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Irrigation rate and fertilization as factors determining yield in tomatoes – mid-early outdoor production

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Abscract

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In the period 2018–2020, an experiment was carried out with tomato variety "Nikolina F1" on leached cinnamon forest soil. The influence of increasing irrigation and fertilizer rates delivered by fertigation on tomato yields was studied. The experiment contained 8 variants at two irrigation rates (1–4 variants – 100% MMC; 5–8 variants – 50% MMC) and increasing levels of fertigation (T1 and T5 – without fertilization; T2 and T6 – N15P8K15; T3 and T7 – N20P12K20; T4 and T8 – N25P16K25). The results show that the formed yields of tomatoes during the studied years are the result of the influence of climatic factors, applied fertilization and irrigation rates. The average yields of tomatoes from the three experimental years range between 2864.0 and 5601.3 $kg.da^{-1}$ with an average yield of 4363.96 $kg.da^{-1}$. With average yields for the three experimental years of 2145.3 $kg.da^{-1}$ for 2018; 5513.63 $kg.da^{-1}$ for 2019 and 5430.5 $kg.da^{-1}$ for 2020, as the plants of variant T3 fertilizes with N20P12K20 and full irrigation rate – 100% MMC realized the highest yields, in 2018 with 23.1 %, in 2019 with 37.2% and in 2020 with 21.6% higher than the average yields for the respective years. The three-factor statistical analysis of the average yield data shows that the influence of the year is the strongest – 67.77% of the formed yields are dependent on the experimental year. The degree of influence of the applied fertigation is 19.5%, of the irrigation rate – 1.3%, of fertigation and the year is 7.48%, and the joint influence of fertilization and the irrigation rate is less than 1%.

Keywords: tomatoes; field production; soil moisture; fertilizing; yields

Introduction

According to Kahnt (1), forms of agriculture can be divided into two groups: "normal" and "extreme", which include several systems of agricultural production. The soil and climatic conditions of Bulgaria, in our region from the point of view of the classification (1; 2) – traditional intensive agriculture is developing. In recent years (3) attempts have been made to implement organic and sustainable agriculture. Intensive agriculture provides opportunities to obtain production under controlled environmental conditions so that under optimal conditions for plant growth and development, they prove their genetic potential. Based on the maximum genetic possibilities of plants, through the methods of intensive agriculture, conditions, and factors are combined to achieve maximum ecologically permissible production of crop production. Among the most important characteristics of intensive production systems is the controlled and scientifically based irrigation and fertilization of crops.

Tomato production in Bulgaria, like all intensive crops and sub-sectors in the years after 1989 experienced a sharp collapse. For a country with good conditions and traditions in vegetable production, this is an incredible failure that has no analog in European agriculture. Therefore, it is not surprising that our markets are sharply dominated by imported tomatoes. The data of the national statistics (4) report that for the ten months of 2018, the import of fresh vegetables grew by 11.7% per year and reached 226.7 thousand tons.

The increase in vegetables is mainly due to an increase in the supply of tomatoes by 8.9 thousand tons or 13.7%. According to the estimates of the Center for Economic Research in Agriculture (SARA) in 2018, about 60% of the tomatoes sold through various trade channels outside of processing and import (5).

Among the unfavorable factors for the recovery and development of vegetable production at a modern level are both the outdated material base and the lack of sufficient irrigated areas and expensive water for irrigation. One of the most economically justified applications of drip irrigation is in the cultivation of vegetable crops. Fertigation is an effective method of delivering nutrients through irrigation in the exact amount that each plant needs according to the type and phase of development. On the one hand, drip irrigation allows a strictly controlled regime for growing crops by precisely dosing the necessary nutrients and water, and on the other hand, the high incomes during the year-round cultivation of crops enable more efficient use and faster repayment of the costs of building the irrigation system.

The research aims to determine the influence of increasing irrigation and fertilizer rates delivered by fertigation on the yields of tomatoes – medium early outdoor production.

