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IRRIGATION WATER PRODUCTIVITY UNDER DRIP IRRIGATION OF TWO CORN HYBRIDS

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Abstract

A field experiment with two maize hybrids was conducted to analyze the influence of irrigation and feeding, with nutrients, on productivity, irrigation efficiency and irrigation water productivity. The experiment was conducted under non-irrigated and irrigated conditions. The object of the research are two maize hybrids: Premeo and Knezha-461. Optimizing the irrigation regime provides an increase in corn yields for grain by 237.1% in Premeo and by 233.1% in Knezha-461 compared to the non-irrigated option. Optimizing the irrigation and nutrition regime leads to an increase in productivity by 340.8% in Premeo, and in Knezha-461 by 313.5%. The corn hybrid Premeo 11.4 kg/mm stands out with the highest irrigation water productivity, followed Knezha-461 with 10.3 kg/mm, average for the study period. A trend towards an increase in the productivity of irrigation water with an increase in the productivity of the maize hybrids was found. It was established that the Premeo corn hybrid has a higher effect per 100 m^3 of irrigation water, on average for all variants - 722.2 kg/ha, while for Knezha-461 the effect is 656.1 kg/ha.

Key words: *corn, irrigation, fertilization, yield, productivity.*

INTRODUCTION

Maize is an important grain forage and food crop. The market in recent decades has offered a wide variety of hybrid varieties of corn. The correct selection of suitable hybrids depends on ecological plasticity, resistance to pest attacks, etc. It is necessary to take into account the agroclimatic resources of the area, such as temperatures (sum of the effective temperatures), precipitation (amount and distribution of the fallen precipitation), stocking of the soil with macro and micro elements, etc. in the cultivation of hybrids of corn.

This requires producers to know their qualities well and the agro-meteorological conditions in the area where they will be grown. Factors that affect productivity, such as climate change, diminishing natural resources, and others, lead to a reduction in the productivity potential of crops (Lobell et al., 2008; Batisti et al., 2009; Tsenov et al., 2009; Easterling, 2011; Sevov, 2013; Nelson et al., 2014). The uneven moistening and the increase in air temperatures bring to the fore the question of the nature of the relationship between corn productivity and climate elements (Zhivkov et al., 2006; Popova, 2006; Simić et al., 2023).

Research and updating of technologies and policies can have a significant impact on more efficient use of water resources (Ziad et al., 2010; Moteva et al., 2016; Kireva et al., 2018; Żarski et al., 2023). Against the backdrop of global warming and drying, Rank et al. (2023) believe that it is necessary to search for and implement water-saving technologies in agriculture, combined with fertilization, mulching and other approaches to reduce the water footprint of crops.

The assimilation of nutrients throughout the growing season is linked in a number of agronomic practices that contribute to optimizing the process and guaranteeing high yields. These practices include structuring the soil, having enough readily available moisture for the plants, combating water deficit and nutrient deficiency. The microelements available in the soil are not sufficient for the development of plants. It is necessary to carry out foliar feeding during the growing season of the crop (Oldham, 2019; Luță et al., 2022).

A number of studies have established the positive influence of mineral fertilization with macroelements on the quantity and quality of the harvest (Samodova, 2008; Ivanov et al., 2021). The one-sided application of mineral fertilizers leads to a disruption of the ecological balance and a decrease in the quality of production (Brzozowska, 2008). The need to supplement nutritional micronutrients is a problem that has been recognized for a long period of time (Blaziak et al., 2003; Suwara et al., 2007; Xue et al., 2023). According to Racz et al. (2021) foliar fertilization cannot replace main fertilization, but it can help plants overcome stressors. Jakab-Gábor et al. (2017), are of the same opinion who consider that foliar fertilization only acts as a corrective to the main fertilization.

Another researcher considers foliar feeding to be the best approach for micronutrient supplementation (Kashyap et al., 2022). Foliar fertilizers act as biostimulators and enhance plant defense mechanisms (Haraga et al., 2023). The team of scientists reported an increase in plant height, higher biomass values, and higher yields. The productivity of corn under different feeding regimes is the subject of research by a number of researchers in different agro-climatic regions of the country. Fields studies prove the positive influence of fertilization on biometric parameters, such as number of rows in one cob, number of grains in one row, number of grains in one cob and weight of grain in one cob (Petrovska et al., 2010; Kuneva et al., 2014). Ma et al. (2015) found that localized application of phosphorus (P) plus nitrogen (N) improved maize grain yield, number of kernels per ear and agronomic nitrogen use efficiency.

