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DISTRIBUTION OF SOIL MOISTURE IN THE PROFILE OF TYPICAL CHERNOZEMS UNDER WIDE-SPACE IRRIGATION AND IMPACT ON THE YIELD OF MAIZE (*Zea mays* L.)

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Abstract

Irrigation in Bulgaria is a common agricultural practice for improving and stabilizing crop yields. Recently, the socio-economic conditions and climate peculiarities set the pattern for practicing water saving irrigation technologies. Irrigation in ever-other-furrow on capillary soils is a way to save water amounts, to improve water use efficiency and to protect soil structure. The goal of the paper is to present the seasonal water depletion in soil profile of chernozems under maize at different intra-furrow spaces and different application depths. The relation of yield to soil moisture unevenness and water deficit is discussed. A two-year experiment in 2009 and 2010 was conducted in Central North Bulgaria, in the experimental field of Maize Research Institute Knezha. The following variants were tested: rainfed (RF) (control), full irrigation at a refill point (RP) 80% of field capacity (FC), 50% deficit irrigation (DI), and 67% DI. The water was distributed as follows: in every furrow (EF), in every-other furrow (EOF) and in ever-third furrow (ETF). Considering the rainfall totals, both years were medium wet, while considering air humidity they were very dry. The yields under rain-fed conditions were high – average 7.01 Mg/ha, while the yields under full irrigation – comparatively low-9.39 Mg/ha. The additional yield under full irrigation in both years was 1.98 and 2.79 Mg/ha respectively, under 50% DI –8.54 and 8.75 Mg/ha, and under 67% DI-8.09 and 8.24 Mg/ha. Yield losses caused by DI relate nonlinearly to the application depth reduction. A 50% reduction of the application depth caused 5.8-6.8% yield losses in 2009 and 8.0-17.7% in 2010. A 67% reduction of the application depth caused 7.0-9.8% yield losses in 2009 and 17.3-18.1% in 2010. Greatest yield losses occurred at 67% DI in ETF, but the smallest ones – at 50% DI in EOF. EOF irrigation technology proved to be water-accumulating. The lower layers of chernozems tended to accumulate available water through all the vegetation season long in a continuous zone. Therefore the space between furrowsdidn't impact significantly the yield even under deficit irrigation.

***Key words:** maize, chernozems, every-other furrow irrigation, available water, yield.*

INTRODUCTION

The atmospheric water supply in the semi-humid climate of Bulgaria is unsecured and irrigation is a good practice for stabilizing the yields of the agricultural crops. At the same time, irrigation in the country is disabled by the poor economic situation and the irrigation systems being out of condition. In the last years, crop water needs are hardly met, because of warming and drought atmospheric processes, settling in the region. Saving water, a simple design and low prices are the desirable features of the contemporary irrigation equipment and technologies. These factors are hardly met all together, because water-saving technologies require great investments in compound equipment. Therefore they are applied to intensive crops over small areas, but not to large-field crops. There are a lot of attempts to reduce the water losses in surface irrigation and to turn this easily applicable and mostly used irrigation technology into a water-saving one. Since last decades some investigations abroad and in our country have proved that furrow irrigation in some particular accomplishment can be likely for obtaining high water use efficiency (WUE), that it can save water under some particular conditions, system design and irrigation schedule. An optimized combination of soil properties, intra-furrow space and application depth, including some water deficit can be successful in terms of obtaining profitable yields. The results from the experiments show that high yields close to the maximum ones can be obtained by applying 80-50% of the biologically optimal irrigational water quantity (Stone et al., 1982; Stone Crabtree et al., 1985; Hodges et al., 1989; Kang et al., 2000). Suitable for that are soils of good water capacity and good capillarity. Technologically, water can be given in every-other furrow (EOF) or every-third furrow (ETF) with reduced application depths, fixed-furrow (FF) or alternate-furrow (AF) irrigation, by constant or variable flow rate. These technologies avoid water losses from evaporation and deep percolation, protect soil structure, contribute for relatively uniform watering, enable high water use and labor efficiency, etc. Evidence for the higher absorption of the irrigational water by wide-spaced irrigation is the results of Sepaskhah and Afshar-Chamanabad (2002). They have established that the infiltration parameters of the every-other furrow irrigation (EOF) are higher than those of the ordinary every furrow irrigation (EF). Hodges et al. (1989) have obtained 0.68 to 0.81-time smaller rate of the advance of water down the furrow at the EOF vs. EF irrigation, depending on soil type and slope. High yields can be obtained by wide-spaced irrigation with small irrigation depths – this is the standpoint of Stone et al. (1982). They have established that maize and soybean produce yields like the maximum ones under 20-50% irrigation deficit. The 73% irrigation depth distributed in EOF provided for 16% higher yield vs. EF distribution (Sepaskhah, Kamgar-Haghighi, 1997). There are experimental results for wide-spaced irrigation on chromic luvisols, smolnitsa and alluvial-meadow soil that correspond to the results from abroad (Moteva, Stoyanova, Matev, 2009).

