paper presents an investigation of the dynamics of the available for plants water content at irrigation and rainfed conditions within the profile of a cinnamonic red forest soil during the vegetation period of two earthed-up crops – maize and soybean. The soil type is widely spread over the irrigated territories in South Bulgaria and the two crops have strategic share in the grain-forage balance in Bulgaria. They are very responsive to water in the process of yield formation. The yields obtained at different available water probability are well founded and the allowable soil water deficit, considering some economic criteria for each crop, is determined. Some conclusions about irrigation of the two crops in water deficit conditions and practical advises are derived. The work is developed on the base of long-term field experiments in the region of Sofia, Bulgaria.

Key words

cinnamonic red forest soil, water deficit, available water, irrigation, yield, Bulgaria

[1] Research Institute for Land Reclamation and Agricultural Mechanization, NCAS, 3 Shausse Bankya Str., 1331 Sofia, Bulgaria
✉ e-mail: m_moteva@abv.bg
[2] University of Forestry, 10 Kliment Ohridski, Blvd., 1734 Sofia, Bulgaria

Received: June 14, 2006 | Accepted: October 6, 2006

Introduction

Bulgaria is situated in a zone of insufficient and variable soil moisture for crops. Fortunately, soil moisture is one of the dirigible crop growing factors. In dry years and in rain-fed conditions the available soil water is exhausted already at the first decades of June, and in moderate years - not later than the first decade of July. For spring crops, which vegetation period passes along with the driest and hottest months of the year - July-August, irrigation is inevitably needed. Recently, the irrigation water losses are great because the irrigation net was destroyed during the years of Transition in Bulgaria. The water prices are very high. These problems are very serious now due to lack of active state policy for a restoration of the irrigation net and scientific-based management of the irrigation processes. Irrigation nowadays, if done, usually operates with very restricted water quantities, that are not adequate to the crop water requirements. In order to gain maximum production it is necessary to manage the irrigation scheduling on the base of well studied soil hydraulic properties, soil moisture regime, and crop sensitivity to water and water deficit.

The goal of the paper is to make popular the results of some field experiments that will be useful for the farmers in South Bulgaria. The soil type tested is mostly spread over the irrigated territories there. The dynamics of available water during the vegetation period of maize (grain) and soybean per integrated layers at different moisture conditions and for years of different moisture probability was investigated. The impact of soil-moisture on crop productivity is presented by the relationship "yield-evapotranspiration".

Material and methods

Data from two six-year series of field irrigation experiments of maize (grain) and soybean have been processed. The experiments have been conducted in Chelopechene field, Sofia region, Bulgaria, during 1987-1989 and 1996-1998 for maize, and 1988-1990 and 1998-2000 for soybean. Three irrigation depths – 100%, 50%, and 33% of the optimum one, corresponding to three levels of pre-irrigation soil moisture – 80%, 75%, and 70% of soil field capacity (FC), have been experimented for maize. For soybean, experiments with 100%, 80%, 60%, 40% optimum irrigation depth have been conducted during the period 1988-1990, and - 100%, 70%, 50%, and 30% of the same irrigation depth during 1998-2000.

Table 1. Soil texture and hydraulic properties

Depth of the layer [cm]	Size of the particles [mm] ill	sand		Saturation conductivity [cm/day]
	<0.002	<0.001	<0.05	
0-28	32	32	36	93
33-45	43	27	30	15.1
61-71	42	25	33	20.2
95-105	24	15	61	39.9

The soil type is a cinnamonic forest one, representative for the irrigation areas in South Bulgaria. Its texture is clay-loamy (Table 1) (Varlev & Popova, 1999). The saturation conductivity of the 0-35-cm soil layer is much less than in the lower ones and varies from 16 to 21 cm/d. In a precise multiple-layer investigation (Koleva, 1974) it has been found that the 20–40-cm layer is characteristic for higher conductivity and intensive moisture exhaustion. The optimum pre-irrigation soil moisture is adopted to be 80% of field capacity (FC) (Boyanov et al., 1970). The available water amounts per integrated layers are presented in Table 2.