The combined application of soil and foliar fertilizers increases the productivity of corn for grain found Ivanova et al. (2023). The influence on the biometric parameters grain yield, weight of 1000 grains, cob length, number of rows in the cob, number of grains in the cob, number of grains in the row, weight of the grain in the cob and weight from the cob has also been proved. The highest values were obtained in the joint action of ammonium nitrate (norm 12 kg/day) + 250 ml/day NPK 2.5 SO_3 with a composition of 3.0 N: 1.5 P: 10 K: 2.5 SO_3 + 250 ml/day SO_3 10% Zn, 3% N (zinc and nitrogen sulphides). Kovalenko et al. (2023) also confirmed the positive effect of applying foliar nutrition to crops, analyzing the formation of biometric parameters of maize hybrids of different maturity groups. Araújo et al. (2021) after conducting a comparative study of several maize hybrids in the conditions of Brazil found variations in the agronomic results of maize hybrids, such as significant differences in the percentages of dry matter, mineral matter, crude protein, etc.

The aim of the present study is to analyze the influence of irrigation and feeding with nutrients during the growing season on the productivity of two maize hybrids, as well as to determine the effectiveness of irrigation and the productivity of irrigation water in two maize hybrids.

MATERIALS AND METHODS

To fulfill the set goal, an experiment was conducted with corn hybrids. A field experiment was carried out under controlled conditions, in the experimental field of Trakia University, Stara Zagora. The study of ecological plasticity in two hybrids of corn was carried out in the period 2021-2022. The experiment was conducted under non-irrigated and irrigated conditions. The object of the research are two maize hybrids: Premeo (FAO 400) representative of a new generation of hybrids from the Artesian technology and Knezha-461: a hybrid from the selection of Bulgarian hybrids of the Institute of Maize, Knezha. The hybrids were grown on a soil type, typically meadow-cinnamon soil.

The productivity of the two maize hybrids was studied under different feeding regimes. The experiment was carried out using the method of fractional plots in 4 repetitions, with the size of a harvest plot 15 m^2. Sowing was carried out in an optimal period for the culture. Irrigation was done with a drip irrigation system. Pre-irrigation humidity was maintained at 80% FC (field capacity), and the irrigation rate was calculated for an active soil layer of 0-80 cm.

Variants of the field experience include var. 1. Control - without fertilization and irrigation; var. 2. Without fertilization + irrigation; var. 3. Feeding with foliar fertilizer (aminosol, nutriplant) + irrigation; var. 4. Feeding with foliar fertilizer (Kinsidro Grow, N-lock) + with irrigation. In options 2, 3 and 4, post-sowing, pre-emergence fertilization with N_{14} was performed. At var. 3 feeding with aminosol, zinc and boron is applied in the 4-6 leaf phase, and with nutriplant it is treated in the 8-10 leaf phenophase. At var. 4 the Kinsidro Grow biostimulator is applied in the phenophase 2-8 leaf, and the nitrogen stimulator in the 3-6 leaf phenophase.

The productivity of the irrigation water in the studied hybrids was established. Irrigation water productivity was defined as the ratio between yield and irrigation rate.

Statistical analysis was performed with Anova.

RESULTS AND DISCUSSIONS

Climatic conditions

In climatic terms, the area in which the experimental field is located refers to the European-continental climatic area. The years of the field climate study are characterized by significant differences in the measured decennial mean temperatures compared to the multi-year period (1930-2020). The average temperature during the corn growing season for the two-year period is 20.3°C, which is 0.9°C higher than the average multi-year temperature values for the region (19.4°C). Regardless of the narrow range of fluctuations of the temperature sums in the two years of the field experience, the data show that differences were recorded in July and August. In August 2021, the average monthly temperature was 2.0°C above normal, and in 2022 it was 2.5°C. In the months of July and August, deviations from the temperature norm were recorded, and in 2021 they were 10.68% and 8.55%. In 2022, an increase in temperature was again measured compared to the norm. The increases in July and August were 9.81% and 10.68%. The recorded temperature values confirm the trends towards climate warming.

