IRRIGATION, AN IMPORTANT COMPONENT OF SUSTAINABLE AGRICULTURE SYSTEM IN WEST ROMANIA

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ABSTRACT

The paper is based on the research carried out during 1976-2003 in Oradea, in a long term trial with ten different crops. The crop rotation with alfalfa, the fertilization system with manure and optimum chemical fertilization determined the maintenance of the soil structure under irrigation on the level of the crop rotation with unirrigated wheat-maize. Soil water reserve on irrigation depth decreased below easily available water content every year and even below wilting point in some years. The irrigation improved the microclimate conditions and optimum water consumption could only be assured using the irrigation. Irrigation determined the increase of the yield level in average with 39% (wheat) to 127% (maize for silo); yield stability (standard deviation) improved with 8.7% (sunflower) to 50.4% (maize for silo). Yield quality and water use efficiency were improved, too, under irrgation. The correlations in the soil - water - plant - atmosphere system sustain too the importance of irrigation in the sustainable agriculture system from Western part of Romania.

Key words: crop rotation, fertilization, irrigation, long term trial

INTRODUCTION

The concept of sustainable agriculture appeared in the sixth decade of the last century as a response to the enviromental pollution. The slogan „we have one Earth which must be protected" at The United National Conference for Human Environment from Stockholm in 1972 and „Broundland Report" of ONU Conference on Enviroment and Development in Rio de Janeiro were the crucial moment to define the sustainable development concept, especially sustainable agriculture. The researchers who published about this problem were Tinbergen (1956), Odum (1971), Clarck and Mun (1986), Hall (1995) referenced by Puia and Soran (1999).

In Romania, 1999 was a reference moment regarding this problem. Prof. Cristian Hera organized the symposium „*The performant sustainable agriculture*", scientifical manifestation of Plant Crop Section belonging to Academy of Agricultural and Forestry Sciences „Gheorghe Ionescu Sisesti". Many and interesting papers were presented at the symposium, such as those written by Puia and Soran, Toncea, Saulescu, Iliescu, Sin and Picu (Hera 1999). Budoi and Penescu (1996), Gus et al. (1998) in the treatises of Soil Management had an important contribution in developing this concept, too. All these papers sustain the crop rotation as central pivot and presume diverse structures of crops. Under this system, the organic fertilization is very important, the chemical fertilization can be used with moderation, the soil tillage must be correctly done, the plants protection is realised by integrated management; all these elements ensure the conservation of the soil, water and biodiversity conservation and obtaining ecological and profitable yields. If it's used correctly, the irrigation is also a component of sustainable agriculture (Doorembos and Kassam, 1986; Doorembos and Pruitt, 1992).

The papers starts from this reason and, through the research concerning soil structure, soil moisture stress, the irrigation influence upon microclimate and plants water consumption, the level, stability and quality of the yield, and the water use efficiency, demonstrate that irrigation is an important component of sustainable agriculture system in West Plain of Romania.

MATERIAL AND METHODS

The research was performed at Oradea in the North part of Cris Plain during 1976-2003, in a long term trial on brown luvic soil.

On the ploughed depth, the brown luvic soil has a high hydraulic conductivity, medium on 20-60 cm depth and very small below 60 cm depth. On 0-20 cm depth the soil has low density (BD = 1.41 g/cm^3) and is compacted on the irrigation depth of the studied crops and on the depth (0-150 cm) for soil water balance. Field capacity (Fc) is medium on all soil profiles and wilting point (Wp) has a medium value to 80 cm depth and a large value below this depth. Easily available wa-

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ter content (W_{ea}) was established by formula (Botzan 1966; Grumeza et al., 1989):

$W_{ea} = Wp + 2/3 (Fc - Wp)$;

Soil reaction is slightly acid, the humus content (1.8%) is small and the total nitrogen content (0.127-0.156 ppm) is small to medium; the mobile potassium content is small to medium, too. The annual fertilization with doses adequate for irrigated crops increased the phosphorus content from 22.0 ppm to 150.8 ppm.

The water source for irrigation is ground water (15 cm depth). The irrigation water has a low natrium content (12.9 %), the salinization potential is low (CSR = -1.7) and SAR index (0.52) is low, too.

The irrigation equipment of the research field allowed to exactly measure and to uniformelly distribute the irrigation water.

