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ASSESSMENT OF YIELD AND WATER USE EFFICIENCY OF DRIP-IRRIGATED COTTON (*Gossypium hirsutum* L.)

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Abstract

Climate change raises the question of demand for more economical ways to use irrigation water. Against the background of different levels of fertilization, cotton varieties have been tested. The experiment was performed under irrigated and non-irrigated conditions. The experiment was performed in the experimental field of the Trakia University, Stara Zagora during the period 2018-2020. Cotton productivity has been established under non-irrigated and irrigated conditions. The analysis of the results shows that the naturally colored variety Isabel, when realizing irrigations, on average for the period forms a yield 39.9% higher than the non-irrigated one. Under irrigated conditions, the Darmi variety increased productivity by 34.3%. An increase of 27.9% was registered for the Helios variety. The Isabel variety has the highest values of the irrigation water efficiency coefficient (0.88-1.11). Against the background of different levels of fertilization, the Darmi variety forms an efficiency coefficient from 0.9 to 1.03. Helios variety is responsive to irrigation, but on average for the three-year period stands out with the lowest values of efficient use of water resources (0.53 - 0.95).

Key words: *cotton, fertilizing, irrigation, productivity, efficiency.*

INTRODUCTION

Negative consequences of global climate change affect crop development in the following two aspects: reduced yields and deterioration of product quality due to lack of soil moisture during the growing season and reduced rainfall, a sharp decline in water resources, accumulation of water, small volumes of water in the dams in annual and perennial aspect, limiting the possibilities for using the water for irrigation. Climate change raises the question of demand for more economical ways to use irrigation water. One of the areas where new or updated technologies and policies can have a significant impact on more efficient use of water resources is crop irrigation (Ziad et al., 2010; Moteva et al., 2016; Kireva et al., 2018; Gospodinova et al., 2020).

Irrigation is an effective means of limiting or preventing the stressful effects of drought on crops. Determining the parameters of growth and development of generative organs under irrigated conditions is crucial, according to Hameed et al. (2017). Results indicated that inter culturing + chiseling produced the highest significant seed cotton production (17.8%) more bolls plant-1 (14.3%) and water intake (17.7%) than no chiseling with inter culturing. However, irrigation interval after eight days produced the maximum yield of seed cotton (14.2%), more 14.3%bolls plant-1and water retention (35.6%) than 12 days irrigation interval. Water stress reduces leaf area, dry matter accumulation, number of knots, number of boxes, and reduce fiber length (Pettigrew, 2004; Mert, 2005). Pettigrew (2004) also reported that varieties produce additional boxes at higher nodes in response to additional irrigation, leading to higher overall yields.

The effect of drip irrigation on fiber yield and quality has been studied by a number of authors. Tracing the water resource in the soil profile in the 0-30 cm layer Ibraginmov et al. (2007) recommend an optimal regime for drip irrigation (70–70–60% of FC) for each of the three main plant growth periods (germination - budding; budding - flowering; onset of ripening - ripening). Seed-lint cotton yield was increased 10-19% relative to that for furrow irrigated cotton. The irrigation scheduling rule developed here should be considered an improved practice for drip irrigated cotton that is applicable to irrigated Calcic Xerosols of Uzbekistan.

Papastylianou et al. (2014) registered a decrease in the leaf area index. The length of the fiber is also shortened in response to water stress, while the index of strength, fineness and uniformity of the fibers are not affected by irrigation levels.

Basal et all. (2009) find that irrigation of cotton with a drip irrigation method at 75% level had significant benefits in terms of saved irrigation water without reducing yield, and high WUE indicated a definitive advantage of employing deficit irrigation under limited water supply conditions.

Increasing irrigation costs and reducing water resources are forcing producers to adapt irrigation strategies to maximize crop yields and increase water efficiency.

The advantage of drip irrigation was pointed out by a team of scientists from India after three years of experiments (Ramamurthy et al. 2009). Irrigation scheduling in hybrid cotton throughdrip based on 0.6 evapotranspiration enhanced seed cotton yield by 37% over broad bed furrow and 72% over thefarmer's practice. The water-use efficiency with drip-irrigated cotton was 28-58% higher than broad bed furrow and 45-68% higher than the flood method of irrigation.

Soil fertility is a prerequisite for achieving high and quality yields. Jayakumar et al. (2015) established the effectiveness of cotton fertilizers in drip irrigation with different irrigation rates. It is recommended that drip fertigation of inorganic fertilizers in combination with biofertigation be used as a viable technique to realize the yield potential of cotton and sustenance of soil fertility.