The application depths are calculated by the formula:

$$m = 10H\alpha\left(\sigma^{FC} - \sigma\right) \qquad (1)$$

where: m – application depth [mm]; H – depth of the root zone [m]; α - bulk density of the root zone [t/m^3]; σ^{FC}- field capacity [% of the absolute dry matter of the root zone]; s - pre-irrigation soil moisture [% of the absolute dry matter of the root zone].

The available water over the soil profile was periodically evaluated by a gravimetrical method. The evapotranspiration for the whole vegetation period was estimated by the water-balance method. The two crops were cultivated at standard agrotechnics for the region. The yields were evaluated at 14% standard grain dampness.

The soil moisture depletion during the vegetation period is illustrated and analyzed for two integrated layers– 0-100

Table 2. Available soil water within integrated layers

Depth [cm]	Field Capacity (FC) [mm]	Wilting Point (WP) [% of FC]	Available soil water content (at FC) [mm]	Readily available soil water content (above 80% of FC) [mm]	Available soil water content at 80% of FC [mm]	Available soil water content at 70% of FC [mm]
0-10	30.7	44.2	17.1	6.1	11.0	7.9
0-50	162.0	45.2	88.8	32.4	56.4	40.2
0-100	327.0	50.0	165.0	65.5	99.5	66.8
50-100	165.9	53.8	76.5	33.2	43.3	26.8

and 50-100 cm. This integration is in conformity with the particular soil properties and the distribution of the root systems of the two crops. The first 40 cm of the soil type tested – cinnamonic red forest soil, drys very quickly, as demonstrated in Tables 1 and 2, and by Koleva et al. (1974), especially in hot weather. The root system of maize consistently spreads down to 60-70 cm depth and the moisture of that layer has the essential share in the evapotranspiration of the crop (Varlev & Popova, 1999). Soybean roots are generally concentrated in the first 0.6 m. Depending on the rainfall pattern or if no irrigation is applied, the plants should generally suffer of water deficit during summer months. However, both crops can effectively extract water from depth of 1.7-1.8 m and more. 100% of the water uptake is established in the 1.0-1.7 m for maize and 0.6-1.3 m for soybean (Doorenbos & Kassam, 1979). Proceeding experiments have shown no relevant to the water deficit yield decrease. Therefore, water availability over the whole soil profile at any moment of the vegetation period and at different meteorological and water deficit conditions, especially in its lower 50-100 cm, is a question of interest. Of course, this does not exhaust the question of plant reaction and adaptation to severe conditions. An attempt for finding some external reason for keeping the yields high at great water insufficiency is made.

A regression analysis was used for establishing the yield response to water, i.e the yield response k_y factor from the equation (Doorenboss & Kassam, 1979):

$$\left(1-\frac{Y_a}{Y_m}\right)=k_y\left(1-\frac{ET_a}{ET_m}\right) \qquad (2)$$

where: k_y – yield response factor; Y_a – actual harvested yield from different variants [kg/da]; Y_m – maximum harvested yield in the optimum variant (80% of FC) [kg/da]; ET_a – actual evapotranspiration [mm]; ET_m – maximum evapotranspiration in the optimum variant [mm];

The two experimental periods include years of various meteorological characteristics. The latter are derived from probability curves, based on 50-year rows, prior to 2000. On Fig. 1 the probability curve of the April-October precipitation sums is drawn. Some of the years are very wet (1991, 1996, and 1999) and some - extremely dry (1987, 1997, and 2000). There are years of moderate conditions (1989, 1990, and 1998). Analogously, the irrigation period July-August for 1991 is very wet, for 2000 - very dry, and for 1989 - moderate (Fig. 2). Certain peculiarities occur with 1997 and 1996. Their probability characteristics for the two mentioned periods are different. The April-October period of 1997 is characterized as dry, but the July-August one – as wet. For 1996 it is just on the contrary – April-October is wet and July-August is dry. This means that the essential precipitation amount in 1997 has fallen in July-August, and in 1996 – in spring months.

