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TESTING OF VARIOUS REGIMES OF IRRIGATION FURROWS IN GRAIN MAIZE

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Abstract

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The purpose of experimental research was exploring the distribution of water in the soil profile under irrigation in one and two furrows. The stability of the manifestations of each irrigation variant on the grain yield was evaluated. The study was conducted with medium early maize hybrid by FAO (390). The study included the variants: 1. Without irrigation (Control); 2. Every Furrow Irrigation (EF), 80% FC; 3. Irrigation of Every Other Furrow (EOF), M=50%; 4. Irrigation of Every Other Furrow (EOF), M=100%; 5. Irrigation of Every Other Two Furrows (EOTF), M = 50%; 6. Irrigation of Every Other Two Furrows (EOTF), M=100%; 7. Irrigation of Every Other Furrow (EOF), M=50%, without first watering; 8. Irrigation of Every Other Furrow (EOF), M=50%, without second watering; 9. Irrigation of Every Other Furrow (EOF), M=50%, without third watering. Furrow irrigation with reduced irrigation rate seems to be the best water-saving technology which uses precipitation effectively during the irrigation season of maize grain and maximum utilization of irrigation water provided stable yield. Synthesis criterion for stability YS_i by Kang, taking into account both the stability and value of production, shows that in terms of technology growing, technologically the most valuable is the variant of full irrigation rate, followed by a variant with reduced irrigation rate and supply of irrigation water in the furrow.

Key words: irrigation, grain maize, water deficit, stability, yield

Introduction

During the last years, unstable weather conditions in Bulgaria against the backdrop of global warming and drought has increased interest in the production of maize in the effective use of water resources. Conventional irrigation was associated with higher consumption of scarce and expensive irrigation water. The reduction of non-productive cost was a subject a number of studies. Key to the success of irrigation for the judicious use of available water resources was the information requirements of plants at critical stages of their growth and the effects of water deficit. Best results were obtained when the shortage of irrigation water had been distributed fairly evenly throughout the growing period considered Eneva (1991). Reducing the irrigation rate of 25 % and 50 % lead to a reduction in yield by 46 $g.kg^{-1}$, and 128 $g.kg^{-1}$ of the optimum, for the 13 year period of study. Water deficit in the growing season as obtained in 50 % reduction in irrigation rate decreased yield by 50-60 $g.kg^{-1}$, according to studies Rafailov (1998). As a result, a number of studies had established the parameters of the reduction in yields in controlled deficit irrigation water (Dagdelen et al., 2008; Petrovska and Genova, 2008; Lamm et al., 2011; Dospatliev, 2012; Matev and Petrova, 2012).

The effects of water deficit covers surveys conducted in different security rainfall years in different soil types. The data showed that conditional permanent water deficit created by repealing irrigations or by reducing the irrigation rate was practically zero in wet years, because they had used all vegetation rainfall (Davidov, 1998; Kipkorir et al., 2002; Popova, 2006; Stoyanova and Gospodinov, 2010; Matev et al., 2012).

In different soil types have been established the parameters of biophysical factors and the coefficient of efficiency of irrigation water, which allowed refinement of irrigation regimes and increased the productivity of irrigation water (Eneva and Todorova, 2001; Kang and Zhang, 2004; Bazitov, 2012). By implementation of irrigation rate during furrows, losses of depth filtration and evaporation of the surface layer

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had been reduced, as a result of reduced wetted surface. The productivity increased influence by accumulated moisture from deeper soil layers (Sepaskhah and Afshar-Chamanabad, 2002; Moteva et al., 2010; Stoyanova and Todorova, 2011).

The purpose of experimental research was exploring the distribution of water in the soil profile under irrigation in one and two furrows and was evaluated the stability of the manifestations of each irrigation variant on the grain yield.

Material and Methods

The study was conducted with medium early maize hybrid by FAO (390), with a population density 70 000 plants per hectare under irrigation and non irrigated 50 000 plants per hectare. Field experiment was according to the block method in four replications with a size of experimental plots 56 m^2, and in the variant of the pervious of irrigation water through two furrows 84 m^2, respectively. The size of the harvest plots at all variants was 24 m^2. Irrigation was done by gravity on short closed furrows.

The study includes the variants: 1. Without irrigation (Control); 2. Every Furrow Irrigation (EF), 80% FC; 3. Irrigation of Every Other Furrow (EOF), M=50%; 4. Irrigation of Every Other Furrow (EOF), M=100%; 5. Irrigation of Every Other Two Furrows (EOTF), M=50%; 6. Irrigation of Every Other Two Furrows (EOTF), M=100 %; 7. Irrigation of Every Other Furrow (EOF), M=50%, without first watering; 8. Irrigation of Every Other Furrow (EOF), M=50%, without second watering; 9. Irrigation of Every Other Furrow (EOF), M=50%, without third watering. Furrow Irrigations in all variants were realized simultaneously by making adjustments to the irrigation rate, according to the respective variant.

