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PEDOLOGICAL DROUGHT INFLUENCE ON SOME PARAMETERS OF SOYBEAN CROPS FROM CRISURILOR PLAIN

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ABSTRACT

The paper is based on the research conducted at the Agricultural Research and Development Station Oradea. Decadal determination of soil moisture, calculus of the water reserve and its dynamic graphs allowed the determination of the number of days with pedological drought, respectively of strong pedological drought. Pedological drought as well as strong pedological drought were present every year during the period 2007-2015 with the only difference that the strong pedological drought in fewer days. The optimum irrigation rate was 2800 m^3/ha. The irrigation determined the increase of the daily water consumption values and total water consumption. Finally, due to drought, an average yield loss of 65% was recorded, as well as a decrease in protein content up to 24% and in gross protein up to 31%. An inverse correlation between the number of days with pedological drought and water consumption of the soybean yield, as well as with the protein content of the grains and the gross protein content was established. These correlations emphasized the necessity of irrigation in the soybean crop in Crisurilor Plain.

Key words: pedological drought, strong pedological drought, water consumption, yield, protein, gross protein, soybean.

INTRODUCTION

Soybean is one of the most important agricultural plants, due to its usage in both human and animal nutrition and industry. In the case of soybeans, its entire amount of biomass can be used, especially the seeds that are rich in protein substances (27.0 to 50.0%), non nitrate extractives (23-30%), fats (18-22%), vitamins and minerals. Soybean flour is used in bread, as additives in soups, protein concentrates and "vegetable meat" etc. Soybean occupies the first place in the world in the production of vegetal fats; it is used in the preparation of margarine, in obtaining plastic and colours for painting; the seeds and green pods are used in the preparation of food rich in vitamins and minerals. Soybeans represent a valuable concentrated fodder; the green plant can be used as green mass, hay or silage (alone or mixed); the groats and oilcakes remaining after the extraction of oil represent valuable fodder (Bîlteanu, 2003; Borza, 2007; Borza and Stanciu, 2010; Stepănescu and Mate, 1972; Domuța, 2011, 2012; Domuţa and Domuța, 2016; Muntean et al., 2008).

Soybean has a special agricultural importance. Because of its symbiosis with bacteria *Rhizobium japonicum*, it fixes 80-120 kg/ha of atmospheric nitrogen in the soil out of the huge amount of 200,000 tons nitrogen that can be normally found in the atmosphere over a hectare of land (Domuţa et al., 2008).

Soybean is a crop with relatively high requirements to humidity. In drought conditions the yield decreases with 31-61% (Enciu, quoted by Domuta, 2009). Drought recorded during the flowering period determines the decrease of the yield with 14-52% and the drought during the period of grain filling determines a higher yield loss. Thus, the soybean yield affected by drought represents 13-59% of the irrigated soybean yield (Berbecel and Valuță, quoted by Domuta et al., 2012; Picu, 2003).

The irrigation of soybean in Crisurilor Plain was studied starting with 1976 by M. Stepănescu. He made research at Girişu Cris (1967-1975) and Oradea (1976-1980) in the field on water balance in the soil. Research of the water balance in the soil

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were continued by M. Buta (1981-1982), M. Colibas (1983-1985), M. Colibas and M. Sandor (1986). Research on the soybean crop was extended by C. Domuta after 1987. Research was performed on the influence of reducing irrigation regime on water consumption, yield and water efficiency, and after 1990 the influence of wheat-maize-soybeans crop rotation has been studied on the physical, chemical and biological soil parameters, on the quality and quantity of wheat yield and on the water used efficiency in comparison with the wheat-maize crop rotation, monoculture and wheat monoculture. In 2007, C. Domuta placed an experience studying the pedological drought, microclimate, water consumption, quantity and quality of soybean yield in the conditions of suspending irrigation in one of the months of the irrigation season for this crop (Borza, 2007; Ciobanu and Domuţa, 2003; Domuţa et al., 2010; Samuel, 2009).

This paper aims to set the number of days with water reserve on the irrigation depth (0-75 cm) below the easily available water content (pedological drought), respectively below the wilting point (strong pedological drought), to determine the influence of the pedological drought on the water consumption, yield and protein content of the soybean grains.

MATERIAL AND METHODS

The paper is based on the research conducted at the Agricultural Research and Development Station Oradea during the period 2007-2015. Oradea is located in the north part of Crisurilor Plain. Crisurilor Plain covers an area of approximately 310,000 hectares, being bounded by Barcăului Plain in the North, by Aradului Plain in the South, by Tasadului Hills, Holod, Zarand and Cigherului depressions in the East and by the border with Hungary in the West.