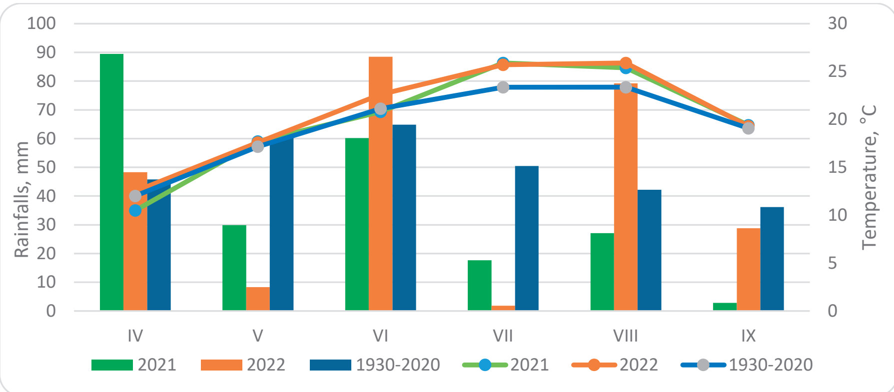

Figure 1. Climatogram for the growing season of corn for the period 2021-2022, the area of the city of St. Zagora

In terms of precipitation, with a precipitation rate of 300.1 mm, 24.3 % less precipitation was recorded in the first year and 15.1% in the second year. The period of the field study is characterized by uneven distribution of precipitation. In 2021, the measured rainfall is relatively evenly distributed, but the 17.7 mm recorded in July is insufficient to provide an optimal amount of moisture for maize development.

Precipitation is more unevenly distributed in the second year. Only 8.3 mm is the amount of precipitation that fell in May, while in June 88.5 mm was recorded. In July, only 1.8 mm was measured. The analysis shows the uneven distribution of the rainfall during the maize growing season on the one hand, and on the other hand, the tendency towards drought is confirmed again.

Given the change of climatic elements and their influence on the growth, development and fruiting of crops, the humidity coefficient and the hydrothermal coefficient (HC) have been determined. The active temperature sums were used to determine the climatic indicators and coefficients. The active temperature sums are determined by the equation:

$$\Sigma T\ {}^{o}C > 10^{o} = (t_1 + t_2 + t_3 + \ldots + t_n),$$

where: $\Sigma T\ {}^{o}C > 10^{o}$ - sum of the effective temperatures (for the period with an average daily temperature >10°) in °C; $t_1, t_2, t_3, \ldots t_n$ - consecutive observations of average day and night air temperatures in °C; 1, 2, … n - index for the consecutive number of the day during the established period.

Ivanov's (1941) humidification coefficient is determined by the following relationship:

$$E = 0.0018*(t + 25)^2*(100-a),$$

where: t - average monthly (decade) air temperature, °C; a - average relative humidity of the air, %.

Values of the hydrothermal coefficient (according to Selyaninov) were calculated by the formula:

$$K = P*10/\sum T^o,$$

where P is the sum of precipitation (mm) for a period of time, ∑To is the sum of the average daily air temperatures (°C) for the same period.

Table 1. Coefficients characterizing the humidity

Year	Ivanov's humidification coefficient																	
	IV			V			VI			VII			VIII			IX		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
2021	0.74	0.45	0.14	0	0.04	0.17	0.12	0.28	0.17	0.27	0.06	0	0.01	0.03	0.1	0	0	0,01
2022	0.02	0.47	0.12	0.03	0.02	0.02	0.1	0.05	0.02	0	0.01	0	0.05	0.14	0.2	0.05	0.14	0.01
Hydrothermal coefficient																		
2021	2.93	2.06	0.84	0	0.24	0.99	0.68	1.18	1	2.06	0.48	0	0.08	0.29	0.72	0	0.04	0.1
2022	0.15	2.66	0.82	0.21	0.11	0.17	0.66	0.33	0.12	0	0.07	0.01	0.46	1.16	1.47	0.34	1.03	0.07

The humidification coefficient and the moisture balance coefficient reflect the warmth and moisture availability of the area. Ivanov's empirical formula for calculating evaporation shows the degree of humidification per ten days for the period during which plants need a sufficient amount of soil moisture. In the last ten days of July, the humidity in the first year is 70% lower than the second. Water deficit during these periods requires irrigation to increase the water supply in the soil.

According to Ivanov's classification, at less than 0.3 there is drought, and at greater than 2.0 there is overwetting. When calculating Selyaninov's hydrothermal coefficient, it is taken into account that if it is less than 0.5, drought is observed, and if it is greater than 2.0, it is correspondingly overwet.

Humidification is distinguished by a coefficient of variation, VC = 23.64%. The values of the hydrothermal coefficient range from 0.00 to 4.93 for 2021, which indicates the nature of the year. High variability is also characteristic of HC during the VI-VII period. Coefficient of variation of the moisture balance for the entire period at HC is very high VC = 31.56 %.

