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Influence of controlled water deficit at different levels of fertilization on the yield of greenhouse tomatoes

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Abstract

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The main objective of this study is to analyze the mutual influence of different irrigation regimes and fertilization rates on the greenhouse tomato yield and on the irrigation water use efficiency. Different irrigation schedulings have been studied in order to establich the impact of water deficit on the tomato productivity and quality. The study is achieved through an experiment with tomatoes in polyethylene unheated greenhouse during 2016-2018. An important role in the technology plays fertilization with different rates. The focus in this experiment is on the effect of a controlled water deficit achieved by reducing the irrigation depth at different levels of plant nutrition on the productivity of greenhouse tomatoes and water use efficiency. In studies interval of irrigation depth and fertilizer rate was found significantly stronger influence of the fertilizer rate on yield. The impact of irrigation on the yield is lower at the lower fertilizer levels. It has greater effect at the higher levels of the irrigation rate. Close to the maximum yield - over 100 Mg/ha can be obtained also by applying the maximum fertilization rate and 80% of the full irrigation depth. The greatest relative additional yield (RAdYn) can be obtained by maximum irrigation depth and maximum fertilizer rate and irrigation has greater effect at maximum and close to it fertilization rates. Maximum water use efficiency can be obtained by a minimum amount of irrigation water and maximum fertilization. Moreover, irrigation has small impact at lower fertilization rates (up to 50%), i.e. WUE is small. The analysis of the the utility function, which summarizes the conditions for obtaining maximum yield and maximum water use efficiency indicates that it maximum value can be obtained at maximum fertilizer rate and 60-70% of the full irrigation depth.

Keywords: tomato; irrigation regime; fertilization; yield; efficiency

Introduction

The area of the greenhouses in BG is around 1600 ha (according to the data of BANSIK, 2018), with more than half of them being used for tomato production. Half of the tomatoes produced were grown in greenhouses. The main costs in vegetable greenhouse production are for water and fertilizer application. This is highly intensified production requires significant amounts of mineral fertilizers increasing the yields. Excessive use in some cases causes pollution of the environment and production, and on the other hand inefficient use of fertilizers. Furthermore, the possibility for applying fertilizers together with the irrigational water makes it possible to dosage the fertilizers according to crop needs. These application rates are optimal and allow achieving efficient use of the water and the fertilizers and minimum contamination in the final product and the environment.

A number of researchers have established the impact of the irrigation regime on the precocity and quality of tomatoes (Marouelli et al., 2007; Ngouajio et al., 2007; Favati et al., 2009). According to Li et al. (2017), nitrogen fertilizers induce higer effect of the irrigational water on the tomato yield. Water is the main limiting productivity factor for crops in arid and semi-arid areas (Badr et al., 2016; Velichkova, 2019a).

The results of this study suggest that dense twin planting can increase crop yields and save substantial amount of irrigational water and can lower the cost of the drip laterals. Çetin et al. (2008) obtained maximum irrigation water use efficiency (22.3 kg m-3) when using 2 m lateral interspacing and a patial canopy cover. Jensen et al. (2010) have developed water-saving irrigation strategies for in some vegetable crops, which was based on field studies. For the conditions of southern

Italy Mediterranean environment, Patanè et al. (2011) have established that in water deficit conditions the irrigation water use efficiency have increased.

When water deficit occurs in the early growth statges the fruit loss (> 44%) was high and the commercial income was negatively influenced. Zhang et al. (2017) have obtained the highest tomato yield when meeting 80% of its crop evapotranspiration (ETc). The authors recommend this irrigation strategy as optimal, while Du et al. (2017) consider best strategy when applying 75% pan evaporation E_p, in drip irrigation and 250 kg N ha^{-1}.

A number of researchers (Chen et al., 2013; Yang et al., 2017) have calculated linear regressions between the quality characteristics and the evapotranspiration, which put the scientific basis of the water saving technologies. The tomato fruits are sensitive to water during flowering and fruit development (stage 2) and fruit ripening (stage 3). The water deficit reduces the yields when appled during stages 2 and 3, while quality is affected by a deficit in stage 3 deficit.

Greenhouse production technologies are some of the most advanced. The specific conditions that are generated within the greenhouses, regardless of their type and construction allow growing of more than one crop in a vegetation season which significantly increases the average yield per unit area. Optimization of the vegetable water and nutrition regime increases the water use efficiency, reduces the water deficit negative effect, solves environmental problems emerging from high fertilization rates which are usually applied in greenhouses (Kostadinova et al., 2013; Velichkova et al., 2019b). The impact of nutrient and irrigation scheduling is also sudied for its effect on the quality of tomatoes. Badr et al. (2016) has established the water use efficiency on tomato yield and quality at four levels of N fertilization Relationships between the nutrient and irrigation schedulings and dry matter, soluble sugars, vitamin C and organic acids have been established by Du et al. (2017) and Lahoza et al. (2016).