Materials and Methods

The experiment was carried out under irrigation conditions during the period 2018–2020, on leached cinnamon forest soil in experimental field "Chelopechene" of ISSAPP "N. Pushkarov". As an experimental culture, a medium-early determinant variety "Nikolina F1" was used – a selection of IG – BAS. The soil in the experimental area is slightly humus (1.44%) with a slightly acidic reaction – pHH_2O – 6.2; pHKCl – 5.4. The mineral nitrogen content is low – 16.1 $mg.kg^{-1}$ soil. The degree of availability of mobile forms of phosphorus and potassium is average – 11.4 mg P.100 g^{-1} and 17.7 mg $K.100g^{-1}$ soil. The experiment contains 8 variants at two irrigation rates (1–4 variants – 100% MMC; 5–8 variants – 50% MMC) and increasing levels of fertilization (T1 and T5 – no fertilization; T2 and T6 – N15P8K15; T3 and T7 – N20P12K20; T4 and T8 – N25P16K25). The experiment (6; 7; 8) was laid out by the method of long plots in four replications, with the size of the experimental plot 7.5 m2. Irrigation was carried out using a drip irrigation system. Drip irrigation wings were selected according to the wetting contours of cinnamon forest soil, the distance between the drippers was 0.30 m, with a water discharge of 2 l h^{-1}. They are placed two in each strip immediately next to the tomato stems on the surface of the field. The plants are planted in a two-row strip according to the scheme 100 + 60 × 30. Nitrogen (ammonium nitrate) and potassium (potassium chloride) fertilizers in all versions with fertilization were introduced three times with the irrigation installation. Fertilizer rates are divided equally and brought to phase mass formation of bundles by fertigation. The phosphorus norm, in the form of double superphosphate, was introduced in autumn with deep plowing.

The yield was determined dynamically during fruiting, by plots and then recalculated in $kg.da^{-1}$. The results were processed using the statistical package Statgraphics – XVII (Anova).

Results and Discussion

Water management and fertilizer inputs are two major factors affecting tomato growth and productivity. The successful agro-ecological and economic development of the plantation as well as the quality of the harvested produce are very sensitive to the appropriate content of water and nutrients in the root zone of the plants (9; 10), which can provide the absorbing area and root capacity.

The total yields for 2018 are between 1620 and 2640 kg per hectare with an average yield ($table^{-1}$) of the test variants of 2145.3 $kg.da^{-1}$. The obtained yields from the experimental variants in this growing year are significantly lower than those cited in the literature, both for the production direction and for the agroecological region in which the experiment is carried out. The reason is the heavy rainfall during the harvest period, which greatly compromised the production (11). The value of the variable p – Value for the measured yields in 2018 is less than the significance level 0, 05. The low value of p – Value corresponds to a significant value (13.96) of the Fisher – F test (Figure 1).

As expected, the control variants under the two irrigation regimes – variants 1 and 5 without fertilization – also produced the lowest yields (Table 1). The yield from the control plants that received a full irrigation rate was higher, compared to that of the variant without fertilization and with reduced irrigation, however, the difference in yields was not statistically proven. The variant T3 with 100% irrigation rate, fertilized with N20P12K20 formed the highest yield in 2018 – 2640 $kg.da^{-1}$, with the obtained yield being 62.9% higher than that of the control without fertilization and with full irrigation rate and by 23.1% of the average yield for the trial variants. The yield from the variant with 50% MMC and fertilization with N25P16K25, although lower – 2560 $kg.da^{-1}$, is without proven difference from that of variant T3, and the yield obtained from it is 66.2% higher than that obtained in the control variant T4 with reduced irrigation and with 19.3% of the average yield for the experiment.

