Relationship between Irrigation Rate and Yield for Grain Maize

Alexander Matev[1*], Stanislav Stamatov[1], Katya Uzundzhalieva[1], Natalya Petrovska[2], Veselina Masheva[1], Blagoy Andonov[1]

[1]Institute of Plant Genetic Resources "Konstantin Malkov" Sadovo, Plovdiv, Bulgaria
[2]Maize Research Institute, Knezha, Bulgaria
[*]Corresponding author. E-mail: sa6_m@abv.bg

ABSTRACT

The aim of the current study is to investigate the influence of reduced irrigation rates on the maize grain yield (group 600 - FAO), grown in Plovdiv region as well as to establish the parameters of the correlation "Additional yield - irrigation rate". The experiment was conducted during the period 2004-2018 in the Agricultural University with the late hybrid "Knezha - 613". The next variants were studied: without irrigation (1); irrigation with 25%, 50% and 75% from the optimal irrigation rate (2, 3, 4) and optimal irrigation rate (5). The results show that reduction of the irrigation rate with 25% reduces the yield with 1-17%. The reduction of the yield is bigger in 50% reduction of the irrigation rate, the difference compared to the optimal irrigation being of 3-33%. The correlation "Additional yield - irrigation rate" can be expressed by the regression equation $Y=1.33x-0.28x^2$ or by the power formula $Y=1-(1-x)^{1.35}$. In both cases the accuracy is the same (R=0.92), but the power formula gives more freedom for expression of that connection and so it is recommended.

Keywords: maize, irrigation rate, water stress, yield, correlation water-yield.

INTRODUCTION

Maize is a crop, which can reach its productive potential only if environmental factors are optimized, one of the most important being the availability of moisture - atmospheric and soil. In the recent decades the application of optimal irrigation rates became more difficult due to lack of water and it`s high cost. That brings the necessity to study the possibilities for reduction of the irrigation rate and the reaction of the crop to the water stress. Maize is a basic agricultural crop in world scale so there are a lot of investigations and published papers on that item, including the water-yield correlation. It can be considered both in terms of irrigation rate and evapotranspiration, but there is still no universal model that is universally valid or satisfies sufficiently large territories, i.e., it has a local character. In that connection Clumpner and Solomon (1987) derive over 300 equations of dependence using data, received from dry, semi-dry and humid climate in 7 states in USA with typical climatic conditions. The authors establish that none of them could be representative for all regions and only the results from one and the same region are close to each other. Later that was confirmed by Mila et al. (2016). The connection between the yield and evapotranspiration is already well studied and several types of formulas have been composed for that purpose. Quite different is the situation with the correlation between the yield and irrigation rate, which can be considered both in connection with the total yield and additional yield. There is limited information on that question in the scientific literature and the available one is limited to regression equations, based preliminary on the absolute values of the yield and irrigation rate. The same express a significant variation, depending on early maturity and characteristics of the hybrid as well as soil and climatic conditions. That is supported in the paper of Kuscu et al. (2013), where authors give the regression correlation between the absolute yield and irrigation rate in drop irrigation of maize and optimizing of the soil humidity in 0-90 cm layer. That is a square dependency and is valid for the region of Bursa (Turkey). On the base of the data, received from an experiment in Ismailia (Egypt), El-Hendawy

Received 22 November 2023; accepted 30 January 2024.

et al. (2008) establish linear dependency between yield and irrigation rate (in absolute values) in R>0.8, and on that base they recommend the irrigations to be done every 4 days. About Vojvodina (Serbia) conditions Kresović et al. (2016) confirm the linear character of the dependency for each experimental year, but the summarized data show that it is square in R^2<0.5. Irmak et al. (2016) express a regression square quotation, according to which if the irrigation rate is increased with 25% over the optimal the yield is reduced is comparable with the yield after 25% irrigation reduction. Results from experiments in South Dakota prove that the reduction of the irrigation rates without affecting significantly the yield is 4-14% (Heeren et al., 2011).