Ten to ten days determinations of soil moisture showed the maintenance of the soil water reserve on irrigation depth (0-50 cm for wheat and bean; 0-75 cm for maize, soybean, sunflower, potato, sugarbeet, alfalfa 1st year, maize for silo; 0-100 cm for alfalfa 2nd year).

Domuta Climate Index (ICD) was calculated using the following formula:

$$ICD = \frac{100\ W + 12.9\ A}{St + Sb};$$

were:

W = water (irrigation, rainfall, ground water), mm
A = air humidity, %
St = the sum of daily average temperature, °C;
Sb = sun brilliance, hours

The climate characterization after ICD value is: < 3 = excessively droughty; 3.1-5.0 = very droughty; 5.1-7.0 = droughty; 7.1-9 = medium droughty; 9.1-12 = medium wet; 12.1-15 = wet I; 15.1-18 = wet II; 18.1-25 = wet III; > 25 = excessively wet.

The crop management practices were the optimum ones, for this part of the country. The used crop rotation was: alfalfa 1st year - alfalfa 2nd year - maize - bean - wheat - soybean - sugarbeet - sunflower - potato. The used fertilization system consisted of 40 t manure/ha for sugarbeet and potato and annual medium rates on crop rotation of 140 kg N/ha, 110 kg P_2O_5 /ha and 90 kg K_2O/ha.

The soil structure was determined with Cseratzki method and water consumption with soil water balance method; balance depth was 0-150 cm.

RESULTS AND DISCUSSION

The influence of irrigation on soil

A right management of irrigation regime (through maintaining the soil water reserve between easily available water content and field capacity on irrigation depth), the application of melioration crop rotation and an organo-mineral system of fertilization for irrigated crops determined the realization of structured degree of 35.98%, with 3% larger than the structured degree determined in wheat- maize rotation. Under unirrigated melioration crop rotation the structured degree (47.52%) was larger than in the wheat - maize crop rotation with 34% (Table 1).

The soil moisture stress

Table 1. The influence of the melioration of crop rotation and irrigation on macrostructure stability of the brown luvic soil. Oradea, 1976-2003

Crop rotation	Ø 5 mm		Ø 2 mm		Ø 1 mm		Ø 0.25 mm		S	
	Aggreg. %	Diff. %	Aggreg. %	Diff. %	Aggreg. %	Diff. %	Aggreg. %	Diff. %	Aggreg. %	Diff. %
Wheat-maize (unirrigated)	1.93	100	1.76	100	2.45	100	29.12	100	35.26	100
Melioration (unirrigated)	3.93	204	0.96	55	1.96	80	40.67	139	47.52	134
Melioration (irrigated)	0.56	29	0.63	36	1.12	48	33.42	114	35.98	103

The periods with soil water reserve below easily available water content on irrigation depth were considered as moisture stress periods (Domuta, 1995).

The soil moisture stress was present in each of 28 studied years, the maximum frequency was found in June in wheat and in August in maize, sugarbeet and alfalfa. In potato the maximum frequency (92%) was registered in July (Table 2).

In some years, soil water reserve on irrigation depth decreased below the wilting point.

The influence on microclimate

The irrigation determined the improvement of microclimate conditions. The value of the index water/temperature + light (Domuta Climate Index) calculated for irrigated maize was larger with 135% in August, 115% in July, 49% in June and 32% in May. In irrigated as compared with dry-land maize, the microclimate was characterized as „medium wet” vs. „medium droughty” in May, „wet II” vs. „medium wet” in June, „wet III” vs. „medium droughty” in July, „wet I” vs. „droughty” in August (Table 3).

Table 2. Monthly periods with soil water reserve below easily available water content on irrigation depth in main crops, under unirrigated conditions from Oradea, during 1976-2003

Crop	Specif.*	Month					
		April	May	June	July	August	September
Wheat	1	12	21	24	10	-	-
	2	82	96	100	70	-	-
Maize	1	2	8	13	23	29	25
	2	21	46	79	88	100	92
Sugarbeet	1	6	10	21	26	28	24
	2	39	48	87	87	100	96
Potato	1	6	8	17	24	21	-
	2	35	54	83	92	83	-
Alfalfa 1st year	1	5	12	19	27	29	27
	2	35	65	96	96	100	100

* - 1= Number of days with soil water reserve below easily available water content
2 = Frequency of days with soil water reserve below easily available water content