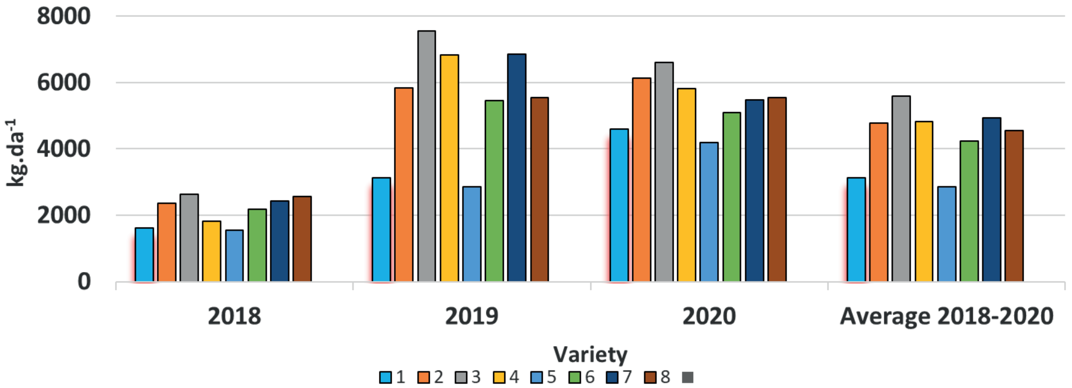

Fig. 1. Tomato yields depending on the irrigation rate and applied fertilization

At the 95% confidence level, the variants of the entire experiment are arranged into 3 homogeneous groups. In general homogeneous groups ie., without proven statistical differences, the yields of variants fall: first group – 1, 4, and 5; second group – 2, 6, and 7 and third – 3 and 8.

In the one-factor analysis (95% LSD) of the yields (Table-2) of the variants with a full irrigation rate, the plants of variant T3 have the highest yield, and the yields are divided into two homogeneous groups: 1st group T1 and T4; 2nd group T2 and T3. In the variants with 50% MMC, the highest yield was measured in variant T4, and the applied fertilization arranges them in 3 homogeneous groups – as T2 and T3 fall into a common group.

Figure 2 shows the results of the bivariate analysis for the degree of influence of fertilization and the applied irrigation rate on tomato yields.

From the data shown in Figure 2, it can be seen that the fertilization factor had the strongest influence on the yields formed in 2018, and its percentage influence is undisputed – 61.3, and the influence of the irrigation rate is almost negligible low – 0.59%. It has already been explained that in terms

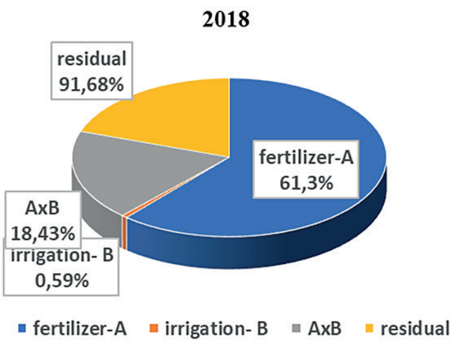

Fig. 2. Percentage participation of the tested factors in the obtained yield for 2018

of climate, the year is characterized by a cool summer and excessive rainfall. The joint impact of the two investigated factors on the investigated indicator – yield of tomatoes is 18.43%.

The yields in 2019 are between 2860.07 (non-fertilized variant at 50% MMC) $kg.da^{-1}$ and 7563.19 (T3.N20P12K20) $kg.da^{-1}$ with an average yield for the experiment of 5513.63 $kg.da^{-1}$ (Table 1). The obtained total yield from variant T3 is 37.2% higher than the average yield for all experimental variants and 2.4 times greater than that of the unfertilized variant at 100% MMC. With the reduced irrigation rate, the plants of variant T7 N20P12K20 have the highest yield, 6864.93 $kg.da^{-1}$, or 24.5% more than the average yield for the experiment, and the ratio between the highest and the lowest yield at 50% MMC is keeping the same (2.4) as at 100% MMC.

