THE EFFICIENCY OF IRRIGATION AND VARIETY ON THE HARVEST RATIO OF THREE COTTON TYPES (*Gossypium hirsutum* L.)

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Abstract: The purpose of this research is to investigate the impact of variety and irrigation on three cotton types, and to study the effectiveness of irrigation on the productivity of these cotton types which were fed by different norms of mineral nutrition. To assess the impact of soil humidity and fertilizer amount, we set up a field trial with three varieties of cotton. The field experiment was carried out within the Faculty of Agriculture, Trakia University, Stara Zagora, Bulgaria between 2018-2019. A two way factorial ANOVA (with variety and irrigation as factors) suggested a significant main effect of irrigation ($p < .001$). Variety showed the strongest impact on the differences in "flowering" of cotton which were 64% in 2018 and 41% for 2019 respectively. We established an efficiency coefficient (KEF) representing the ratio of the additional harvest and the actual irrigation rate. The KEF of irrigation water varied depending on the cotton varieties and the levels of fertilization. The highest values of KEF were recorded after fertilization by N_8 as given by units of cultivar Helius ($EF = 0.67$). The effect of irrigation, expressed as a harvest per unit of irrigation water considerably varied over years. It was established as a ratio between the irrigation rate and the additional cotton produce. At zero fertilization Helius, each cubic meter of water carried an average 2.24 kilograms of cotton harvest over two years. Optimizing the water supply and fertilizing with N_{16} provided 2.83 kilograms. On average, the Darimi variety irrigation effect ranged from 0.63 kilograms (N_{24}) to 2.43 kilograms per cubic meter (N_{16}) during the given period.

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Introduction

Cotton (*Gossypium hirsutum* L.) is one of the most important industrial crop worldwide. Bulgaria forms the northern boundary of the production of this strategic plant culture. Nevertheless, in recent decades cotton has become a scarce culture due to high cultivation cost. This issue has been further impacted by a decline in the price of processed fiber and by a difficulty to obtain supplies such as fertilizers, chemicals and fuel. On contrary, in recent years the European Union has set higher support frameworks aiming to enhance the financial stability of the cotton industry (AR, 2017). Of the member states of Euro Zone, only Greece, Spain and Bulgaria have been deemed as having suitable climatic conditions.

Previous research demonstrated that temperature is a limiting factor impacting cotton growth. According to Milkovski et al. (1969) temperature of 0 degree Celsius provides optimal conditions for the growth and maturation of cotton. Varieties with short growing period which mature within 120 days and which are also suitable for cultivation in northern latitudes are typical for Bulgaria. Unfavorable culmination of average daily temperature, combined with precipitation deficiency reduced the productive potential of the cotton varieties (Dimitrova, 1995; Dragica et al., 2010; Earl & Jones, 2018; Stoilova & Bozhinov, 2004). The ecological plasticity of cotton has been tested outside the country and was considered as a prerequisite for the search of a selection of Bulgarian varieties. For example, experiments conducted in Syria (1995) tested a Bulgarian variety of cotton called Beli Izvor resulting in a record harvest of 5620 kg/ha, what was deemed as the highest among all tested varieties including American, Greek, Turkish, Spanish (Borero, 1996).

The productivity of cotton differs depending on humidity conditions during the growing season. Even under optimum temperature conditions, humidity presents another dominant factor. Previous research established, that the correlation coefficient between the yield and water supply in May to August 1969 was $r = .76$ (Milkovski et al., 1969). The rising cost of water irrigation and the reducing water resources forced farmers to adapt strategies of irrigation leading to maximum crop yield and efficiency of water use. The introduction of new and more drought-resistant cotton varieties as well as effective water management aimed to increase the efficiency of irrigation. Leaf index and dry matter harvest increased with escalated use of irrigation water as found in a field study by Dağdelen (2009). From an economic viewpoint, 25.0% of saving of irrigation water (T_{75}) resulted in 34.0% reduction in the net income. However, the net income of the T_{100} treatment was found to be reasonable in areas with no water shortage.

