The hydric stress influence on quantity and quality of the maize yield in the Crisurilor Plain conditions

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SUMMARY

The paper is based on the researches carried out in an experiment placed on the preluvosoil from Agricultural Research and Development Station Oradea, Crisurilor Plain during 2008–2011in the following variants: V_1=Irrigated, without irrigation suspending; V_2=Irrigated, irrigation suspending in May; V_3=Irrigated, irrigation suspending in June; V_4=Irrigated, irrigation suspending in July; V_5=Irrigated, irrigation suspending in August; V_6=Unirrigated. The hybrid used: Fundulea 376. In the variant with optimum irrigation, water reserve on 0–75 cm depth was maintained between easily available water content and field capacity. Pedological drought was determined every year and the irrigation was also needed. The irrigation determined the increase of the total water consumption and yield gain in comparison with unirrigated variant. Irrigation suspending in different months determined the yield losses very significant statistically. The biggest protein content was registered in the variant without irrigation suspending; the values registered in the variants with irrigation suspending in May, June, July and August and in the unirrigated variant are smaller, with differences statistically assured. There was a direct link between de Martonne aridity index values and water consumption, yield and protein content and an inverse link between pedological drought and yield quantity and protein content. These are the arguments for irrigation opportunity in maize from Crişurilor Plain

Keywords: *pedological drought, de Martonne aridity index, water consumption, hydric stress, maize yield, maize quality, irrigation*

INTRODUCTION

The Crişurilor Plain occupies the central part of the Western Plain of Romania and maize and wheat are cropped on the biggest surfaces (Borza, 2006, 2007). The first researches from this area regarding the maize irrigation were started on the chernozem from Girişu de Criş in 1967 by Stepănescu and Mihăilescu. (Domuţa, 2010, 2011).

The researches regarding the irrigation participation in the total water consumtion from in the Crişurilor Plain were carried out during 1976–2010 on the preluvosoil from Oradea in the research field from soil water balance study. (Domuţa, 2009b). The results researches emphasized the need of the irrigation in the optimum water consumption, the increase of the water consumption and yields gains very significant statistically in irrigated variant vs. unirrigated variant. Most of the years, the water use efficiency improved using the irrigation. (Domuţa, 1995, 2009a; Grumeza and Kleps, 2005). The researches from the other areas emphasize the positive influence of the irrigation on water use efficiency (Borza, 2008, 2009; Nagy, 2010; Pakurar et al., 2010; Stan and Năescu, 1997).

Irrigation suspending in different months of the vegetation period determines the yield losses and the smaller water use efficiency (Borza, 2007).

MATERIAL AND METHODS

The paper based on the researches were carried out in Agricultural Research and Development Station Oradea during 2008–2011 on the preluvosoil. There is a big hydro stability (47.5%) of the aggregates (Φ = 0.25 mm) on ploughingland; bulk density (1.41 g cm^{-3}) indicates a low settling and total porosity is median; hydraulic conductivity is big (21.0 mm h^{-1}) on 0–20 cm. The watering depth (0–75 cm) was a fixed one (Grumeza et al., 1989) and field capacity (FC = 24.2% = 2782 m^3 ha^{-1}) and wilting point (WP = 10.1 = 1158 m^3 ha^{-1}) have median values. Easily available water content (Wea) was established in function of texture: Wea = WP + 2/3 (FC – WP); their values for 0–75 cm are 19.5% and 2240 m^3 ha^{-1} (Brejea, 2010).

A drill is the water source for irrigation and their quality for irrigation is very good: pH = 7.2; Na^+ = 12.9%; mineral residue = 0.5 g l^{-1}; CSR = -1.7; SAR = 0.52.

The following variants were studied: V_1=Unirrigated; V_2=Irrigated without the irrigation suspending in the maize irrigation season; V_3=Irrigated, with irrigation suspending in May, 4–9 leaves; V_4=Irrigated, with irrigation suspending in June, 10–18 leaves; V_5= Irrigated, with irrigation suspending in July, tassel growth – grains filling; V_6=Irrigated, with irrigation suspending in August, grains filling-ripening. The surface of the experiment plot was 50 m^2. Number of repetition=4; Irrigation method used was sprinkler with modifications for rectangular plots. Cultivar used: Fundulea 376. Fertilization system: $N_{120}P_{90}K_{60}$.