At a confidence level of 95%, the results of all experimental variants are arranged in 4 homogeneous groups: 1st group the two control variants without fertilization T1 and T5; 2nd group – variants T2, T6, and T8; 3rd group – variants T4 and T7; 4th group – T3. Variant T3.N20P12K20 is statistically proven to have a higher yield than all other variants in the experiment. The combination of the provided irrigation regime during the vegetation period at 100% MMC and the fertilizer combination of N20P12K20 have provided an optimal nutrient and water regime for the realization of a high yield, especially for field production. (12) in an experiment with tomatoes outdoors found that fertigation with 100% WSF (water-soluble fertilizer fertigation) significantly increased fruit yield (79.2 Mg ha$^{(-1)}$) compared to control furrow irrigation and drip irrigation, with higher fruit yield at fertigation, higher length, higher leaf area index, total dry matter production, and more fruiting plant

With both irrigation rates (Table 2), the applied fertilization with N20P12K20 ensured the highest yields, but with the full irrigation rate, there are proven differences between all the fertilizer options, i.e. 4 homogeneous groups, then with the reduced variants T2 and T4 fall into one group.

The two-factor analysis carried out confirms the trend from 2018. And in 2019, applied fertilization had the greatest impact on yields – 89.81%. (Figure 3). The participation

Table 1. Influence of irrigation rate and fertilization on yields (kg.da^{-1}) of tomatoes

Variants	2018			2019			2020		
	Yields	St.dev	Median	Yields	St.dev	Median	Yields	St.dev	Median
1	1620.0	126.614	1653.89	3134.03	108.407	3173.61	4581.0	247.255	4648.81
2	2354.0	162.277	2323.27	5845.14	208.785	5785.42	6131.0	321.954	6143.75
3	2640.0	239.437	2632.77	7563.19	305.001	7660.42	6601.0	182.805	6657.56
4	1830.0	283.396	1836.11	6842.01	627.435	7081.25	5826.0	300.481	5846.53
5	1540.0	304.925	1620.13	2860.07	111.258	2855.56	4192.0	369.956	4265.98
6	2180.0	228.387	2188.89	5459.72	538.866	5486.81	5099.0	319.156	5025.69
7	2438.0	222.754	2504.86	6864.93	527.754	6961.81	5477.0	222.999	5502.78
8	2560.0	217.393	2589.59	5539.93	456.504	5545.83	5537.0	238.667	5513.59
Average	2145.25	455.136		5513.63	1669.75		5430.5	792.836	
Median	2267			5692.535			5507		
Stnd.error	114.841			204.0			140,747		
F-Ratio	13.96			70.74			31.70		
P-Value	0.0000			0.0000			0.0000		
95.0% LSD	335.197			595.436			410.813		
99.0% LSD	454.249			806.919			556.723		

Table 2. Yields (kg.da^{-1}) of tomatoes depending on fertilization at different irrigation rates

Variants	2018			2019			2020		
	Yields	St.dev	Median	Yields	St.dev	Median	Yields	St.dev	Median
100% PPV									
1	1620.0	126.614	1653.89	3134.03	108.407	3173.61	4581.0	134.28	4648.81
2	2354.0	162.277	2323.27	5845.14	208.785	5785.42	6131.0	134.28	6143.75
3	2640.0	239.437	2632.77	7563.19	305.001	7660.42	6601.0	134.28	6657.56
4	1830.0	283.396	1836.11	6842.01	627.435	7081.25	5826.0	134.28	5846.53
Average	2111,0	460.126		5846.09	1766.51		5784.75		
Median	2092.0			6343.6			5978.5		
Stnd.error	106.069			184.089			134.28		
F-Ratio	19.52			111.14			41.35		
P-Value	0.0001			0.0000			0.0000		
95.0% LSD	326.83			567.143			413.757		
99.0% LSD	458.193			795.095			580.058		
50% PPV									
5	1540.0	304.925	1620.13	2860.07	111.258	2855.56	4192.0	369.956	4265.98
6	2180.0	228.387	2188.89	5459.72	538.866	5486.81	5099.0	319.156	5025.69
7	2438.0	222.754	2504.86	6864.93	527.754	6961.81	5477.0	222.999	5502.78
8	2560.0	217.393	2589.59	5539.93	456.504	5545.83	5537.0	238.667	5513.59
Average	2179.5	462.48		5181.16	1551.01		5076.25	614.139	
Median	2309.0			5499.8			5288.0		
Stnd.error	122.989			222.159			146.931		
F-Ratio	13.68			56.93			17.84		
P-Value	0.0004			0.0000			0.0001		
95.0% LSD	378.966			684.542			452.74		
99.0% LSD	531.284			959.679			634.709		