It had been studied the distribution of irrigation water in the soil horizon at the time of water in each furrow in the furrow and in two furrows. The contours of the moisture in the soil profile were made based on soil samples taken vertically at a point located at 35 cm radially from the center of the wetted furrow in dry furrow and ridge between them. Samples were processed by weight-thermostat method. Vertisol soil type on its mechanical structure belongs to medium clayey soils (64-67%) with good water holding capacity. Water supply (452 mm) was uniformly distributed on the 0-100 cm soil layer, and the values of 10 cm were between 43 and 46 mm.

Statistical program Anova was used for processing of grain yield data. Stability and technological value of the maize grain yield was based on analysis of variance for grain yield. The stability σ_i^2 and S_i^2 by Shukla, W_i ecovalence by Wricke and stability criterion YS_i by Kang were calculated. Effectiveness of various options has been established through a system of indicators, including average yield, total production, production cost and rate of profitability.

Cultivation of maize for grain used for the purpose of the experiment was carried out according by standard technology for the country.

Results and Discussion

The quantity of precipitation during the growing season of maize grain and the amount of irrigation norms had the best influence on the formation of productive water supply. During the studied period the amount and distribution of precipitation had been characterized as extremely uneven (Table 1).

Mechanical composition of Vertisols soil type created conditions for reducing the speed of vertical infiltration and increased

Table 1
Weather conditions during the vegetation period of grain maize, Stara Zagora

Year	Months						Sum IV-IX	Sum VII-VIII
	IV	V	VI	VII	VIII	IX		
Rainfalls, mm								
2004	13.1	62.4	211.5	70.5	46.2	51.7	455.4	116.7
2005	27.7	51.1	35.8	226.4	103.4	79.4	523.8	329.8
2006	36.5	17.8	44.7	29.4	35.7	31.2	195.3	65.1
Average	25.8	43.8	97.3	108.8	61.8	54.1	391.5	170.6
1951-2006	33.9	50.4	61.0	63.1	40.4	41.5	290.3	103.5
Temperature,°C								
2004	12.3	15.6	20.3	23.2	21.6	18.2	18.5	22.4
2005	11.9	17.6	19.9	23.0	22.8	18.3	18.9	22.9
2006	12.4	17.4	21.2	23.0	24.1	18.7	19.5	23.6
Average	12.2	16.9	20.5	23.1	22.8	18.4	19.0	23.0
1930-2006	12.0	17.1	21.0	23.5	23.2	19.0	19.3	23.4

the radius of the lateral spread of water. This feature was of great importance in irrigation furrows. The distribution of moisture in the soil horizon at the time of irrigation water in each furrow in one and in two furrows was illustrated in this study (Figures 1, 2, 3, 4 and 5). The contours of damping were defined in the distribution of moisture in the soil profile before and after the implementation of the second and third watering.

In the variant with optimum irrigation could be observed even distribution of moisture in the soil horizon (Figure 1). After two irrigations, in the layer below 10 cm, the moisture was highest 90-100% FC. Moisture in the soil profile below 40 cm was also high 80-90% FC after the second watering. After the third irrigation data to moisten in the soil horizon showed that the humidity in 60-100 cm layer was about 70-80% FC. Merging the humidity contours provided enough moisture throughout the period of development of grain maize.

The profiles of the irrigation water in the variants with furrow irrigation showed that the surface layer adjacent to the roots of plants was less damped, whilst in depth the moisture was bind as a result of lateral filtration. Permanently drought at the plow layer was established for variant of filing under reduced irrigation rate (Figure 2). The contours of the humidity illustrated water deficit 10 days after completion of the second irrigation. Horizontal distribution of irrigation water provided moisture profile in the soil close to the FC (Figure 2c). After a third watering the humidity was 60-70% FC in the layer 30-70 cm. The moisture profile showed that during the flowering the plants had enough moisture.

The amount of moisture available for water flow through the furrow with optimum irrigation rate indicated a relative humidity higher than 80% FC (Figure 3). Figures 4 and 5 presented humidity profiles at the time of irrigation by watering through two furrows where the humidity was below 70% FC. Ten days after the completion of the second watering at layer 80-100 cm the moisture reserve was lower than 70% FC. Depletion of water resources was not compensated by a third filed irrigation rate (Figure 4). Plants were permanently subjected to water deficit. Irrigation with 100% through two furrows was enough to provide moisture closer to the optimum after the second irrigation (Figure 5). The period before third watering was characterized with intensive depletion of available soil moisture. The contours of the damping were extremely low at low humidity, close to the lower limit of the available moisture. The moisture value of the humidity was 50-60% FC after an intense period of exhaustion. Filed watering provided humidity 60-70% FC. An area under irrigation furrow to 30 cm was characterized with 70-80% moisture by FC.