Soil moisture of 0–75 cm depth was determined ten to ten days. In the variant without irrigation suspending the moment of the irrigation use was when the soil water reserve on 0–75 cm depth decreased to easily available water content. In the variant with irrigation suspending in different months didn't irrigate in these months.

De Martonne aridity index (IdM) was used for climate characterization: climate indicator was use:

$$I_{dM} = \frac{12P}{t+10}$$

In wich:
P = rainfall (and irrigation) (mm),
t = month average temperature (^{o}C).

Characterization classes after de Martonne aridity index: 15–24 demiarid; 24–30 moderate dry; 31–35 moderate wet I; 36–40 moderate wet II; 41–50 wet; 51–60 wet I; 61–80 wet II; 81–100 very wet; over 100 excesive wet.

Water consumption was determined using the soil water balance method and water use efficiency was determined like report between field and water consumption (Brejea, 2009).

The protein content of the maize grains was established using the total nitrogen content by formula: total N × 6.25. Total nitrogen was determined by Kjeldahl method.

Results research was processed by variance analysis and with the regression functions (Domuţa, 2006).

RESULTS AND DISCUSSION

Climate elements

The researches were carried out in the specifical climate conditions: annual average temperature over the multiannual average, rainfall and air humidity smaller than multiannual average in 2008, 2009, 2011 and over the multiannual average in 2010 *(table 1)*.

Pedological drought

In the year 2008, in unirrigated maize, the soil water reserve on 0–75 cm decreased bellow easily available water content 81 days: 6 days in May, 20 days in June, 24 days in July, 31 days in August; soil water reserve decreased bellow wilting point 7 days (4 days in July and 3 days in August). Pedological drought was registered in the variants with irrigation suspending in the month without irrigation *(table 2)*.

The biggest number with pedological drought was registered in 2009, 108 day. Pedological drought started in April (3 days) and it was determined all the days of the month May, July and August; in June pedologiccal drought was determined in 12 days *(table 2)*. Strong pedological drought was determined in 32 days: 9 daysin June, 10 days in July and 13 days in August *(table 3)*.

The smallest number of days with pedological drought (20 days:10 days in July and 10 days in August) was registered in 2010. Strong pedological drought didn't determined in 2010.

In 2011, pedological drought started in April (7 days); it was determined all the days of the May and june and was determined in 10 days in July and in 15 days in August. Strong pedological drought was determined in 20 days: 6 days in June, 4 days in July and 10 days in August.

There is an inverse link between the number of days with pedological drought and the maize yield level *(figure 1)*. The same type of link was quantified between number of days with pedological drought and yield gains obtained using the irrigation.

Climate drought

The most known climate indicator from Romania is de Martonne aridity index and this indicator was used for characterization of the microclimate created by irrigation using (Domuţa, 2012).

Maintaining the soil water reserve between easily available water content and field capacity determined to use the following irrigation rate: 3320 m^3 ha^{-1} in 2008, 4200 m^3 ha^{-1} in 2009, 500 m^3 ha^{-1} in 2010, 3500 m^3 ha^{-1} in 2011. In the variant with irrigation suspending, the values of the irrigation rates were smaller. Irrigation rates had the specifical values for every year *(table 4)*.

Table 1.

Climate elements (Oradea, 2008–2011)

