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INFLUENCE OF NITROGEN FERTILIZATION RATES ON THE PRODUCTIVITY OF MAIZE UNDER NON-IRRIGATION CONDITIONS

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Abstract

The aim of the study is to study the effect of different nitrogen fertilization rates on the productivity of maize grown under non-irrigation conditions in the Plovdiv area. The experiment was conducted in the period 2004-2007 in the AU-Plovdiv on alluvial-meadow soil. The following fertilization levels N_0, N_8, N_{16} and N_{24} were tested. As a source of nitrogen, ammonium nitrate (NH_4NO_3) was used. The results show that as the fertilizer rate increases, the yield increases, with N_8 increasing between 1 and 5% and N_{16} between 2 and 8%. The difference between N_{16} and N_{24} is less than 2%, with the average for the four years practically coinciding (907 and 908 kg/da, respectively). A squire relationship between the fertilization rate and the yield was established at R^2 = 0.732. From an economic point of view, the best results are obtained at N_0 and N_{16}, which gives reason to believe that in the Plovdiv area, fertilization of maize under non-irrigation conditions is ineffective. The highest nitrogen fertilizer use efficiency (NFUE) was obtained at N_{16}, with an average yield of 2,375 kg/da from every 1 kg/da of nitrogen. Slightly lower (5.5%) is NFUE at N_8. Nitrogen fertilization rates have little impact on the 1000 seeds weight and test weight.

***Key words**: maize, yield, nitrogen fertilization.*

INTRODUCTION

Increasing the efficiency of cultivation of different crops is related to the optimization of agro-technical activities for the certain soil and climatic conditions. Hristov & Tashkov (1970) consider fertilization to be the second most important agro-technical activity after irrigation. This makes it one of the main agrotechnical components of maize cultivation. Studies in this area have identified scheme and rates of fertilization, which give the highest yield. However, they are not always optimal in terms of economic point of view. For example, according to Liangl & MacKenzie (1994), in order to obtain the maximum yield of maize for grain, it is necessary to fertilize it with 30-35 kg/da nitrogen, but the economically optimal rate is in the range 17.9-27.3 kg/da. Similar to these are the results reported by Halvorson et al. (2005). The authors note that with increasing nitrogen the NFUE decreases. They found that for conditions of "Arkansas River Valley" in Colorado the best economic results are obtained at the rate of 26.5 kg/da. Nitrogen fertilization rates, which are recommended for growing corn in central Italy, are also relatively high (Mazzoncini et al., 2008). Based on results of long term field experiment, the authors found an increase in yield to the rate of 30 kg/da. High nitrogen fertilization rates significantly and positively affect the harvest index and the 1000 seeds weight (Wajid et al., 2007). The authors recommend a nitrogen rate of 25 kg/da, in which the yield increases by 22.8% and the absolute seeds weight - by 7.8%, compared to those at the rate of 15 kg/da. Another group of researchers found that corn productivity was maximized when applying significantly lower nitrogen fertilization rates - between 10 and 17 kg/da (Cambouris et al., 2016; Gehl et al., 2005; Torbert et al., 2001; Matev, 2001; Arif et al., 2010; Siam et al., 2008). Dawadi & Sah (2012) found a maximum yield when fertilizing with N_{20}, but recommended N_{16} because of better economic results due to the minimum yield losses (2.8%). The results of a number of studies have proved that corn with high nitrogen norms is ineffective in regard to grain yield, and it has been found that they should not exceed 10 kg/da. For example, Woldesenbet & Haileyesus (2016) found that grain yield increased to the rate of 9.2 kg/da, with negligible difference between the results at rate 6.9 and rate 9.2 kg/da, i.e. the smaller rate is optimal. In support of this are the data published by Raicheva-Mehandzhieva (1971), Wilhelm et al. (1987), Adediran & Banjoko (1995), Liu & Wiatrak (2011; 2012). For maximum yields, Onasanya et al. (2009) recommended fertilization with $N_{12}P_4$ and economically rates N_6P_4.

It is clear from the references made that the optimization of nitrogen fertilization in maize for grain cannot be done on a global scale, but must be done for specific soil and climatic conditions, in accordance with other agrotechnical activities.

The aim of the study was to determine the effect of increasing rates of nitrogen fertilization on yield and its components for grain corn, as well as to explore the possibilities to increase the economic efficiency of fertilization with nitrogen by optimizing the rates.