Applying large amounts of artificial fertilizers causes, on one hand, crop nutrition disbalance, and on the other soil and water pollution. The greenhouse main production purpose is to achieve better crop development through balanced crop cultivation. Production of greenhouse crops depends on the technology of cultivation and the market requirements. In a short period of the year, growing vegetable crops requires big and, in many cases, unfounded fertilization application rates. The absorbation rate of the nutrients applied and the impact of the varietal and species characteristics on it is not sufficiently understood.

In the current market situation in which there is high demand of environmentally friendly production but at the lowest possible cost, there is great need for establishing the water-yield-fertilization relationship on economically but not on biologically optimal level (Varlev et al., 1994). Numerous researchers have estimated the irrigation - fertilization interaction from the point of view of its effect on the yield and the water use efficiency in greenhouse tomato growing (Liu et al., 2009; Zotarelli et al., 2009; Michela et al., 2015).

The main objective of this study is to analyze the mutual influence of different irrigation schedulings and fertilization rates on the greenhouse tomato yield and on the irrigation water use efficiency. Especially important is the problem with recruitment date information on the reaction of tomatoes in a complex interaction of factors irrigation and fertilization rate at different levels of intensification. These underdeveloped aspects of tomato production in greenhouses and making recommendations on the practice in Bulgarian agriculture warranted to work on tasks in the current study.

Material and Methods

The goal of the study is achieved through an experiment with tomatoes in polyethylene unheated greenhouse during 2016-2018, in Plovdiv region with geographical coordinates are 42°09' north latitude and 24° 45' East GMT (GPS).

The experiment was performed with the hybrid variety "Vitellio F1". The experiment was based on the block method on a flat surface design according to the scheme 110+50+35, with 10 m^2 harvest plot (Barov, 1982) in four repetitions.Different irrigation schedulings have been studied in order to establich the impact of water deficit on the tomato productivity and quality. An important role in the technology plays fertilization with different rates.

The experimental field is situated at an altitude of 164 m. The type of soil is Alluvial-meadow and has the following content of nutrients in the test 0-0.30-m zone (Table 1).

Table 1. Nutrient content of the layer 0-0.30 m

Test	$N\text{-}NH_4$	$N\text{-}NO_3$	Total mineral nitrogen	P_2O_5	K_2O	CaO	Fe	MgO
Depth of soil layer	mg/kg	mg/kg	mg/kg	mg/100g	mg/100g	mg/100g	mg/kg	mg/100g
0-30 cm	16.74	100.45	117.19	6.67	20.09	48.5	1964.03	9.71

The soil has a thin humus layer (average 0.25 m). The content of humus in the surface layer is in the range of 1.5-2.0%. FC (Field Capacity) is around 14-16%. The soil has good aeration. The total porosity varies from 30% to 42%. The water permeability is high but the water-retaining capacity is small.Phenological and biometric observations were conducted in order to establish the impact of the nutrition and irrigation scheduling on the development and productivity of the tomatoes. The experiment is based on two factors:

Factor X_1 – irrigation: The interaction of different soil water deficit with three levels of nutrition on the productivity of the tomatoes was investigated. The irrigation was carried out with a system of drip irrigation.

Factor X_2 - fertilization: the experiment contained basic fertilization at three nutrition rates: 50%, 75% and 100%. The 100% nutrition rate contained P_{23} (as P_2O_5), K_{25} and $S_{9.2}$ (as K_2SO_4). The reduction of nutrition rate was 50% ($P_{11.5}$, $K_{12.5}$, $S_{4.6}$) and 75% ($P_{17.25}$, $K_{18.75}$, $S_{6.9}$).

During the vegetation is carried out feeding at three levels of N (as NH_4NO_3), and K (as KNO_3) on the background of basic fertilization. When realizing a 100% rate fertilizer to nourish are embedded respectively N_{50} and K_{23}. As a result of the reduced rates of feeding of tomatoes are imported N_{25}, K_{11} and $N_{37.5}$, $K_{17.25}$ respectively at 50 and 75% fertilization rates.

The crop was planted at the beginning of April each year of the experiment. The pre-irrigation soil moisture maintained was 75% to 80% of FC and the application depths were calculated for the active 0-30 cm soil layer.