Agricultural year	October	November	December	January	February	March	April	May	June	July	August	September	Average/ Total
						Average air temperature (°C)							
2008	10.3	3.7	-0.4	1.4	3.4	6.5	11.6	16.9	21.0	20.9	22.0	15.4	11.0
2009	12.3	6.7	3.2	-1.0	0.3	5.4	14.4	17.3	19.8	23.1	22.2	15.5	11.6
2010	11.3	7.7	3.0	-1.3	2.4	6.1	11.5	16.2	19.8	22.4	21.6	15.2	11.3
2011	8.2	9.2	0.5	-0.1	-1.2	6.0	12.4	16.8	21.2	21.8	22.6	19.3	11.4
Average 1931–2007	10.6	5.3	0.6	-2.0	0.3	5.0	10.5	15.8	19.1	20.8	20.0	16.2	10.2
						Rainfall (mm)							
2008	75.1	62.6	29.4	21.3	12.5	67.9	43.3	38.9	92.1	69.3	27.3	46.0	585.7
2009	29.9	33.7	62.6	21.2	36.1	60.2	13.3	27.1	97.6	21.9	89.4	8.4	501.4
2010	91.5	86.0	55.6	63.1	48.8	24.3	61.2	118.9	82.8	81.6	82.3	72.9	869.0
2011	52.5	76.7	91.2	25.5	19.4	28.7	19.0	56.5	35.2	125.3	8.9	30.8	569.7
Average 1931–2007	39.7	48.7	50.4	34.3	38.7	34.6	46.1	61.1	84.9	70.9	58.7	45.3	613.4
						Air humidity (%)							
2008	77	82	86	82	74	71	67	65	68	67	61	67	72
2009	75	74	81	85	82	73	53	53	64	57	91	56	70
2010	80	85	81	86	87	74	77	76	73	75	77	78	79
2011	76	78	90	88	83	73	60	64	62	69	64	64	73
Average 1947–2007	79	84	88	85	86	86	72	72	73	69	71	75	78

Table 2.

Number of days with pedological drought in maize in different variant with water provisionmnet (Oradea, 2008–2011)

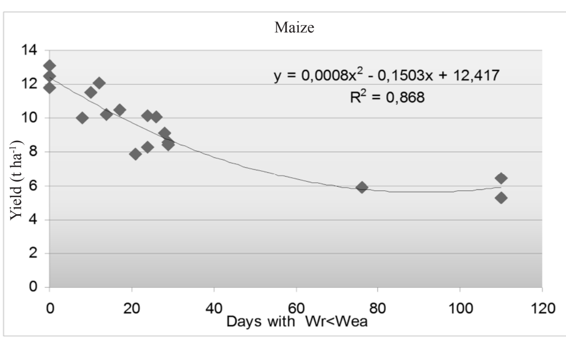
Variant	Month					April–August
	April	May	June	July	August	
2008						
Unirrigated	0	6	20	24	31	81
Irrigated, without suspending irrigation in the crop's irrigation season	0	0	0	0	0	0
Irrigated, with irrigation suspended in May	0	6	0	0	0	6
Irrigated, with irrigation suspended in June	0	0	18	0	0	18
Irrigated, with irrigation suspended in July	0	0	0	21	0	21
Irrigated, with irrigation suspended in August	0	0	0	0	27	27
2009						
Unirrigated	3	31	12	31	31	108
Irrigated, without suspending irrigation in the crop's irrigation season	0	0	0	0	0	0
Irrigated, with irrigation suspended in May	0	24	2	0	0	26
Irrigated, with irrigation suspended in June	0	0	5	1	0	6
Irrigated, with irrigation suspended in July	0	0	0	25	1	26
Irrigated, with irrigation suspended in August	0	0	0	0	30	30
2010						
Unirrigated	0	0	0	10	10	20
Irrigated, without suspending irrigation in the crop's irrigation season	0	0	0	0	0	0
Irrigated, with irrigation suspended in May	0	0	0	0	0	0
Irrigated, with irrigation suspended in June	0	0	0	0	0	0
Irrigated, with irrigation suspended in July	0	0	0	10	0	10
Irrigated, with irrigation suspended in August	0	0	0	0	10	10
2011						
Unirrigated	7	31	30	10	15	93
Irrigated, without suspending irrigation in the crop's irrigation season	0	0	0	0	0	0
Irrigated, with irrigation suspended in May	7	31	0	0	0	38
Irrigated, with irrigation suspended in June	7	-	30	3	0	40
Irrigated, with irrigation suspended in July	7	-	0	10	0	17
Irrigated, with irrigation suspended in August	7	0	0	0	15	22

Table 3.

