

# DETERMINATION OF THE WATER INFLUENCE ON THE CROP DEVELOPMENT COEFFICIENTS

Mitev G.V.

## ОПРЕДЕЛЯНЕ ВЛИЯНИЕТО НА ВОДАТА ВЪРХУ КОЕФИЦИЕНТИТЕ НА РАЗВИТИЕ НА РАСТЕНИЯТА Митев, Г.В

**Abstract:** *The water is involved in all physiological processes and is extremely important for the growth and development of plants and for the formation of yields. Due to the growing variations in the climate, resulting in intense rainfall, followed by prolonged dry periods, crop-developed sustainable crops can only be achieved by efficient water use. The alternatives for water use have been considered, with the necessary quantities determined in different ways of supplying water.*

**Keywords:** *water, plant growth factors, alternatives to water use*

### Introduction

The ability of the soil to retain water directly addresses the possibilities and retains the water required for the plants in the corn-soaked soil layer. After rainfall or irrigation, the soil reaches its marginal land moisture (FC) and then begins draining, [4, 5, 7, 9]. Soil water balance is a procedure for calculating the incomes and costs of water needed for cultivation of cultivated plants [8, 10, 18]. The main part of the incoming water comes from natural rainfall. Geographer C. W. Thornthwaite (1899-1963) first used the water balance approach in the soil. In order to understand correctly the concept of water balance in the soil, its component components must be elucidated [2, 3, 6].

The growth and development of a culture can be described by the coefficients that represent a stage of development and the equation [12, 16, 33, 40]:

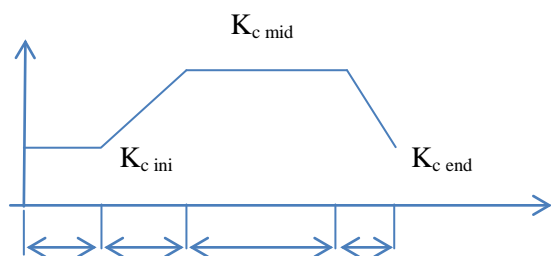
$$K_c = K_s K_{cb} + K_e \quad (1)$$

Where  $K_c$  is the coefficient describing the crop under consideration;

$K_s$  - the coefficient describing the stressful conditions under which the crop under consideration is developing;  
 $K_{cb}$  - the main coefficient representing the crop under consideration, providing optimal growth and development conditions;

$K_e$  - the coefficient describing the evaporation of water in the soil.

Applying the Double Coefficient Approach the approach to describing the growth and development of plants using double factors requires the daily values for the evapotranspiration in the upper soil layer to be determined.



**Fig.1.** Presentation of the stages of growth and development of plants through the specific coefficient for the respective crop

The more commonly used approach is to use the effect of calculating the evapotranspiration in the upper layer of the soil over a period of several days (seven or ten days), equation (2).

$$K_c = \overline{K_{cb}} + K_e \quad (2)$$

Where:  $K_c$  is the coefficient describing the development of plants under specific conditions.

This approach is used for precise planning, irrigation design, and typical irrigation management activities. It is used in a number of simulation modeling schemes such as WinISAREG, [31, 37].

The approach for describing the growth and development of plants through the mean values of the coefficient  $K_c$  over time is presented in Figure 1, which shows the change of the coefficient values during the vegetation period. At the beginning, when about 95% of the plants have emerged, the values of  $K_{c\ ini}$  are low, [43].

There follows a rapid increase in the coefficient corresponding to the stage of rapid growth of plants. The maximum values of the coefficient are observed in the middle of the growing season or at the maximum development of the plants. The period in which  $K_c = K_{c\ mid}$  is defined as the period of accumulation of the yield.

When going to the end of the extraction period, the plants pass into the so-called. Technological maturity, i.e there is a moment in which the process of picking can begin. The values of  $K_c$  decrease and reach low values at the end of the vegetation period,  $K_{c\ end}$ , (Allen et al., 1998; Pereira and Allen, 1999; Allen et al., 2005a) [11,13,17].

The evaporation (the loss of water from the soil) is a dominant component in the initial period of plant growth, and therefore the coefficient  $K_{c\ ini}$  depends on the frequency of wetting of the soil surface.

The coefficient  $K_{c\ ini}$  is calculated by the model in which the equilibrium of the plant (living or plant residue) soil is expressed in two different stages (Allen et al., 1998; 2005b, Pereira and Allen, 1999). In the first stage, the exposure is limited by the available energy in the surface soil layer. In the second stage, the evaporation depends on the available water in the soil. The depth of water evaporation,  $D_e$ , is determined by the amount of REW for the first stage and the total TEW for Stage 2 evaporation water.

The coefficient  $K_{c\ ini}$  is determined by equation 3 when the water supply interval  $t_w$  is less than the duration of the drought stage 1,  $t_1$ , ( $t_w \leq t_1$ ), i.e. when the process Found in the early stages of plant growth, [14, 26, 27,].

$$K_{c\ ini} = \frac{E_{so}}{ET_{o\ ini}} = 1.15 \quad (3)$$

where:  $E_{so}$  is the potential evaporation (potential evaporation) of the soil, [mm];

$ET_{o\ ini}$  - the reference equation for the initial period when  $t_w > t_1$ , [mm].