MATERIALS AND METHODS

A furrow irrigation experiment with "Knezha 511" maize variety (FAO 500) has been conducted in Knezha Region (Central North Bulgaria) in 2009 and 2010. It was put in a randomized complete block design in four replications. The variants consisted of three soil moisture regimes: rain-fed (RF), full irrigation at a refill point (RP) of 80% of FC; 50% deficit irrigation (DI); 67% DI. Each application depth was distributed as follows: in every furrow (EF); in every other furrow (EOF); and in every third furrow (ETF). The harvested plots were 42 m^2. The furrow length of the experimental plots was 18 m. The application depth at *RP* was calculated as: $m=10xHx\alpha(\beta_{FC}-\beta_{RP})$, where β is the moisture percentage by weight; a – bulk density, g/cm^3; H – depth of the root zone, m (Kostyakov, 1951). Grain yield was estimated at 14% standard humidity of the grains. Land preparation, fertilizers and weed control were applied according to the standard agricultural practices of the region.

The experimental field of Maize Research Institute Knezha is situated to 43.46^o N, and asl 117 m. The climate is moderate continental. The high July-August air temperatures together with very low relative air humidity – down to 30-35% are peculiar for the region. The period July-August is also very dry with average rainfall total 105.0 mm and longer than 10-day drought periods. The water content in the top 25-cm soil layer at sowing, as established in a long-term statistical investigation, is readily available (RAW) (Georgieva et al., 2010). Irrigation of maize is practiced within the period 3rd decade of June-2nd of August (Slavov et al., 2000; Georgieva et al., 2011). Soil is a typical chernozem – loamy, fertile and capillary with good water holding capacity. The total water content at FC is TWC=335.9 mm, available water content AWC=152.3 mm, bulk density average for 0-100-cm soil layer is *a*=1.31 g/cm^3. The hydrological properties of the soil can be seen on Figure 1.

A soil moisture grid 10/35 across the furrows was compounded for every variant, 48 hours after an application was given, by the gravimetric method.

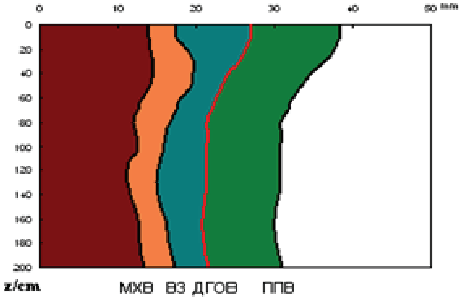


Figure 1. Hydrological constants in soil profile 0-200 cm of typical chernozems (Georgieva et al., 2010)

Table 1. Probability of the meteorological factors

Period	Rainfalls				Air temperature				Vapour pressure deficit			
	April-Sept.		July-Aug.		April-Sept.		July-Aug.		April-Sept.		July-Aug.	
Years	∑R mm	Proba-bility (%)	∑R mm	Proba-bility (%)	Σ°C	Proba-bility (%)	Σ°C	Proba-bility (%)	∑D hPa	Proba-bility (%)	∑D hPa	Proba-bility (%)
2009	309.0	55.0	124.8	23.2	3497.1	25.2	1426.2	29.2	1598.7	49.0	699.9	47.0
2010	306.5	58.9	61.6	78.8	3555.4	17.3	1479.7	11.3	1916.7	17.3	878.0	17.3

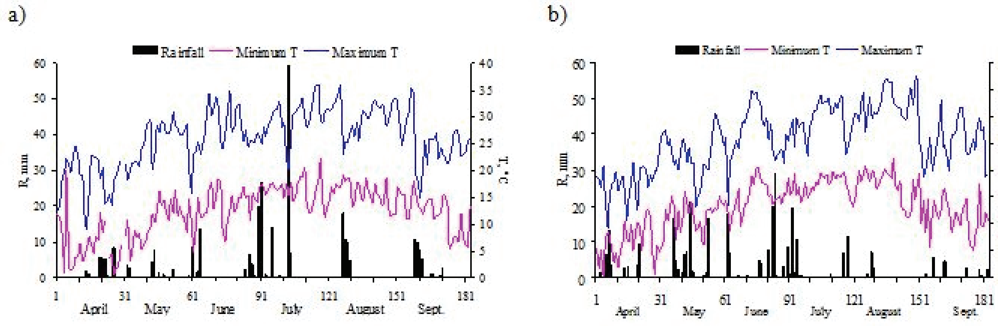


Figure 2. Daily rainfalls, minimum and maximum air temperature: a) 2009; b) 2010

A variance analysis was applied to establish the significance of irrigation impact.