Table 3. The modifications of the water/temperature + light index (Domuta Climate Index - ICD) under the influence of the irrigation in maize. Oradea, 1976-2003

Variant	May		June		July		August	
	ICD	%	ICD	%	ICD	%	ICD	%
Unirrigated	8.9	100	10.7	100	8.6	100	6.3	100
Irrigated	11.8	132	15.91	149	18.5	215	14.8	235
Variation interval of differences	0-383		0-302		0-795		28-3126	

The irrigation influence on water consumption

The irrigation determined the increase of the values of daily water consumption. Under irrigations the total water consumption had values larger than total water consumption of unirrigated crops, the differences being between 36.6% (wheat) and 108.4% (maize for silo as second crop).

Most of total water consumption was covered by rainfall during crop vegetation. To ensure the optimum water consumption of these crops (maintaining the water reserve between easily available water content and field capacity) the irrigation was necessary every year; irrigation supplied between 33.7% (wheat) and 58.7% (maize for silo as second crop) of total water used; the maximum values varied between 61.0% (maize) and 103.2% (maize for silo as second crop) (Table 4).

The irrigation influence on yield level

The average yields obtained during 1976-2003 under irrigation was higher than under dryland, the relative differences being between 39% (wheat) and 127% (maize for silo as second crop).

The amplitude of the variation interval for yield differences between irrigated and non-irrigated plots was 104% in sunflower, 116% in wheat crop, 176 % in alfalfa crop 2nd year, 218% in sugar beet crop, 291% in alfalfa 1st year, 353 % in soybean, 358 % in potato, 800 % in bean, 805% in maize for grains and 25745% in maize for silo as second crop (Table 5).

The influence of irrigation on yield stability

The quantification of the yield stability was made using the „standard deviation" indicator. In all crops, the irrigation determined the increase of yield stability, the differences between standard deviations for irrigated and unirrigated conditions was 8.7% (sunflower) and 50,4% (maize for silo as second crop) (Table 6).

The influence of irrigation on quality of yield

In irrigated maize, the quantity of total nitrogen in grain was bigger than unirrigated maize with 19.7%. Taking into consideration the yield differences between irrigated and unirrigated maize, results much more protein (135,4%) under irrigated conditions,(Table 7). The participation of the big potato in the yield of the irrigated variant was of 84.4% with 11.6% more than unirrigated variant (Table 8).

Table 4 . The water consumption S (e + t) and the covering sources. Oradea, 1976-2003

Crop	S(e+t), m^3/ha			Covering sources of S(e+t) optimum, m^3/ha				
						S_m (irrigation rate)		
	Unirrigated	Irrigated	Difference irrigated-unirrigated %	Ri-Rf	Rv	m^3/ha	%	variation interval %
Wheat	3138	4289	36.6	535	2307	1447	33.7	0-61.8
Maize	4253	6223	46.3	509	3237	2477	39.8	13.5-61.0
Sunflower	3947	5900	49.5	933	2798	2169	36.8	6.2-63.0
Soybean	3828	5826	52.2	563	3049	2214	38.0	9.4-61.5
Bean	3211	4184	30.3	324	2472	1388	33.2	7.0-71.4
Sugar beet	4618	6992	51.4	840	3459	2694	38.5	8.3-67.9
Potato	3803	5292	39.2	516	2953	1823	34.4	7.1-61.1
Alfalfa 1st year	4681	6698	43.0	525	3578	2595	38.7	9.1-64.7
Alfalfa 2nd year	5074	7791	53.5	945	3796	3050	39.1	14.3-61.2
Maize for silo 2nd crop	1378	2872	108.4	-145	1333	1685	58.7	10.5-103.2

Ri - Initial reserve; Rf - Final reserve, Rv - Rainfalls during vegetation;

Table 5. The yield level in main crops, under irrigated and unirrigated conditions. Oradea, 1976-2003