Under these conditions, for the coefficient  $K_{c\ ini}$  the equation can be written[11]:

$$K_{c\ ini} = \frac{TEW - (TEW - REW) \exp\left[\frac{-(t_w - t_1) E_{so} \left(1 + \frac{REW}{TEW - REW}\right)}{TEW}\right]}{t_w E_{so\ ini}} \quad (4)$$

Where TEW is the total quantity of water available for evaporation in the soil, [mm];

REW - actual water available for evaporation in the soil, [mm];

$t_w$  - the average duration of the time interval in which soil moisture is applied, [h];

$t_1$  - period of the first stage of plant growth, [h]; The duration of step 1 =  $t_1$  (soil drying) is determined by the equation:

$$t_1 = \frac{REW}{E_{so}} \quad (5)$$

The average duration of the sludge application interval is:

$$t_w = \frac{t_{ini}}{n_w} \quad (6)$$

Where  $t_{ini}$  is the length of the start period, [h];

$n_w$  - the number of events in which the soil has entered (ie rainfall count and / or number of irrigations).

The depth of evaporation of water from the soil is determined by the percentage of sand and clay, such as:

$$REW_{est} = 0 - 0.15S_a \text{ корато } S_a > 80 \quad (7.a)$$

$$REW_{est} = 11 - 0.6CL, \text{ корато } CL \geq 50 \quad (7.6)$$

$$REW_{est} = 8 + 0.08CL, \text{ корато } S_a < 80 \text{ и } CL < 50 \quad (7. б)$$

Where  $S_a$  is the percentage of sand in the evaporable soil layer at depth of [%];

CL - the percentage of clay in the evaporable soil layer at depth, [%];

In the case of the initial soil temperature,  $ET_{o\ ini} \geq 5$  mm/d the total quantity of vaporizable water, TEW, is determined by equation (8)

$$TEW_{est} = 1000(\theta_{FC} - 0.5\theta_{WP})Z_e \quad (8)$$

When  $ET_{o\ ini} < 5$  mm/d then

$$TEW_{est} = 1000(\theta_{FC} - 0.5\theta_{WP})Z_e \left(\frac{ET_{o\ ini}}{5}\right)^{0.5} \quad (9)$$

The values of REW and TEW should be corrected when the amount of water in the evaporable soil layer is low [11]. In this way, it is possible to determine the depth of absorption of water in the soil supplied by natural rainfall ( $P_n$ ) and irrigation ( $I_n$ ) corresponding to the number of irrigations ( $n_w$ ).

$$P_{mean} = \frac{(\sum P_n + \sum I_n)}{n_w} \quad (10)$$

Where  $P_{mean}$  is the depth of water absorption in the soil, [mm];  $P_n$  - the quantity of water supplied by the valves, [mm];

$I_n$  - the quantity of water supplied (by irrigation) artificially, [mm];  $n_w$  - the number of irrigation events, [number].

Each value of  $P_n$  and  $I_n$  must be limited by the conditions  $P_n \leq TEW$  and  $I_n \leq TEW$ . By establishing the presence of water in the evaporable soil layer on the first day (i.e., the first day after sowing), the values of REW and TEW are determined by equations 11 and 12.

$$REW = REW_{est} \left[ \min \left( \frac{P_{mean} + \frac{W_{ini}}{n_w}}{TEW_{est}} + 1 \right) \right] \quad (11)$$

$$TEW = \min \left[ TEW_{est} \left( P_{mean} + \frac{W_{ini}}{n_w} \right) \right] \quad (12)$$

Where  $W_{ini}$  is the presence of water in the evaporable soil layer on the first day of the reporting period, [mm].

When only part of the soil surface is moistened, such as furrowing, by using drifting systems or drip irrigation, the values of  $I_n$  must be corrected only for the part of soil  $f_w$ , to which water is supplied

$$I_n = \frac{I}{f_w} \cdot 100 \quad (13)$$

Where  $f_w$  is the part of the water to which the water is supplied [%]; Therefore, the values for  $K_{c\ ini}$  defined by equations 3 and 4 must be reduced in accordance with  $f_w$ , equation 14.

Therefore, the values for equations 3 and 4 must be reduced in accordance with equation 14.

$$K_{c\ ini} = (K_{c\ ini} \overline{K_{cb} + K_e}) f_w \quad (14)$$

The use of equations (13) and (14) requires further verification and confirmation as TEW is determined by the soil water retention value,  $Z_e$ , while REW is determined by the texture characteristics of the soil and can easily be recalculated, [15,30,36]. A methodology for graphical determination of  $K_{c\ ini}$ , (Allen et al., 1998) was developed and TER values were determined empirically for REW determination

$$REW = \frac{TEW}{TR} \quad (15)$$

In the case of  $ET_o \geq 5$  mm d<sup>-1</sup>, the ratio of TER is expressed by equation 12, but if  $ET_o < 5$  mm d<sup>-1</sup>, an equation should be used, (16).

$$TR = 4 - [0.05 - 0.002(TEW - 15)](P_{mean} - 10) \quad (16)$$

$$TR = 4 \sqrt{\frac{ET_o}{5}} - [0.05 - 0.002(TEW - 15)](P_{mean} - 10) \quad (17)$$

Thus, the mean depth of soil moisture,  $P_{mean}$ , (equation 12) and the vaporized TEW, from the surface soil layer, is expressed.