Pedoclimatic conditions

The soil from the field of water balance in the soil from Oradea is a luvosoil which has the following profile: Ap = 0-24 cm, El = 24-34 cm; Bt_1 = 34-54 cm; Bt_2 = 54-78 cm; Bt/c = 78-95 cm, C = 95-145 cm.

The luvosoil from the research field is characterized by a very high hydro stability of the soil aggregates of more than 0.25 mm, 47.5% on the layer of 0-20 cm. The bulk density -1.41g/cm^3 - characterizes a poorly compacted soil at a depth of 0-20 cm; for the other studied depths, the apparent weight highlights a moderately and strongly compacted soil (Brejea, 2010). The soil is strongly compacted on the watering depth of 0-50 cm, 0-75 cm and 0-150 cm.

The soil has a total medium porosity at a depth of 0-60 cm and a little porosity at a depth of 60-150 cm. The values of the total porosity decrease on the soil profile from the surface to depth. The hydraulic conductivity is high at a depth of 0-20 cm, medium at a depth of 20-40 cm and 40 cm, low and very low at the following studied depths (Brejea, 2010).

The field capacity has an average value throughout the soil profile and the wilting coefficient also has an average value up to the depth of 80 cm and higher values below this depth (Borza, 2011).

The active humidity range (IUA) or useful water capacity has a high value at the depth of 0-80 cm and an average value at a depth of 80-150 cm. The active humidity range has a high value on the watering depth used in the research field. Depending on the soil texture, the easily available water content was set at 2/3 IUA (Brejea and Domuţa, 2005; Domuţa, 2009).

The soil in the research field has a slightly acid reaction throughout the studied depth, with increasing values from surface to depth. Humus supply is poor, and the one with total nitrogen is low-medium on the entire studied depth.

The soil is well provisioned with phosphorus 150.8 ppm and the content of mobile potassium is low-medium, with values increasing from the ploughed layer (124.5 ppm on the depth range 0-20 cm) towards the depth (145.4 ppm on the depth range 100-150 cm).

The soil content in exchangeable magnesium on the soil profile has a similar evolution pattern with the potassium content, the soil being averagely supplied with this item along the whole profile.

The main elements of the climate during the period 2007-2015 are characterized as follows: air temperature of 11.9ºC compared to 10.3ºC representing the mean temperature during 1976-2006. The air humidity was 73% in comparison to 78% representing the multi-annual average value. Regarding the precipitation, it is shown that the average recorded during one agricultural year was with 19.7 mm less than the annual average, which is 594.0 mm compared to 613.7 mm. During the soybean vegetation period the multiannual average was 337.7 mm compared to 367 mm. Year 2010 had the most rainfall recorded during the agricultural year, but also during the period April-September (869 mm, respectively 435.3 mm). The year with the least rainfall during the agricultural year and during the soybean vegetation period was year 2012 (491.7 mm, respectively 303.3 mm) (Table 1).

Table 1. Climate elements, Oradea 2007-2015 (according to the Meteorological Station Oradea)

Specification	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Average/ Total
Air temperature (°C)													
2007-2015	11.4	7.3	2.0	1.1	1.7	6.6	12.3	17.0	23.1	22.9	22.5	16.7	11.9
1931-2006	10.6	5.3	0.6	-2.3	0.3	5.0	10.5	15.8	19.1	20.8	20.0	16.2	10.2
Rainfall (mm)													
2007-2015	55.9	50.7	42.8	36.5	31.3	39.2	33.6	64.9	66.3	69.9	55.6	47.4	594.0
1931-2006	39.7	48.7	50.4	34.3	38.7	34.6	46.1	61.1	84.9	70.9	58.7	45.3	613.7
Air humidity (%)													
2007-2015	78	83	87	86	82	70	64	67	66	63	66	68	73
1931-2006	79	84	88	85	86	77	72	72	73	69	71	75	78

Variants studied

The research was performed in long trial experiments called fields of soil water balance financed by the Research Institute of Irrigation and Drainage Baneasa-Giurgiu. Similar experiments like the one from Oradea, were located in all the interest areas for irrigation in Romania. The studied variants were:

V_1 – unirrigated;

V_2 – irrigated with maintaining of soil water reserve on the irrigation depth (0-75 cm).