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Another body of research suggests that the parameters of irrigation water such as gravity and drip influenced irrigation efficiency (Ibraginmov et al., 2007). Optimizing the irrigation regime and using drip irrigation (70-70-60% of field capacity (FC) provided efficiency gains of 35-103% as compared to furrow irrigation. Cotton yield increased by 10-19% after supplying water to the root zone of the plant. The effects of water deficiency on quantitative parameters and on harvest quality have been also studied by a number of researchers (Cetin & Bilgel, 2002; Mahan & Payton, 2018; Onder et al., 2009; Saldzhiev & Raykov, 2011; Stoyanova & Kuneva, 2019; Wanjura et al., 2002; Wang et al., 2011). Accordingly, the low nitrogen (N) level in the solution drastically reduced vegetative growth components, number of bolls, seed cotton and fiber harvest (Malavolta et al., 2004). To this end, Aujla et al. (2005) concluded that reducing the water amount decreased the agronomic efficiency of N. Drip irrigation increased agronomic performance of imported N as compared to gravity irrigation. Moreover, according to Yang et al. (2012), single fertilization reduced labor costs without impacting the yield as reports in their field study conducted in the Yangtze River Valley in China.

Previous investigations also suggest, that the harvest of cotton transformed biomass (Bange & Milroy., 2004; Brodrick et al. 2013) which is an important component determining the cotton harvest success through its reproduction (Yang et al., 2011). Thus, the application of biologically active substances increased the resistance of the cotton plants to abiotic factors. Kerby et al. (1993) found that the application of biologically active substances during critical periods of phenological development optimized the balance between vegetative and generative growth. Growth regulators stimulated physiological processes in plants and formed a larger leaf-stem mass (Delchev, 2003). The structural elements yield determined factors such as the rate of fertilization, seeding density and variety, the degree of weeding and soil preparation. Each of these elements of agrotechnics was investigated by a number of researchers (Koleva & Petrova, 2014; Barakova et al., 2018; Barakova et al., 2019). For instance, Zhao et al. (2010) found a significant correlation between root length density and cotton yield during the flowering stage and bud opening. Trends in the effects of drought on the crops were analyzed by various models predicting the yield of the crop (Wang et al., 2011; Popova et al., 2014; Yang et al., 2015; Dochin et al., 2018; Kostadinov et al., 2019).

Based on the above discussed limitations of previous research, the purpose of this study is to analyze the impact of specific factors of variety and irrigation on cotton yield, and to study the effectiveness of irrigation on the productivity of cotton varieties after adding various amounts of mineral nutrition.

Materials and Methods

To assess the impact of humidity of soil and fertilizer norm, we conducted a field trial with three varieties of cotton. The field experiment was conducted in within the Faculty of Agriculture, Trakia University, Stara Zagora, Bulgaria in 2018-2019. The region had a planar nature with an elevation height of 169 m. The geographic coordinates were as following; 42 ° and 41' north latitude and 23 ° and 19' east longitude GMT (GPS). The experimental field was located in a zone of moderate continental climate of Europe. Data on the climate elements was collected from the National Institute for Meteorology and Hydrology.

The experiment was set up with the following varieties of cotton: Helius, Darmi and Isabell. These varieties are a Bulgarian selection cultivated between 2007-2010. The short vegetation period is characteristic for Bulgarian selection varieties. Helius is characterized by a high yield of unprocessed cotton and produce of fiber and its vegetation period is 131 days. In the Darmi variety, the harvest ratio is about 39.5%. The vegetation period is 116-122 days. The fiber is white medium-fine, with good uniformity, maturity and has a good strength. The Isabell variety launched a new generation of varieties with naturally colored fiber with a high ecological and economic effect. The first variety is characterized by a brown fiber and a high yield (37-38%). Isabell has a naturally colored tan to cream line, which is short, medium-fine, with good uniformity and extensibility. The vegetation period of this early variety is 109 - 111 days.

The study was conducted on a meadow-cinnamic soil type under irrigated and non-irrigated conditions. The power of the soil profile was 103-105 cm, with well formed layers. The humus layer depth ranged between 0-45 (50) cm, while layer B had less power. The soil layer C reached a depth of 103-105 cm. The mechanical composition of the soil was given by a medium sandy loam. The soil density (as measured by the method of Kaczynski) of the surface layer was 1.07 g/m³ and reached 1.34

g/m³ in the 60-80 cm deep layer. The relative density (given by the pycnometric method) ranged from 2.65 to 2.72. The marginal field moisture capacity in layers 0-40 cm was 31.6%. The average stock of humus in the soil was 3.42% - 4.04%.

The field experience was based on the method of fractional plots in 4 repetitions with the size of the plots being 15m² (1.80m x 8.34m). The value of irrigation drip was 75% FC in soil layers between 0-50 cm. In the control condition, each cotton variety was left without fertilization and watering. The norms of fertilization and irrigation levels were defined based on previous studies and literary data (Gospodinova et L., 2019.).