The  $K_{c\ mid}$  and  $K_{c\ end}$  maturity coefficients are defined by Allen et al. (1998). They correspond to irrigation frequency and rainfall and are characteristic of the subtropical regions where  $RH_{min} = 45\%$  and  $u_2 = 2$  m s<sup>-1</sup>. When climatic conditions differ from these values, it is necessary to adjust the values for  $K_{c\ mid}$  and  $K_{c\ end}$ .

The following equations 18 and 19 are used for this purpose.

$$K_{c\ mid} = K_{c\ mid\ (tab)} + [0.04(u_2 - 2) - 0.04(RH_{min} - 45)] \left(\frac{h}{3}\right)^{0.3} \quad (18)$$

$$K_{c\ end} = K_{c\ end\ (tab)} + [0.04(u_2 - 2) - 0.04(RH_{min} - 45)] \left(\frac{h}{3}\right)^{0.3} \quad (19)$$

Where  $u_2$  is the average daily wind speed value for the beginning of the period, [ms<sup>-1</sup>];

$RH_{min}$  - the average daily moisture value of the soil for the beginning of the period, [%];

$h$  - the height of the plants, [m]. Indicative values of plant height are given by Allen et al. (1998) and Pereira and Allen (1999).

No adjustments to the  $K_{c\ end}$  are required when its values do not exceed 0.45, i.e., When the plants are allowed to cease their vegetation and dry out in the fields. In the absence of minimum humidity data  $RH_{min}$ , they can be calculated from equation 20 [11]:

$$RH_{min} = \frac{100 e^0(T_{min})}{e^0(T_{max})} \quad (20)$$

Where  $e^0(T_{min})$  is the value of the saturated vapor pressure at a minimum temperature;

$e^0(T_{max})$  - the value of the saturated vapor pressure at the maximum temperature.

The amount of water in the soil before the plants are subjected to water stress ( $p$ ) is defined as the mean value of the water present in the root zone and which can be reduced to such an extent that the plants are subjected to water stress. Consequently, soil water content is a critical point to be taken into account when presenting irrigation recommendations and defining irrigation schedules. Also, the plant water stress factor can be determined in this way [11].

Consequently, the  $p$  criterion appears to be fundamental in the simulation models for determining irrigation schedules and irrigation norms. The values for the main crops are also presented.

$$p = p_{tab} + 0.04(5 - ET_c) \quad (21)$$

But is limited to  $0.1 \leq p \leq 0.8$ .

For the initial period of plant growth, the value of  $p$  is taken as  $p \leq 0.6$  to ensure good water supply of the plants (Allen et al., 1998) [156].

#### Exposition

The WINISAREG program (developed by Teixeira and Pereira, 1992, [37]) determines soil water balance by processing a combination of soil, crop and meteorological data (rainfall, air temperature, direction and velocity The wind, the loss of water from

the soil and the plants (evapotranspiration), so it is possible to develop a schedule for use and supply of water for the needs of the plants in the various stages of their growth and development.

The reference  $(ET_a)$  is determined by FAO 56 methodology using the Penman-Monteith method (Allen et al., 1998). For this purpose, an EVAP software 56, [11] is used. Plant information was processed using a KCISA software product, [Rodrigues et al., 2000], [43].

The crop development coefficients in their individual periods (Kc) and the factor describing the reduction of water to the stress conditions MAD (p) is determined for the climate in Bulgaria for the period 2012-2016.

Soil, climate and plant data have been collected and systematized for Northeastern Bulgaria [1, 2, 7, 9, 38, 39, 41, 42].

**Options for simulating the water consumption of plants.**

The WINISAREG program offers two basic simulations aimed at:

Use of water to obtain maximum yield; Delivering water at a specified time and quantity. The first option provides basic information on the presence of water in the surface soil layer as well as in the lower layers of root system development. The presence of water is represented as a percentage of the total amount of water available (% TAW). The limitations are expressed in the number of days before the beginning of the harvest, during which the supply of water is stopped for the purpose of obtaining quality produce.

The second option offers alternatives to fix the time for water delivery and quantity. This wide range of alternatives makes it possible to evaluate the alternatives and the results of the simulations.

**Planning the simulation models**

Simulation planning is designed to find optimal conditions where maximum yields can be obtained at maximum efficiency of water use. Maximum efficiency of water use is locked in minimizing delivery costs and minimizing deep water penetration below the root system area. Ie. Maximum water efficiency can be obtained in the following cases:

- Preservation of water from precipitation in the cornobondable soil layer;
- Avoiding movement of water in the lower layers of the soil and becoming unusable;
- Reduce the evaporation of water from the surface of the soil.