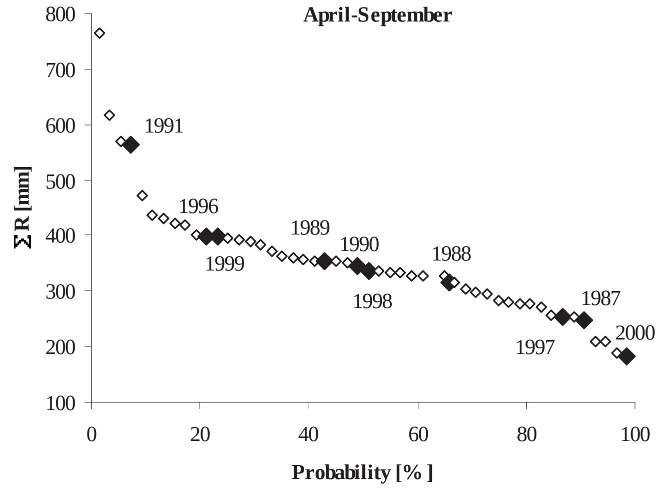

Figure 1. Probability curve of the April-October precipitation sums

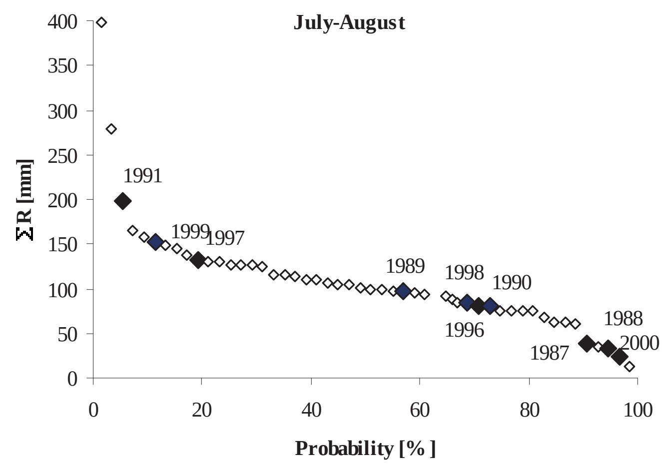

Figure 2. Probability curve of the April-October effective temperature sums

Results

The dynamics of soil moisture during the vegetation period and its availability for plants are demonstrated for years of different moisture characteristics. As water supply for plants in wet years is guaranteed, they are disregarded in this analysis and the investigation starts with the year of moderate conditions – 1989. The probability of the April-October precipitation sum in 1989 is 43%, and of the July-August one – 57%. The dynamics of soil moisture in 1989 under maize crop is represented in Fig.3. A dense line with circles marks the available water in the 1-m soil layer and a dashed one with triangles – the available water in the 50-100-cm layer. Further, the two dense horizontal lines show the levels of the pre-irrigation soil moisture: 80%-of-FC and the 70%-of-FC, respectively. The latter is often permitted on farm level. Analogously, the