Distribution of irrigation water in the soil profile was the result of vertical and lateral filtering. The contours of the distribu-

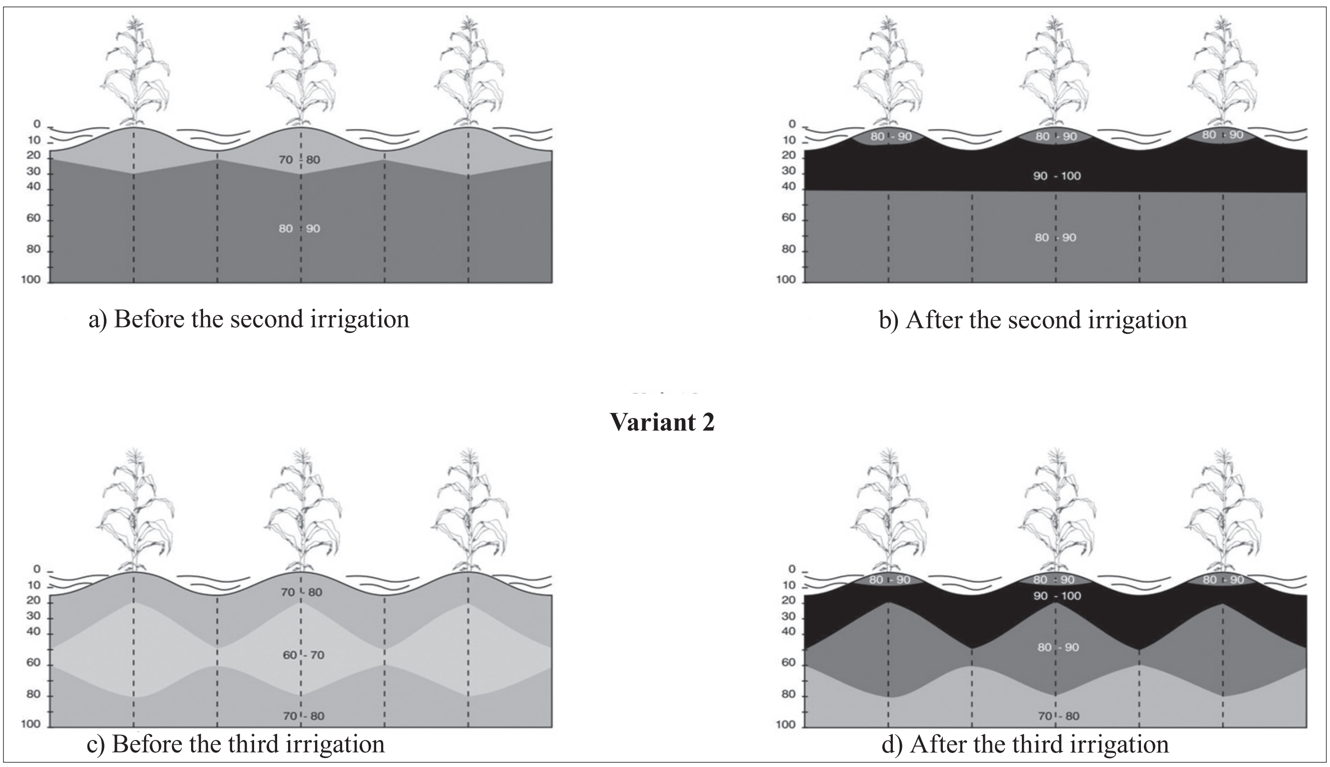


Fig. 1. Distribution of moisture in the soil profile at variant with optimum irrigation