It is clear from the brief literature review that the correlation between the yield and irrigation rate is not clear enough with the exception of the expressed quotations, which are valid only for specific conditions and show only its existence. Besides the quotations (linear or quarter), there are also other possibilities for expression of such kind of dependences, such as the square formula of Varlev (1981, 2008), Varlev et al. (1994), Varlev and Popova (1999), and the power formula of Davidov (1982, 1994, 1998, 2004), which can express also the correlation concerning the additional yield.

The aim of the current study is to investigate the influence of reduced irrigation rates on the maize grain yield (group 600 - FAO), grown in Plovdiv region as well as to establish the parameters of the correlation “Additional yield - irrigation rate”.

MATERIAL AND METHODS

The data in the current study are obtained from field experiments for irrigation rate of maize for grain in Plovdiv region. The experiment was conducted during the period 2004-2018 in the experimental field of the Agricultural University with the late hybrid “Knezha - 613”. The repetitions are: 1) without irrigation; 5) optimal irrigation rate (100% of the irrigation rate); 2, 3, 4) irrigation, respectively, 25%, 50% and 75% from the rate of repetition 5. In 2018 repetitions 2, 3, 4 have been irrigated respectively 40, 60 and 80% from the maximum irrigation rate.

Irrigation was done when the moisture is 75% from the limit field moisture content in 0-80 cm layer in repetition 5. The irrigation rates are counted to supplement the soil moisture up to the level of the limit field moisture content in the same soil layer. Repetitions (2, 3 and 4) were irritated simultaneously with repetition 5 with the respective correction of the irrigation rates.

Irrigation was carried out by gravity in short closed furrows 6 m long. The experiment was set up using block method in 4 repetitions with 25 m^2 of each plot and 10 m^2 of each harvest plot. Sowing was carried out at a density of 60000 plants per ha and a row spacing of 0.7 m. All repetitions were fertilized with 16 kg/da N, introduced before the last inter-row treatment, in the form of ammonium nitrate. Soya has been used as a predecessor of the maize.

The data about the yields were statistically processed by ANOVA1 having established the degree of evidence of yield differences between option 5 and the other trial options.

There are two ways of establishment of the correlation between the additional yield and the irrigation rate:

1) Regression of $Y=ax^2+bx$ type;
2) Power formula $Y=1-(1-x)^n$.

In both quotations X is the relative irrigation rate and Y - relative additional yield. The first formula is quarter and the second is with variable power rate n. For establishment of the parameters of the dependency the method of the smallest quarters was used.

RESULTS AND DISCUSSION

The meteorological conditions during the vegetation period have significant influence on the elements of the irrigation regime, as well as on the additional yield in case of irrigation of reduced rates. Concerning the temperature sum in 2004 it has been average and 2007 - warm. The other 4 years are average. Concerning the rainfall 2005 and 2007 have been most humid. For 2007 that is due to huge rainfall in early June and early August when the crop is wax-ripening stage and their influence is insignificant. During the reproductive period the same year has been extremely dry with 0.7 mm rainfall. Very similar is the situation in 2004, 2006 and 2008, and the rainfall is evenly distributed during the first two years. The last year of the experiment was average dry with extreme spring drying.

The elements of the irrigation regime during the experimental years are in line with the meteorological conditions. Most important are the rainfall and its distribution. In 2009 big influence has the temperature and the lack of air humidity. Data are given in Table 1. The number of the irrigation is between 1-2 (2.4 averages).

The maize hybrid, used for the aims of the investigation is high-yielded and in non-irrigation conditions in in favorable years (2004, 2005 and 2006) gives about 1000 kg/da yield (Table 2). In years, when distribution of rainfall is not equal and longer dry periods during the reproductive period, yields are twice lower and are 400-500 kg/da. During the time of the experiment drying in the time of the vegetation period has strongest influence on the yield and in 2009 from the repetition without irrigation have been harvested only 70 kg/da. With the optimization of the soil moisture the yields grow significantly compared to the non-irrigated repetition and is between 815-1353 kg/da. These differences are very well expressed during meteorologically unfavorable years and are 2.5 times, while in 2009 - more than 10 times. Reduction of the irrigation rates with 25% has no significant negative effect on the yield and the reduction is with 1-17%. More significant is the reduction when irrigation is done with ½ from the necessary rate and can reach up to 30% in some years. The table shows that irrigation with 75% reduced rate is without practical significance.