The years of the experiment were of medium conditions as to the probability of exceedance of April-September rainfall totals; very hot as to air temperature totals; and 2009 was medium as to the vapor pressure deficit totals, but 2010 was very dry

(Table 1). The daily distribution of the rainfalls during the vegetation period can be seen on Figure 2. Long drought periods are observed in June, July and August in both years.

RESULTS AND DISCUSSIONS

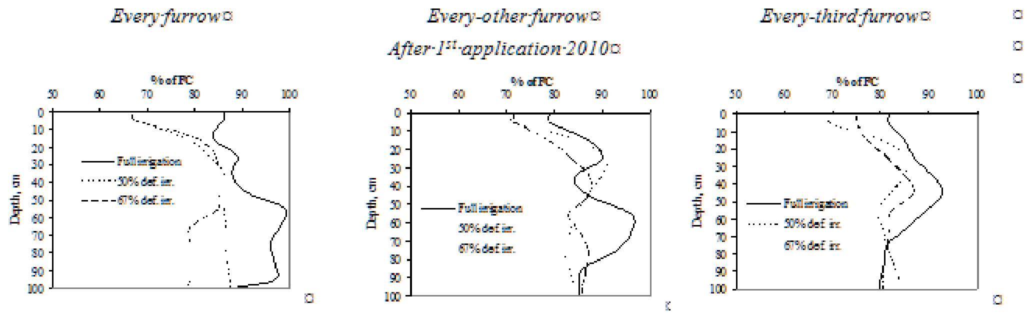
Soil moisture is one of the main factors for yield formation. Its availability predisposes the rate of the physiological processes and dry matter accumulation. Lack of water works for slowing down plant development and obstructs formation of the reproductive organs.

Full irrigation in EF ensured high moisture-around 90% of FC through the soil profile (Figure 3). Deficit irrigation in EF ensured around 85% of FC in 20-50-cm soil layer. The top 0-20 cm of the soil could not be enough moisturized. Applying 67% DI in EF caused insufficient moisturizing of the 60-100-cm layer. Moisture in this layer did not raise up to RP.

Distribution of soil moisture after the 1st application when irrigating in EOF is similar to that in EF. The 50% and 67% DI keeps moisture of the 40-100-cm layer around RP, the top 20 cm-s quickly dries up down to 70% of FC. Full irrigation in EOF ensured readily available water (RAW) through the whole soil profile, but moisturizing is lower than that in EF, probably due to percolation losses, because of high water quality delivered to the irrigated furrows. This is the reason for the water losses occuring at full irrigation in ETF.

Full irrigation after the 2nd application at the three ways of distribution of the water refilled soil moisture up to 90% of FC. Irrigation in EF and EOF did it for the layer 40-100 cm, but irrigation in ETF – for the lower 50-100-cm layer. The top 0-30 cm remained dry (Figure 3).

Soil water depletion mostly depends on evapotranspiration. Soil reservoir is refilled only by the atmospheric rainfalls in the rain-fed variants. The insufficiency and intermittence of rainfalls hinder crop productivity. It is seen on Figures 4 and 5 that depending on the distribution of the rainfalls and on the evapotranspiration increase, soil moisture depleted to RP at mid June, 48 DAS in the vegetative stage in 2009 and mid July, 83 DAS, during silking in 2010.