Productivity of the corn hybrids

The results of the irrigation options show that when the moisture in the soil horizon is optimized, the grain yields increase. By ensuring a sufficient amount of readily available moisture, in combination with the nutritional regime, an increase in yield values was reported for all hybrids. According Żarski et al. (2023) the complex influence of irrigation and fertilization contribute to yield increases, on average by approximately 25% and over 80% during dry seasons.

Knezha-461 is a hybrid that is responsive to irrigation and that is why the results show times higher yields under irrigated conditions. At var. 1 yields range from 2833.0 kg/ha to 4850.0 kg/ha. Var. 2 is characterized by higher productivity – 15150.0 kg/ha and 10440.0 kg/ha, in the first and second year. The increase, on average for the period, is 233.1% and is the result of the irrigations. The statistical processing of the results shows a high level of reliability ($p \leq 0.1\%$). Optimizing soil moisture contributes to the increase in hybrid productivity. The yields are higher with the top dressing variants. During the first year of the study, var. 4 has the highest yields – 20950.0 kg/ha.

While in the second year, var. 3 stood out with 11153.3 kg/ha, which was 333.3 kg/ha more than var. 4 on average for the period, the analysis shows that at var. 4 the highest yield was reported – 15885.0 kg/ha. Next var. 3 with 13810.2 kg/ha. At var. 2, irrigation was carried out without feeding during the vegetation period, but the yields were also relatively high. On average for the period, 12795.0 kg/ha were registered. The increase in the var. 4, compared to the non-irrigated option, is 313.5%, on average for the study period.

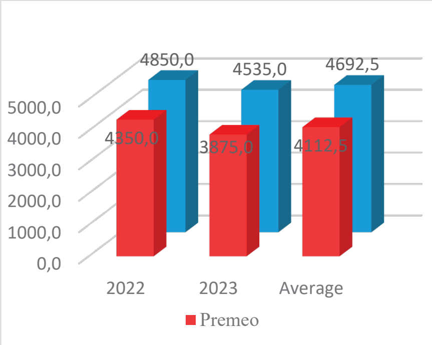

Figure 2. Grain yield for the 2021-2022 period, kg/ha

Premeo is a hybrid of Artesian technology, i.e. these hybrids are distinguished by greater yield resistance in years with insufficient rainfall or when the soil horizon is not sufficiently provided with available moisture. These characteristics of the hybrid enable it to produce a yield of 3500.0 kg/ha in the first year, under non-irrigated conditions and without feeding. The second experimental year is also characterized by high productivity in var. 1 of 4350.0 kg/ha. The responsiveness of maize to irrigation water is again expressed in an increase in the hybrid's productivity. When optimizing the moisture in the soil horizon (var. 2), an increase in the productivity of corn is observed. On average for the period of the study, yields were 13233,0 kg/ha, and by year it was as follows 16733,0 kg/ha and 9733,0 kg/ha. After feeding during the growing season with foliar fertilizers, a jump in the parameters of the yields is reported at Premeo. The increase in the var. 3 and 4 is higher and is due to the efficiency of the assimilation of the applied foliar fertilizers rich in nutritional elements. Irrigation contributes to a 237,1% increase in yield. On average for the period, the highest results were registered for var. 3 (240,8 %). When comparing the irrigation variants with the highest yield, stands var. 3.

Productivity of the irrigation water

During the field study period, a different number of irrigations were conducted in different years.In 2021, 6 irrigations were carried out to maintain the moisture in the soil horizon. In 2022, 4 waterings were implemented. Maize responds to water stress by leaf curling during the hot hours of the day, reducing water transpiration from the crop. In the highly stressed plants, curling of the leaves has been reported already early in the morning. Water stress can lead to lower leaf area index (LAI) and biomass due to reduced intercepted photosynthetically active radiation (IPAR) and radiation use efficiency (RUE) studies have shown by Song et al. (2019). In the non-irrigated variants, under the influence of water deficit, the corn remains in this condition at night. Permanent water deficit reduces the productivity of the culture. During the growing season of corn for grain, the time for supplying irrigation water was established based on the amount and distribution of precipitation and as a result of tracking moisture in the soil horizon in the 0-80 cm layer.