To report the occurrence and course of the main phenological phases of cotton growth, we translated biometric measurements and phenological observations during the experiment. The data was statistically processed by MS Excel. The evaluation of the influence power of factors was calculated on Plohinski (Lakin, 1980). It was defined as part of inter-group variation in total variation of the sum of the squares and was calculated as follows:

$$h_x^2 = \frac{D_x}{D_y},$$

where D_x - was the sum of the squares of the x factor, D_y - presented the total sum of squares (SS). We sought to establish the main effects of both factors (variety and irrigation), as well as their interaction on the yield of the three varieties of cotton.

Results and Discussions

Agro-climatic conditions

The climatic conditions during the vegetation of cotton were specific and differed during the two years both in terms of temperature, quantity and distribution of rainfall. Particularly vulnerable were plants grown under conditions of natural water supply. In the formation of cotton harvest, heat and humidity were an important factor for flowering-start and ripening of harvest which occurred during the months of July to August.

Table 1. Climatic characteristics of the study period				
Factor		Average for the period 1930-2019	2018	2019
N	mm	Average (V-X) 299.74 mm	347.4	274.2
	P %	299.74 mm	29.5	51.7
T°	°C	Average (V-X) 1178.0 °C	1245.0	1246.0
	P %		90.4	91.5
N	mm	Average (VI-VIII) 156.85 mm	187.4	171.8
	P %		72.7	68.3
T°	°C	Average (VI-VIII) 681.7 °C	713.0	724.0
	P %		79.3	87.1
Source: Authors				

To determine the probability (P), we used data on precipitation and average daily temperatures from the past 90 years and calculated the provision according to the following formula:

$$P = \left(\frac{n-0.3}{m+0.4} \right) * 100,$$

where m is the number of the year in the upstream row, and n is the total number of years in the series. The analysis revealed that cotton grew in conditions with limited resources and unsustainable temperature and moisture. Temperature was crucial for the development and maturation of cotton. The growth and yield of cotton (*Gossypium hirsutum* L.) were highly inhibited by low temperatures, especially in stages of germination and bud emergence, according to studies by Ashraf (2002). Jakimov et al. (2013) also established the adverse impact of lower temperatures on the cultivation of cotton. In the period from June to September, both years in the experiment were characterized by higher than average temperature 1178.0 °C (values present the average diurnal) with a security of 90.4 and 91.5 % in terms of factors of heat. During the two years, we did not measure extremely high temperatures which can damage the development of plants. The increase in temperature leading to a

decrease in yield had been established by Rishi et al. (2007). Specifically, photosynthetic apparatus studies (Wise et al., 2004) showed that moderately high temperatures (35-42 °C) can cause direct injury to the crops of Pima cotton (*Gossypium barbadense*) grown under irrigation in the US desert south-west.

Although cotton is a fairly drought tolerant culture, our results showed a responsiveness to optimizing the factors of water. Therefore the analyzes are separated and we focused on the amount and distribution of rainfall. During the period from May to October of the first year, the sufficiency of rainfall was 29.5% what can be defined as medium wet. With 51.7% probability of rainfall, the second test year was characterized as medium dry. The amount of rainfall during the first experimental year during the months of great tension of climatic factors from July to August was 102.2 mm.

The total amount of rainfall registered in 2019 was 63.1 mm. An uneven distribution of rainfall within ten-day periods was typical for both testing years. In line with the results of a field study, in the second experimental year, the water deficit impacted the moisture phenophase critical for the start of flower-maturing. This adversely affected the generative development and productivity of cotton, despite the plant is characterized as a relatively drought resistant crop. The relationship between the total amount of rain and its effectiveness is complex and it depends on the amount and timing of rainfall relative to the crop. Mahan & Payton (2018) established a relationship between rain and harvest ratio as relatively weak with an $r^2 = .35$. The efficient use of rainfall continues to be examined especially in areas with unstable moisturizing.

The results of the two-factor analysis of variance (ANOVA) are presented in tables 2 and 3 displaying the proportion of cotton flowering of three varieties (A) under different irrigation (B) schedules during 2018 and 2019.