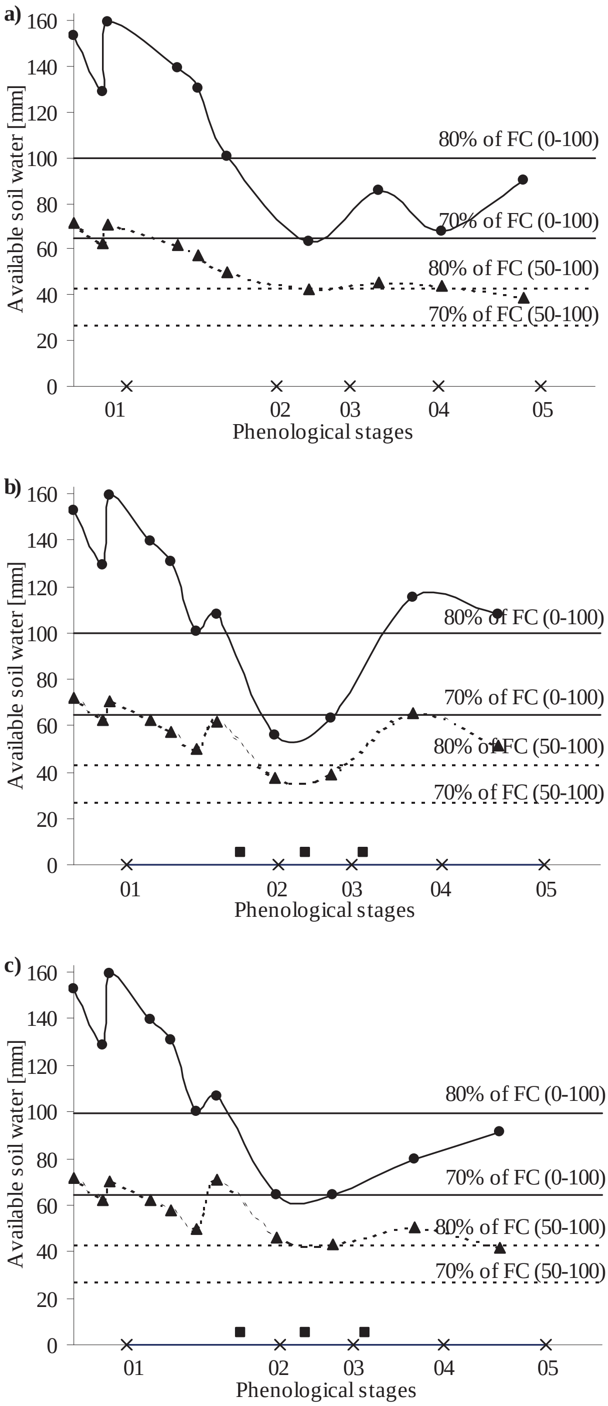

Figure 3. Dynamics of soil moisture for maize in 1989: a) rainfed conditions; b) irrigation with 50% of the optimum irrigation depth; c) irrigation with 33% of the optimum irrigation depth

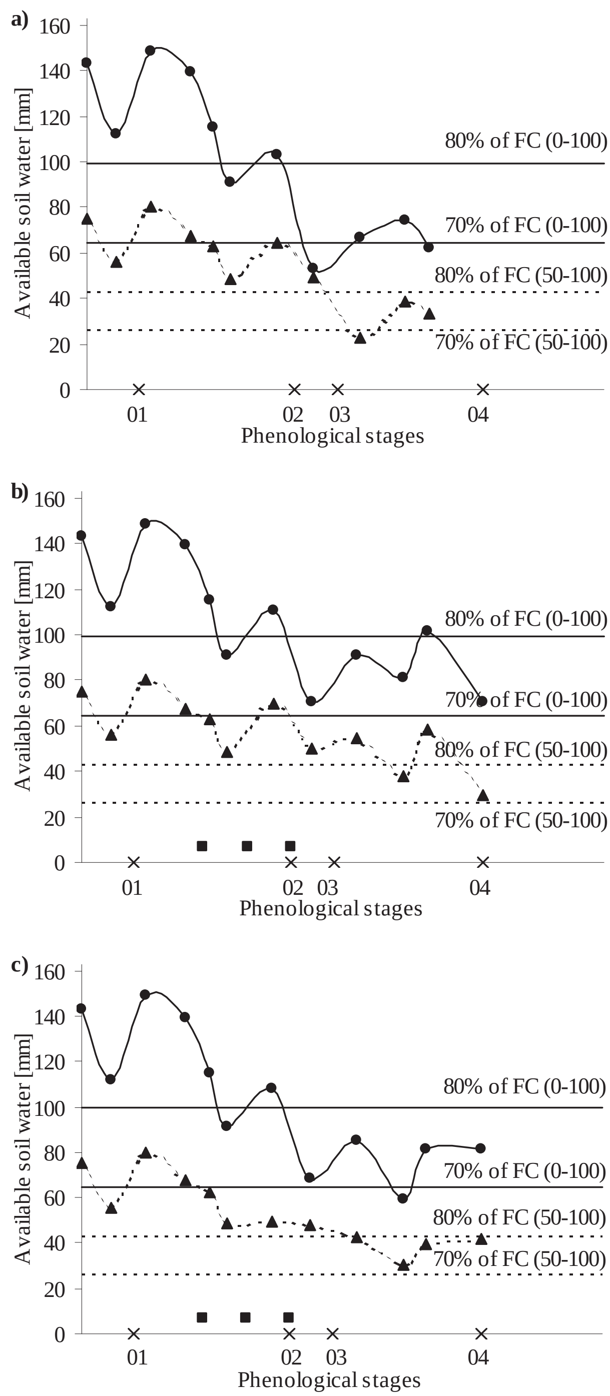

Figure 4. Dynamics of soil moisture for soybean in 1989: a) rainfed conditions; b) irrigation with 60% of the optimum irrigation depth; c) irrigation with 40% of the optimum irrigation depth

dashed horizontal lines show the same moisture levels of the 50-100-cm layer.