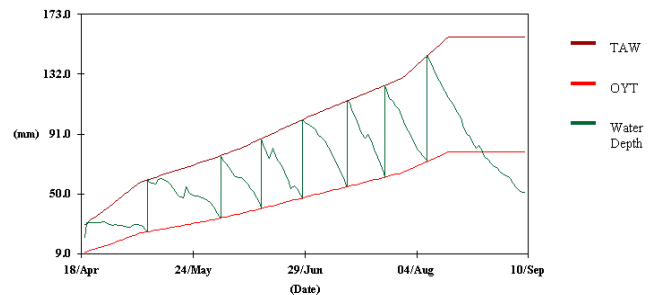
Comparing strategies to simulate the use of water for plant needs.

In order to obtain practical water use schedules for the needs of plants, several (simulated) alternatives have been developed.

All alternatives refer to crops grown in one place, such as corn, sunflower, soybean and alfalfa.

First alternative: Need for water to maximize yield. By supplementing the "soil reservoir", ie the volume of soil occupied by the root system of the plants, up to the level of PPP, water supply can be optimized to maximize yields and maximize water efficiency without Negative phenomena such as surface runoff and / or water penetration below the root system area. In order to determine the optimum yield threshold, the optimal yield line (OYT) is used as the lower limit for the reduction of water in the soil. The upper limit is the capacity of the soil to retain water, i.e., FC.

Consequently,  $(TAW = \theta_{FC})$ . The water quantity change ranges in the interval between TAW and OYT  $(OYT \leq D_{r,i} \leq TAW)$ . The simulation of data for one year shows the following results, fig. 2. Due to the decrease of the water in the soil in the initial period of the plant development, the delivery must take place on May 10 with a quantity of 35.6 mm. The second water supply is after 23 days with an amount of 42.7 mm, and so on.



**Fig.2.** Graphical presentation of a schedule for water supply for plant use, 2015 for maize to maximize yield

The irrigation events are seven (7) and the total amount of water required to deliver (in addition to fallen rainfall) in order to obtain a maximum yield is 373.50 mm. The necessary information that each user should receive is presented in Table 1. Additional information needed to analyze water consumption is presented in Table 2.

**Table 1.** Needs of plant water presented as a simulation delivery schedule obtained using WINISAREG

No	Date of delivery	Quantity	Deep percolation under the root zone
		[mm]	[mm]
	10/05	35.6	0
		0	
	03/06	42.7	0
		0	
	16/06	47.7	0
		0	
	29/06	53.5	0
		0	
	14/07	58.8	0
		0	
	26/07	62.8	0
		0	
	01/08	72.3	0
		0	
O: ВСИЧК		373.	0
		50	
Average delivery interval, [days]			1
			2
Yields reduction due to the water stress, [%]			2

**Table 2.** Data obtained by the simulation models

No	Parameters	Dimension	Value
1	Really available water, (RAW)	[mm]	10.20
2	Really available water on the season end,	[mm]	0
3	Total available water in the down soil layer at the beginning of the season (drilling)	[mm]	20.40
4	Total available water in the next soil layer at the beginning of the season (drilling)	[mm]	64.20
5	Total available water at the beginning of the season	[mm]	20.40
5	Total available water at the end of the season	[mm]	51.10
6	Deep percolation under the root zone	[mm]	0.00

7	Accumulated rains during the vegetation period	[mm]	92.30
8	Not use water during the season	[mm]	0.00
9	(Max evapotranspiration)	[mm]	507.80
10	Actual evapotranspiration during the season	[mm]	499.30
11	Relationship ETa/ETm	[-]	0.98
12	Underground water contribution	[mm]	0.00
13	Maximum water consumption on the day 22/07	[l. s-1d-1]	0.559

Simulation of water consumption for 4 crops such as maize, sunflower, soybeans and lucerne for the period 2006 - 2016 shows the following results, fig. 3.

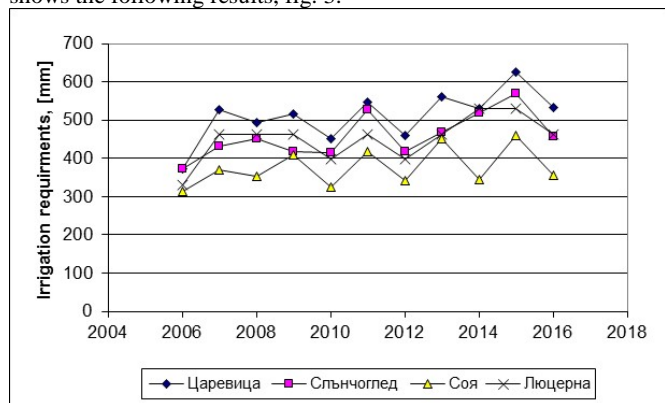


Fig. 3. Annual water requirement for corn, sunflower, soybeans and alfalfa to maximize yield

Alfalfa requires minimum water volumes of 331 mm in 2006 and reaches a maximum of 529 mm in 2015. At the same time, corn needs a minimum of 527 mm of water and rises to 547 mm per year, reaching values of 624 mm over 2015, which is the largest water consumption for this ten-year period. Sunflower needs water in the range of 452 - 568 mm, (see Table 3). Frequency analysis shows that in years with low consumption of 50%, the need for water supply ranges from 356 mm to 527 mm for all crops, fig. 4.