Table 2. Two-factor dispersion analysis of the factors: A - variety and B - irrigation for cotton flowering under irrigation conditions in 2018.							
Source of variation	SS	df	MS	F	P-value	F crit	Power of influence
Variety (A) n.s.	48864.13	2	24432.06	4.90	.02	3.40	9%
Irrigation (B)***	358197.7	3	119399.23	23.95	.00	3.01	64%
Interaction (AxB) n.s.	45454.38	6	7575.73	1.52	.21	2.51	8%
Errors	119643.5	24	4985.15				19%
***, **, * – significant at $p \leq 0.001$, $p \leq 0.01$ and $p \leq 0.05$; n.s. – Insignificant							
Source: Authors							

Table 3. Two-factor dispersion analysis of the factors: A - variety and B - irrigation for cotton flowering under irrigation conditions in 2019.							
Source of variation	SS	Df	MS	F	P-value	F crit	Power of influence
Variety (A) n.s.	120559.06	2	60279.53	3.53	.04	3.40	12%
Irrigation (B)***	411138.75	3	137046.25	8.03	.00	3.01	41%
Interaction (AxB) n.s.	55650.50	6	9275.08	0.54	.77	2.51	6%
Errors	409653.33	24	17068.89				41%
***, **, * – significant at $p \leq 0.001$, $p \leq 0.01$ and $p \leq 0.05$; n.s. – Insignificant							
Source: Authors							

There was a main effect of "irrigation", $F(2, 24) = 23.95$, $p < .001$ followed by the main effect of "variety" $F(2, 24) = 4.90$, $p = .016$. The interaction between the two factors was not significant (Table. 2). In 2019 the highest "flowering" indicator (Table 3) by a main effect of irrigation ($F(2, 24) = 8.03$, $p < .001$). Secondly, the main effect of variety and the interaction of the two factors remained insignificant. These results suggest that while irrigation is an important factor impacting the cotton the "flowering" indicator, the role of variety and the interaction between irrigation and variety remains less pronounced.

Cotton productivity and irrigation efficiency

As a result of the manifestation of specific climatic conditions during the two years, the corresponding yields were obtained in accordance with the methodology and the irrigation standards implemented. The data presented in Table 4 shows the obtained produce and irrigation parameters implemented to the studied cotton varieties. During the first year of testing, high yields were determined by the

influence of natural water supply. Better humidification in 2018 provided a 27.4% higher helius harvest on average as compared to 2019, which was characterized by average dryness. This trend was also confirmed by Aujla et al. (2005). During 2018 considered as a humid year, the amount of rainfall between flowering and betting of the buds provided enough accessible moisture. The watering and higher fertilisation background created good conditions for the formation of a large vegetative mass. Additional harvest was only obtained for the Helius Zero Fertilizer variant. The Darmi variety formed an additional harvest of 111.7 to 133.4 kg/ha in fertilization with N_0 and N_{16} . However, other researchers concluded that the optimum rate of N for the maximum accumulation of the cotton biomass and forming the yield is differs from the potential yield (Boquet, 2005; Yang et al., 2011).

The color dyed variety Isabell was responsive to irrigation and formed a further extraction at three levels of fertilization (N_0 ; 8; 16). With the high dose of N and under the influence of the given irrigations, it developed a greater vegetative mass. Particular buds remained unhatched and as a result, it reduced the productivity of cotton. The coefficient of performance is the ratio between the additional yield and the actual irrigation rate. Efficiency values varied widely across the three varieties, depending on water supply and fertilizer levels. The achieved irrigation rate during the year with better water supply did not lead to increased yield in any of the cotton variants. Cetin & Bilgel (2002) also found that watering resulted in a lower overall cotton harvest. Accordingly, Earl & Jones (2018) developed a model to optimize irrigation in years with sufficient rainfall. The 'Isabell' variety was responsive to the supplied irrigation water of 300 mm across two irrigations. At fertilization levels from N_0 to N_{16} and under the influence of the additionally supplied irrigation water, an additional yield was obtained, with an efficiency coefficient of 0.19-1.04.