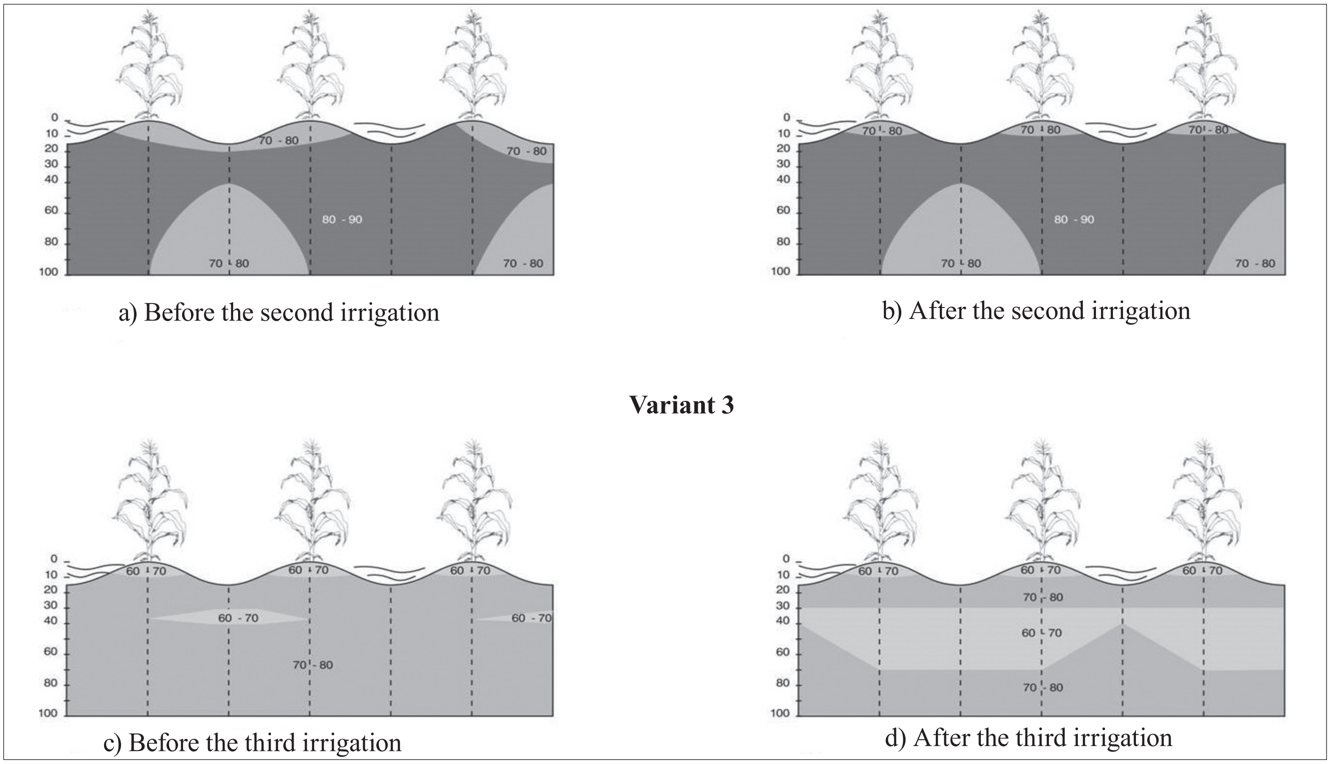


Fig. 2. Distribution of moisture in the soil profile by irrigation of every other furrow, M=50%