The optimum water supply conditions are not of interest, because soil moisture varies within the boundaries of the readily available water. Therefore, three cases of moisture conditions are chosen – rainfed conditions (case (a) in Fig. 3), irrigation with 50% of the optimum irrigation depth (case (b) in Fig. 3), and irrigation with 33% of it (case

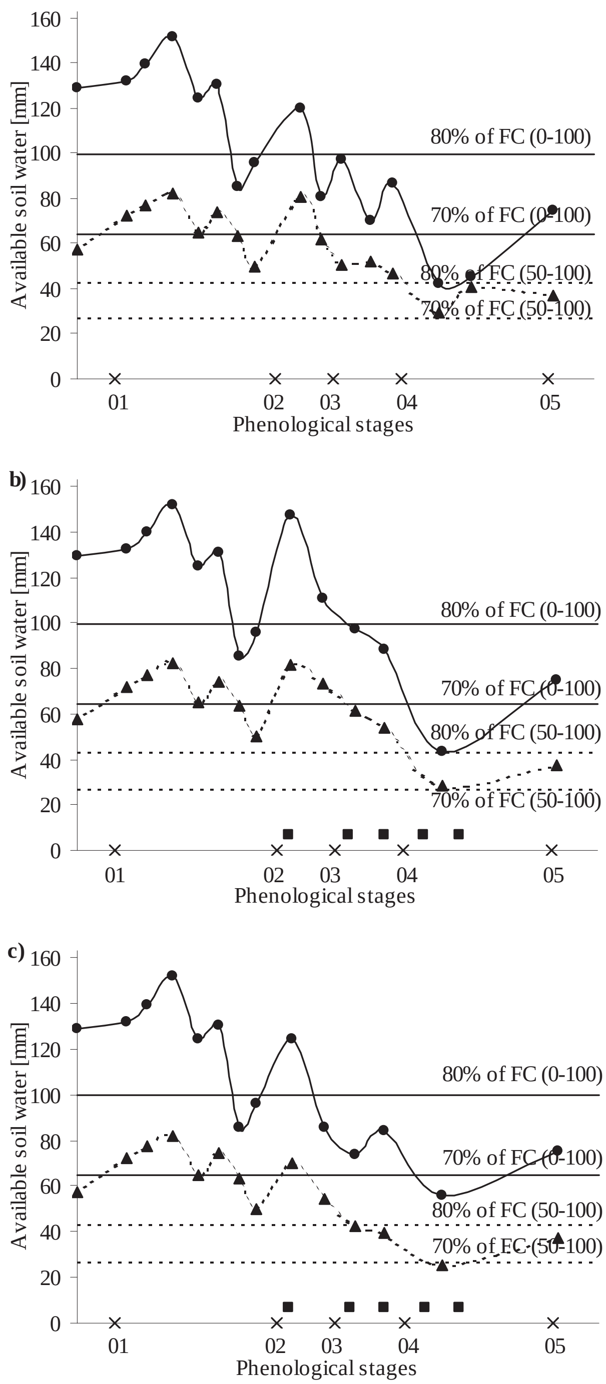

Figure 5. Dynamics of soil moisture for maize in 1987: a) rainfed conditions; b) irrigation with 50% of the optimum irrigation depth; c) irrigation with 33% of the optimum irrigation depth