The reduction in water available for cotton production is forcing researchers to focus on increasing water efficiency by introducing new varieties of drought-resistant cotton or water management. New irrigation technologies are being developed, suitable for limited water supply, as well as for specific topographic and soil conditions. O'Shaughnessy et al. (2010) created algorithms for automatic cotton irrigation.

In a market economy, the efficient use of water is associated with the optimization of mineral nutrition, labor and energy. Optimization of irrigation water, analysis of the impact of sufficient available moisture on productivity and product quality, determining the efficiency of water resources is embedded in the developments of many researchers (Matev et al., 2014, Matev et al., 2018; Kuneva et al., 2015; Earl et al., 2018).

The main goal in the present study is: to study the productivity of three varieties of cotton under non-irrigated and irrigated conditions; establishing the effect of irrigation.

MATERIALS AND METHODS

The experiment was performed in the experimental field of the Trakia University, Stara Zagora, which is located in the region of Eastern Central Bulgaria, covering the Thracian lowland, located at 42°41'51.75" north latitude, 23°19'18.722" east longitude and 169m above sea level. According to the climatic zoning, the region falls within the European-continental area and the Transitional-Continental sub-area from it.

The three-year field experiment was performed with three varieties of cotton. Against the background of different levels of fertilization were tested varieties Bulgarian selection (2007-2010) - Helius, Darmi and Isabell. Isabell is characterized by a naturally colored light brown to creamy fiber that is short, medium fine, with good uniformity and extensibility. The vegetation period of this early variety is 109 - 111 days. In Helios and Darmi the vegetation period is on average 131 days, respectively, and in Darmi it varies in the range of 116 to 122 days.

The experiment was performed under irrigated and non-irrigated conditions. The experiment was set by the method of fractional plots in 4 replications, with a plot size of 15m^2 (1.80 x 8.34m) in the period 2018/2020. The soil type is typically meadow-cinnamon soil with a clearly formed humus horizon of 0 to 45 (50) cm. The maximum field moisture content in the layer 0 - 40 cm is 31.6%. The soil is on average stocked with humus - 3.42% - 4.04%. The supply of irrigation water is realized with a drip irrigation system at 75% FC in the layer 0-50cm.

The main fertilization was done with triple superphosphate in normal P8 in the fall. Nitrogen fertilization was performed once before sowing with nitrogen fertilizer (NH_4NO_3). Four levels of fertilizer rate were tested ($N_{0,8,16,24}$). Herbicide treatments and double hoeing of the crop were carried out. The beginning of the harvest begins in September, after cracking of 50-60% of the boxes.

RESULTS AND DISCUSSIONS

Climatic characteristics

In terms of climate, Bulgaria belongs to the zone of unstable humidification, in case of drought in July-August due to which obtaining high and stable yields of cotton are impossible without irrigation. On the other hand, the limited temperature resources set specific requirements and features of cotton irrigation in our country in order to achieve high profitability with a relatively good early maturity.

The air temperature in the soil of the experimental field is not characterized by significant differences in the values measured for the period 2006-2020 (Figure 1). The fluctuations are larger in the first and third experimental years.

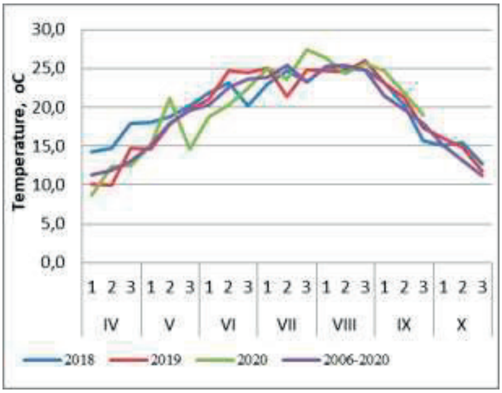

Figure 1. Temperature conditions in the area of the town of St. Zagora during the cotton vegetation for the research period and the period, 2018-2020

In 2018, sowing and the beginning of the vegetation took place at higher than normal temperatures. The average monthly temperatures for April and May exceed by 3.68 and 1.94ºC, respectively, the annual norm set for a period of 90 years. During this year, the vegetation of cotton took place during prolonged summer drought and higher temperatures. In June, July and August the total amount of precipitation was 187.2 mm, with only 27 mm of precipitation recorded in August.