The following variants were tested: 1. Deficit irrigation (50% of the full irrigation depth) without fertilization; 2. Deficit irrigation (75% of the full irrigation depth) without fertilization; 3. Full irrigation without fertilization (control); 4. Deficit irrigation (50% of the full irrigation depth) and 50% of the full fertilization rate; 5. Deficit irrigation (75% of the full irrigation depth) and 50% of the full fertilization rate; 6. Full irrigation with 50% of the full fertilization rate; 7. Deficit irrigation (50% of the full irrigation depth) and 75% of the full fertilization rate; 8. Deficit irrigation (75% of the full irrigation depth) and 75% of the full fertilization rate; 9. Full irrigation with 75% of the full fertilization rate; 10. Deficit irrigation (50% of the full irrigation depth) and full fertilization; 11. Deficit irrigation (75% of the full irrigation depth) and full fertilization; and 12. Full irrigation and full fertilization.

The irrigation system consisted of drip irrigation pipes with attached-in drippers with a flow rate of 1.11 l/h. Full irrigation during the first experimental year was realized throuhg 33 applications with irrigation depth 4950 m^3/ha. The irrigation depth in the second year was 4050 m^3/ha and 27 applications were given. In the third year were given 29 applications and the irrigation depth was 4350 m^3/ha. The methodology is not set control variant without irrigating tomatoes, because under the conditions of intensive production of tomatoes grown in greenhouses, it is impossible to obtain an output without irrigation.

The irrigation water use efficiency (*IWUE*) for every irrigated plot was calculated as (eq. 1):

$$IWUE_n = \frac{Y_n}{M_n}, \text{kg/m}^3 \quad (1)$$

where: $IWUE_n$ – the irrigation water use efficiency in the *n* irrigated plot (variant), kg/m^3; Y_n – the yield from the *n* irrigated plot (variant), kg/ha, M_n – the irrigation depth of the *n* irrigated plot (variant), mm (m^3/ha).

Multiple regression analysis of the combined effect of the two factors: the irrigation depth and the fertilization rate on the yield and on *IWUE*, was developed. The conditions for obtaining maximum the relative additional yield from the *n* variant ($RAdY_n$) and maximum $RIWUE_n$ (Relative *IWUE*) were established through optimization of the multiple regression models.

The irrigation depth and the fertilizer rate were considered factors of the regression model, while $RAdY_n$ and $RIWUE_n$ were considered parameters for estimation.

In order to isolate the impact of the meteorological conditions, the estimated parameters were introduced in relative values (%). The additional yield due to irrigation was calculated in relative units (eq. 2):

$$RAdY_n = \frac{Y_n - Y_0}{Y_0} * 100\% \quad (2)$$

where: $RAdY_n$ – the relative additional yield from the *n* variant, %; *n* – the number of the irrigated plot (variant) (*n*=1, 2…36); Y_n – the yield from the *n* variant, kg/ha; Y_o – the yield from the control variant (var. 3), kg/ha; Y_n - Y_o - the additional yield in kg/m^3.

The relative *IWUE* was calculated as (eq. 3):

$$RIWUE_n = \frac{IWUE_n}{IWUE_3} 100, \% \quad (3)$$

where: *RIWUE* – the relative *IWUE*, %; $IWUE_3$ - the *IWUE* in var. 3 in the relevant year

A generalized parameter of optimization: an average utility function (*AUF*) was developed in order to establish the conditions for obtaining maximum $RAdY_n$ at maximum *RIWUEn*. The following average utility function (*AUF*) was chosen (eq. 4):

$$AUF = \frac{1}{n}\sum_{i=1}^{n} U_i \quad (4)$$

where: *AUF* – average utility function; U_i – the utility function (*UF*) for each of the two parameters $RAdY_n$ and $RIWUE_n$; *n* – number of the parameters considered. The maximum and minimum values of the experimental results were selected as utility limits.

The utility function of the relevant parameters was determined through the equation (eq. 5):

results were selected as utility limits.

$$U_i = \frac{Z_i - Z_{min}}{Z_{max} - Z_{min}} \quad (5)$$

where: Z_i - the value of the parameter at a random point in the experiment, Z_{min} and Z_{max} – the minimum and maximum values.

The factors were coded as shown in Table 2. The minimum values noted as (-1) and the maximum values as 1. A second power polynomial was chosen to describe the regression model surface of distinctiveness. Its general appearance was (eq. 6):

$$Y = b_o + b_1x_1 + b_2x_2 + b_{12}x_1x_2 + b_{11}x_1x_1 + b_{22}x_2x_2 \quad (6)$$

Statistica, Mathcad and Excel software were used for data processing and illustration. The full model was optimized without removing the insignificant coefficients because they contain certain process information. The effect of each factor by itself on the parameters was estimated through a procedure of consecutive cutoff.