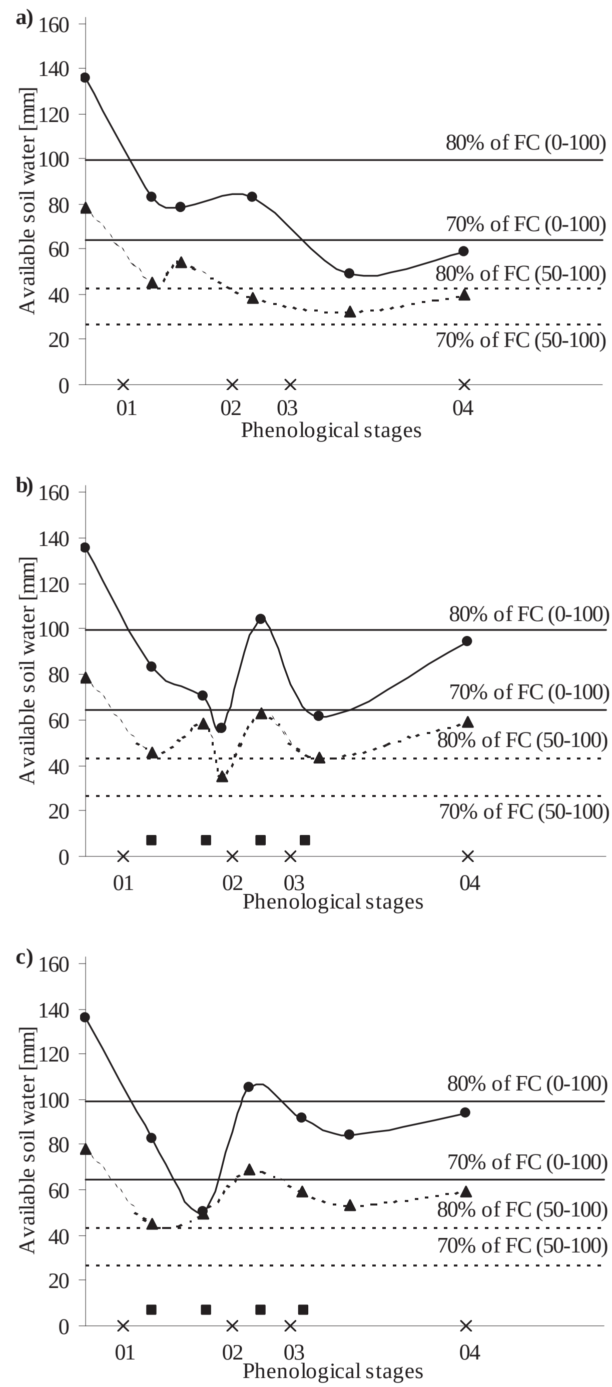

Figure 6. Dynamics of soil moisture for soybean in 2000: a) rainfed conditions; b) irrigation with 50% of the optimum irrigation depth; c) irrigation with 30% of the optimum irrigation depth

(c) in the same figure). Analogously, for soybean - rainfed conditions, irrigation with 60% and 40% of the optimum irrigation depth are illustrated on Fig 4abc.

The vegetation period shown in the above-mentioned figures is represented in biological coordinates, i.e. the crop phenological development. The codes refer to the following phenological stages: for maize: 01 – emergence; 02 – vegetative (9^{th} leaf) stage; 03 – tasseling; 04 – milk maturity; and 05 – wax maturity; for soybean: 01 – emergence; 02 – mass flowering; 03 – pod filling; and 04 - ripening. The