Crop	Variant	Yield level			
		Average		Variation interval	
		kg/ha	%	kg/ha	%
Wheat	Unirrigated	4547	100	2736-7100	100
	Irrigated	6343	139	3993-8300	105-221
Maize	Unirrigated	6608	100	1510-12600	100
	Irrigated	11993	181	17880-16480	107-912
Soybean	Unirrigated	1836	100	300-3400	100
	Irrigated	3087	168	1380-4080	107-460
Bean	Unirrigated	1439	100	180-2720	100
	Irrigated	2170	151	1321-3770	105-905
Sunflower	Unirrigated	2289	100	1350-3140	100
	Irrigated	3394	148	1757-4580	106-210
Sugar beet	Unirrigated	39895	100	18960-80900	100
	Irrigated	64453	162	44850-87800	109-327
Potato	Unirrigated	24137	100	11500-43700	100
	Irrigated	38284	159	20670-66050	106-464
Alfalfa 1st year	Unirrigated	45472	100	18500-89800	100
	Irrigated	69905	154	30500-120850	113-404
Alfalfa 2nd year	Unirrigated	60953	100	29500-118590	100
	Irrigated	96822	159	57000-145420	119-295
Maize for silo as 2nd crop	Unirrigated	13890	100	0-31000	100
	Irrigated	31470	227	10160-44640	115-25860

Table 6. Standard deviation of yields in unirrigated and irrigated crops. Oradea, 1976-2003

Variant	Crops for grain									
	Wheat		Maize		Sunflower		Soybean		Bean	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Unirrigated	922	100	3271	100	580	100	814	100	820	100
Irrigated	642	69.6	1879	57.4	530	91.3	547	67.2	680	82.9
	Crops for stalk and roots									
	Sugar beet		Potato		Alfalfa 1st year		Alfalfa 2nd year		Maize for silo 2nd crop	
	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%	kg/ha	%
Unirrigated	9240	100	9440	100	37950	100	30160	100	9310	100
Irrigated	6920	79.9	5480	58.1	33630	88.6	25720	85.3	4620	49.6

Table 7. The influence of irrigation on protein content in maize. Oradea, 1987-1993

Variant	Total nitrogen content in maize kernels		Protein content in kernels	
	%	%	kg/ha	%
Unirrigated	1.42	100	556.94	100
Irrigated	1.70	119.7	1311.52	235.4

Table 8. The influence of the irrigation on the big tubers share from potatoes. Oradea, 1976-2003

Variant	The big tubers share		Variation interval of big tubers share
	Values %	%	
Unirrigated	75.6	100	71.6-82.5
Irrigated	84.4	111.6	80.1-92.4

The influence of irrigation on water use efficiency

Excepting the sunflower, in all crops, the irrigation determined an improvement of water use efficiency, i.e. for 1 m^3 water used a higher yield was obtained than under unirrigated conditions. The relative differences had medium values between 2% (wheat) and 25% (maize for silo as second crop) (Table 9).

The rainfall favorability

Picu (2003), calculated the rainfall favorability as procentual ratio between yield obtained under unirrigated condition and yield obtained under irrigation. Calculating this index for all studied crops for the 28 years of study resulted in favorability ratios under 60% in 65% of the years for maize for silo as second crop, in 59% for maize, in 50% for alfalfa 1st year, in 48% for alfalfa 2nd year, in 45 % for bean, in 43% for sugar beet, in 39% for potato, in 35% for sunflower and 15% of years for wheat (Table 10).

Correlations in the soil-water-plant-atmosphere system

Over the years the correlations in the soil-water-plant-atmosphere system for all studied crops (Domuta, 1995, 1997,1999, 2000, 2003; Domuta et al., 2000) were calculated. The paper presents the correlations for maize, one of the most important crops in this area.

Between number of days with water reserve below easily available water content and yield, respectively water use efficiency, and between number of days with water reserve on irrigation depth below wilting point and yield, very significant negative correlations were determined. The correlations between number of days with water reserve below easily available water content and yield gain obtained using the irrigation was positive and very significant.

Very significant positive correlations between microclimate conditions and yield, respectively

Table 9. Irrigation influence on water use efficiency. Oradea, 1976 – 2003

Variant	Crops for grain									
	Wheat		Maize		Sunflower		Soybean		Bean	
	kg/m^3	%	kg/m^3	%	kg/m^3	%	kg/m^3	%	kg/m^3	%
Unirrigated	1.45	100	1.55	100	0.58	100	0.48	100	0.45	100
Irrigated	1.48	102	1.93	125	0.58	100	0.53	110	0.52	115
Crops for stalk and roots										
	Sugarbeet		Potato		Alfalfa 1 st year		Alfalfa 2nd year		Maize for silo as second crop	
	kg/m^3	%	kg/m^3	%	kg/m^3	%	kg/m^3	%	kg/m^3	%
Unirrigated	8.64	100	6.35	100	9.71	100	11.94	100	10.08	100
Irrigated	9.22	106.7	7.23	114	10.44	108	12.42	104	10.95	109