Every furrow

Every other furrow

Every third furrow

After 1st application 2010

After 2nd application 2009

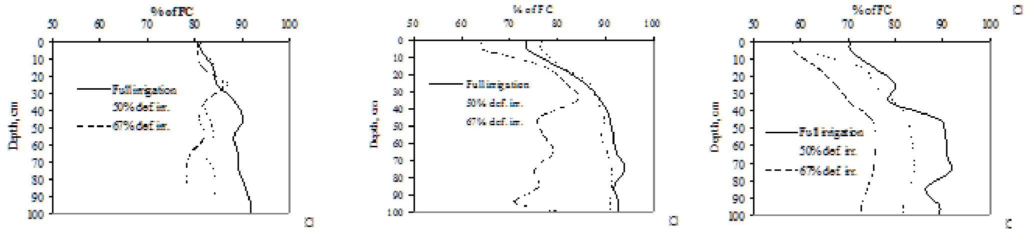


Figure 3. Distribution of soil moisture in the soil profile

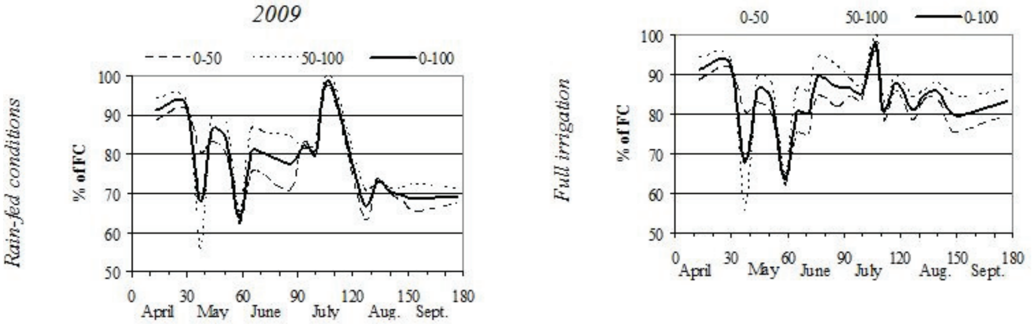


Figure 4. Dynamics of soil moisture through the vegetation period in 2009

Considering the same dates of sowing in both years, the great time range of soil water depletion is evidence for the significance of the meteorological factors especially rainfall distribution, for soil moisture depletion. Since thexperimental years were medium related to rainfalls, soil moisture depleted beneath 70% of FC lately. That happened in wax maturity when availability of soil water was not important.

We assume that distribution of soil moisture in soil profile at EF is uniform, while the distribution in EOF and ETF should vary across and along the furrow direction even at full irrigation. At full irrigation in EOF, the top 15-cm soil layer under the dry furrows remained dry. The remaining part of the soil profile was wet in the range 70–95% of FC (Figure 6). At full irrigation in ETF – part of the soil profile under the dry furrows and the adjacent rows also remained dry. Moisture under the wetted furrow increased up to 92-98% of FC at a depth of 40-100 cm. It was around 90% of FC in the layer 50-100 cm under the adjacent row. Moisture decreased gradually in depth and perpendicularly away from the wetted row. Apparently, full irrigation in wide-spaced furrows is the reason for deep percolation losses of water, resulting in uneven distribution of soil moisture through the soil profile.

At 50% DI in EOF, only a small part of the profile did not get RAW. Soil moisture was higher than 70% of FC in the 30-100-cm layer, mostly in the range 81-86% of FC. After the 2nd application the top 30-cm layer remained dry. At 50% DI in ETF, RAW in the range 70-86% of FC was established generally in the layer 40-100 cm (Figure 6). At 67% DI in EOF, the root zone 1-m in depth × 35 cm radially was moisturized in the range 70-89% of FC. The driest parts were located under the dry furrow and the adjacent row in the top 0-20 cm. At 67% DI in ETF, RAW after the 1st application was established in the lower 50-100-cm soil layer and after the 2nd one – under the wetted and furrow mainly (Figure 6).

Longitudinal mosturizing (along the furrows) in wide-spaced irrigation was uneven (Figure 7 and 8). At full irrigation in EOF – soil moisture was high and uniformly distributed only under the wetted furrow. Under the row and the dry furrow RAW was discovered in the right part of the profile.

At 50% DI the available water in soil profile was below 50 cm. At 67% DI in EOF the top 20 cm under the wetted were dry 48 h after the application was given. The remaining part of the profile was evenly moisturized in the range 70-93% of FC. Plants could take water from beneath 40 and 60 cm under the row and the dry furrow. The moisture in the layer 40-80 cm was between 70 and 80% of FC, and in the 80-100-cm layer – more than of 80% of FC.

At full irrigation in ETF, moisture under the wetted furrow was readily available through the whole profile, but with higher values at the end of the furrows. This was the tendency under the whole plot, the dry furrow and the adjacent rows inclusive. No tendency of moisture distribution was noticed at DI in ETF, due probably to the small amount of the given water (Figure 8).