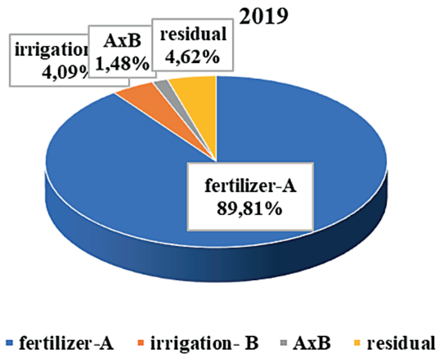

Fig. 3. Percentage participation of the tested factors in the obtained yield for 2019

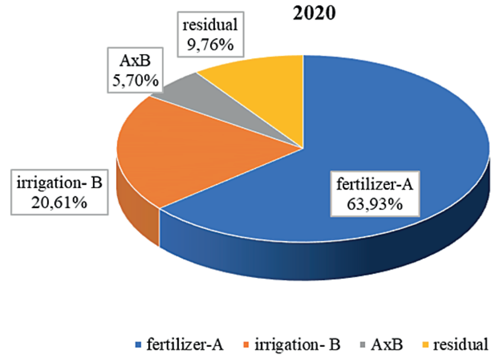

Fig. 4. Percentage participation of the tested factors in the obtained yield for 2020

of the irrigation rate as a degree of influence is reduced to 4.09%, and the combined influence of fertilization and irrigation on the formation of tomato yields is only 1.48%.

In global practice, it has already been conclusively demonstrated (10) that technologies such as drip irrigation can maintain or increase yields while improving WUE efficiency and ensuring balanced fertilizer addition, thus reducing losses that lead to soil pollution environment. The average yield (5430.5 kg. da^{-1}) of tomatoes in the 2020, experiment is comparable to that of 2019, and the obtained yields (Table 1) from the experimental variants are from 4581 to 6601 kg.da^{-1}. With a standard error of 2020 of 140.7 the highest reported yield (variant T3.N20P12K20 – 6601 kg.da^{-1}) is 44.1% greater than that in the unfertilized variant with 100% MMC where it is also the lowest measured yield and with 21.6% of the average yield for the experimental variants.

The dispersion analysis of all the experimental data for the yields at a level of proof of the differences of 95% arranges the experimental data into 5 homogeneous groups: 1st group – T1 and T5 variants; 2nd group – T6 and T7; 3rd group – T3; 4th group – T2 and T4 and 5th group – T8.

The plants from variant T3 have proven to have the highest yield (Table 2) of the fertilized variants at full irrigation rate, and the variants are in 3 homogeneous groups. Yields in variants T2 and T4 are without proven differences. With reduced irrigation, the yield in variant T4 is the highest, but without statistically proven differences with the yields of variants T2 and T3.

The two-factor analysis of yield data confirms the regularities obtained in previous years. With the greatest influence on the yield of tomatoes in 2020, once again applied fertilization – 63.93%, followed by the irrigation rate – 20.61% and 5.70% for the joint action of the two tested factors (Figure 4).

Influence of the factors irrigation rate, fertilization, and experimental year on the formed yields of tomatoes 2018-2020.