The vegetation period of cotton in 2019 passed under relatively favorable humidity and temperature conditions. The measured average monthly temperatures show an excess for all months compared to the average values, the most significant differences being in May (+1.94°C), June (+ 2.27°C), August (+1.83°C) and September. (+1.53°C). In 2019, the peak of the fallen rainfall was established in June by 108.7 mm. In August, the amount of precipitation was only 11.2 mm, which at high temperatures led to dripping of some of the knots and reduced yields.

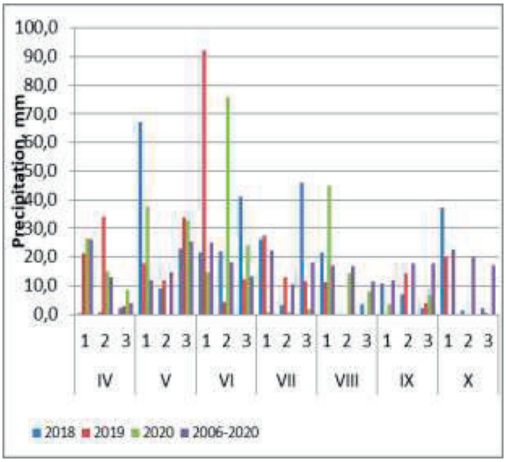

Figure 2. Dynamics of precipitation during the experiment period 2018-2020 in the region of Stara Zagora

In the third year the temperature sum from May to September is 3375ºC, which is only 3ºC less than in 2019 and 3ºC more than in 2018. The high temperatures had an adverse effect in July (average monthly temperature 25.5ºC at 23.7 and 23.8ºC for 2018 and 2019) and the lack of precipitation, which caused heavy dripping of buds and flowers. The year is characterized as the driest for the study period. A peak of 114.5mm was registered in June, which is the highest amount of precipitation per month during the considered three-year period. Figure 2 shows the uneven distribution of precipitation during the growing season.

The influence of climatic factors on the growth and development of crops is expressed in coefficients.

The hydrothermal coefficient (according to Selyaninov) is established by the formula:

$$HTK = P*10/\sum To ,$$

The humidity coefficient of Ivanov (1941) is determined by the following dependence:

$$E = 0,0018*(t + 25)2*(100-a),$$

When calculating the humidity coefficient and the moisture balance coefficient, the active temperature sums (ºC), relative humidity (%), the sum of precipitation (mm) were used.

Table 1. Coefficients characterizing the humidity during the period 2018-2020

Years	Months																	
	IV			V			VI			VII			VIII			IX		
	I	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Humidity coefficient of Ivanov																		
2018	1,14	0,91	1,36	1,00	1,07	1,40	1,23	1,59	1,14	1,37	1,87	1,01	1,86	2,21	2,01	1,79	1,33	1,25
2019	0,69	0,64	1,19	1,02	0,99	1,26	1,10	1,73	1,72	1,94	1,43	1,74	1,87	2,30	2,57	2,00	2,08	1,10
2020	0,86	0,98	1,06	1,01	1,42	0,90	1,11	0,89	1,42	1,98	2,17	3,55	2,57	1,97	2,12	2,31	1,98	1,36
Hydrothermal coefficient (HTC)																		
2018	0,01	0,04	0,12	3,71	0,48	1,14	0,99	0,95	2,03	1,13	0,13	1,97	0,86	0,00	0,14	0,46	0,35	0,13
2019	2,09	3,41	0,18	1,22	0,67	1,71	4,39	0,17	0,50	1,10	0,60	0,46	0,45	0,00	0,00	0,00	0,67	0,23
2020	3,06	1,22	0,66	2,49	0,00	2,24	0,78	3,73	1,07	0,03	0,03	0,06	1,70	0,59	0,32	0,14	0,00	0,36

According to Selyaninov's HTC, it is accepted that at values of the coefficient lower than 0.5, drought is reported, and at HTC> 2.0, overwetting is observed. HTC according to Selyaninov for the three economic years is calculated only for the period with a biological minimum of 10 °C, ie. for the months of April-September.

Ivanov's coefficient is more accurate, because the average daily temperature, the amount of precipitation and the relative humidity of the air are involved in determining the values of the coefficients. The empirical formula for calculating the evaporation of Ivanov shows the degree of moisture in ten days for the period during which the plants need a sufficient amount of moisture in the soil. In the last ten days of July, the humidity in the first year is 70% lower than in the second. The water deficit during these periods requires irrigation to increase the water supply in the soil.