Table 2. Levels of variation of the independent factors

Factors		Coded value of the factor				Natural value of the factor			
		Lower level	Basic level		Upper level	Lower level	Basic level		Upper level
Irrigation depth	X_1	-1	0		1	50%	75%		100%
Fertilizer rate	X_2	-1	0	0.5	1	0%	50%	75%	100%

Results and Discussion

In this study, the focus was on the combined effect of different irrigation schedulings and fertilization rates. The application of fertilizers through a drip irrigation system allowed controlling the amount of nutrients and providing them at particularly sensitive to water and nutrition crop growing stages: from the beginning of the redness of the fruit and the beginning of harvesting to the mass ripening and harvesting. When soil moisture is in the range 80-85 (90) % of the field capacity (FC), the fruits grow big, no blooming is observed, and the percentage of non-standard production is smaller established by Waister et al. (1970) and Shaban et al. (2014).

The specific greenhouse conditions allow intensive cultivation, whereby the average yield is significantly increased.

The results of the statistical analysis show great variation of the tomato yield (Fig. 1). The results in Table 3 show the range of productivity of the crop as dependent on the irrigation scheduling. The highest yield - 114300 kg/ha - was obtained from Var. 7 (50% of the full irrigation depthe and 75% of the full fertilization rate) in the first year. The three-year average yield from Var. 7 was 80353 kg/ha.

The yield obtained by applying full irrigation and 75% of the full fertilization rate (Var. 9) ranged from 98340 to 106180 kg/ha. While keeping the fertilization rate at a level of 75% of the full fertilization rate, the yield increased with increasing of the irrigational water amounts. The effect of irrigation was for 10.8% to 26.8% increase of the yield (Table 3).

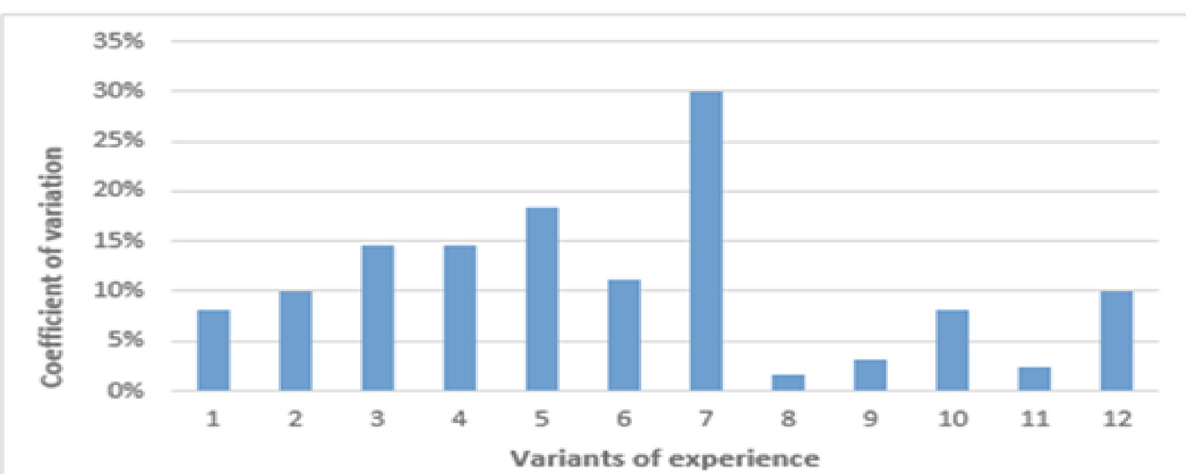

Fig. 1. Three-year coefficient of variation of yield in the separate variants

Table 3. Greenhouse tomato yield under three irrigation regimes and three fertilizer rates, 2016-2018

Variant	2016	2017	2018	Average
	kg/ha	kg/ha	kg/ha	kg/ha
1	27900	22850	26140	25630
2	30800	24100	28500	27800
3	38930	28110	30100	32380
4	66900	49200	50240	55447
5	75100	52880	51110	59697
6	74130	68140	56240	66170
7	114300	65210	61550	80353
8	87030	90250	89910	89063
9	106180	101210	98340	101910
10	78480	95400	91170	88350
11	105040	100300	99850	101730
12	82200	103650	101560	95803

Vasileva et al. (2016) has established positive influence of fractional fertilization on the tomato export of total nitrogen and phosphorus. The highest coefficients using the fertilizer of K_2O, P_2O_5 and total N were determined at fractional introduction of the potassium norm.

The variation in yield (over the years of the experiment) is greatest in the Var. 7 (Figure 1), followed by Var. 5 and the lowest in Var. 8. The 50% supply of the full irrigation depth proved to be a limiting factor. Under the influence of the limited water volume fertilizer norms $N_{37.5}$, $K_{17.25}$ not are extracted by the plants. The nutrients nitrogen (in the form of nitrate and nitrite forms) and potassium are especially important for plant development. The results of Stoyanova et al. (2018a) demonstrate the positive effect of higher rates of fertilization.