In years with high water consumption (75%) it reaches values from 418 to 547 mm, and in years with very high consumption (90%) (dry years) ranges from 460 to 624 mm.

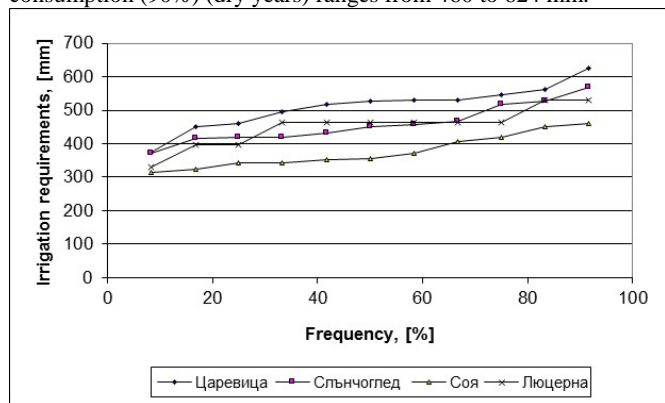


Fig. 4. Frequent analysis of the distribution of the need for water for growth and development of plants in order to obtain maximum yield for the period 2006-2016 for the district of BRS Blachlen, Ruse.

Second alternative: Simulation of water in the root system up to 85% of the total water available (85% TAW)

In this case, the planning of the simulation experiment and the subsequent analysis show that soil moisture should be reduced by 30% of the TAW value and further supplemented to 85% of the TAW value. It can immediately be assumed that the number of water supplies and the total amount of water required for plants is

expected to decrease. At the same time, the yields are expected to decrease by about 9 - 13%, Figure 5.

Compared to the data presented in Table 2, the number of water supplies (irrigation) over the same period of time for maize will be reduced from 7 to 6 and annual water consumption from 527 to 347 mm. At the same time, the reduction in yield due to the lack of sufficient water ranges from 1 to 16% for the selected years with low, medium and high water consumption.

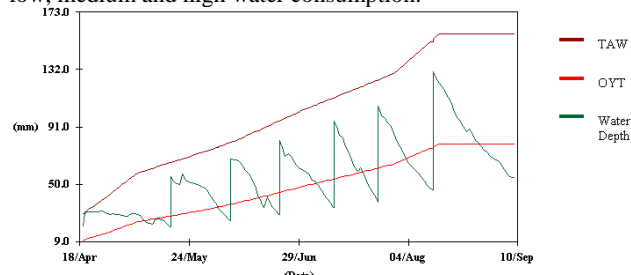


Fig. 5. Simulate a change in the amount of water available to plants when water available to plants decreases by 30% of TAW and the next water supply is to complement 85% of TAW

The comparison for the reduction of the yields between the simulated crops is presented in Fig. 6.

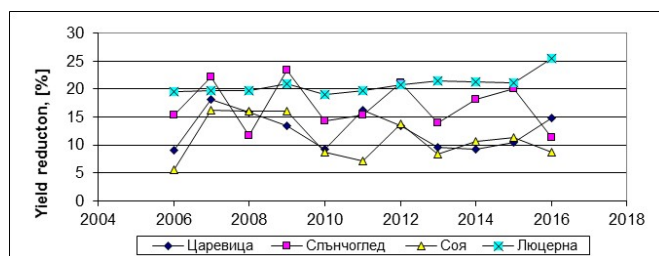


Fig. 6. Loss of yields for simulated cultures at TW reduction to 30% and supplementation to 85% of TAW

Third alternative: Water supply at fixed dates. The supply of water for plant needs at fixed dates as a percentage of TAW has two options:

The first is that the Management Allowable Depletion (MAD) is equal to the p portion of the TAW, which can be reduced in the root system area to the extent before the water stress (MAD = p), Fig. 7.

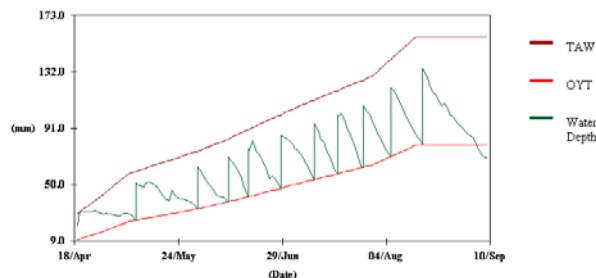
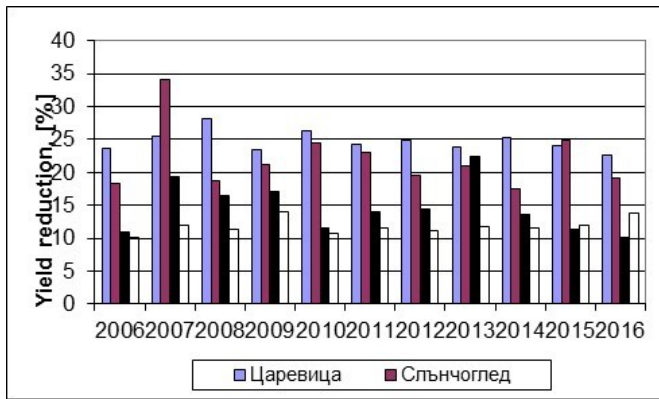