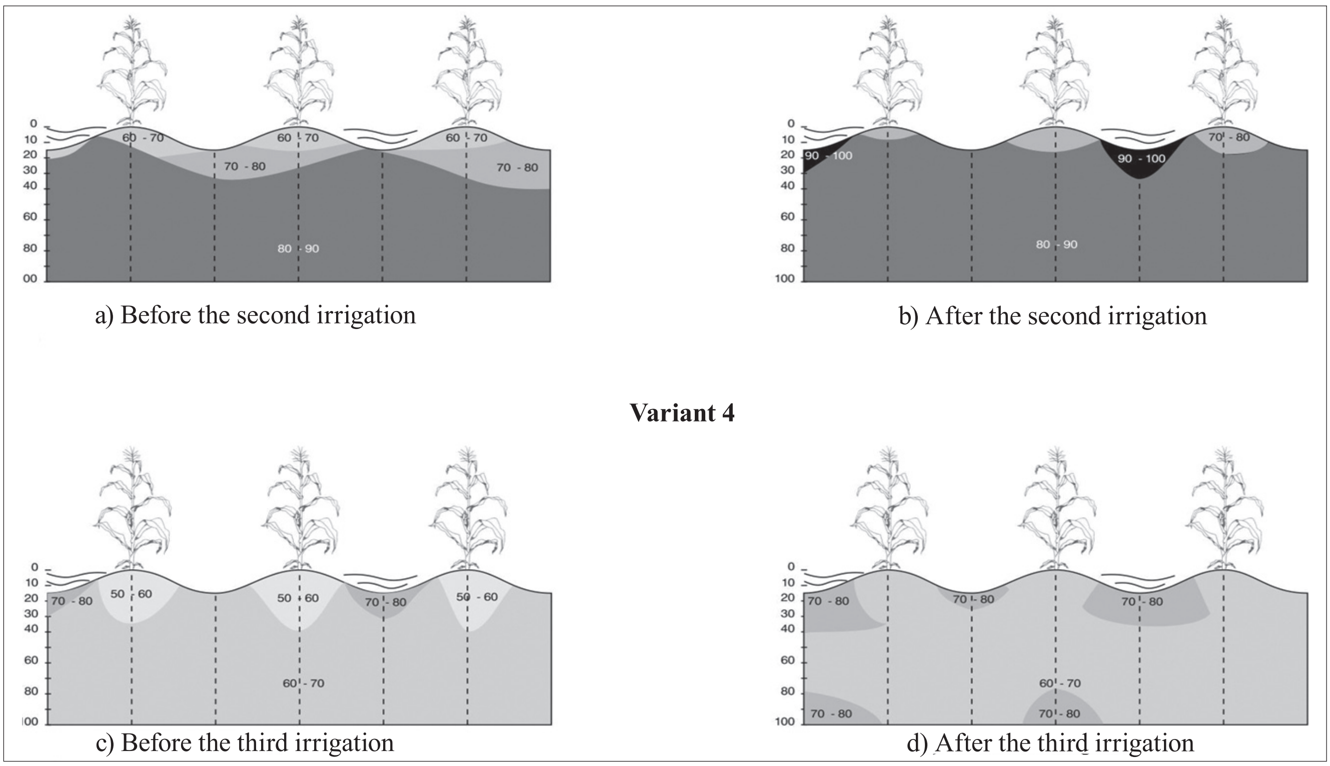
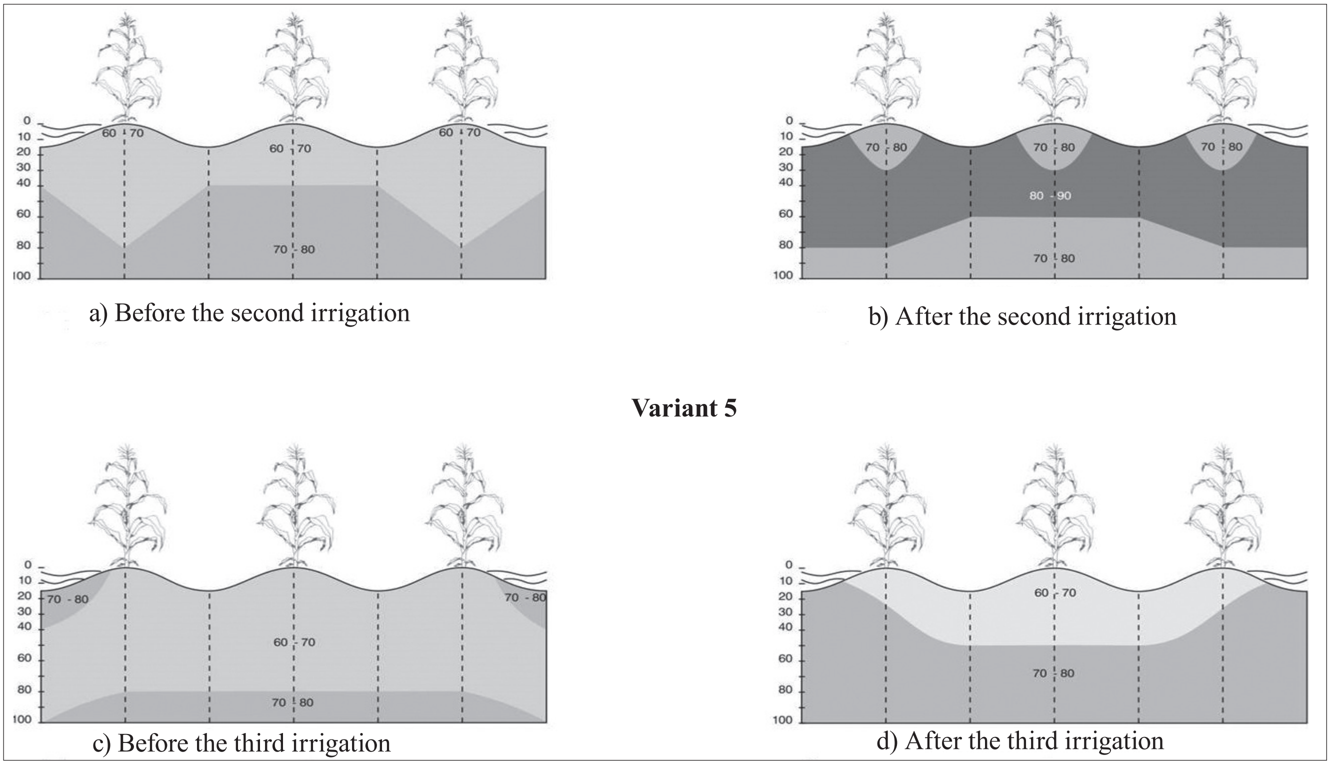