The average yields of tomatoes from the three experimental years ranged between 2864.0 and 5601.3 kg.da^{-1}, with the high yield (Figure 1) reported for variant T3 fertilized with N20P12K20. The highest measured yield in the experiment was 1.96 times greater than that obtained in variant T5 – without fertilization at 50% irrigation rate and with 28.4% of the average yield for the experiment. If we look at the yields separately (table 3) depending on the irrigation

Table 3. Average tomato yields for the period 2018–2020

Variants	Average	Median	Standard deviation	Average	Median	Standard deviation	Average	Median	Standard deviation
	the two irrigation rates			100% MMC			50% MMC		
1	3118.33	3134.0	1470.56	3118.33	3134.0	1470.56	2864.0	1326.0	2860.0
2	4776.67	5845.0	2102.96	4776.67	5845.0	2102.96	4246.33	1798.58	5099.0
3	5601.33	6601.0	2609.31	5601.33	6601.0	2609.31	4926.67	2264.23	5477.0
4	4832.67	5826.0	2649.54	4832.67	5826.0	2649.54	4545.67	1719.64	5537.0
5	2864.0	2860.0	1326.0						
6	4246.33	5099.0	1798.58						
7	4926.67	5477.0	2264.23						
8	4545.67	5537.0	1719.64						
Total	4363.96		1925.11	4582.25		2146.31	4145.67	1743.1	

rate and with both methods of irrigation, the leading yield is in variant T3 N20P12K20. At 100% irrigation rate, the yield in variant T3 is 22.2% higher than the average for the variants and by 79.6% than the control variant T1, in the variants with 50% MMC these values are 18.8 and T5 – 72, 02%.

The results shown in Table 3 show the degree of influence of the tested factors and their combinations on the formed yields. Low values of p-Value correspond to high values of Fisher's criterion – F. Only in the case of the combined influence on yields of the irrigation rate and fertilization, the value of the variable P-Value is higher than the level of significance (0.05).

As expected, the influence of the year (Figure 5) with all its variables is the most pronounced – 67.77% of the formed yields are dependent on the experimental year. The degree of influence of the applied fertilization is 19.5%, and the irrigation rate is involved at 1.3%. The combined influence of fertilization and year is relatively high – 7.48%. The combined influence of the remaining factors is below one percent. Both irrigation and fertilization are essential factors for tomato growth and affect fruit yield and quality (13;14;15). In their study with tomatoes under solar greenhouse conditions, (10) found that the interactions between irrigation and fertilization significantly affect the yield, WUE, PFP, and quality of tomatoes, and during the growing season, fruit yield and WUE were more sensitive to irrigation than to fertilization, and PFP is more sensitive to fertilization than to irrigation. In our experience, both in the individual experimental years and in the averaged three-year yield results, the main factor influencing the formation of tomato yields is fertilization, while the impact of the irrigation rate and the combined influence of the factors is significantly less. The reason for this is that in conditions of field production, outdoors, the dependence on climatic effects is very great and the irrigation regime is much more difficult to control.

The three-factor dispersion analysis arranges the fertilization options into three homogeneous groups (Table 4). The highest yield of tomatoes for the period 2018–2020 is variant T3.N20P12K20, but it falls into a homogeneous group with the plants of variant T2, i.e. without statistically proven differences in yields. With an average yield of 5264.02 $kg.da^{-1}$ variant T3.N20P12K20 formed a 20.65% higher yield than the averages for the experimental variants and 1.76 times greater than that of the control variants – without fertilization.