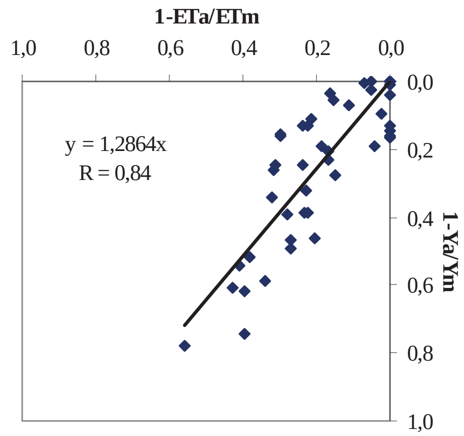

Figure 7. Yield-evapotranspiration relationship for maize

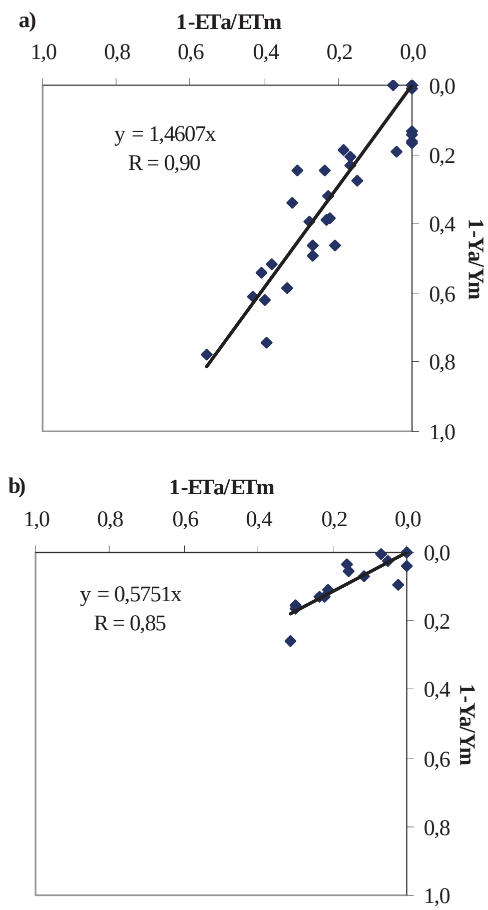

Figure 8. Yield-evapotranspiration relationship for maize: a) dry years; b) wet years

little squares near the horizontal axis in (b) and (c) cases in the figures denote the time of giving an application.

In Fig. 5 and 6, the depletion of the available water during the vegetation period in 1987 for maize and in 2000 for soybean is presented. Considering the probability rows, these years are very dry. The probability of the April-October precipitation sum in 1987 is 91% and in 2000 – the greatest one – 99%. 2000 is the driest year in the preceding 50-year period. The July-August precipitation sum has 91% probability in 1987 and 97% in 2000. These two years are chosen to derive certain conclusions about soil moisture dynamics under maize and soybean in extremely dry conditions. The (a), (b), and (c) cases are the same as in Fig. 3 and 4. There are certain differences in (b) and (c) cases for soybean. The applied irrigation depths are 50% and 30% of the optimum one.

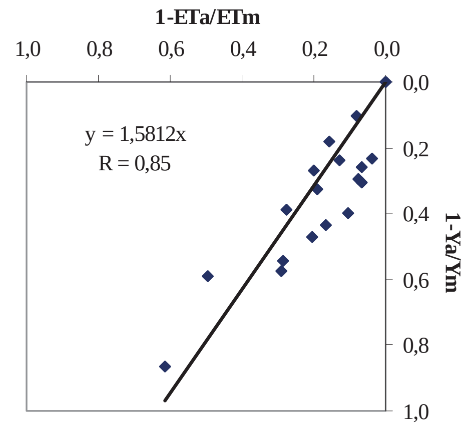

Figure 9. Yield-evapotranspiration relationship for soybean

The impact of the water deficit applied on the yields is illustrated in Fig. 7 for maize and Fig. 9 for soybean. The relative evapotranspiration deficit is plotted against the relative yield decrease. On the base of all experimental data obtained, k_y factor for both crops is established – 1.28 for maize and 1.58 for soybean. The results correspond to those of other authors in Bulgaria (Varlev and Popova, 1999; Mladenova-Stefanova and Petrova, 2001). The same dependence is drawn for dry years on Fig. 8a and for wet years - on Fig. 8b.