High yields of 80353 kg/ha to 101910 kg/ha were recorded at 75% and full fertilization and feed rates, respectively. The variation in productivity in this case can be explained by the influence of the amount brought irrigation water. Zotarelli et al. (2009) also establishes that the regulated water deficit limit the development of the root system and tomato yield. The reduction of the feeding rate combined with the specific effect of the water deficit (50% of the full irrigation depth) set conditions for reduced extraction from soil of the nutrients that are involved in the metabolism of the plants. The experimental results demonstrate the significant influence of N on the vegetative growth, yield and quality of the tomatoes (Du et al. 2017). The reduction in yields could also be interpreted as a consequence of the influence of the limited potassium fertilization. Potassium is involved in a number of oxidation processes and also plays an important role in regulating water plants. A solution of Potassium nitrate was applied to the drip irrigation system. A deficiency of potassium is a precondition for reducing root growth, yield, fruit appearance and content of carotenoids (Ghebbi et al., 2007; Schwarza et al., 2013).

The results of the regression analysis for the yield are presented in Table 4. This table was extracted from Statistica software. The coefficient of determination is $R^2 = 0.78$. The Fisher's Test result is $F(5, 30) = 25.69$ at a probability $p < 0.00000 < 0.05$. These statistical features are sufficient grounds to consider the model adequate to the behavior of the studied parameter. This model describes 78% of the parameter's variation. From the table and the regression model can be seen that fertilization has considerably stronger impact on the tomato yield than irrigation (in the considered interval of the irrigation depth).

Table 4. Results from the regression analysis for tomatoes yield

N=36	Regression Summary for Dependent Variable: Yd $R=0.90037672$, $R^2=0.81067825$, Adjusted $R^2=0.77912462$ $F(5.30)=25.692$, $p<.00000$, Std.Error of estimate: 13.959					
	Beta	Std.Err. of Beta	B	Std.Err. of B	t(30)	p-level
Intercept			64.83830	5.039006	12.86728	0.000000
X1	0.226725	0.080567	9.56724	2.889876	3.31060	0.002331
X2	0.847584	0.080002	33.56721	3.168364	10.59449	0.000000
X1X2	0.088560	0.080567	4.23543	3.853168	1.09921	-0.280421
X1X1	-0.090191	0.079440	-5.60333	4.935403	-1.13533	0.265225
X2X2	0.014584	0.080002	0.95697	5.249453	0.18230	0.856574

3D Surface Plot of Yd X1 and X2
Yd = 64.8383+9.5672*x+33.5672*x*x+4.2354*x*y+).957*y*y

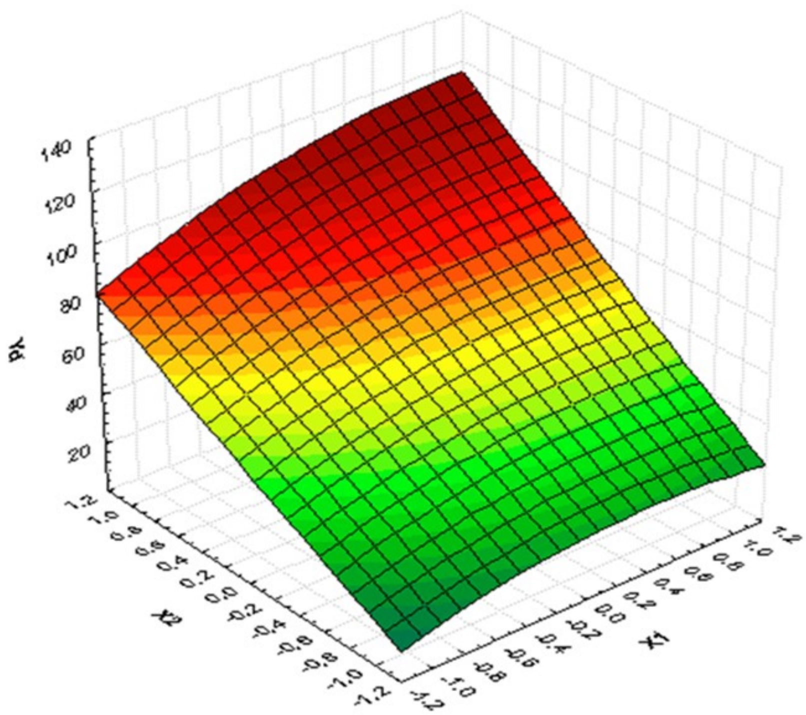

Fig. 2. Dependence of the tomato yield on the irrigation depth (X1) and the fertilizer rate (X2)

The results of the regression analysis for the parameter $RAdY_n$ are presented in Table 5. This table was extracted from Statistica software. It shows that the coefficient of determination is R^2 =0.79 and the Fisher's Test result is F (5, 30) = 28.02 at a probability $p < 0.0000 < 0.05$. These statistical features are sufficient grounds to consider the model adequate to the behavior of the studied parameter. This model describes more than 79% of the parameter's variation.