Table 2. Irrigation parameters, productivity of maize hybrids for grain, irrigation norms and irrigation water productivity, for the period 2021-2022

Hybrids of corn	Variant	Yield (Y), kg/ha		Irrigation norm (M), Mm		Irrigation water productivity (IWP), kg/mm	
		2021	2022	2021	2022	2021	2022
Premeo	1	3500.0	4350.0	-	-		-
	2	16733.0	9733.0	1800	1200	9.30	8.11
	3	21467.0	13133.0	1800	1200	11.93	10.94
	4	19633.0	10627.0	1800	1200	10.91	8.86
Knezha -461	1	2833.0	4850.0	-	-	-	-
	2	15150.0	10440.0	1800	1200	8.42	8.70
	3	16467.0	11153.3	1800	1200	9.15	9.29
	4	20950.0	10820.0	1800	1200	11.64	9.02

The productivity of the irrigation water is the ratio between the yield and the irrigation rate. The results of the present experience show that this indicator shows a dynamics of values that varies by year and variant. According to variants in both hybrids in var. 2 lower values of irrigation water productivity are calculated. In the case of the Premeo hybrid, the highest productivity was found in var. 3, ranging from 10.94 kg/mm to 11.93 kg/mm over the years (Table 2). Knezha-461 stands out with 11.64 kg/mm at var. 4 (2021). In the second year, the productivity of the irrigation water is the highest with lime. 3. As per Wang et al. (2022) determination of water productivity is important in the construction of hydromelioration systems and in combating global climate change.

Table 3. Grain yield, additional yield, irrigation standards and effect of 100 m^3 of irrigation water for the period 2021-2022

Hybrids of corn	Variant	Yield (Y), kg/ha		Additional yield (AY), kg/ha		Irrigation norm (M), mm		Effect of 100 m^3 of irrigation water, kg/ha	
		2021	2022	2021	2022	2021	2022	2021	2022
Premeo	1	4210.0	4095.0	-	-	-	-		
	2	9200.0	11997.4	13233.0	5383.0	1800	1200	735.17	448.58
	3	11733.0	13268.8	17967.0	8783.0	1800	1200	998.17	731.92
	4	10113.0	13576.9	16133.0	6277.0	1800	1200	896.28	523.08
Knezha -461	1	4850.0	4535.0	-	-	-	-		
	2	10440.0	12320.7	12317.0	5590.0	1800	1200	684.28	465.83
	3	11153.3	13754.8	13634.0	6303.3	1800	1200	757.44	525.28
	4	10820.0	13138.9	18117.0	5970.0	1800	1200	1006.50	497.50

The effect of 100 m^3 of irrigation water is determined by calculating the ratio between the additional yield and the irrigation rate. Table 3 shows that the values of this indicator are highest in the first experimental year with var. 4 (1006.5 kg/ha). With the same variant, in the second year, 497.5 kg/ha are reported, which is 50.5% less, regardless of the smaller number of irrigations realized. The phenophase of corn for grain is important when implementing irrigation. A number of authors report dependencies between the phenological development of crops and the irrigation regime. (Brar et al., 2016; Katiyar et al., 2018). Studies have established a positive linear relationship between the duration of some phenophases and irrigation, which predetermines and increase grain yield. Lower parameters characterize the effect of 100 m^3 in the second year.

On average for the period at Knezha-461, the highest effect per 100 m^3 of irrigation water is recorded at var. 4 (752.0 kg/ha). Average for the period, with the highest effect per 100 m^3 of irrigation water, var. 3 (Premeo) with 865.0 kg/ha followed by var. 4 (Knezha-461) with 752.0 kg/ha. The analysis of the results of the two corn hybrids studied shows that Premeo is characterized by a higher effect per 100 m^3 of irrigation water, an average of 722.2 kg/ha for all variants. With Knezha-461, the average effect of the variants was calculated to be 656.1 kg/ha.

CONCLUSIONS

Optimizing the irrigation regime provides an increase in corn yields for grain by 237.1% in Premeo and by 233.1% in Knezha-461 compared to the non-irrigated option. Optimizing the irrigation and nutrition regime leads to an increase in productivity by 340,8 % (var. 3) in Premeo, and in Knezha-461 by 313.5% in var. 4.

The corn hybrid Premeo (var. 3) 11.4 kg/mm stands out with the highest irrigation water productivity, followed by var. 4 (Knezha-461) with 10.3 kg/mm, average for the study period. A trend towards an increase in the productivity of irrigation water with an increase in the productivity of the maize hybrids was found.

It was established that the Premeo corn hybrid has a higher effect per 100 m^3 of irrigation water, on average for all variants – 722.2 kg/ha, while for Knezha-461 the effect is 656.1 kg/ha.

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