Irrigation impact was significant in all variants of irrigation and water deficit applied (Table 2 and 3), except for 67% DI in EF and in ETF in 2010. The yield under rain-fed conditions in both years was 6.92 and 7.09 Mg/ha respectively. Relative yield varied from 126.6% to 140.3% in 2009 and from 104.7 to 127.9% in 2010. Yield increase was considerably small due to the mid and mid-moist conditions considering rainfalls and air humidity, which favored the yield accumulation under RF (col. 7 and 8 of Table 2 and 3).

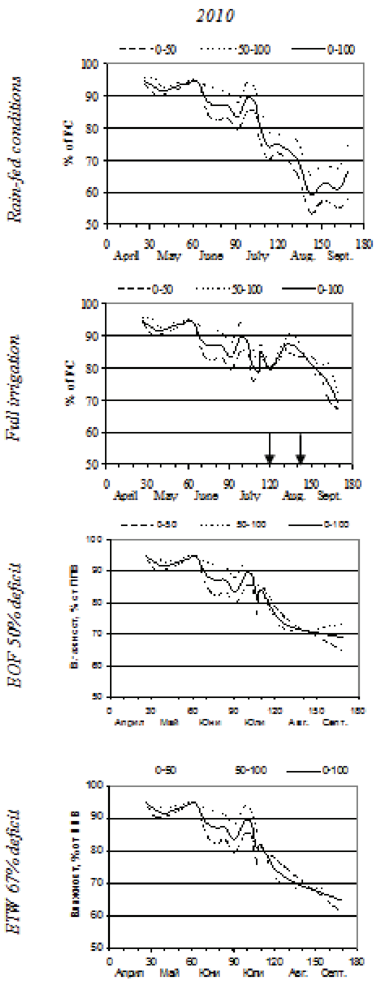


Figure 5. Dynamics of soil moisture through the vegetation period in 2010

Water deficit had significant effect in all studied cases, except for 50% DI in EOF in 2009. The latter proved to be efficient. Like yields were obtained by 50% of the needed irrigational water distributed in EOF and by the full needed amount. The relative yield was 94.2% since the increase in WUE compensated the lack of water.

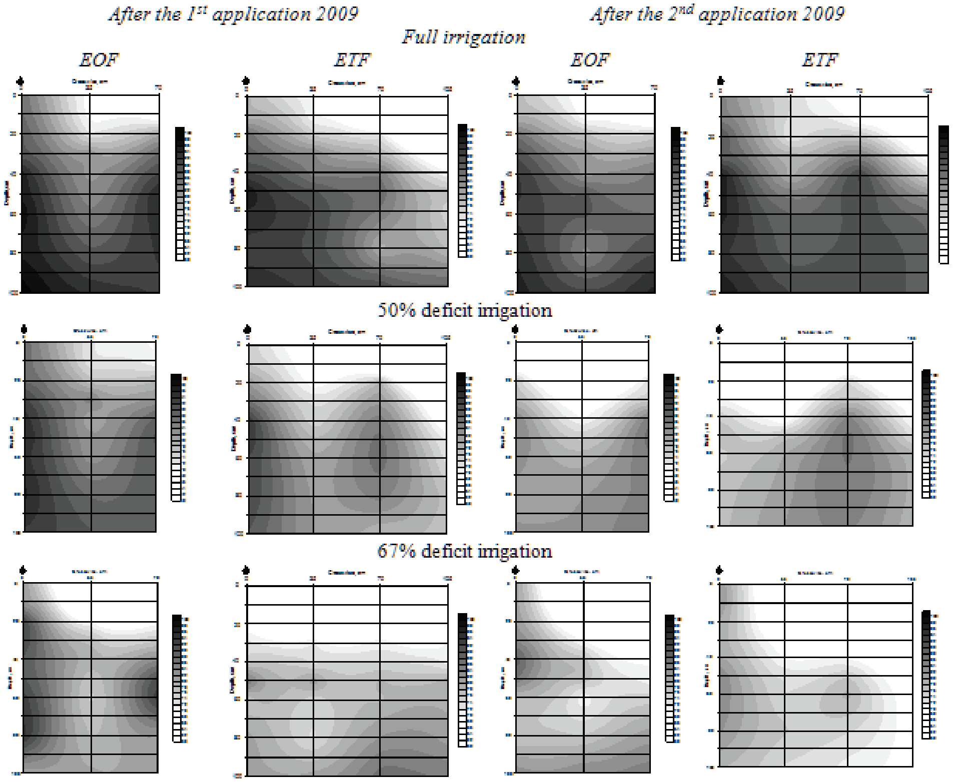


Figure 6. Distribution of soil moisture, which is above 70% of FC across furrow direction in 1-m soil profile