Fig. 3. Distribution of moisture in the soil profile at variant of filing of irrigation water in a furrow



a) Before the second irrigation

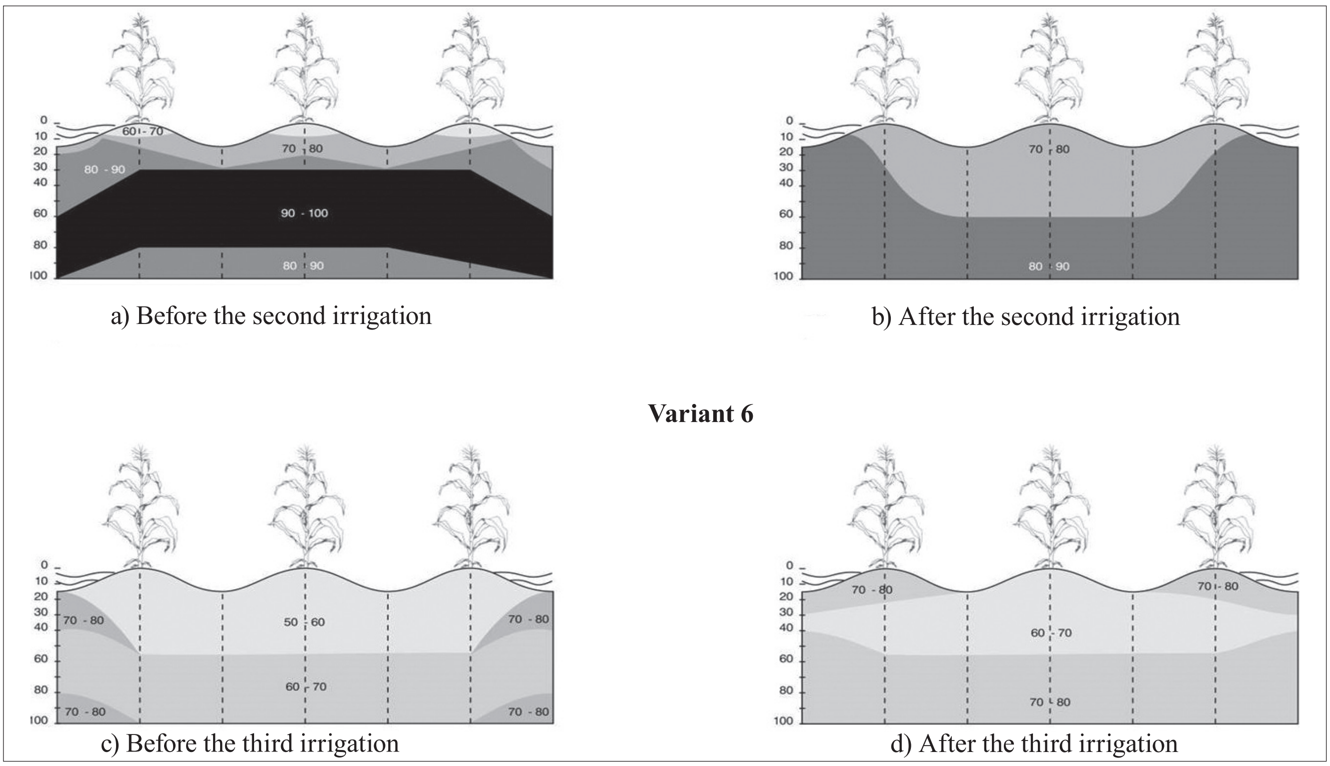
b) After the second irrigation

Variant 5

c) Before the third irrigation

d) After the third irrigation

Fig. 4. Distribution of moisture in the soil profile by irrigation of every other furrow, M=50%



a) Before the second irrigation

b) After the second irrigation

Variant 6

c) Before the third irrigation

d) After the third irrigation

Fig. 5. Distribution of moisture in the soil profile at variant of filing of irrigation water through two furrows

tion of the irrigation water showed that the wet soil can absorb less water, but the irrigation water reached a greater depth.

Increasing the distance between the irrigation furrows led to decrease of the degree of wetting of the soil profile. The degree of damping was lower at irrigation through furrows after every watering. Important for irrigation through furrows was uneven wetting of the plow layer. Higher humidity before irrigation was a prerequisite for a more even distribution of irrigation water at the soil profile. Soil was less water-permeable before irrigation. In the implementation of the irrigation rate by filing through one or two furrows irrigation water was distributed over a smaller area. Vertical filtering helped to increase the humidity of irrigation furrows of greater depth.

Grain yield of maize was the result of the cumulative effect of the realized irrigation rate and provided of the year with precipitation (Table 2) The yield was highest for optimal irrigated variant in the three years of the study (8160 kg.ha^{-1}). The increase compared to non-irrigated variant was 30.54%. Yields of variants 3 and 4 were ranged from 7337 to 7868 kg.ha^{-1}. Irrigation through two furrows afforded lower yields 6837 to 7026 kg.ha^{-1}.

Analysis of variance for grain yield found that the influence of the investigated variants was 99.7% of the total variation of the data (Table 3). Years have the greatest impact on grain yield – 93.5% of the variation. It is result by the unequal response options to changes in environmental conditions.