Table 1. The irrigation regime components

Year	Number of irrigation applications	Variants			
		(5) 100%	(4) 75%	(3) 50%	(2) 25%
		Annual irrigation rates (mm)			
2004	2	160.2	120.2	80.1	40.1
2005	1	80.0	60.0	40.4	20.0
2006	2	144.6	108.4	72.3	36.2
2007	3	270.3	202.7	135.2	67.6
2008	3	250.7	188.0	125.4	62.7
2009	4	354.3	265.7	177.2	88.6
2018*	2	130.0	104.0	72.0	52.0
average	2.4	198.6	149.9	100.4	52.5
*irrigation rates: 100, 80, 60 and 40%					

Table 2. Yield by variants and years and source data for determine of the parameters of the connection "Additional yield-irrigation rate"

Variant		Yield kg/da	Additional yield		Yield kg/da	Additional yield	
			kg/da	relative		kg/da	relative
1		2	3	4	5	6	7
2004					**2005**		
1 (dry)	0.00	970^{st}	0	0.000	1210^{st}	0	0.000
2 (25%m)	0.25	1031^{ns}	61	0.167	1276^{ns}	66	0.496
3 (50%m)	0.50	1133^{b}	163	0.445	1309^{ns}	99	0.692
4 (75%m)	0.75	1205^{c}	235	0.699	1339^{ns}	129	0.902
5 (100%m)	1.00	1306^{c}	336	1.000	1353^{a}	143	1.000
GD kg/da		P5%=78, P1%=113, P0.1%=170			P5%=139, P1%=202, P0.1%=303		
2006					**2007**		
1 (dry)	0.00	959^{st}	0	100.0	489^{st}	0	0.000
2 (25%m*)	0.25	1020^{a}	61	106.4	706^{c}	217	0.302
3 (50%m)	0.50	1092^{c}	133	113.9	999^{c}	510	0.710
4 (75%m)	0.75	1179^{c}	220	122.9	1148^{c}	659	0.918
5 (100%m)	1.00	1199^{c}	240	125.0	1207^{c}	718	1.000
GD kg/da		P5%=47, P1%=69, P0.1%=103			P5%=100, P1%=140, P0.1%=197		
2008					**2009**		
1 (dry)	0.00	417^{st}	0	0.000	70^{st}	0	0.000
2 (25%m)	0.25	619^{c}	201	0.303	257^{b}	187	0.251
3 (50%m)	0.50	790^{c}	372	0.560	548^{c}	478	0.642
4 (75%m)	0.75	893^{c}	476	0.715	700^{c}	630	0.846
5 (100%m)	1.00	1081^{c}	664	1.000	815^{c}	745	1.000
GD kg/da		P5%=93, P1%=130, P0.1%=184			P5%=106, P1%=148, P0.1%=209		
2018					**Average**		
1 (dry)	0.00	650^{st}	0	0.000	680	0	0.000
2 (40%m)	0.40	783^{ns}	133	0.365	813	133	0.290
3 (60%m)	0.60	839^{a}	189	0.519	959	279	0.608
4 (80%m)	0.80	$965^{в}$	315	0.865	1061	381	0.830
5 (100%m)	1.00	1014^{c}	364	1.000	1139	459	1.000
GD kg/da		P5%=167, P1%=242, P0.1%=364					
*m - full irrigation rate							

In Table 2, columns 3 and 6 is given the absolute additional yield by repetitions and years, on which base are calculated its relative values, compared to the repetition with optimal irrigation rate (columns 4 and 7). They, together with the respective relative irrigation rates (column 1), are the source data for determination of the parameters of the dependency "Additional yield-irrigation rate". The empiric points are uploaded in rectangular coordination system, where the values on the abscissa represent the relative irrigation rates and, on the ordinate, the corresponding relative additional yield. The points are approximated with a curved line, subordinate to the used for that case equilibrium. Figure 1A expresses graphically the square regression dependency which approximates experimental points by convex parabola in R=0.921. At Figure 1B are compared the experimental and calculated values. The closer the points are to the diagonal of the coordinate system, the lower is the difference between the experimental and calculated values of the additional yield. The deviations can be clearly seen also in Figure 1C. There is no clear tendency for the direction of the deviations and the variation is -19 to +15%, nevertheless the high correlation index.