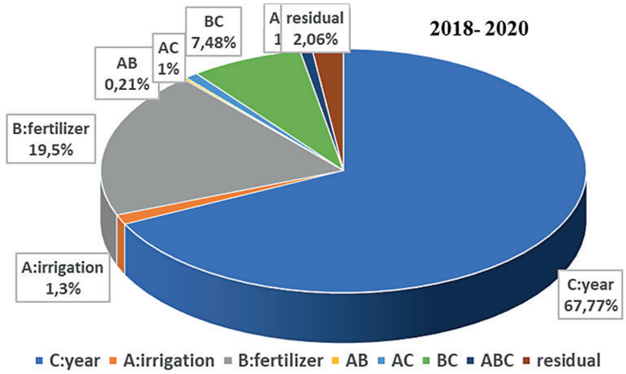

Fig. 5. Percentage participation of the tested factors for a three-year research period on the formed yields

The irrigation rate factor (Table 5) also turns out to be well chosen and divides the yields from the trial variants into two homogeneous groups with proven (95 and 99% LSD) differences. Referring to the irrigation rate factor, the average yields for 2018–2020 at 100% MMC are 10.49% higher than those for plants with reduced irrigation.

Conclusion

The formed yields of tomatoes in the studied years are the result of the influence of climatic factors, applied fertilization, and irrigation rates

In 2018, yields between 1620 and 2640 kg per hectare

Table 4. Effect of tested factors on tomato yield 2018–2020

Source of variation	Sum of squares	Amount of sq. %	Degrees of freedom	Average sq.	F-ratio	P-Value
A:Irrigation rate	4.54091E6	1.30	1	4.54091E6	45.64	0.0000
B:Fertilization	6.79513E7	19.50	3	2.26504E7	227.67	0.0000
C: Year	2.36221E8	67.77	2	1.18111E8	1187.21	0.0000
AxB	741546	0.21	3	247182	2.48	0.0675
BxC	2.60632E7	7.48			43.66	0.0000
AxC	3.04947E6	0.88	2	1.52474E6	15.33	0.0000
AxBxC	2.8285E6	0.81	6	471417	4.74	0.0004
Error	7.16298E6	2.06	72	99485.8		
Total sum	3.48559E8		95			

Table 5. Three-factor variance analysis of tomato yield data – 2018–2020

Variants of fertilization	Average yield	95% LSD	99% LSD
1	2987.85	X	X
2	4511.48	X	X
3	5264.02	X	X
4	4689.16	X	X
average	4363.13	181.509	240.911
Variants of Irrigation	Average yield	95% LSD	99% LSD
1	4580.61	X	X
2	4145.64	X	X
average	4363.13	128.347	170.35

were realized; in 2019, between 2860.07 and 7563.19kg.da^{-1}; in 2020, between 4581 and 6601 kg.da^{-1}, with average yields for the three experimental years of 2145.3kg.da^{-1} for 2018; 5513.63 kg.da^{-1} for 2019, and 5430.5kg.da^{-1} for 2020. The average yields of tomatoes from the three experimental years range between 2864.0 and 5601.3 kg.da^{-1} with an average yield of 4363.96 kg.da^{-1}.

In all three experimental years, plants from variant T3 fertilized with N20P12K20 and a full irrigation rate of 100% MMC achieved the highest yields of tomatoes, in 2018 at 23.1%, in 2019 at 37.2% and in 2020, at 21.6 % higher than the average yields for the respective years.

The statistical analysis of the influence of the tested factors on the formed yields shows that in all three studied years, the strongest influence on the formed yields was exerted by the fertilization factor, and its influence is indisputable – in 2018 – 61.3%; in 2019 – 89.81%; in 2020 – 63.93%. The influence of the irrigation rate is significantly lower: in 2018 – 0.59%; in 2019 – 4.09%; in 2020 – 20.61%. The joint impact of fertilization and irrigation rate on tomato yields over the years is uneven: in 2018 – 18.43%; in 2019 – 1.48%; in 2020 – 5.70%.

The three-factor statistical analysis of the averaged data on tomato yields from the experimental years shows that the influence of the year with all its variables is the most pronounced – 67.77% of the formed yields are dependent on the experimental year. The degree of influence of the applied fertilization is 19.5%, and the irrigation rate is involved at 1.3%. The combined influence of fertilization and year is relatively high – 7.48% and the combined influence of fertilization and irrigation rate is below 1%.

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