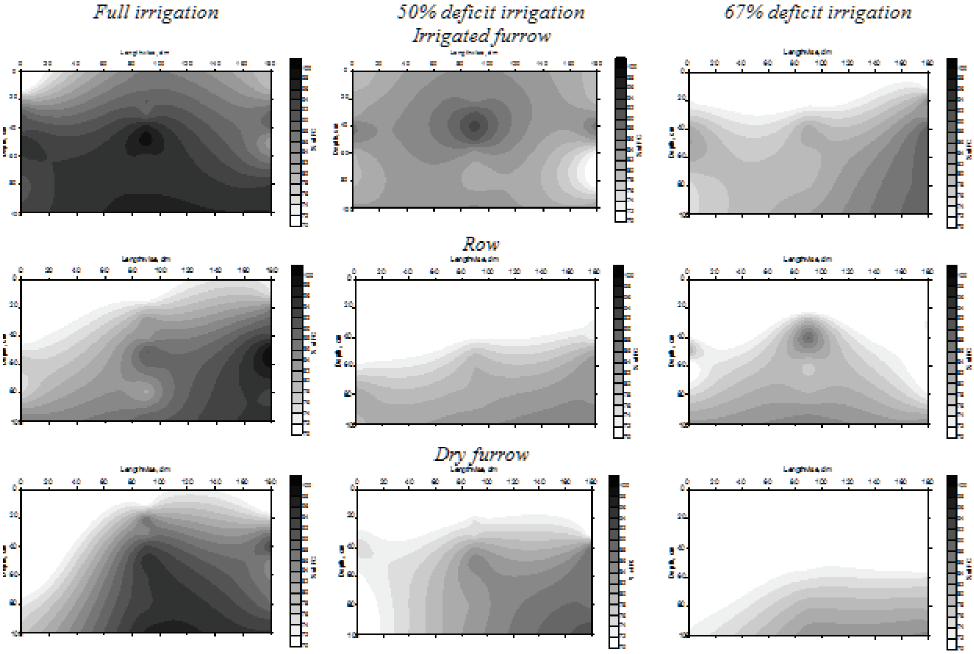


Figure 7. Distribution of soil moisture along furrow direction after 1st application 2009 in EOF

This was probably due to the specific distribution of water in relation to the hydrological properties of the soil. 90.2-93.0% relative yield was obtained under 67% DI. It appeared high because of the moist conditions of the year. In 2012, 88.4-92.0% relative yield was obtained by 50% DI and 81.9-82.7% - by 67% DI (col. 10 and 11 of Tables 2 and 3). Water deficit at every variant of water distribution (EF, EOF or ETF) caused significant yield decrease (col. 14 of Tables 2 and 3). In 2009 and 2012 the relative yield at 50% DI in EF was 93.2% and 88.4% and at 67% DI - 93% and 82.3% respectively (Col. 13 of Tables 2 and 3). In EOF relative yield was 90.3% and 90.9% under 50% DI; and 87.9% and 81.7% under 67% DI. In ETF, relative yield was 93.9% and 89.5% under 50% DI; and 90.6% and 80.5% under 67% DI. These yields were very close to the maximum ones. The combination of a mid weather (in terms of moisturizing) and good capillary soil properties catered for water supply with RAW in the deep horizons of the soil profile. The distance between the furrows didn't significantly impact the yield regardless of application depth (col. 17 of Tables 2 and 3). This is probably due to the hydrological properties of the soil, which allowed an even distribution of the irrigational water at a depth 40-100 cm (also seen on Figure 6). In this soil layer the wetted by irrigation contours connected, the infiltrating water overflowed and was available to the plants.