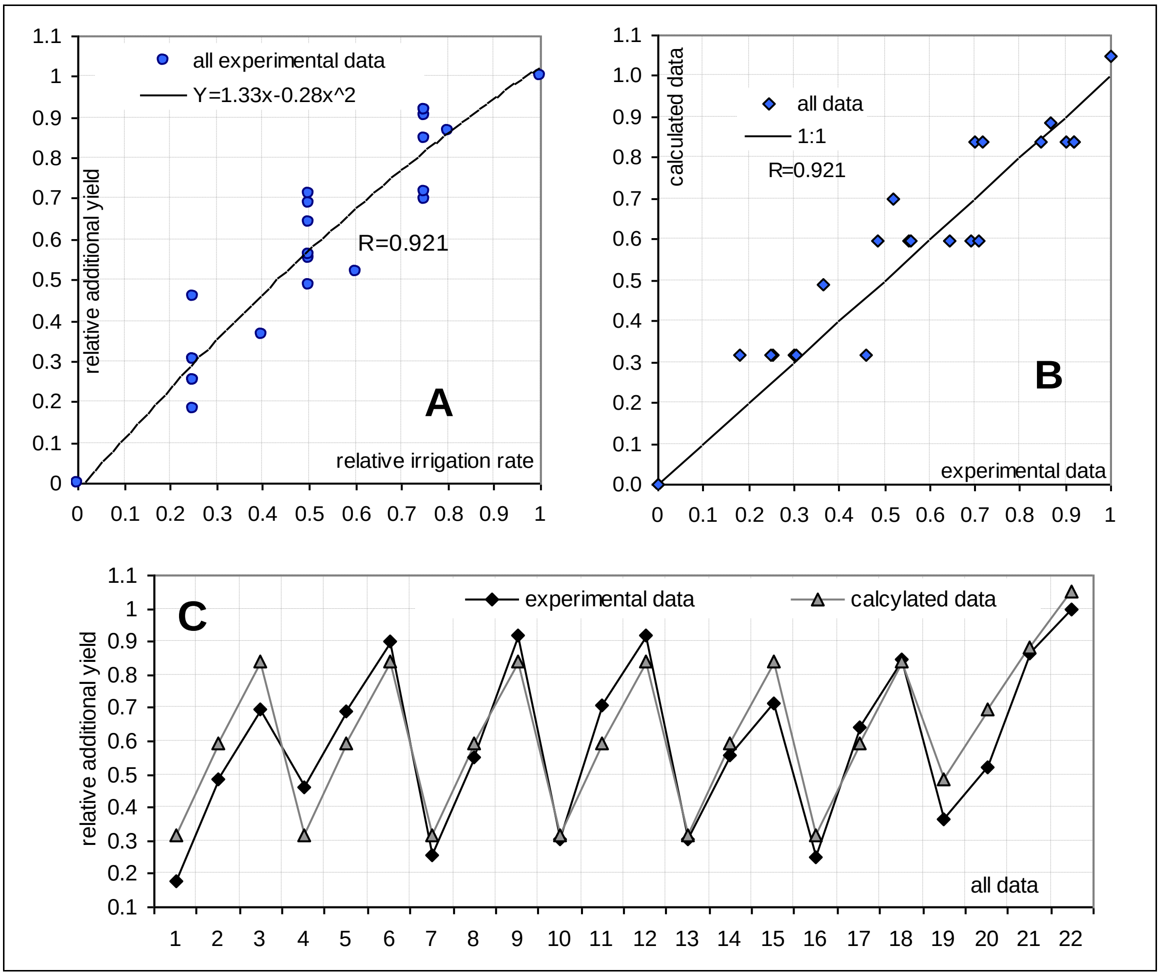

Figure 1. Regression relationship "Additional yield-irrigation rate"