Number of days with strong pedological drought in unirrigated maize (Oradea, 2008–2011)

Year	Month					April–August
	April	May	June	July	August	
2008	0	0	0	4	3	7
2009	0	0	9	10	13	32
2010	0	0	0	0	0	0
2011	0	0	6	4	10	20

Figure 1: **Correlation between the number of days with pedological drought (WR-Wea) and maize yields (Oradea, 2008–2011)**



The irrigation use determined bigger values of the water/temperature report calculated by de Martonne aridity index. In average on the studied period the differences were of 57.9% in Aprilie, of 78.6% in May, of 83.9% in June, of 110.3% in July and of 111.5% in August. The period Aprilie-August in unirrigated maize was characterizated like "demiarid" in 2008, 2009 and 2011 and like "moderate wet II" in 2010. The irrigation determined a microclimate characterized like "wet" all the year study. The diffrences between the values of the de Martonne aridity index calculated for variant with optimum irrigation and the values of the de Martonne aridity index in unirrigated maize were of 117% in 2008, of 157% in 2009, of 11% in 2010 and of 140% in 2011 *(table 5)*.

A direct link were quantified between the values of he de Martonne aridity index and maize yield. The same type of link was registered between the values of the de Martonne aridity index and yield gains determined by irrigation *(figure 2–3)*.

Table 4.

Irrigation rate of the maize in different variant of water provisionment (Oradea, 2008–2011)

Variant	Month					April–August
	April	May	June	July	August	
2008						
Irrigated, without suspending irrigation	-	500	1020	1100	700	3320
Irrigated, suspending irrigation in May, 4–9 leaves	-	-	1020	1100	700	2820
Irrigated, suspending irrigation in June, 10–18 leaves	-	500	-	1100	700	2300
Irrigated, suspending irrigation in July, tassel growth – grains filling	-	500	1020	-	700	2220
Irrigated, suspending irrigation in August, grains filling-ripening	-	500	1020	1100	-	2620
2009						
Irrigated, without suspending irrigation	500	900	500	1300	1000	4200
Irrigated, suspending irrigation in May, 4–9 leaves	500	-	500	1300	1000	3300
Irrigated, suspending irrigation in June, 10–18 leaves	500	900	-	1300	1000	3700
Irrigated, suspending irrigation in July, tassel growth – grains filling	500	900	500	-	1000	2900
Irrigated, suspending irrigation in August, grains filling-ripening	500	900	500	1300	-	3200
2010						
Irrigated, without suspending irrigation	-	-	-	500	-	500
Irrigated, suspending irrigation in May, 4–9 leaves	-	-	-	500	-	500
Irrigated, suspending irrigation in June, 10–18 leaves	-	-	-	500	-	500
Irrigated, suspending irrigation in July, tassel growth – grains filling	-	-	-	-	-	-
Irrigated, suspending irrigation in August, grains filling-ripening	-	-	-	500	-	500
2011						
Irrigated, without suspending irrigation	300	600	1200	500	800	3500
Irrigated, suspending irrigation in May, 4–9 leaves	300	-	1200	500	800	2800
Irrigated, suspending irrigation in June, 10–18 leaves	300	600	-	500	800	2200
Irrigated, suspending irrigation in July, tassel growth – grains filling	300	600	1200	-	800	2900
Irrigated, suspending irrigation in August, grains filling-ripening	300	600	1200	500	-	2600

Table 5.

Characterization of the microclimate during the irrigation season of the maize by de Martonne aridity index (IdM) (Oradea, 2008–2011)

Year	Specification	Unirrigated		Irrigated		Difference
		Value	%	Value	%	%
2008	IdM value	23.0	100	50.0	217	117
	Characterization	Demiarid		Wet		
2009	IdM value	21.0	100	54.0	257	157
	Characterization	Demiarid		Wet I		
2010	IdM value	37.0	100	41.0	111	11
	Characterization	Moderate wet II		Wet		
2011	IdM value	20.0	100	48.0	240	140
	Characterization	Demiarid		Wet		
Average	IdM value	26.0	100	49.0	188	88
	Characterization	Moderate dry		Wet		

Figure 2: **Correlation between the values of the de Martonne aridity index (IdM) and yields in maize crop (Oradea, 2008–2011)**