Table 2
Influence of irrigation regime on grain yield of maize, kg.ha^{-1}

Factor A / Factor B	2004		2005		2006		Average (Factor B)	
	kg.ha^{-1}	%	kg.ha^{-1}	%	kg.ha^{-1}	%	kg.ha^{-1}	%
1. Without irrigation (Control)	3363	100.00	7563	100.00	7828	100.00	**6251**	**100.00**
2. Every Furrow Irrigation (EF), 80 % FC	4573	136.98	9565	126.47	10343	132.13	**8160**	**130.54**
3. Irrigation of the Every Other Furrow (EOF), M=50 %	4078	121.26	8610	113.84	9323	119.10	**7337**	**117.37**
4. Irrigation of the Every Other Furrow (EOF), M=100 %	4293	127.65	9220	121.91	10090	128.90	**7868**	**125.87**
5. Irrigation of the Every Other Two Furrows (EOTF), M=50 %	3780	112.40	8028	106.15	8643	110.41	**6837**	**109.37**
6. Irrigation of the Every Other Two Furrows (EOTF), M=100 %	3840	114.18	8323	110.05	8915	113.89	**7026**	**112.40**
7. Irrigation of the Every Other Furrow (EOF), M=50 %, without first watering	3703	110.11	7938	104.96	8613	110.03	**6751**	**108.00**
8. Irrigation of the Every Other Furrow (EOF), M=50 %, without second watering	3938	117.10	8425	111.40	9170	117.14	7178	114.83
9. Irrigation of the Every Other Furrow (EOF), M=50 %, without third watering	4138	123.04	8828	116.73	8808	112.52	**7258**	**116.11**
Average (Factor A)	**3967**	**-**	**8500**	**-**	**9081**	-	**7183**	

LSD, kg.ha^{-1}: F. A $p \le 0.5=60$ $p \le 0.01=80$ $p \le 0.001=104$
F. B $p \le 0.5=105$ $p \le 0.01=139$ $p \le 0.001=180$
AxB $p \le 0.5=181$ $p \le 0.01=240$ $p \le 0.001=311$

Table 3
Analysis of variance for grain of maize, average for 2004-2006

Source of variation	Degrees of freedom	Sum of squares	Influence of factor, %	Mean squares
Total	107	6004104	100	-
Tract of land	3	3116	0.3	1038.7**
Variants	26	5988060	99.5	230310.0***
Factor A – Years	2	5629232	93.5	2814616.0***
Factor B - Irrigation rates	8	318312	5.3	39789.0***
A x B	16	40516	0.7	2532.3***
Pooled error	78	12928	0.2	165.7
*p≤0.5 **p≤0.1 ***p≤0.01				

The reason for the large differences in weather conditions had been studied for over three years. The power of influence of irrigation regime was 5.3%. Reaction of the two factors (A x B) – 0.7%. It has been shown at $p \leq 0.5$. It were calculated the stability variants σ_i^2 and S_i^2 by Shukla, W_i ecovalence by Wricke and stability criterion YS_i by Kang. The stability variants (σ_i^2 and S_i^2), taking into account the corresponding linear and nonlinear interactions unidirectional assessed the stability of the variants.

These variants, which showed lower values, were found to be more stable, because they interacted less with the environmental conditions. Negative values of the indicators σ_i^2 and S_i^2 were considered 0. In fairly high values of any of the two parameters σ_i^2 or S_i^2 were considered to be unstable. The most unstable manifests non-irrigated control (Variant 1) followed by variants 4, 7, 8 and 9 (Table 4).

Important information about the technological value of the options given indicator YS_i by Kang for simultaneous assessment of yield and stability, based on the reliability of the differences in yield and the variant interaction with the environment. According to the stability criterion YS_i the Variant 2 was the most technologically valuable. It combined high grain yield with very good stability over the years. Variant 3 received high valuation in terms of growing technology of irrigated maize. It had combined good grain yield with high stability during the years of the study. Variants 4, 6 and 7 also have good evaluations. Variants 5, 7 and 8 received low evaluations and should be avoided.

Efficiency of irrigation was expressed by the presented analysis of economic indicators. Results of two different climatic elements years are shown in Tables 5 and 6. The low value of the additional yield in the first year was obliged to unfavorable weather conditions. In the first year of the field study hail fell at the end of leaf formation stage that destroyed much of the foliage. Sowing recovers partially, but it had a strong negative impact on the yield of the crop. The high cost of production (0.20-0.26 lv.kg^{-1}) was a result of the low return on production costs (Table 5). In 2006, the cost of production was lower and varied in the range of 0.9-0.11 lv.kg^{-1} (Table 6). Return on their costs of production, expressed by the rate of return was highest in the variants with irrigation in a furrow with reduced irrigation rate (112.3%) and cancellation of second irrigation at the time of irrigation water in the furrow with reduced irrigation rate (117.4%).

Conclusions

Furrow irrigation with reduced irrigation rate seems to be the best water-saving technology which uses precipitation effectively during the irrigation season of maize grain and maximum utilization of irrigation water provided stable yield.