Figure 2A shows the degree of dependence between the relative irrigation rate and relative additional yield. It is shown graphically by convex parabola with power indicator n=1.35 and R=0.92, i.e., the accuracy of the two ways used to express this dependence is practically the same. That can be seen also in the other two graphics (Figure 2B and 2C). Deviations are comparable with these in the regression dependency (Figure 4). The difference is basically in the difference between maximum rate and 70% from it and within that difference the calculated additional yield increases with smaller step. That is comparable to a greater extend with the biological characteristics of maize in terms of its reaction to lower irrigation rates. For example, when the irrigation rates are reduced with 25% the additional yield is only 10% lower, but in the regression dependency that reduction is more significant. The most essential difference between two models is the structure of the formulas, to which they are subordinate. With the exception of the relative irrigation rate (x), are variable and are valid for the approximation of a well-defined group of empirical points. This does not make it unusable, and it is no accident that it is the only version of this dependence proposed in the specialized scientific literature. On the other hand, the power formula has a simplified structure and at the same time gives much more freedom to express this dependence. The only thing that changes in this formula is the power indicator, which constructs the curve in such a way that it is sufficiently reliable. In relation to this possibility, the accuracy of the power formula was investigated by varying the power index over a relatively large range (n=1.15÷1.55) to track the variation of R. The results are presented visually in Figure 3, and the parameters are plotted in Table 3.

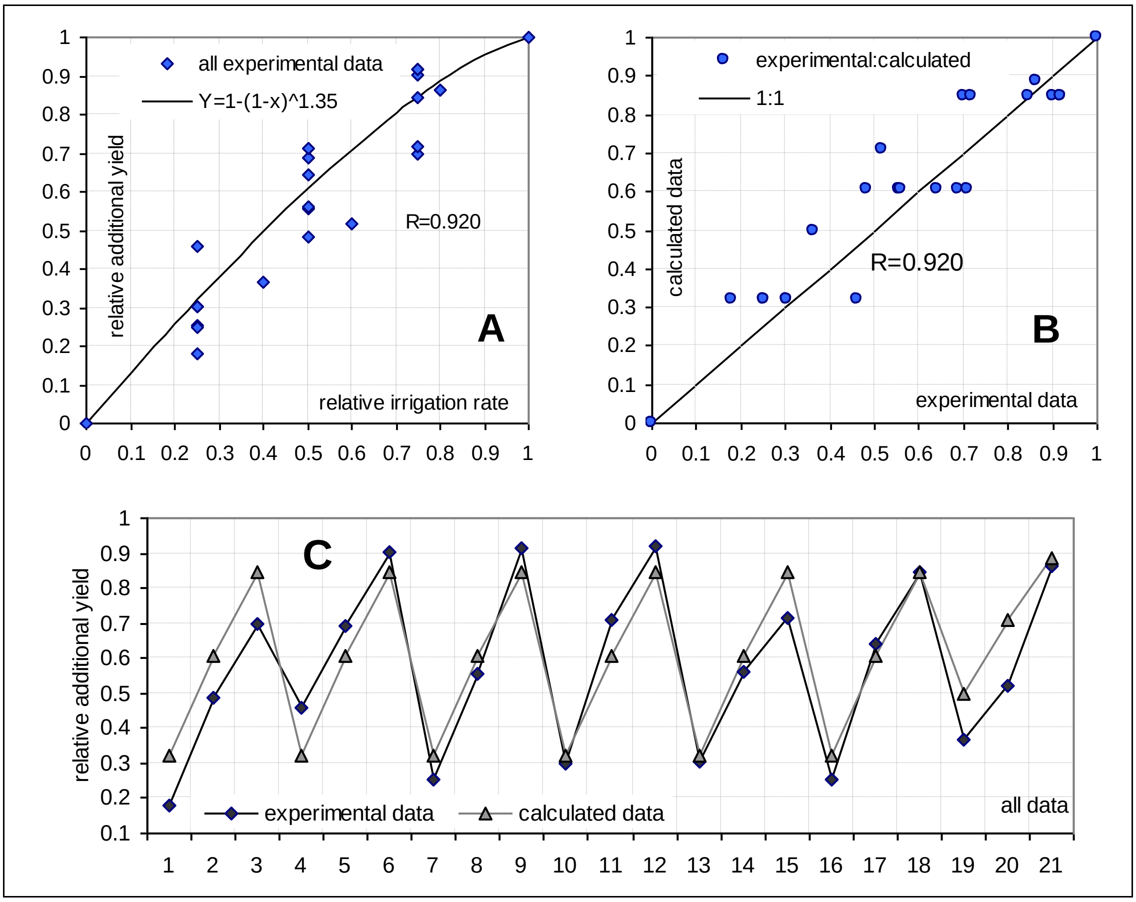

Figure 2. Power relationship "Additional yield-irrigation rate"