The soil humidity was determined from 10 to10 days to maintain the water reserve on the irrigation depth between the easily available water content and field capacity.

Crop management

It was used a crop technology considered to be optimal. Ten field and fodder crops are studied in the field of water balance in the soil, fact that allowed an ideal crop rotation with an ameliorative crop (alfalfa) and two pulses for grains (soybean follows: 1st year alfalfa – 2nd year alfalfa – 3rd year alfalfa – maize – bean – wheat – sugar beet – soybean – sunflower – potato. The soil tillage during the sowing, maintenance and harvesting period were within the optimum parameters. The source of water for irrigation had a good quality.

Determinations and analysis

The soil moisture was determined gravimetrically on the depth range of 0-50 cm, and neutronically on the depth range of 50-150 cm. Neutronic determination was performed with a "neutron probe" produced by the Institute of Physics and Nuclear Engineering Bucharest – Magurele. The device provided a good precision, the standard deviation values between the humidity determined neutronically and the one determined gravimetrically was of 1.27% on depth range of 50-100 cm and 0.45% on the range depth of 100-150 cm (Domuţa, 1995, 2005).

The soil water reserve was determined according to the known formula and the obtained data were represented graphically (Domuţa, 2005). The annual charts also contained the values of the field capacity, easily available water content and wilting point coefficient. The values of these parameters were represented on millimetric paper joining the points representing the water reserves in the soil on the watering depth. Therefore, the number of days with water reserve under the easily available water content (pedological drought) respectively under the wilting point coefficient (strong pedological drought) could be counted with a good accuracy (Domuţa and Domuța, 2016).

Plant water consumption. Data regarding the water reserve allowed the use of the soil water balance method to calculate the water consumption; the depth balance was of 0-150 cm (Grumeza and Klepş, 2005; Luca et al., 2008; Tuşa, 1992; Vâjială, 1978).

Yield. To establish that the differences between the variants are statistically significant, the analysis of variance was used, the experiment being placed according to the block method; the number of repetitions was four.

The grain protein content was determined in laboratory of the Agricultural Research and Development Station Oradea according to Kjeldahl method. The result was the total nitrogen (N^+) and the protein was calculated according to the formula Nt x 6.25 (Bîlteanu, 2003).

The regression functions were calculated by using Microsoft Excel. Out of the five types of functions available within the program (linear, logarithmic, polynomial, exponential and power) the function with the highest value of R^2 was chosen.

RESULTS AND DISCUSSION

Pedological drought and strong pedological drought

Pedological drought and strong pedological drought are two indicators quantified based on the graphs of the dynamics of the soil water reserve on 0-75 cm depth. These graphs were obtained using the soil moisture determined ten to ten days.

On average during 1976-2006, on 0-75 cm depth, the water reserve decreased below the easily available water content for 70 days and under the wilting point coefficient for 8 days.

In the period 2007-2015 there were 71 days with pedological drought (variation range of 12 days in 2010 to 108 days in 2009) and the number of days with strong pedological drought was 10 (variation interval 0-26 days).

Both during the period 1976-2006 and 2007-2015, the highest number of days with pedological drought was recorded in August (27 days, respectively 23 days) (Table 2).

Table 2. Pedological Drought and strong pedological drought in the unirrigated soybean crop from Crișurilor Plain. Oradea, 2007-2015

Year	Number of days/month												Total	
	April		May		June		July		August		September			
	a	b	a	b	a	b	a	b	a	b	a	b	a	b
2007	8	0	24	0	26	0	25	4	21	2	-	-	104	6
2008	0	0	6	0	20	0	24	0	31	5	-	-	81	5
2009	3	0	31	0	12	3	31	13	31	10	-	-	108	26
2010	0	0	0	0	0	0	0	0	7	0	5	-	12	0
2011	5	0	3	0	2	0	1	6	1	14	10	-	48	20
2012	2	0	12	0	7	0	9	12	9	13	15	-	79	25
2013	0	0	0	0	5	0	31	0	31	4	7	-	74	4
2014	2	0	10	0	15	0	6	0	10	2	20	-	76	2
2015	3	0	3	0	15	0	20	3	15	0	10	-	66	3
Average 2007-2015	3	0	11	0	11	0	16	4	23	6	7	-	71	10
Average 1976-2006	-	0	7.2	2.0	13.5	2.0	21.6	6.0	27.2	0	18.0	-	70	8.0

a = pedological drought; b = strong pedological drought.