Table 10. The analysis of the favorability for the crops on Cris Plain. Oradea, 1976-2003

Crop	Years grouping (%) in the favorability classes					
	91-100	81-90	61-80	41-60	21-40	0-20
Wheat	11	15	59	15	-	-
Maize	11	11	19	26	26	7
Sunflower	8	24	36	32	-	-
Soybean	4	25	29	21	21	-
Bean	19	12	34	12	8	15
Sugarbeet	14	14	29	29	14	-
Potato	11	21	29	21	18	-
Alfalfa 1st year	4	15	31	31	15	4
Alfalfa 2nd year	-	29	14	38	10	-
Maize for silo second crop	-	15	19	15	23	27

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Table 11. Correlation in the soil - water - plant - atmosphere system in maize. Oradea, 1976-2003

Correlation	Regression function	Correlation coefficient
Correlation between soil moisture stress and yield		
No.of days with WR<WP x yield	$y = 601.33\ x^{0.9047*}$	$R = 0.88^{ooo}$
No. of days with WR<W x yield	$y = 158.88\ e^{-0.0148*}$	$R = 0.66^{ooo}$
No. of days with WR<W x WUE	$y = 3.5236\ e^{-0.0144*}$	$R = 0.62^{oo}$
No. of days with WR<W x yield gain.	$y = 0.0935\ x^{-0.0127}$	R = 0.78***
Correlation between microclimate and yield		
ICD x yield	$Y = -0.2931x^2+13.57x-21.108$	R = 0.88***
Correlation between water use efficiency and yield		
WUE x yield	$Y = -0.0004x^2+0.6312x128.48$	R = 0.77***

WR = water reserve on 0-75 cm depth;
WP = wilting point;
WEA = easily available water content;
WUE = water use efficiency; kg/m^3
ICD = Domuta Climate Index

between water consumption and yield were found. These correlations show the importance of maize irrigation in this area (Table 11).

CONCLUSIONS

The paper is based on the research carried out during 1976-2003 at Oradea, in a long-term trial with ten different crops.

The use of irrigation as a component of sustainable agriculture is supported by the following arguments:

- The evolution of soil structure. Under the conditions when alfalfa was used in the crop rotation, and the fertilization system included manure the soil structure was maintaining to the level of unirrigated crop rotation wheat – maize.

- The decrease of soil water reserve on irrigation depth below easily available water content every year and in some years even below wilting point level.

- The droughty microclimate of unirrigated crops and the positive influence of the irrigation on water/temperature + light index, the differences obtained in maize crop reaching 3126% in August.

- The improvement of the crops water consumption the differences in comparison with unirrigated crops were between 36.6% (wheat) and 108.4% (maize for silo as second crop). The optimum water consumption can only be assured using irrigation. Irrigation provided between 33.2% (sunflower) and 58.7% (maize for silo as second crop) of the total water consumption.

- Yield gains from irrigation, were between 39% (wheat) and 127% (maize for silo as second crop). The amplitude of variation were between 110% (sunflower) and 25760% (maize for silo as second crop). The quality of yield is better than under unirrigated conditions.

- Standard deviation values for yield were smaller than under unirrigated conditions with relative values between 8.7% (sunflower) and 50.4% (maize for silo as second crop).

- The increase of water use efficiency with values between 2% (wheat) and 25% (maize).

- A favorability of rainfall under 60% was found in 65% of years for maize for silo as second crop; in 59% for maize for grains; in 50% for alfalfa 1st year; 48% for alfalfa 2nd year; 45% for bean; 43% for sugar beet; in 39% for potatoes; in 35% for sunflower; in 15% for years for wheat.

- The negative correlations between number of days with moisture stress in the soil and yield, respectively water use efficiency;

- The positive correlations between number of days with moisture stress in the soil and yield gain obtained using the irrigation;

- The positive correlations between water/temperature + light index (Domuta Climate Index) and yield, respectively between water consumption and yield.