Synthesis criterion for stability YS_i by Kang, taking into account both the stability and value of production, shows that in terms of technology growing, technologically the most valuable was the variant of full irrigation rate (Variant 2), followed by a variant with reduced irrigation rate and supply of irrigation water in the furrow (Variant 3).

Cancelation of the second irrigation (Variant 8) had a good economic effect (117.4%) and also could be recommended for the practice application.

Table 4
Stability parameters for grain yield with relation to years

Variants	$\bar{x}$	σ_i^2	S_i^2	W_i	YS_i
1.Without irrigation (Control)	6250.8	4946.1**	1503.1**	8256.7	-10
2. Every Furrow Irrigation (EF), 80 % FC	8160	94.3 ^{ns}	127.5**	265.1	10+
3. Irrigation of the Every Other Furrow (EOF), M=50%	7336.7	-52.0^{ns}	192.1**	481.8	6+
4. Irrigation of the Every Other Furrow (EOF), M=100 %	7867.5	5814.0**	1072.9**	9606.8	3+
5. Irrigation of the Every Other Two Furrows (EOTF), M=50 %	6836.7	1428.0**	-55.6 ^{ns}	2784.1	-8
6. Irrigation of the Every Other Two Furrows (EOTF), M=100 %	7025.8	-335.3 ^{ns}	-182.8 ^{ns}	41.1	1+
7. Irrigation of the Every Other Furrow (EOF), M=50 %, without first watering	6750.8	774.1**	196.3**	1766.9	-9
8. Irrigation of the Every Other Furrow (EOF), M=50 %, without second watering	7177.5	14.4**	449.1**	585.1	-6
9. Irrigation of the Every Other Furrow (EOF), M=50 %, without third watering	7257.5	4609.1**	8512.1**	7732.5	1+

Table 5
Economic efficiency of irrigation for maize grain in 2004

Variants of irrigation	Additional yield	Gross output	Production costs	Net profit	Cost price	Rate of profitability
	kg.ha^{-1}	lv.ha^{-1}	lv.ha^{-1}	lv.ha^{-1}	lv.kg^{-1}	%
1. Without irrigation (Control)		672.6	740.00	-67.40	0.22	-9.1
2. Every Furrow Irrigation (EF), 80 % FC	1210	914.60	981.60	-67.00	0.21	-6.8
3. Irrigation of the Every Other Furrow (EOF), M=50%	715	815.60	878.10	-62.50	0.22	-7.1
4. Irrigation of the Every Other Furrow (EOF), M=100 %	930	858.60	981.60	-123.00	0.23	-12.5
5. Irrigation of the Every Other Two Furrows (EOTF), M=50 %	417	756.00	878.10	-122.10	0.23	-13.9
6. Irrigation of the Every Other Two Furrows (EOTF), M=100 %	477	768.00	981.60	-213.60	0.26	-21.8
7. Irrigation of the Every Other Furrow (EOF), M=50 %, without first watering	340	740.60	843.60	-103.00	0.23	-12.2
8. Irrigation of the Every Other Furrow (EOF), M=50 %, without second watering	575	787.60	843.60	-56.00	0.21	-6.6
9. Irrigation of the Every Other Furrow (EOF), M=50 %, without third watering	775	827.60	843.60	-16.00	0.20	-1.9

Table 6
Economic efficiency of irrigation for maize grain in 2006

Variants of irrigation	Additional yield	Gross output	Production costs	Net profit	Cost price	Rate of profitability
	kg.ha^{-1}	lv.ha^{-1}	lv.ha^{-1}	lv.ha^{-1}	lv.kg^{-1}	%
1. Without irrigation (Control)	0	1565.6	740.00	825.60	0.09	111.6
2. Every Furrow Irrigation (EF), 80 % FC	2515	2068.60	981.60	1087.00	0.09	110.7
3. Irrigation of the Every Other Furrow (EOF), M=50 %	1495	1864.60	878.10	986.50	0.09	112.3
4. Irrigation of the Every Other Furrow (EOF), M=100 %	2262	2018.00	981.60	1036.40	0.10	105.6
5. Irrigation of the Every Other Two Furrows (EOTF), M=50 %	815	1728.60	878.10	850.50	0.10	96.9
6. Irrigation of the Every Other Two Furrows (EOTF), M=100 %	1087	1783.00	981.60	801.40	0.11	81.6
7. Irrigation of the Every Other Furrow (EOF), M=50 %, without first watering	785	1722.60	843.60	879.00	0.10	104.2
8. Irrigation of the Every Other Furrow (EOF), M=50 %, without second watering	1342	1834.00	843.60	990.40	0.09	117.4
9. Irrigation of the Every Other Furrow (EOF), M=50 %, without third watering	980	1761.60	843.60	918.00	0.10	108.8

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