The optimum irrigation regime

To maintain the water reserve on the depth of 0-75 cm between the easily available water content and field capacity, the average irrigation regime during 2007-2015 was 2,800 m^3 / ha, the variation range was 500 m^3 ha^{-1} (in 2010) and 4300 m^3 ha^{-1} (in 2009). Monthly irrigation regime had the highest monthly value in August of 900 m^3 ha^{-1}, the variation range was 600 m^3 ha^{-1} (2007) and 1200 m^3 ha^{-1}. During the period 1976-2006, an average irrigation regime of

2730 m^3 ha^{-1} was necessary. The highest value of monthly irrigation regime was recorded in July (Table 3).

Table 3. Optimum irrigation regime used in the soybean from Crișurilor Plain. Oradea, 2007-2015

Year	Number of days/ month										Total	
	April		May		June		July		August			
	∑m	n	∑m	n	∑m	n	∑m	n	∑m	n	∑m	n
2007	200	1	400	1	700	2	1000	2	600	2	2900	8
2008	-	-	500	1	850	2	1000	2	1000	2	2850	7
2009	400	1	-	-	500	1	1200	3	1300	3	4300	10
2010	-	-	-	-	-	-	-	-	500	1	500	1
2011	300	1	300	1	300	1	800	2	1000	3	2700	8
2012	-	-	400	2	600	2	700	2	1200	3	2900	9
2013	-	-	-	-	300	1	1200	3	1200	3	2600	7
2014	300	1	300	1	700	2	500	1	1000	3	2800	8
2015	300	1	300	1	600	2	700	2	900	2	2800	8
Average	170	1	240	1	500	1	920	2	900	2	2730	7

∑m = irrigation rate; n = number of rates.

The influence of irrigation on the water consumption of soybean crop

During 2007-2015, the use of irrigation determined the increase of the daily water consumption as follows: 31.3 m^3 ha^{-1} in comparison to 28.8 m^3 ha^{-1} per day in April, 37.8 m^3 ha^{-1} per day in comparison to 31.5 m^3 ha^{-1} in May, 48.6 m^3 ha^{-1} per day in comparison to 39.6 m^3 ha^{-1} per day in June, 58.5 m^3 ha^{-1} in comparison to 44.0 m^3 ha^{-1} per day in July, 45.4 m^3 ha^{-1} per day in August and 30 m^3 ha^{-1} per day in comparison to 20.2 m^3 ha^{-1} per day. During 1976-2007, the average values of the daily water consumption for irrigated soybeans were lower than during the period 2007-2015.

Mathematical modelling of the daily water consumption data revealed higher values of correlation coefficients under irrigation conditions in both studied periods as seen in Table 4.

Table 4. Mathematical modelling data of the daily water consumption of the soybean crop in the conditions from Crisurilor Plain

Period	Variant	Functions	Regression coefficient
2007-2015	Unirrigated	$y = - 0.0035 x^2 + 0.5731 x + 17.867$	$R^2 = 0.7949$
	Irrigated	$y = - 0.0047 x^2 + 0.8452 x + 16.093$	$R^2 = 0.8256$
1976-2006	Unirrigated	$y = - 0.0038 x^2 + 0.6219 x + 10.083$	$R^2 = 0.8665$
	Irrigated	$y = - 0.0047 x^2 + 0.9129 x + 7.4637$	$R^2 = 0.9188$

On average, during the studied period, the value of total water consumption for irrigated soybean (6374 m^3 ha^{-1}) was higher with 44% than in the case of unirrigated soybean. A higher value (6374 m^3 ha^{-1}) was recorded during the period 2007-2015 compared to the total water consumption value for irrigated soybeans during 1976-2006 (5893 m^3 ha^{-1}). A similar situation was recorded in unirrigated conditions: 4426 m^3 ha^{-1} in comparison to 3915 m^3 ha^{-1}.

Both during the period 2007-2015 and 1976-2006, the main source (52%) for covering the total water consumption was represented by the rainfalls recorded during the vegetation period of the soybean. Irrigation covered 31% and 38% and the water consumed from the soil reserves covered 10% and 17%, respectively. In conditions without irrigation, the water from the rainfalls recorded during the soybean vegetation period covered 87% of the total water consumption of the soybean and the soil water reserves covered 25% of the total water consumption during 2007-2015 and

10% of the total water consumption of soybean during 1976-2006 (Table 5).

Some correlations with various mathematical expressions were quantified between the total water consumption and some parameters of the soybean crop (Table 6).