The data in Table 5 shows that there is no combined effect of the studied factors on $RAdY_n$. Each factor has its own individual effect on the yield. In order to estimate the effect of each factor, a consecutive cutoff procedure was applied. The results show that the fertilizer level has the greatest effect, while the irrigation depth has much smaller effect. $RAdY_n$ is highest at full irrigation and maximum fertilizer rate (Fig. 3). Irrigation has maximum effect at maximum fertilizer rate.

Table 5. Results from the regression analysis for relative additional yield

N=36	Regression Summary for Dependent Variable: RAdYd R=0.90754064, R^2=0.82364453, Adjusted R^2=0.79425195 F (5.30)=28.022 p<.00000, Std.Error of estimate: 0.43090					
	Beta	Std.Err. of Beta	B	Std.Err. of B	t(30)	p-level
Intercept			1.068824	0.155544	6.87152	0.000000
X1	0.164568	0.077759	0.188791	0.089205	2.11638	0.042719
X2	0.886843	0.077214	1.123295	0.097801	11.48550	0.000000
X1X2	0.034530	0.077759	0.052817	0.118940	0.44406	0.660184
X1X1	-0.020992	0.076671	-0.041711	0.152346	-0.27379	0.786123
X2X2	-0.027561	0.077214	-0.057838	0.162040	-0.35694	0.723636

3D Surface Plot of RadYn against X1 and X2 RAdYn = 1.0688+0.1888*x+1.1233*y-0.0417*x*x+0.0528*x*y-0.0578*y*y

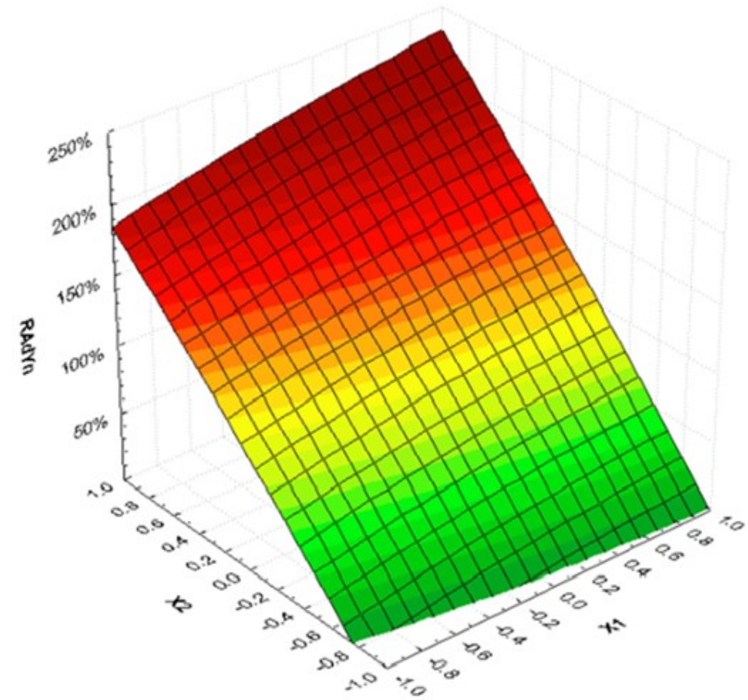

Fig. 3. Dependence of the relative additional yield on the irrigation depth (X1) and the fertilizer rate (X2)

The results of the regression analysis for the parameter $IWUE_n$ are presented in Table 6. This table was extracted from Statistica software. It shows that the coefficient of determination is R^2=0.86 and the Fisher's Test result is F (5, 30) = 43.5 at a probability p <0.0000 <0.05. These statistical features are sufficient grounds to consider the model adequate to the behavior of the studied parameter. This model describes more than 86% of the parameter's variation.

The data in Table 6 shows that there is combined effect of the studied factors on $IWUE_n$. In order to estimate the effect of each factor, a consecutive cutoff procedure was applied. The results show that the level of fertilization had the three times bigger than irrigation effect on the *IWUE*, which is due to the fact that under non-irrigation conditions zero yield is obtained.

Table 6. Results from the regression analysis for irrigation water use efficiency

N=36	Regression Summary for Dependent Variable: IWUEn R=0.93744144, R^2=0.87879646, Adjusted R^2=0.85859597 F (5.30) = 43.504 p<.00000, Std.Error of estimate: 4.0365					
	Beta	Std.Err. of Beta	B	Std.Err. of B	t(30)	p-level
Intercept			19.82719	1.457081	13.60747	0.000000
X1	-0.402629	0.064464	-5.21926	0.835638	-6.24584	0.000001
X2	0.802367	0.064012	11.48384	0.916166	12.53468	0.000000
X1X2	-0.195007	0.064464	-3.37049	1.114184	-3.02507	0.005060
X1X1	0.063485	0.063562	1.42540	1.427123	0.99879	0.325883
X2X2	-0.022007	0.064012	-0.52187	1.517934	-0.34380	0.733393