MATERIALS AND METHODS

The experiment is carried out during the period 2004-2007 at the Agricultural University of Plovdiv (Bulgaria) on alluvial-meadow soil. The Knezha-613 hybrid was used. Different levels of nitrogen fertilization are tested under non-irrigation conditions as follows: T0-N_0, T1-N_8, T2-N_{16} and T3-N_{24}. Ammonium nitrate (NH_4NO_3) is used. The experiment is based on the method of split-plots design in three repetitions. The size of the experimental plots is 20 m^2, and the harvest - 10 m^2. The sowing density is 6500 plants/da, with a row spacing of 0.7m. Nitrogen fertilization was performed once in a phase of 5-6 leaves, just before the last inter-row treatment. Fertilization with phosphorus and potassium is carried out in the autumn. The rates are determined according to the soil reserve. Harvesting was performed at technical maturity with grain moisture of 13-14%. The data for yield, 1000 seed weight and test weight by variants and repetitions are processed by analysis of variance using the ANOVA1 program to establish the warranties of differences. The relationship between the nitrogen rate and the yield is determined using the least squares method. The NFUE coefficient is determined in two reciprocal ways: 1) as an additional yield of 1 kg/da nitrogen; 2) amount of nitrogen to produce 1 kg of additional yield. On the basis of current cost prices and production prices, an analysis has been made to determine the optimum nitrogen rate from an economic point of view. All agrotechnical activities (soil tillage, plant protection, etc.) are observed during the experiment. The corn was grown after soybean.

RESULTS AND DISCUSSIONS

Meteorological characteristics of the experimental years

In terms of precipitations during vegetation period, the experimental years are very different, and under non-irrigation conditions the amount of yield and the effect of nitrogen fertilization depend to a large extent on the amount and distribution of the precipitations during vegetation period. With regard to this indicator, the first year of the experiment (2004) is characterized as average, with a total rainfall of May-September of 234 mm and a 45% probability. During the same period of the second (2005) year, the amount of precipitation is 456 mm. It is humid with a 6% probability. The third year of the experiment (2006) is also an average with 49% probability and amount of precipitations 228 mm. The most humid (463 mm) with 4% probability is 2007. That, however, is extremely uneven distribution of rainfall, especially in July when practically lacking. During the other three years, precipitations are distributed more evenly.

In terms of air temperature, the first experimental year is average with 55% probability. Averages warm are 2005 and 2006 with probability respectively 34 and 28%. Warmest is the fourth year of experience (2007) which has a 9% probability. Despite those differences, all experienced years are favorable for normal growth, development and timely ripening.

Grain yield

The yield data for variants and years, as well as the average for the all experimental period, are presented in Table 1. The amount and distribution of precipitations during the growing season significantly affect the yield, regardless of the level of nitrogen fertilization. This influence is very well expressed in the wet 2005. The yield for all four values of nitrogen fertilization exceeds 1100 kg/da, while in extreme 2007 it is more than twice as low (approximately 500 kg/da). In average in terms of rainfall years (2004 and 2006) yields are comparable in quantity - more than 900 kg/da.

Table 1. Grain yield depending on nitrogen rate

Variant	Yield kg/da	to N_0			to N_{24}		
		±Y kg/da	%	w	±Y kg/da	%	w
2004							
N_0	931	St.	100.0	St.	-52	94.7	a
N_8	949	18	101.9	n.s.	-34	96.5	n.s.
N_{16}	970	39	104.2	n.s.	-13	98.7	n.s.
N_{24}	983	52	105.6	a	St.	100.0	St.
LSD (kg/da) 5% = 41 1% = 62 0.1% = 100							
2005							
N_0	1175	St.	100.0	St.	-45	96.3	n.s.
N_8	1187	12	101.0	n.s.	-33	97.3	n.s.
N_{16}	1210	35	103.0	n.s.	-10	99.2	n.s.
N_{24}	1220	45	103.8	n.s.	St.	100.0	St.
LSD (kg/da) 5% = 119 1% = 180 0.1% = 290							
2006							
N_0	889	St.	100.0	St.	-43	95.4	n.s.
N_8	928	39	104.4	n.s.	-4	99.6	n.s.
N_{16}	959	70	107.9	n.s.	27	102.9	n.s.
N_{24}	932	43	104.8	n.s.	St.	100.0	St.
LSD (kg/da) 5% = 79 1% = 120 0.1% = 193							
2007							
N_0	488	St.	100.0	St.	-19	96.3	c
N_8	493	5	101.0	a	-14	97.2	c
N_{16}	498	10	102.0	b	-9	98.2	b
N_{24}	507	19	103.9	c	St.	100.0	St.
LSD (kg/da) 5% = 4 1% = 7 0.1% = 11							
W - warranty; Y - yield							