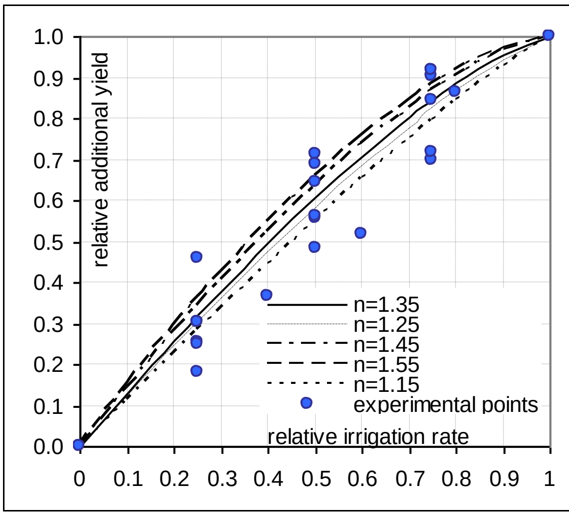

Figure 3. "Additional Yield – Irrigation Rate" Relationship by different power indicator

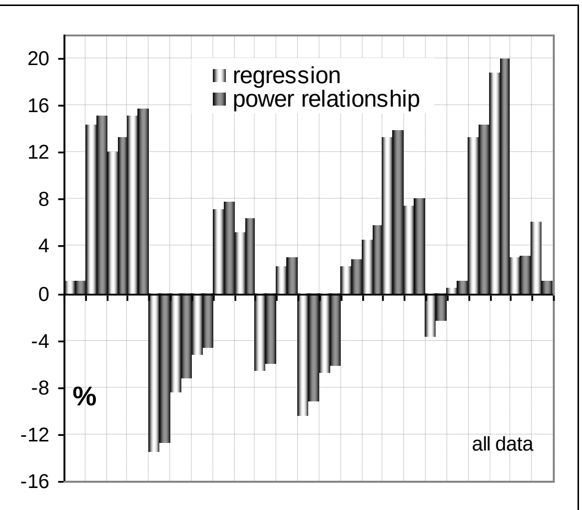

Figure 4. Relative deviations using regression and power model

In the range studied, the difference in relative incremental yield between the smallest and largest values of n did not exceed 10%, and then only at irrigation rates between 40 and 70%. This can be clearly seen in Figure 3. On the other hand, there is practically no variation of R, i.e. in this whole range (n=1.15÷1.55) the relationship is representative. From this it can be concluded that, with the same accuracy, the step formula gives much more freedom of expression of the relationship between additional yield and irrigation rate, compared to the regression model. This gives it an advantage when choosing a way to express the dependence.

Table 3. The Parameters of the relationship "Additional Yield - Irrigation Rate"

Equation	Power indicator (n)	R
$Y=1-(1-x)^n$	1.15	0.921
	1.25	0.921
	1.35	0.920
	1.45	0.920
	1.55	0.919
	2.00	0.914
$Y=bx-ax^2$	2.00	0.921

CONCLUSIONS

The number of irrigations in maize for the Plovdiv area varies from 1 to 4, depending on the nature of the year. In average and wet years with evenly distributed rainfall, optimizing the irrigation regime ensures an increase in yield of 12-25%. In years with prolonged droughts during the reproductive period, the yield can increase by more than 2.5 times.

Reducing irrigation rates by 25% reduces yield by between 1-17%. The losses are greater when irrigating 50% of the rate, where the difference to optimally irrigated maize is in the range of 3-33%.

There is a positive relationship between yield and irrigation rate. This can be represented by the regression equation or by the power formula. In both cases, the accuracy is the same (R=0.92), but the power formula gives more freedom to express this relationship and is therefore recommended.

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