Yield losses, caused by the irrigational water deficit were smallest, when applying 50% DI in EOF (Figure 9). The results from both experimental years showed that the distribution of the application water in every other furrow contributed for obtaining the highest yields

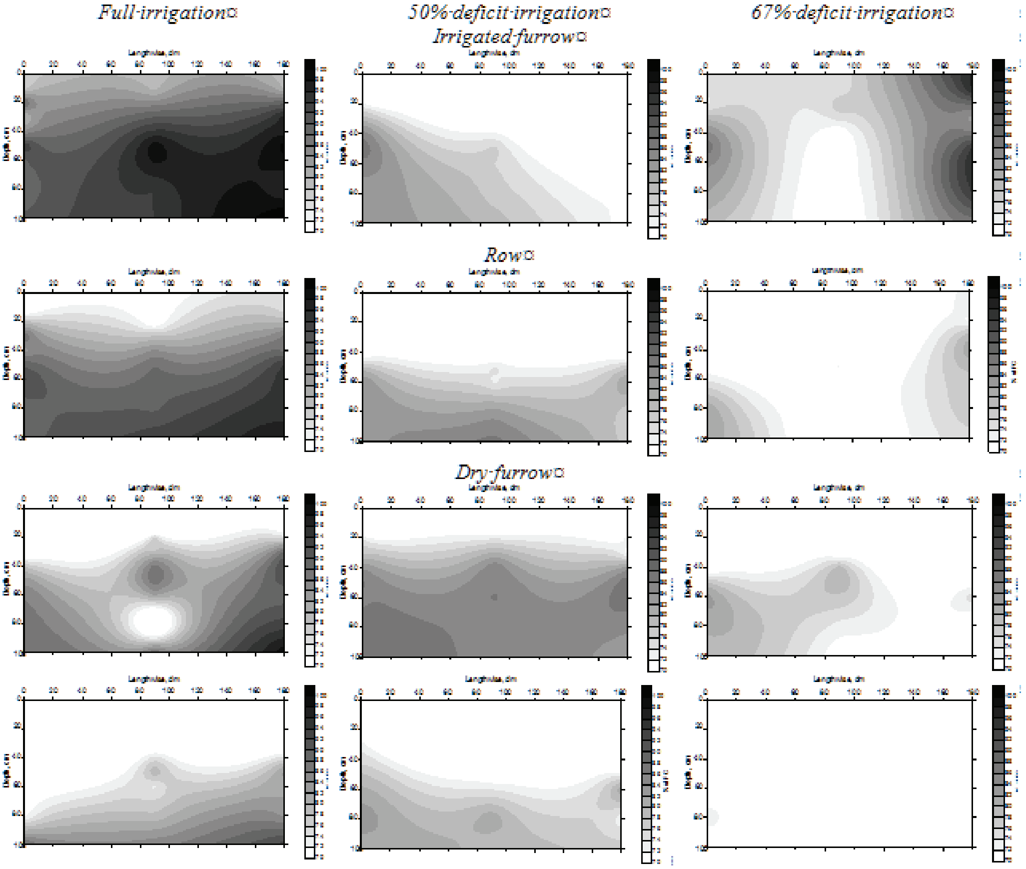


Figure 8. Distribution of soil moisture along the furrow after 1st application 2009 at ETF

Table 2. Significance of irrigation impact in 2009

Var.	Intra-furrow space	Irrigation depth		Grain Yield	Irrigation impact			Water deficit impact			Water deficit impact within EF/EOF/ETF			Intra-furrow space impact		
					Difference	Relative yield	Signnif.	Difference	Relative yield	Signnif.	Difference	Relative yield	Signnif.	Difference	Relative yield	Signnif.
		Mm	%	Mg/ha	±	%		±	%		±	%		±	%	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	RF	-	-	6.92	St.	100		-279	71.3	ooo						
2	EF	134.4	100	9.71	+2.79	140.3	+++	St.	100.0		St.(1)	100		St.[1]	100.0	
3	EOF	134.4	100	10.13	+3.21	146.4	+++	+0.42	104.3	-	St.(2)	100		+0.42	104.3	-
4	ETF	134.4	100	9.68	+2.76	139.8	+++	-0.04	99.6	-	St.(3)	100		-0.04	99.6	-
5	EF	67.2	50	9.06	+2.14	130.9	+++	-0.66	93.2	o	(1)-0.66	93.2	o	St.[2]	100.0	
6	EOF	67.2	50	9.15	+2.23	132.2	+++	-0.56	94.2	-	(2)-0.98	90.3	oo	+0.09	101.0	-
7	ETF	67.2	50	9.09	+2.16	131.2	+++	-0.63	93.5	o	(3)-0.59	93.9	o	+0.03	100.3	-
8	EF	44.8	33	9.03	+2.11	130.4	+++	-0.68	93.0	o	(1)-0.68	93.0	o	St.[3]	100.0	
9	EOF	44.8	33	8.91	+1.99	128.7	+++	-0.80	91.7	oo	(2)-1.22	87.9	ooo	-0.12	98.7	-
10	ETF	44.8	33	8.77	+1.84	126.6	+++	-0.95	90.2	oo	(3)-0.91	90.6	oo	-0.26	97.1	-
GD$_{5\%}$ = 0.589 Mg/ha GD$_{1\%}$ = 0.799 Mg/ha GD$_{0,1\%}$ = 1.070 Mg/ha																