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Table 1

Average yield of experiments with winter wheat cultivars, under irrigation and dry-land in six localities from the South of Romania (2002)

Locality	Average yield under: irrigation (kg/ha)	Average yield under: dry-land (kg/ha)	Yield percentage diminution
Caracal	8560	5601	34.6
Marculesti	4716	3075	34.8
Teleorman	5963	3594	39.8
V. Traian	6941	3794	45.3
Fundulea	4858	1918	60.5
Simnic	(8560)	380	95.6

Table 2

Percentage diminution of some plant features under water stress conditions as compared to irrigation

Locality	Plant number	Plant height	Grain filling period	Spike number	Grain/ear	TKW	Test weight
Caracal	0	14,9	15,0	7,9	10,2	14,1	0,9
Teleorman	0	10,0	19,2	12,0	12,0	11,9	1,0

V.Traian	34,9	21,0	16,9	42,5	12,2	2,9	8,1
Fundulea	4,9	28,8	24,9	6,9	28,9	29,5	3,9
Simnic	27,6	61,7	30,0	65,0	64,5	53,1	10,7
Media	13,5	27,3	21,2	26,9	25,6	22,3	4,9

Table 3

Minimum, maximum and average yields registered at Fundulea in 2002 in international trials WWEERYT with genotypes grouped depending on the originating country

Source	Average yield of the tested genotypes (kg/ha)	Maximum yield of the tested genotypes (kg/ha)	Minimum yield of the tested genotypes (kg/ha)
Romania	2368	2953	2073
Russia	2327	2453	1980
Ukraina-Odessa	2224	3013	1287
Hungary	2181	2780	1320
Ukraina-Mironovka	2108	2753	1500
Moldova	1927	2560	1293
Bulgaria	1898	2873	1313
Turkey	1893	2420	1487
Azerbaidjan	1460	1553	1367
Kazahstan	1422	1833	853
LSD 5%	243	275	

Table 4

Correlations between yield under water stress conditions and different traits

Locality	Average	Correlation coefficients between yield under water stress conditions and:

	yield diminution because of water stress (%)	yield under irrigation	plant height under stress conditions	plant height under irrigation	heading time	spike/m²	grain/ear	TKW
Caracal	34,6	**0,48**	0,29	-0,31	-0,12	0,20	0,11	-0,30
Teleorman	39,8	**0,80**	0,35	0,31	**-0,85**	**0,58**	-	-
Valu Traian	45,3	0,04	0,33	0,20	**-0,40**	**0,42**	**0,40**	0,22
Fundulea	60,5	0,00	**0,46**	-0,31	**-0,46**	**0,52**	0,30	-0,17
Simnic	95,6	-0,01	**0,41**	**-0,62**	-0,04	**0,40**	**0,50**	0,15

The bold characters are significant at the probability level of 0.05

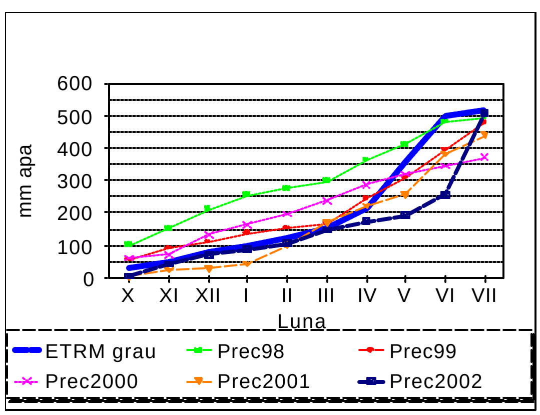

Figure 1. Average evapotranspiration and rainfall during 1999-2002 at Fundulea (mm water; month; wheat evapotranspiration; rainfall)