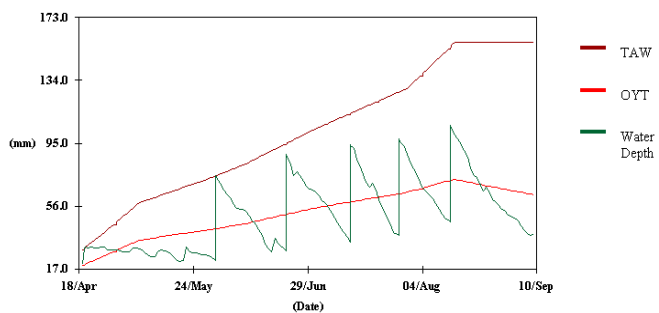
Fig.7. Simulate the net quantities of water to be delivered on fixed dates when MAD = p

The difference between Figures 2 and 7 is within the upper bounds of the set limits. In the first case, (Figure 2), water is supplied to the water to reach PPP (100% FC) and the subsequent delivery is in an amount equal to 85% of the FC. Amounts of water required for plants ranged from 337 mm at the lowest level of consumption to 499 mm for average consumption, 550 mm for high and 574 mm for very high water consumption for corn. Similar results are obtained for other cultures. In the second embodiment, it is required to start supplying water when MAD < p and reaches values that would be set according to the experience of the conducting simulation. The reduction in yields due to the water stress obtained when MAD < p for the crops studied is shown in Fig. 8.



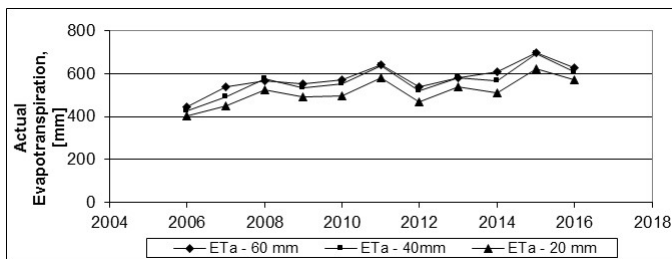
**Fig. 8.** Reduction in yields due to water stress caused by the use of MAD <math>p</math> as a water supply strategy

Fourth alternative: Water supply in fixed quantities Simulation planning was done at 60, 40 and 20 mm. The quantity of water supplied by 60 mm is widely used in practice for the studied crops, fig. The remaining 40mm and 20mm quantities are selected based on mathematical calculations aiming obtaining wide spectrum of possibilities for analysis.

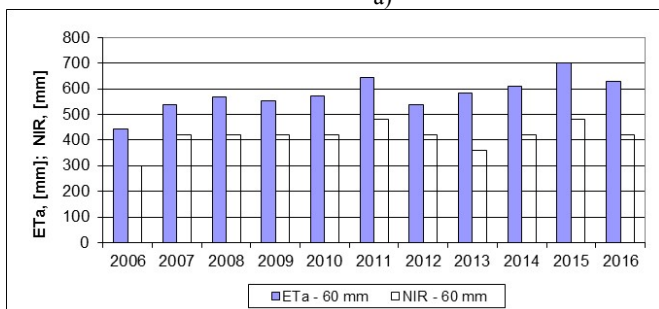


**Fig. 9.** Simulate supply of water for plants at a fixed amount of 60 mm for maize.

The comparison for the actual evapotranspiration and the water supply recommendations for the 60 mm fixed amount for the maize culture studied is presented in Fig. 10. The simulation procedure performed on other crops shows that the best results are obtained with alfalfa, with yield losses ranging from 8 to 12%. Soybeans should not be irrigated with such large irrigation regulations due to the penetration of water under the root zone. It is logical to observe and inefficient use of precipitation.



a)



b)

**Fig.10.** Comparison of the simulated actual evapotranspiration when a crop (corn) is irrigated with 20, 40 and 60 mm of water in: (a), actual evapotranspiration; (b) the need for water

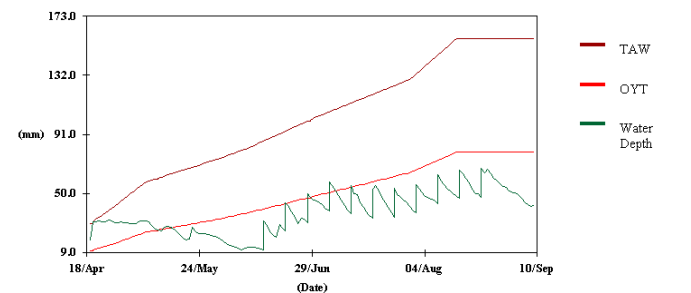
In the typical years of this crop, representing 50%, 75% and 90% of the water supply, the quantities of water supplied are between 360 and 480 mm. The optimal amount of water supplied is 40 mm.