The climatic conditions during the cotton growing season are specific and differ during the three years, both in terms of temperature and in terms of the amount and distribution of precipitation. Particularly vulnerable are plants grown in conditions of natural moisture. In the formation of cotton yields, the temperature sums during the vegetation and the moisture during the flowering-beginning of ripening period, which takes place during the months of July-August, are of great importance.

To determine the security (P) in the present study, data on the amount of precipitation and the sum of the average daily temperatures for a 91-year period were used. Collateral calculation was performed according to the following formula:

$$P = ((n-0,3)/(m+0,4))*100,$$ where

m is the consecutive number of the year in the ascending series, and n is the total number of years in the series.

Depending on its security, the years can be in terms of precipitation: wet years - at P <15%, medium wet - at P <25%, average years at P =

50% and in the range between 25 and 75%, medium dry at - P> 75%, dry years at P> 90%.
The statistical evaluation of the experimental years in terms of the temperature sum was made for the period for the period May-October (Table 1). The analysis shows that for the 90-year series of data (from 1930 to 2020) the three years are characterized as warm, with security of 10.6%, 9.5%, respectively, and the last year is the warmest with security 5.1%. Temperature is crucial for the development and maturation of cotton. During the vegetation period and during the three years no extremely high temperatures were measured, which would damage the development of the plants.
The analysis shows that the cotton is grown in conditions of optimal temperature resources and unstable moisture. Although cotton is a relatively drought-resistant crop, the results show its responsiveness in optimizing the water factor. In order to assess the water supply of plants, it is necessary to know not only the total value of precipitation during the cotton growing season, but also their distribution throughout the period.
The provision with precipitation for the period May-October in the first year is 29.2%, which defines the period as average, but with values close to moderately humid. With 42.3% and 52.2% security, the second and third experimental years are characterized as average in terms of the growing season. For the period characterized by higher average daily temperatures in June-August, the provision with precipitation in the first year characterizes the period with values close to moderately humid (27.0%). Regardless of the registered precipitation in the second year of the field survey, the period is characterized by an average coverage of precipitation (31.4%). The lower amount of precipitation in the third experimental year defines it as average in terms of rainfall (50.0%). The uneven distribution of precipitation determines the need for irrigation for soil moisture supply.

Cotton productivity

The productivity of the three varieties of cotton, under natural moisture supply and irrigation, is presented in Figures 3 and 4. The different stresses of the meteorological conditions predetermine the higher productivity in the first year of the Polish experiment.

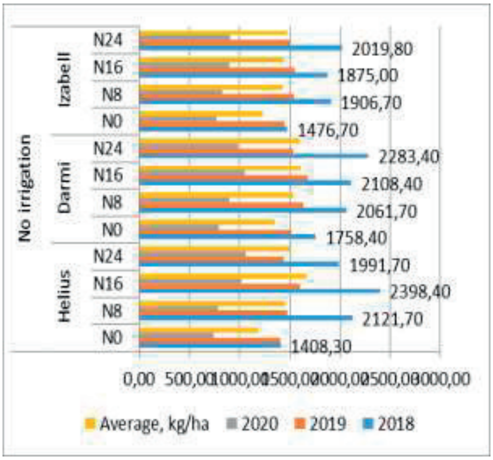

Figure 3. Productivity of cotton under non-irrigated conditions, kg/ha

With natural moisture content, the three varieties of cotton form a high yield. In Helios, the average yield for 2018 of the four levels of fertilization is 20.3% higher than that obtained under irrigated conditions.

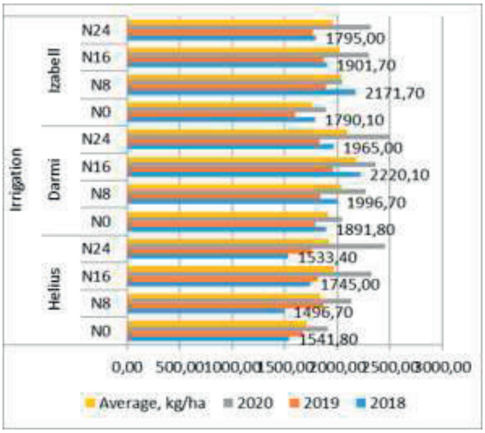

Figure 4. Productivity of cotton under irrigated conditions, kg/ha

Darmi achieved a higher yield by 1.7% compared to irrigated cotton, on average for fertilization levels. Only naturally colored Isabelle increases irrigation productivity by 5.7%. Therefore, it is necessary to analyze the effect of the supplied irrigation water.