Table 5. The influence of pedological drought on the water consumption in the soybean crop from Crișurilor Plain. Oradea, 2007-2015

Period	Variant	Value	∑ (e + t) m^3 ha^{-1}	Covering sources of the ∑ (e + t) *					
				Soil water reserve		Rainfall		Irrigation	
				m^3 ha^{-1}	%	m^3 ha^{-1}	%	m^3 ha^{-1}	%
2007-2015	Unirrigated	Minimum	3815	300	6	2540	60	-	-
		Maximum	5060	1670	40	4760	94	-	-
		Average	4426	1100	25	3316	75	-	-
	Irrigated	Minimum	5468	110	11	2540	34	500	9
		Maximum	7448	608	8	4760	87	4300	58
		Average	6374	1110	17	3316	52	2760	31
1976-2006	Unirrigated	Average	3919	836	21	3083	79	-	-
	Irrigated	Average	5893	573	10	3083	52	2235	38

*participation of the source in the total water consumption in the studied year.

Table 6. Correlations between the water consumption of the soybean crop in the conditions of Crisurilor Plain. Oradea, 2007-2015

No.	Correlations	Regression function	R^2
1	Total water consumption – yield	$y = – 0.000 x^2 + 5.246 x – 14853$	0.802
2	Total water consumption – protein content	$y = – 2E – 0.06 x^2 + 0.029 x – 57.58$	0.841
3	Total water consumption – gross protein yield	$y = – 000 x^2 + 2.530 x – 7284$	0.801

Influence of pedological drought upon yield

As a result of drought, during 2007-2015, the grain yield in the unirrigated plots was less by 65% than the irrigated one; the variation range of the yield was 18-64%. During 1976-2006, the difference of the optimum supplied variant with water was 42%; the variation range of the yield's relative differences was 19-92% (Table 7).

During all the years under study, the differences were statistically highly significant.

Table 7. Effect of pedological drought and strong pedological drought on soybean yield in Crișurilor Plain. Oradea, 2007-2015

Specification	Variant	Average		Variation ranage	
		Kg/ha^{-1}	%	Kg/ha^{-1}	%
2007-2015	Irrigated	3696	100	3170 - 4310	100
	Unirrigated	1276	35	650 - 2760	18 - 64
LSD 5% = 295; LSD 1% = 520; LSD 0.1% = 880.					
1976-2006	Irrigated	3130	100	1380 – 4080	100
	Unirrigated	1806	58	300 – 3400	19 - 92
LSD 5% =190; LSD 1% = 316; LSD 0.1% = 710.					

The drought also negatively influenced the grain protein content (30.9% compared to 40.5%).

The variation range of the protein content was 29.2-6.8% without irrigation and 38.7-3.9% in irrigation conditions (Table 8).

The gross protein yield represented 69% out of the irrigated variant yield. The variation range of the protein yield was between 234 and 1015 kg ha^{-1} without irrigation and 1287-1612 kg ha^{-1} under irrigation (Table 9).

Table 8. The Influence of the pedological drought and strong pedological drought on the grain protein content in Crişurilor Plain. Oradea, 2007-2015

Variant	Average		Variation Range	
	Protein concentration (%)	%	Protein concentration (%)	%
Irrigated	40.5	100	38.7-43.9	100
Unirrigated	30.9	76	29.2-36.8	(-16) - (-36)
LSD 5% = 1.9; LSD 1% = 4.2; LSD 0.1% = 7.6.				

Table 9. The Influence of the pedological drought and strong pedological drought on the total protein yield of soybean grains in Crişurilor Plain. Oradea, 2007-2015

Variant	Average		Variation range	
	Kg ha^{-1}	%	Kg ha^{-1}	%
Irrigated	1403	100	1287- 1612	100
Unirrigated	439	69	234-1015	15-54
LSD 5% = 230; LSD 1% = 490; LSD 0.1% = 870.				

Correlations of the pedological drought indicator

A negative connection was quantified between the number of days with pedological drought determined in unirrigated soybean crop and water consumption of irrigated soybean.

Negative correlations were also quantified between the number of days with pedological drought and yield, respectively between the protein content of grains and protein yield. All four correlations were statistically highly significant (Figure 1).

The obtained results highlight the presence of pedological drought and strong pedological drought in soybean crop and the positive influence of irrigation upon the daily and total water consumption, on grain yield and grain protein content.