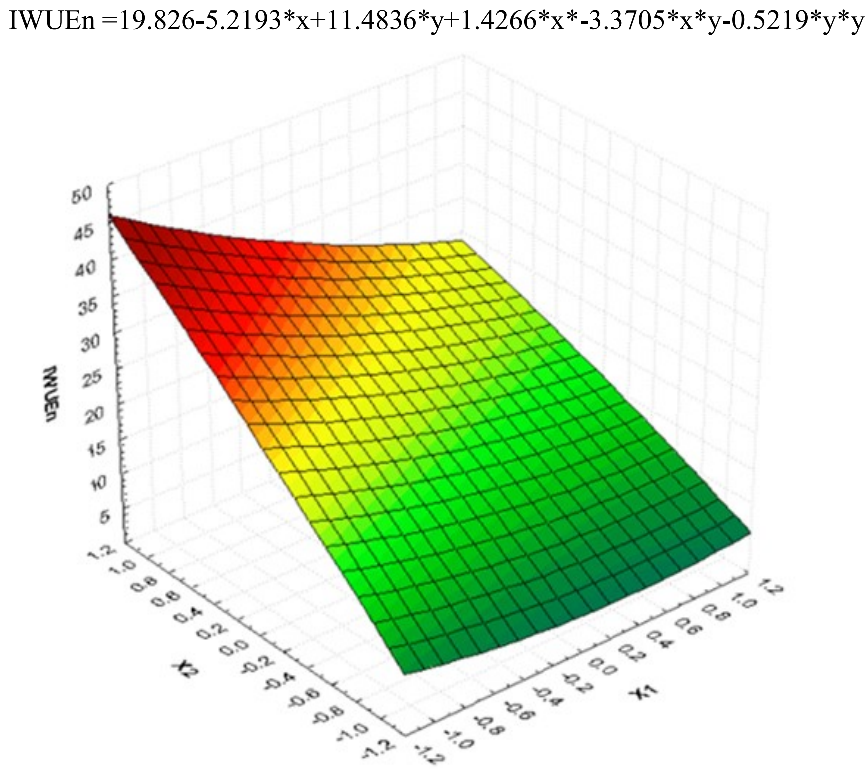

Fig. 4. Dependence of RIWUE on the irrigation depth (X1) and the fertilizer rate (X2)
IWUEn =19.826-5.2193*x+11.4836*y+1.4266*x*-3.3705*x*y-0.5219*y*y

It appears on Figure 4 that the maximum efficiency of the irrigation water is obtained by minimum irrigation depth and maximum fertilizer rate. Irrigation has less effect when the fertilization is less –when 50% of the full fertilization rate is applied. The results show that under conditions of water deficit under controlled conditions, can reduce irrigation norms to increase the productivity of irrigation water.

Generalized utility function

Table 7 shows that the major impact on utility function has the fertilizers rate. The optimization of the model shows that the function has a maximum value AUF_{max} = 0.743 at the maximum fertilization rate and the minimal irrigation depth. Further, it is seen on the graphical interpretation (Fig. 5) that the function that determines both maximum yields and maximum WUE has a maximum at the maximum fertilizer rate. Also, a value of AUF close to the maximum one can be obtained by applying the full (maximum) fertilizer rate and 60%-70% of the full irrigation depth. The irrigation depth has no effect on the yield in the range of the low fertilization rates.

Table 7. Results from the regression analysis for Average Utility Function (AUF)

N=36	Regression Summary for Dependent Variable: AUF R=0.90911355, R^2=0.82648744, Adjusted R^2=0.79756868 F(5.30)=43.504 p<.00000, Std.Error of estimate: 4.0365					
	Beta	Std.Err. of Beta	B	Std.Err. of B	t(30)	p-level
Intercept			0.377361	0.044474	8.48499	0.000000
X1	-0.091071	0.077130	-0.030116	0.025506	-1.18076	0.246977
X2	0.897525	0.076589	0.327699	0.027964	11.71869	0.000000
X1X2	-0.070728	0.077130	-0.031185	0.034008	-0.91700	0.366556
X1X1	0.017073	0.076051	0.009779	0.043560	0.22450	0.823891
X2X2	-0.022169	0.076589	-0.013410	0.046331	-0.28945	0.774230