Discussion

The cinnamonic forest soils are the essential soil types in the irrigated lands in South Bulgaria. Therefore, the spring grain crops are predominantly grown on them. As it is seen from this investigation, they are very suitable for crops with deeply spread root system. The surface tilled 0-20 cm layer is nonstructural and allows minimum water transition from the deep layers to the soil surface. Thus, the evaporation losses from the deep layers are considerably restricted. Soil moisture is kept in the lower layers and is used mainly for transpiration, i.e. for yield formation. The lines of depletion of the available water content in the 50-100-cm soil layer in a year of moderate meteorological conditions (1989), drawn in Fig. 3 and 4, show that soil moisture hardly subsides the 70%-of–FC boundary. It happens just at the end of the growing season for both crops – nearly at wax maturity of maize and ripening of soybean, when water is not the limiting factor for yield formation. At rainfed conditions [(a) – cases in Fig. 3 and 4] this decrease in soil water content occurs a bit earlier – at milk maturity of maize and pod filling of soybean, but water for plants at this moisture level is readily available. The (b) and (c) cases demonstrate the moisture conditions at small irrigation depths. It is obvious that maize and soybean may successfully be grown up on this soil type in moderate moisture conditions, as there is enough moisture for them in the lower layers. The line of the water exhaustion in the 1-m root zone crosses the 80%-of-FC level line before tasseling of maize and flowering of soybean. As the presenting moisture depletion lines of the two integrated layers are not parallel and the moisture depletion in the 0-100 cm layer anticipates that in the 50-100-cm one, it is clear that the drying of the soil profile runs mainly in the surface layers.

Soil moisture dynamics during the vegetation period in very dry years is presented in Fig. 4 and 5. It is seen that even under rain-fed conditions and at very small irrigation depths the deep soil layer keeps enough moisture for both crops.

The yield results from irrigation with reduced application depths, which causes accumulation of water deficit during the whole vegetation period, show that crop growth and development are not seriously disturbed. Though the high sensitivity of both crops to water, the decrease of the yield is not adequate to the water deficit applied (Fig. 7 and 9). The k_y factor in equation (2) results in 1.29 for maize and 1.58 for soybean. These values may be considered proof because in the regression analysis a great number of data points have been processed, and the correlation coefficients are very high – 0.84 for maize and 0.85 for soybean. As air humidity in Bulgarian climate conditions is insufficient for optimum growing of the two experimented crops, they manifest higher sensibility to water than in the cases, cited by FAO. Therefore k_y values are higher than the recommended ones by Doorenbos & Kassam (1979), especially for soybean. The latter refers to the most sensible to water in our climatic conditions crops with k_y>1.

The investigation of maize sensibility to water in dry and wet years shows higher sensibility in dry years - k_y=1.46 at R=0.90 (Fig. 8a), and considerably smaller sensibility in wet ones - k_y=0.58 at R=0.85 (Fig. 8b).

Conclusions

1. Soil-moisture regime in the cinnamonic forest soils in Bulgaria permits successful growing of maize and soybean even in very dry years. This is due to the fact that the surface nonstructural layers restrict the evaporation from the lower layers. The accumulated there moisture is spent to the highest degree for transpiration. In very dry years, soil moisture in the 50-100-cm layer hardly subsides 70% of the field capacity and even under rainfed conditions there is easily available water for plants until tasseling for maize and flowering for soybean.
2. In Bulgarian climate conditions maize and soybean manifest high sensitivity to water. The k_y factor in the FAO 'relative yield decrease-relative evapotransiration deficit' dependence is 1.29 for maize and 1.58 for soybean. The correlation between the experimental data and the approximating functions is very high. The sensitivity is incomparably greater under dry weather conditions than under wet ones.

References

Boyanov P., Tatarova-Krasteva V., Koleva S. 1970. An investigation of the admissible minimum soil moisture at irrigation conditions. Soil Science and Agrochemistry, 5(2):9-17 (in Bulgarian)

Doorenbos J., Kassam A.H. 1979. Réponse des rendements ŕ l'eau. Bulletin FAO d'irrigation et de drainage No. 33, Rome, 144 pp.

Koleva S. (1974) An Investigation of the Water Exchange within the system soil-plant-atmosphere. Thesis. Petersburg, 153 pp. (in Russian)

Mladenova-Stefanova B., Petrova V. 2001. Relationship 'water-yield" at maize and possibilities for economic use of irrigation water. 19th Regional Conference of ICID, Chesh. Republic, 4-8 June, CD Version

Varlev I., Popova Z. 1999. Water-Evapotranspiration-Yields. Sofia, 144 pp. (in Bulgarian)

acs72_08