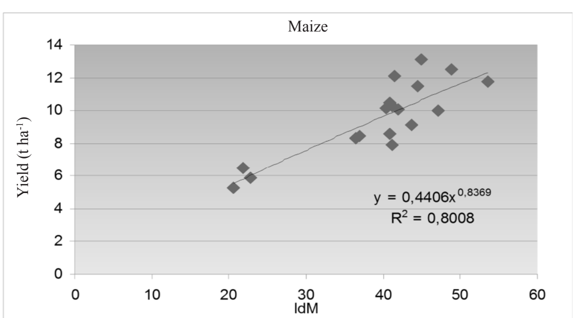
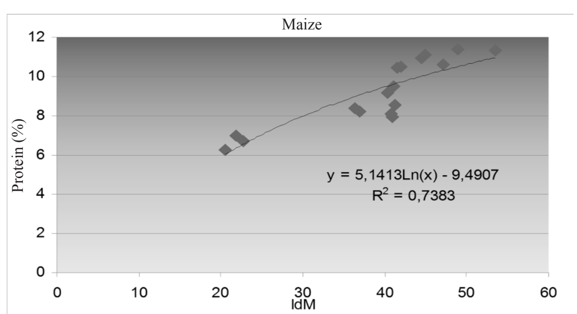


Figure 3: **Correlation between the values of the de Martonne aridity index (IdM) and the protein content of the maize grains (Oradea, 2008–2011)**



Hydric stress influence on maize water consumption

Regression functions for daily water consumption of the maize from studied variants were calculated and the smallest correlation coefficient was registered in unirrigated variant (R^2=0.6327) and the biggest correlation coefficient (R^2=0.8761) was registered in the variant without irrigation suspending. In the variant with irrigation suspending, the correlation coefficients values was smaller than in the variant without irrigation suspending *(figure 4)*.

In average on the studied period, in the variant without irrigation suspending was registered a maize total water consumption of 7142 m^3 ha^{-1}, with 59% bigger than the total water consumption (4501 m^3 ha^{-1}) of the unirrigated variant. In the variant with irrigation suspending, the values of the total water consumption were smaller than the values registered in the variant without irrigation suspending *(table 6)*.

Figure 4: **Regresion functions of the maize daily water consumption in the studied variants (Oradea, 2008–2011)**