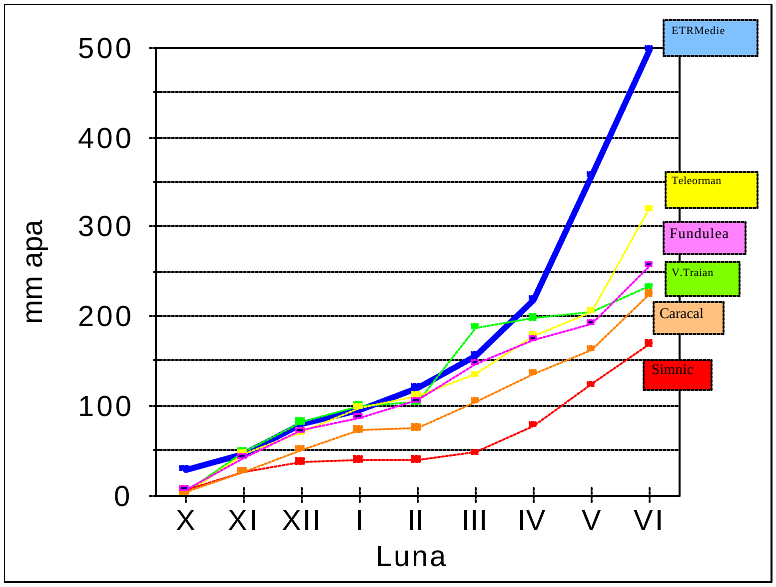

Figure 2. Average evapotranspiration and rainfall during the vegetation period in six locations of Southern of Romania in 2001-2002 year (mm water; month).

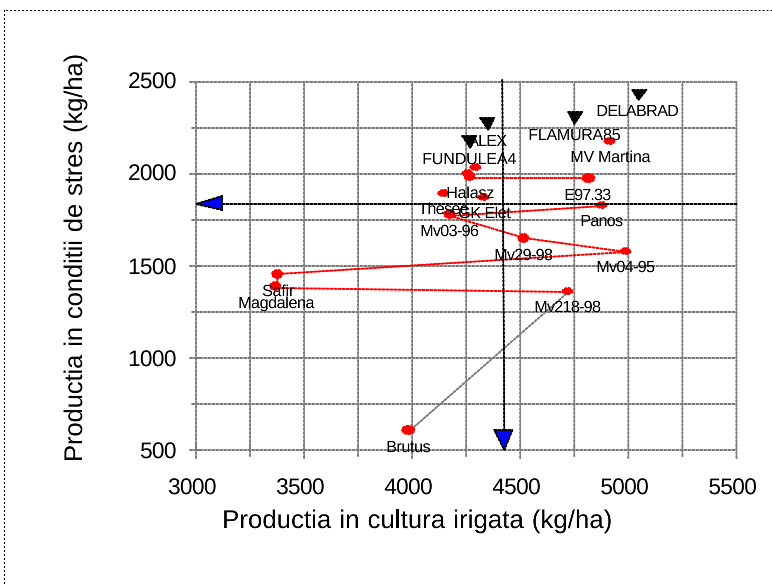

Figure 3. Yield obtained by some Romanian and foreign cultivars under irrigation and non-irrigation, in 2002 at Fundulea (arrows indicate the experiments average yield)(Yield under stress conditions; yield under irrigation).

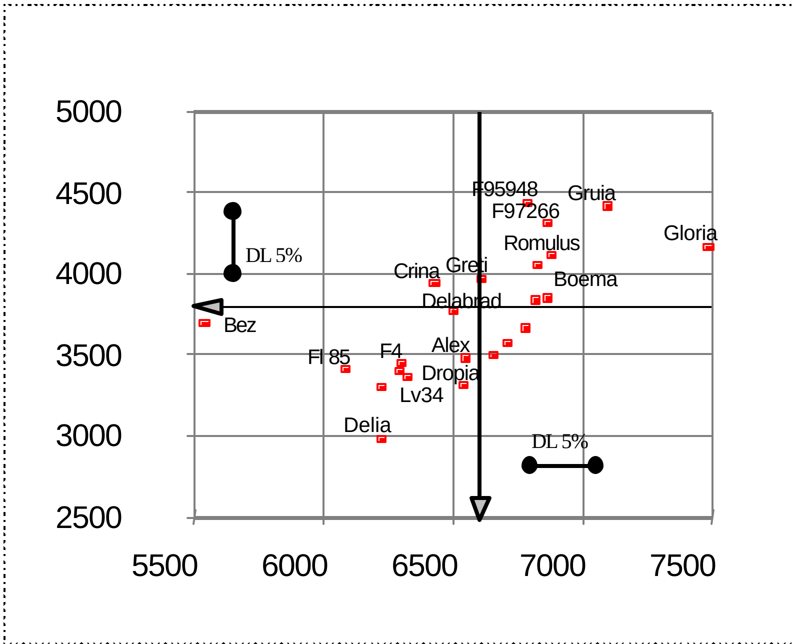

Figure 4. Average yields in four locations, obtained in 2002 by Romanian new lines and cultivars under irrigation and non-irrigation (arrows indicate experiments average yield)(Yield under non-irrigation; Yield under irrigation; LSD).