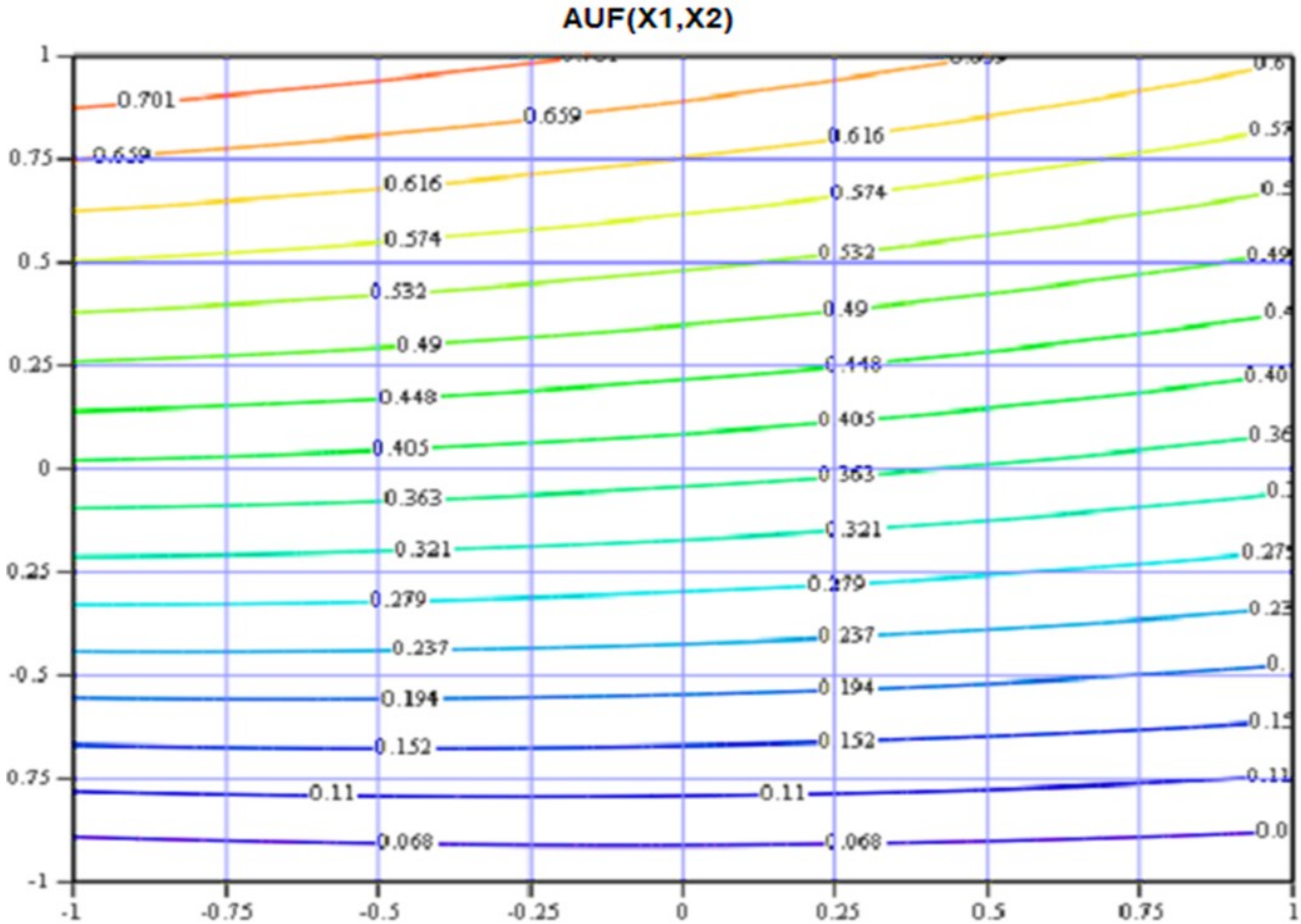

Fig. 5. Dependence of the average utility function on the irrigation depth (X1) and the fertilizer rate (X2)

Conclusions

The focus in this experiment is on the effect of a controlled water deficit achieved by reducing the irrigation depth at different levels of plant nutrition on the productivity of greenhouse tomatoes and water use efficiency. In studies interval of irrigation depth and fertilizer rate was found significantly stronger influence of the fertilizer rate on yield. The impact of irrigation on the yield is lower at the lower fertilizer levels. It has greater effect at the higher levels of the irrigation rate. Close to the maximum yield - over 100 Mg/ha can be obtained also by applying the maximum fertilization rate and 80% of the full irrigation depth. The greatest relative additional yield ($RAdY_n$) can be obtained by maximum irrigation depth and maximum fertilizer rate and irrigation has greater effect at maximum and close to it fertilization rates.

Maximum water use efficiency can be obtained by a minimum amount of irrigation water and maximum fertilization. Moreover, irrigation has small impact at lower fertilization rates (up to 50%), i.e. WUE is small. The analysis of the the utility function, which summarizes the conditions for obtaining maximum yield and maximum water use efficiency indicates that it maximum value can be obtained at maximum fertilizer rate and 60-70% of the full irrigation depth.

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