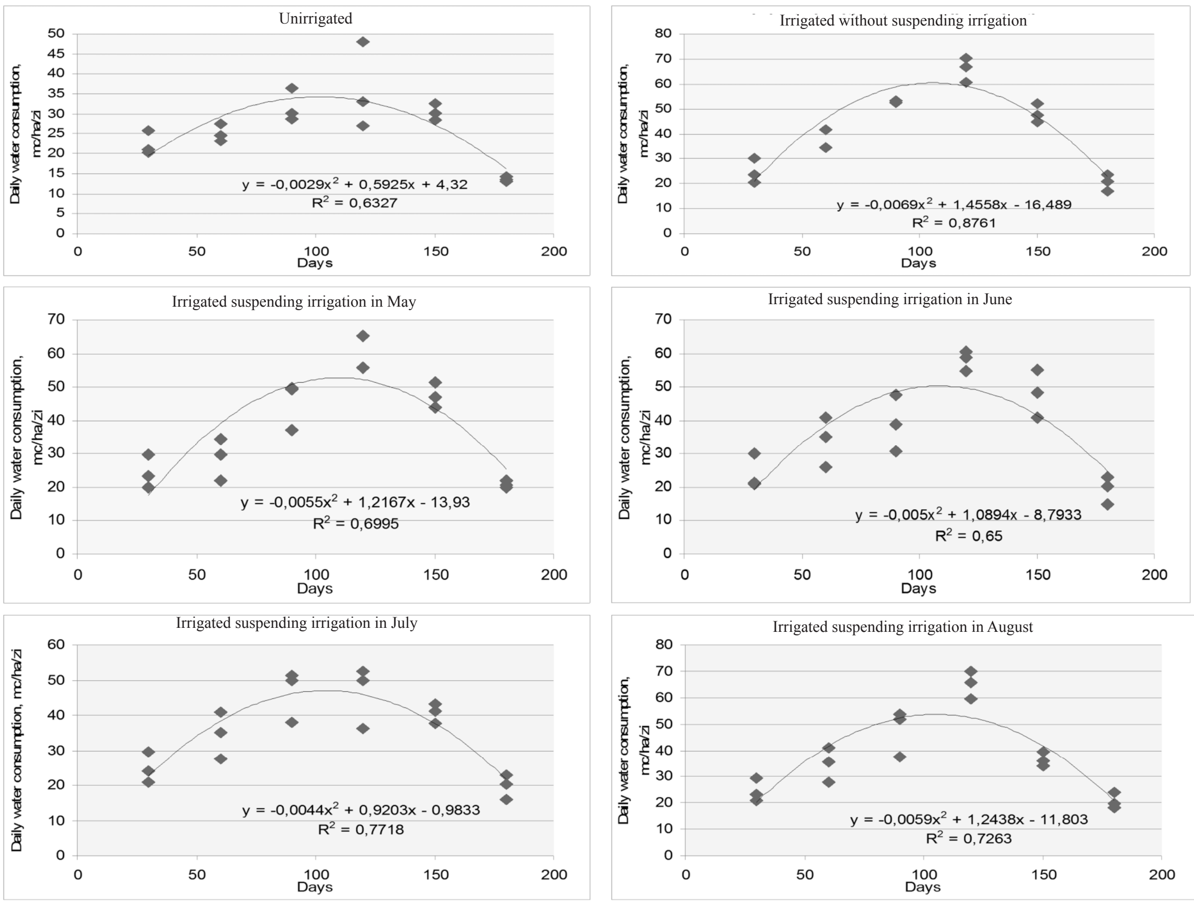


Table 6.

Total water consumption - ∑ (e+t) and the covering sources in maize (Oradea, 2008–2011)

Variant	∑ (e+t)			Covering sources of the water consumption					
				Soil reserve		Rainfall during vegetation period		Irrigation	
	(m^3 ha^{-1})	(%)	(%)	(m^3 ha^{-1})	(%)	(m^3 ha^{-1})	(%)	(m^3 ha^{-1})	(%)
1. Unirrigated	4501	100	63	1347	30.0	3154	70.0	-	-
2. Irrigated, without suspending irrigation	7142	159	100	1108	15.5	3154	44.2	2880	40.3
3. Irrigated, suspending irrigation in May, 4–9 leaves	6716	149	94	1207	18.0	3154	47.0	2355	35.0
4. Irrigated, suspending irrigation in June, 10–18 leaves	6731	150	94	1402	20.8	3154	46.9	2175	32.3
5. Irrigated, suspending irrigation in July, tassel growth – grains fillin)	6239	130	87	1085	17.4	3154	50.6	2000	32.0
6. Irrigated, suspending irrigation in August, grains filling-ripening	6622	147	93	1363	20.6	3154	47.8	2105	31.6

Hydric stress influence on yield level

In average on the studied period, the biggest value of the yield, 12473 kg ha^{-1} was registered in the variant with optimum regime of soil water reserve on watering depth (0–75 cm). The irrigation suspending determined the yield losses of 28% in the variant with irrigation suspending in July, the yield losses of 25% in the variants with irrigation suspending in June or August and yield losses of 10% in the variant with irrigation suspending in May; all the yield losses are very significant statistically. The biggest yield loss, 53%, was determined in unirrigated maize *(table 7)*.

Hydric stress influence on protein content of the maize grains

The biggest protein content of the maize grains were determined in the variant without irrigation suspending all the years studied; in average on the studied period, the protein content of the maize grains was of 11.29%. In the variants with irrigation suspending the protein content decreased significant statistically (-6%) in the variant with irrigation suspending in May, distinguee significant (-15% by irrigation suspending in June), very significant statistically (-24% and -29% by irrigation suspending in July or August). The smallest protein content of the maize grains was registered in the unirrigated variant (-41%) *(table 8)*.