Simulating the need for water for soybeans using the intended 20 mm, 40 mm and 60 mm quantities indicates that the minimum required water supply is 240 mm and the maximum 480 mm at the 60 mm delivery rate. The yield reduction ranges from 43% to 7%. The number of water supply events, maximum use rates and evapotranspiration values can be presented in a similar way.

**Fifth alternative:** Delivery of water at fixed dates and quantities

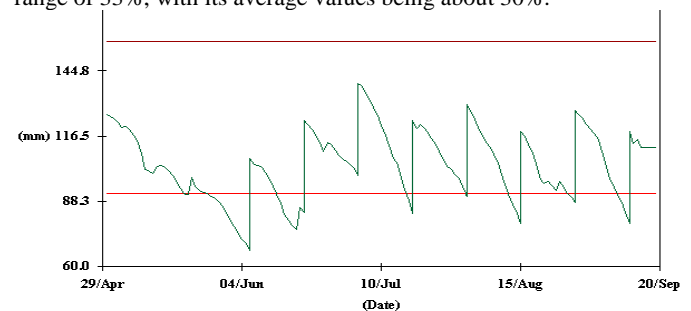
Due to the simplified procedure for supplying water to plants, this strategy is widely used in practice. The limited water resources and the lack of water during the vegetation of the plants support the application and, Fig.11.

At the same time, there are several hidden obstacles, mainly in delivering too little or too much water. In both cases there is a negative impact such as yield reduction, deep root penetration, surface water runoff, and water efficiency.



**Fig. 11.** Strategy for the 20 mm water delivered at a time step of 7 days

Water delivery at 20 mm at 7 day interval requires 220 mm of water to be delivered at 11 events (deliveries). The available water in the soil is between 70 and 85 mm, but the actual yield is below the optimal yield line (OYT). The decrease in yields is in the range of 33%, with its average values being about 30%.



**Fig. 12.** Strategy for eight-fold delivery of 40 mm water

The situation could be corrected if an irrigation rate of 40 mm was applied to an 8-fold delivery, Fig. 12. The total amount of water delivered is 320 mm, and the increase in water in the soil is in the range of 70 mm minimum and 137 mm maximum. The decrease in yields is within 16% in the years with high water consumption and the efficiency of the use is high, fig.13.



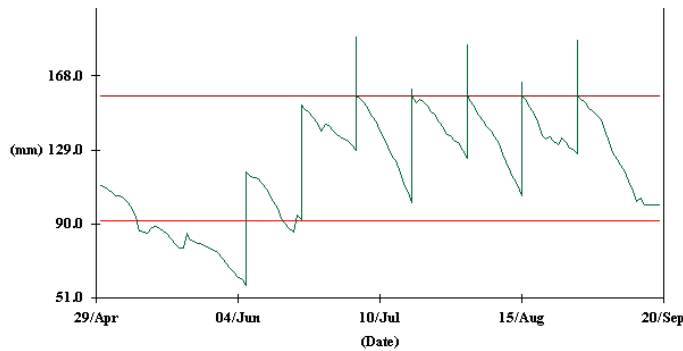


Fig. 13. Strategy for a 14-fold delivery of 60 mm water

The application of a 60 mm irrigation rate at 14 day intervals shows that the excess water reaches 117 mm, the efficiency of water use being reduced to 87% and the yields by 11%, Fig. 14.

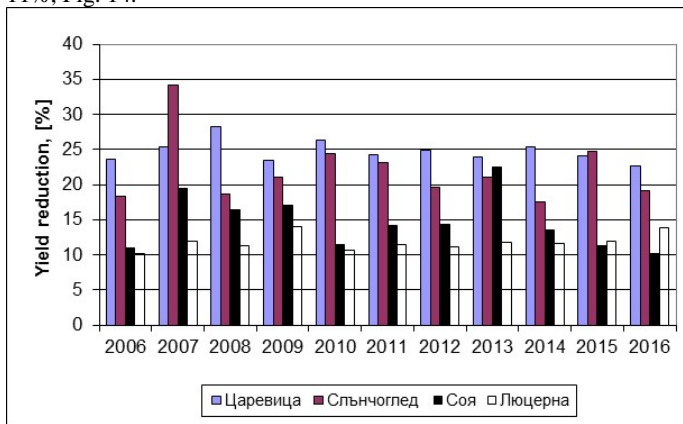


Fig. 14. Comparison of the decrease of yields in the supply of water at fixed quantities and dates

By using the WINISAREG program, the years corresponding to the different probabilities of applying recommendations for the supply of water to plant needs can be determined. The amounts of water and their application time, depth penetration below the root system caused both by precipitation and water supply, the effectiveness of their application, water efficiency, actual evapotranspiration, and relative reductions in yields are being compared to assess the water use strategies. Years representing 50%, 75% and 90% of the probabilities of applying water recommendations correspond to average dry, dry and very dry conditions in which crops are grown. Typical years are selected by frequency analysis of net water needs for plants. The results of the five alternatives considered are summarized in Table 3.