The statistically significant correlations of the pedological drought indicator with the protein content and the quantity of protein per area unit are other arguments concerning the opportunity of irrigation in Crisurilor Plain.

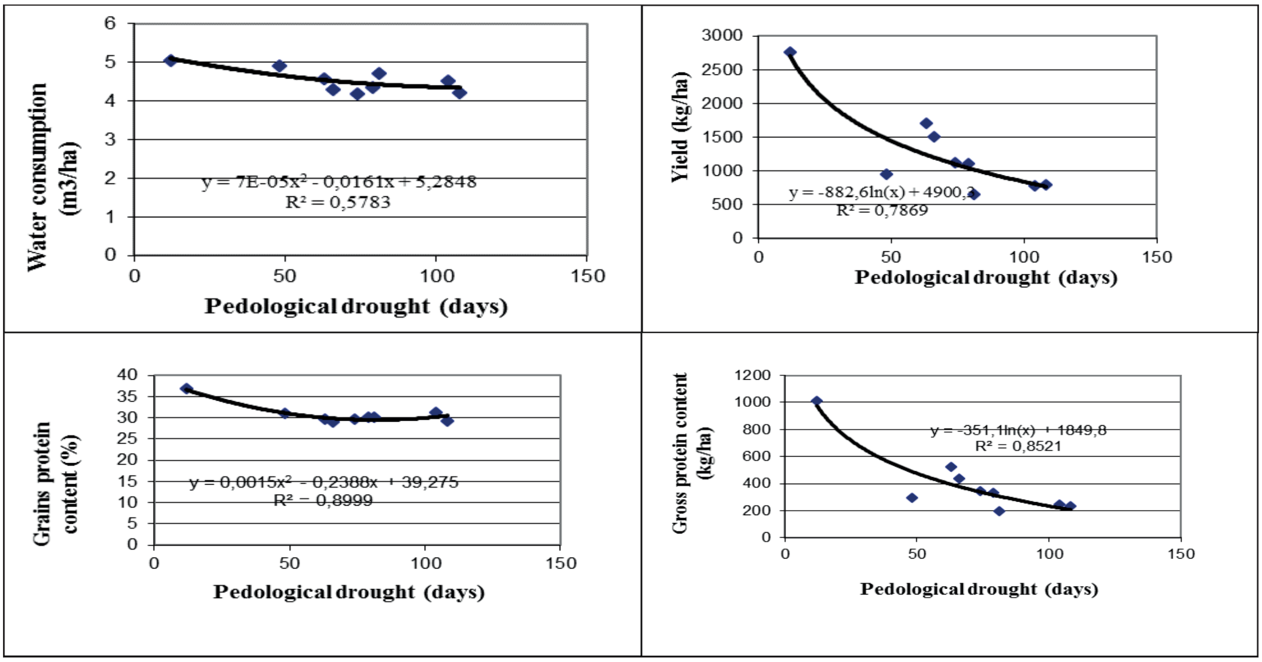

Figure 1. Correlations of pedological drought indicator in the soybean crop from Crisurilor Plain. Oradea, 2007-2015

CONCLUSIONS

The research made at the Agricultural Research and Development Station Oradea during the period 2007-2015 led to the following conclusions:

On the irrigation depth (0-75 cm) in the case of unirrigated soybean, the water reserve decreased below the easily available water content (pedological drought) and below the wilting point coefficient every year, the number of days with pedological drought was between 12 days and 108 days.

For maintaining the water reserve on the depth of 0-75 cm between the easily available water content and the field capacity, he irrigation regime was between 500 m^3/ha (in 2010) and 4300 m^3 ha^{-1} (in 2009).

Without irrigation, the daily and total water consumption had lower values. The modelling of the daily water consumption values highlighted lower values of the regression coefficients without irrigation during 2007-2015 and during 1976-2006. Irrigation had a share of about 31% on average (variation range 9-58%) in covering the optimum water consumption for the soybean crop.

In each year of the period 2007-2015, drought caused yield losses that were statistically very significant. Compared to the irrigated variant, the yield in the unirrigated variant represented on average 35%, with a variation range of 18-64%.

Without irrigation, the protein content of soybean was lower (30.9% versus 40.5%) and the protein yield (439 kg/ha) represented 69% out of the protein yield in the case of the irrigated variant (1403 kg/ha)

Reverse correlation between the number of days with pedological drought and the water consumption of soybean, yield, the protein content of the grains, respectively the quantity of protein also reflect the necessity of soybean irrigation in Crisurilor Plain.

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