The relative differences of the gross protein quantity in comparison with the variant without irrigation suspending had bigger values, the relative differences registered regarding the yield were of: -15% in the variant with irrigation suspending in May, -36% in the variant with irrigation suspending in June, -45% in the variant with irrigation suspending in July, -47% in the variant with irrigation suspending in August and -74% in unirrigated maize.

Table 7.

The influence of the irrigation suspending in different months of the vegetation period on maize yield in the conditions (Oradea, 2008–2011)

Variant	Yield		Difference		Statistical significance
	(kg ha^{-1})	(%)	(kg ha^{-1})	(%)	
1. Irrigated, without suspending irrigation	12473	100	-	-	Ct
2. Irrigated, suspending irrigation in May, 4–9 leaves	11242	90	-1231	-10	000
3. Irrigated, suspending irrigation in June, 10–18 leaves	9390	75	-3083	-25	000
4. Irrigated, suspending irrigation in July, tassel growth – grains filling	8970	72	-3083	-28	000
5. Irrigated, suspending irrigation in August, grains filling-ripening	9397	75	-3076	-25	000
6.Unirrigated	5893	47	-6580	-53	000

Note: $LSD_{5\%}$ = 213, $LSD_{1\%}$ = 350, $LSD_{0.1\%}$ = 667

Table 8.

The influence of the irrigation suspending in different months of the vegetation period on protein content of maize grains (Oradea, 2008–2011)

Variant	Protein		Difference		Statistical significance
	(%)		(%)		
1. Irrigated, without suspending irrigation	11.29	100	-	-	Ct
2. Irrigated, suspending irrigation in May, 4–9 leaves	10.63	94	-0.66	-6	0
3. Irrigated, suspending irrigation in June, 10–18 leaves	9.55	85	-1.74	-15	00
4. Irrigated, suspending irrigation in July, tassel growth – grains filling	8.59	76	-2.70	-24	000
5. Irrigated, suspending irrigation in August, grains filling-ripening	7.99	71	-3.30	-29	000
6.Unirrigated	6.68	59	-4.61	-41	000

Note: $LSD_{5\%}$ = 0.59, $LSD_{1\%}$ = 1.15, $LSD_{0.1\%}$ = 1.96

CONCLUSIONS

The researches regarding the irrigation suspending in the vegetation period of the maize were carried out during 2008–2011in Agricultural Research and Development Station Oradea and a following conclusions there were:

– Pedologial drought was determined every year in unirrigated variant; in the month with irrigation suspending, the pedological drought was determined, too. Strong pedological drought was determined in 7 days in 2008, in 32 days in 2009, and in 20 days in 2011; strong pedoogical drought didn't registered in 2010, the year with rainfall more than multianual average.
– Maintaining of the soil water reserve between easily available water content and field capacity determined to use an irrigation rate of 3320 m^3 ha^{-1} in 2008, of 4200 m^3 ha^{-1} in 2009, of 500 m^3 ha^{-1} in 2010 and of 3500 m^3 ha^{-1} in 2011;
– The differences between the values of the de Martonne aridity index from optimum irrigated variant and unirrigated variant were of 117% in 2008, of 157% in 2009, of 11% in 2010 and of 140% in 2011;
– The irrigation determined the increase of the daily water consumption. As consequence, the maize total water consumption in the variant with optimum irrigation increased with 59%. The total water

consumption values decreased in the variants with irrigation suspending;
- The average of the yield maize obtained in the variant without irrigation suspending was of 12 473 kg ha^{-1}. The irrigation suspending determined the yield losses very significant statistically. The biggest yield loss was registered in unirrigated variant, -53%;
- There were the bigger value of the grain protein content in the variants without irrigation suspending. In the unirrrigated variant and in the variant with irrigation suspending the protein content of the maize grain are smaller; the differences are statistically assured.
- The inverse links, statistically assured, were registered between the number of days with pedological drought and yield level and protein content of the yield maize, respectivelly;
- The direct links were quantified between the water/temperature report (de Martonne aridity index) and yield level and protein content of the maize grains. The links are statistically assured.

The researches sustain the irrigation like the main measure for drought control in the Crişurilor Plain.

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