Table 3. Significance of irrigation impact in 2010

Var.	Intra-furrow space	Irrigation depth		Grain Yield	Irrigation impact			Water deficit impact			Water deficit impact within EF/EOF/ETF			Intra-furrow space impact		
					Difference	Relative yield	Signnif.	Difference	Relative yield	Signnif.	Difference	Relative yield	Signnif.	Difference	Relative yield	Signnif.
		mm	%	Mg/ha	±	%		±	%		±	%		±	%	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	RF	-	-	7.09	St.	100		-198	78.2	ooo						
2	EF	134.4	100	9.07	+1.98	127.9	+++	St.	100.0		St.(1)	100		St.	100.0	
3	EOF	134.4	100	9.17	+2.08	129.4	+++	+0.11	101.2	-	St.(2)	100		+0.11	101.2	-
4	ETF	134.4	100	9.22	+2.13	130.0	+++	+0.15	101.7	-	St.(3)	100		+0.15	101.7	-
5	EF	67.2	50	8.01	+0.92	113.0	+++	-1.05	88.4	ooo	(1)-1.05	88.4	ooo	St.	100.0	
6	EOF	67.2	50	8.34	+1.25	117.6	+++	-0.73	92.0	ooo	(2)-0.83	90.9	ooo	+0.33	104.1	-
7	ETF	67.2	50	8.26	+1.17	116.4	+++	-0.81	91.1	ooo	(3)-0.96	89.5	ooo	+0.24	103.0	-
8	EF	44.8	33	7.46	+0.37	105.2	-	-1.61	82.3	ooo	(1)-1.61	82.3	ooo	St.	100.0	
9	EOF	44.8	33	7.49	+0.40	105.7	+	-1.57	82.7	ooo	(2)-1.68	81.7	ooo	+0.04	100.5	-
10	ETF	44.8	33	7.42	+0.33	104.7	-	-1.64	81.9	ooo	(3)-1.80	80.5	ooo	-0.04	99.5	-
GD$_{5\%}$ = 0.389 Mg/ha GD$_{1\%}$ = 0.526 Mg/ha GD$_{0,1\%}$ = 0.700 Mg/ha																

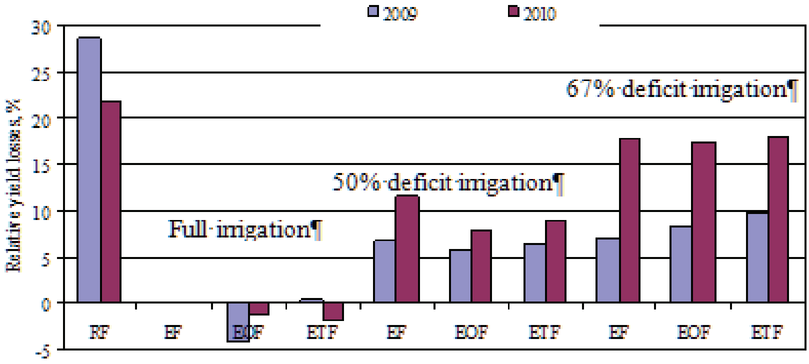


Figure 9. Relative yield losses

under deficit irrigation. This proved to be the most effective technology for maximizing the effect of the irrigational water and saving water by using soil hydrological properties for the best. This way of distribution of the application irrigational water is some kind of localized irrigation technology. It presupposes reduction of the open water evaporation losses, preservation from deep percolation losses, as well as considerably uniform water supplying of the 40-100-cm soil layer. By keeping the top soil layer dry, evaporation from soil is also slowed down. Thus irrigational water is mostly used for crop production purposes. These results are similar to the results of such studies on chromic luvisols and smolnitsa (Moteva, 2005; Stoyanova, 2008) in Bulgaria.

CONCLUSIONS

Applying 50% irrigation deficit by distributing water in every-other-furrow on chernozems proves to be the most effective technology for maximizing the effect of the irrigational water on maize yield and saving water by using soil hydrological properties for the best. In medium and mid-moist years moisture is uniformly distributed in the 40-100-cm soil layer during all the growing season and is available for the plants. With 50% of the irrigational water needed, 92-94% of maximum yield can be obtained in medium and mid-moist year.

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