Empirical Probabilities		Year	Rains mm]	Actual ETa[mm]	Recommendation smm]
Average water consumption 50%	Maize	2008	141	552	491
	Soybean			421	308
	Sunflower			519	392
	Alfalfa			497	373
Total option 1 (50% probability)					1564
High consumption 75%	Maize	2014	244	578	487
	Soybean			436	305
	Sunflower			555	412

	Alfalfa		519	373	
Total option 2 (75% probability)					1577
Very high consumption 90%	Maize	2015	255	645	502
	Soybean			528	404
	Sunflower			588	398
	Alfalfa			555	448
Total option 3 (90% probability)					1752

Table 3. Summary table of simulation of five alternatives for using water for crops for spring crop maize

Conditions	Recommendations (IR)	Deep percolation: (DP)		Actual ET (ETa)	Water efficiency (IE)	Yields reduction (IRL)	
		Напомяване	Валежи				
		Y1	Y2				Y3
		[mm]	[mm]	[mm]	[mm]	[%]	[%]
Average water consumption							
a)		527	0	0	721	100	2.20
b)		441	0	0	567	100	13.40
c)	MAD = p	499	0	0	630	100	1
	MAD < p	443	0	0	551	100	16.40
)	60 mm	420	0	0	570	100	12.00
	40 mm	400	0	0	550	100	16.00
	20 mm	340	0	0	467	100	27.30
e)		280	0	0	428	100	38.00
High water consumption							
a)		547	0	0	637	100	1
b)		449	0	0	585	100	9.20
c)	MAD = p	550	0	0	732	100	1.00
	MAD < p	494	0	0	518	100	18.10
)	60 mm	420	0	0	628	100	17.80
	40 mm	440	0	0	577	100	16.30
	20 mm	380	0	0	522	100	26.30
e)		360	0	0	520	91	28.00
Very high water consumption							
a)		624	0	0	812	100	1
b)		545	0	0	747	100	10.40
)	MAD = p	574	0	0	721	100	4.00
	MAD < p	569	0	0	652	100	14.50
)	60 mm	420	0	0	699	100	17.80
	40 mm	480	0	0	694	100	18.00
	20 mm	420	0	0	580	100	26.20
e)		400	< 15	< 5	548	99	19.00

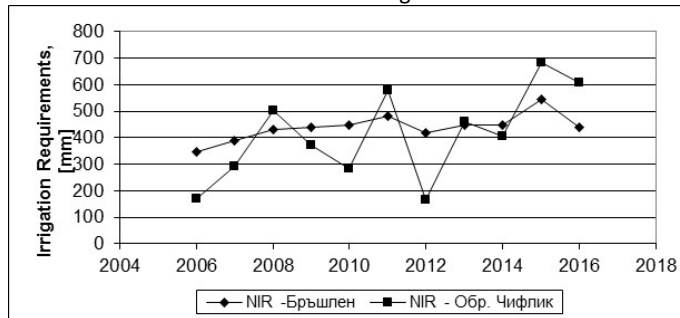
The results of simulation of the above-mentioned crops and alternatives are summarized in Table 4. The presented years differ from those presented as opportunities.

**Table 4.** Example of balance of water components for typical years determined by frequency analysis for four independent crops sunflowersoybeans and alfalfa at MAD <p

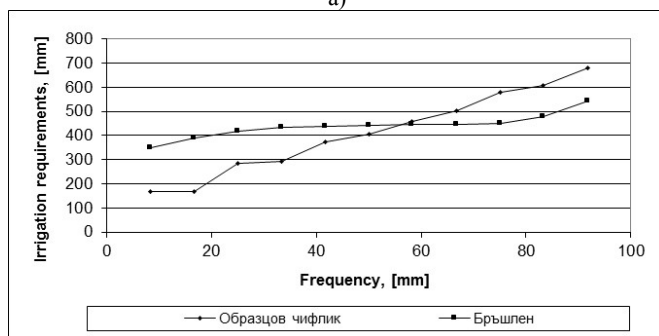
Table 5. Rainfall reported over the monitored period 2006 - 2016, [mm]

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Rainfall [mm]	173	143	141	123	144	241	132	275	244	255	271

Comparison of simulated recommendations for using water for other regions



a)



b)

Fig. 15. Simulation of the water consumption of plants on an annual basis for two different sites, Model Chef and BRS)

### Conclusions

Simulation alternatives have been applied for an 11-year period for 3 crops such as corn, sunflower and alfalfa. Due to the reduction of irrigation areas and the changing climatic conditions, it is found that soybeans are not suitable for cultivation, at least until the technology is optimized in their effective use of water, Table 3.

The crops above are grown in many regions of the country but under different soil and climatic conditions and with the application of similar or improved technologies. Consequently, the recommendations for supplying the necessary quantities of water will vary.

It is interesting to compare the consumption of water from the same crops but grown at 25, 50, 75 and 150 km as well as cultivation of the same crops when in the soil are imported water-accumulating materials that retain larger amounts of water in the cornbondable soil layer

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