Table 3. Irrigation parameters, productivity and the effect of irrigation on three cotton varieties, for the period 2018-2020, for the Stara Zagora

Variants		Yield without irrigation (Yn)	Yield by irrigation (Yir)	Irrigation norm (M)	Additional yield (Yad)	Efficiency factor (EF)
Variety	Fertilization rate	kg/ha	kg/ha	mm	kg/ha	
Helios	N_0	1185,30	1707,30	550,00	522,00	0,95
	N_8	1459,30	1833,20	550,00	373,90	0,68
	N_{16}	1672,70	1963,00	550,00	290,30	0,53
	N_{24}	1497,80	1915,10	550,00	417,30	0,76
	Average	*1453,80*	*1859,40*	*550,00*	*405,60*	*0,74*
Darmi	N_0	1355,60	1908,60	550,00	553,00	1,01
	N_8	1533,70	2035,50	550,00	501,80	0,91
	N_{16}	1613,50	2179,10	550,00	565,60	1,03
	N_{24}	1601,10	2094,70	550,00	493,60	0,90
	Average	*1526,00*	*2054,50*	*550,00*	*528,50*	*0,96*
Izabell	N_0	1231,3	1760,2	550,00	528,90	0,96
	N_8	1427,6	2037,4	550,00	609,80	1,11
	N_{16}	1440,8	2023,5	550,00	582,70	1,06
	N_{24}	1474,4	1959,6	550,00	485,20	0,88
	Average	*1391*	*1945,2*	*550,00*	*554,20*	*1,01*
		1456,9	1953	550,00	496,10	0,90

Unproductive water consumption is particularly worrying against the background of reduced water resources. Over the next two years, yields are higher under irrigated conditions. In the last year, the optimization of soil moisture has contributed to increased productivity at Helius by 144.3%, Darmi by 145.7%, Isabelle by 156.4%, on average for the four levels of fertilization.

On average for the three-year period, characterized by different security of the climatic elements, an increase in productivity was registered at Helius by 27.9%, Darmi - by 34.3% and Isabel by 39.9%. Against the background of natural moisture and different levels of nutrients, Helius and Darmi have the highest average yield for three years in the N_{16} variant.

Isabelle is responsive to fertilization and the average yield of this variety is the highest at N_{24}. In conditions of optimizing the moisture in the soil horizon, a similar trend is reported for all three varieties. Not the highest fertilization rate guarantees high yields, and N16 has the highest productivity. The available moisture in the soil creates conditions for better absorption of the available nitrogen.

During the three years of the field experience, a different number of irrigations were realized, depending on the amount and distribution of the registered precipitation. In the first year, two irrigations were applied, in the second four, and in the fifth five irrigations were carried out to maintain optimal conditions in the soil horizon. Table 3 presents the results of irrigated and non-irrigated variants for the studied varieties.

The ratio between the additional yield and the irrigation rate gives us the efficiency coefficient. The parameters of the additional yield depend on the stress of the meteorological factors and on the levels of fertilization.

The table presents the average yields and the additional yield formed under the influence of irrigation. Helios forms 405.6 kg/ha of additional yield under the influence of the realized irrigations during the vegetation. Darmy and Isabella are more responsive to

irrigation, with 528.5 kg/ha and 554.2 kg/ha additional yield, on average for the varieties. Regarding the levels of nitrogen fertilization, against the background of optimization of the water resource at Helios, it was found that the lowest additional yield was registered when N16 was introduced. Nitrogen (N_{16}) imported from Darmi was most effectively utilized. Isabelle, when optimizing the water factor, formed an additional yield of 582.2 kg/ha and 609.8 kg/ha when fertilizing with N16 and N8, respectively.
The values of the efficiency coefficient vary from 0.53 to 1.11. On average for the period with the lowest EF, Helios stands out (0.74). Isabel is the variety that responds best to irrigation, with an EF of 1.01 on average for all levels of fertilization. The reduction of the unproductive costs of irrigation water depends on the analyzes of the productivity of irrigation water for each variety.

CONCLUSIONS

The following conclusions can be drawn from the field study:
Naturally colored variety Isabel, when watering, on average for the period forms a yield of 39.9% higher than non-irrigated. Under irrigated conditions, the Darmi variety increased productivity by 34.3%. An increase of 27.9% was registered for the Helios variety.
The Isabel variety has the highest values of the irrigation water efficiency coefficient (0.88-1.11). Against the background of different levels of fertilization, the Darmi variety forms an efficiency coefficient from 0.9 to 1.03. Helios variety is responsive to irrigation, but on average for the three-year period stands out with the lowest values of efficient use of water resources (0.53 - 0.95).

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