Table 4. Irrigation parameters, productivity and the effect of irrigation on three cotton varieties, for the period 2018-2019, for the Stara Zagora						
Variant		Variety	Irrigation norm	Yield	Additional yield	Efficiency factor (EF)
№	Fertilization rate		mm	kg/ha	kg/ha	
2018						
1	N ₀	Helios	300	1541.8	133.5	0.45
2	N ₈		300	1496.7	-625.0	-2.08
3	N ₁₆		300	1745.1	-653.4	-2.18
4	N ₂₄		300	153.4	-458.3	-1.53
5	N ₀	Darmi	300	1891.8	133.4	0.44
6	N ₈		300	1996.7	-65.0	-0.22
7	N ₁₆		300	2220.1	111.7	0.37
8	N ₂₄		300	1965.1	-318.4	-1.06
9	N ₀	Isabell	300	1790.1	313.4	1.04
10	N ₈		300	2171.8	265.0	0.88
11	N ₁₆		300	1901.7	56.7	0.19
12	N ₂₄		300	1795.1	-224.8	-0.75
2019						
1	N ₀	Helios	600	1668.7	267.9	0.45
2	N ₈		600	1870.0	400.8	0.67
3	N ₁₆		600	1817.0	212.3	0.35
4	N ₂₄		600	1758.9	320.4	0.53
5	N ₀	Darmi	600	1793.0	277.3	0.46
6	N ₈		600	1590.4	200.9	0.33
7	N ₁₆		600	1954.6	276.1	0.46
8	N ₂₄		600	1828.9	272.2	0.45
9	N ₀	Isabell	600	1597.6	146.8	0.24
10	N ₈		600	1892.6	347.7	0.58
11	N ₁₆		600	1869.4	320.4	0.53
12	N ₂₄		600	1765.2	266.2	0.44
Source: Authors						

The additional harvest ratio obtained during the second experimental year was higher. The applied irrigation rate (600 mm) reduced the negative effect of water shortage on the plant biomass growth and flower staining. The overall impact of fertilization and irrigation during the dry year of 2019 provided

higher additional yield. These results were also supported by Dağdelen (2009). The efficiency ratio was significantly higher than during the first year. The optimization of provided humidification and the stable temperature factor resulted in an additional harvest of 146.8 kg/ha to 400.8 kg/ha. After importing N₈ to the Helius and Isabell cotton varieties, they provided the highest additional yield. The efficiency of irrigation water was 0.67 for Helius and 0.58 for Isabel. The Darmi variety results at different fertilization levels were set at narrow limits and the coefficient of efficiency varied from 0.33 to 0.46.

Furthermore, the results showed a heterogeneous manifestation of the water factor in each variety. The efficiency of the use of irrigation water depended on the climatic factors. The recorded additional harvest ratio in after natural water supply reduced the effect of irrigation water. Investigating the optimization of the water amount used on the cotton varieties enabled to precisely establish the effect of irrigation water. Accordingly, the parameters of the irrigation water (AIW) for cotton (*Gossypium hirsutum* L.) in context of the climate circumstances were also established by García-Vila et al. (2009). The effect of irrigation, expressed as a harvest ratio per unit of irrigation water varied greatly over the years. At zero fertilization Helius, each cubic meter of water carried 2.24 kilograms of cotton, averaged over the two years. Over the year with unfavourable climatic factors, the fertilization with N₁₆ for each cubic meter of water carried 2.83 kg of cotton. The effect of irrigation water on Darmi variety was relatively uniform when providing a sufficient quantity of readily available water. Artificially brought water supplied in the form of 4 irrigations resulted in collecting 2.16 to 2.20 kilograms of cotton per cubic meter. Against the background of fertilization with N fertilizer at a dose of N₈, each cubic meter irrigation water brought 2.99 kg of cotton. The average harvest for the period of irrigation of Darmi ranged from 0.63 (N₂₄) to 2.43 (N₁₆) kilograms per cubic meter. The high additional harvest in 2018 considered as a wet year, did not contribute to the effect of irrigation. The highest irrigation water use efficiency was obtained with reduced ½ irrigation rate (Onder et al., 2009). The Dye Isabell cotton type was characterized by varying influence of irrigation water under different levels of fertilization. The highest average effect of irrigation during the given period was registered following fertilization by N₁₆.

Conclusions

According to the two-factor ANOVA, with sorting and irrigation as factors, we detected highly significant effects ($p < .001$), with irrigation showing the greatest influence on the yield. Furthermore, the strongest influence on the differences in cotton "flowering" were given by cotton variety (64%) in 2018, followed by this factor (41%) for 2019. The natural water supply in the first trial year provided high additional harvest rate. The values of the additional produce in the second trial year were higher. In all three cotton varieties, optimizing water supply provided an increase in additional yield at times.

The coefficient of efficiency of irrigation water varied depending on the varieties and the levels of fertilization. The highest values of the ratio were recorded at fertilization to N₈ in cultivar Helius, (EF = 0.67) and in Isabelle is calculated (EF = 0.58). The effect of irrigation, expressed as yield per unit of irrigation water varied greatly over the years. Optimizing the water supply and fertilizing with N₁₆ provided 2.83 kilograms per cube. The different influence of irrigation water on different fertilization levels was reported for the Isabell cotton variety. On average, the highest irrigation effect was registered after using the N₁₆ fertilization variant.

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