In general, for the conditions of the present experiment, the fertilization of maize under non-irrigation conditions has a relatively small effect on its productivity. Differences compared to non-fertilized variant are not statistically warranted for three of total four experimental years (2004, 2005 and 2006) but for the last one (2007) are warranted due to the extremely low LSD values. Fertilization with N_8 increased the yield by an average of 10 kg/da or 1.1% compared to the non-fertilized control (Figure 1). Depending on the conditions of the year, this increase ranges from 1.0 to 4.4%. With an increase in the rate of another 8 kg/da (N_{16}), maize responded positively, with a yield increase of 3-8% in the more favorable years and only 2% in the extreme 2007. On average, over four years, applying N_{16} nitrogen fertilization, yield increases by 4.4% or 38 kg/da. Compared to N_8, at N_{16} the yield is on average 28 kg/da or just over 1% and is not statistically warranted. Studies on the fertilization of grain corn in different regions of Bulgaria show that the optimum nitrogen rate varies within a range close to N_{16} (Nikolov, 1970; Dimitrov, 1973; Furdzhev, 1973; Zhivkov & Matev, 2002; 2005). Further increasing the nitrogen rate to N_{24} practically no influence on the size of the yield, as compared to that of N_{16} rate difference is only 1 kg/da (0.1%) and not be warranted statistically. Compared to the non-fertilized control, the application of the N_{24} rate increases the yield from 3.9 to 5.6% or 43-52 kg/da and it is not statistically warranted too. During extremely dry reproductive periods additional yield is less than 20 kg/da but is statistically warranted.

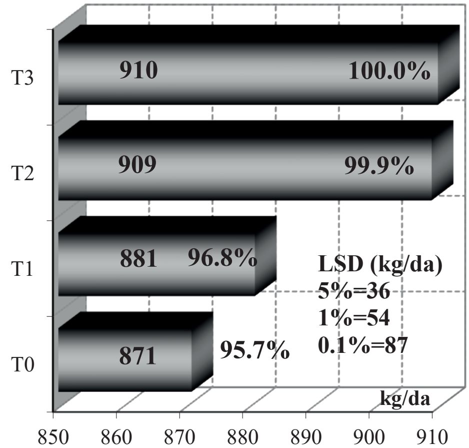

Figure 1. Grain yield depending on nitrogen rate - average for 2004-2007

There is a squire relationship between the relative yield and the relative nitrogen rate (Figure 2). It is established on the basis of data from all variants and years. It is graphically represented as a curve representing a convex parabola that approximates the experimental points at R^2 = 0.732. According to this relationship, fertilization with N_{12} (or 50% of the maximum nitrogen rate) gives 99% of the maximum yield. In the range of 85 to 120% (between N_{20} and N_{30}) of the maximum rate, the yield is maximum, after which it begins to decrease. Figure 3 illustrates the yield change with increasing relative nitrogen rate in the range 0 to 1.4 or between N_0 and N_{34}. The curve is drawn according to the equation of Figure 1, and the results can be used to optimize nitrogen fertilization for grain corn grown under non-irrigation conditions.

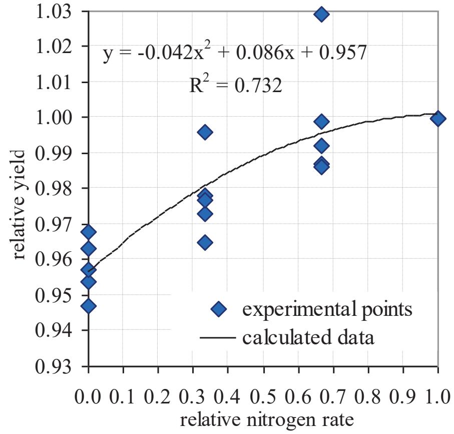

Figure 2. Crop relationship between relative yield and relative nitrogen rate

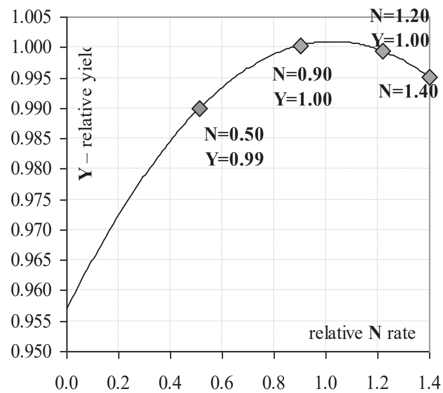

Figure 3. Yield change with increasing relative nitrogen rate

Nitrogen fertilizer use efficiency (NFUE), depending on the rate value

In this study the NFUE is expressed in two ways:

1) As an additional yield (kg/da), obtained from 1 kg/da nitrogen. It is calculated by the formula:

$$NFUE(1) = \frac{\Delta Y}{N_i}$$

Where: $\Delta Y = Y_{Ni} - Y_{N0}$ is the additional yield due to nitrogen fertilization (kg/da); Y_{Ni} - yield at N_i rate (kg/da) and Y_{N0} - yield without fertilization (kg/da);

2) As the amount of nitrogen (kg/da) required to obtain 1 kg/da of additional yield. Is calculated by a reciprocal of the previous formula:

$$NFUE(2) = \frac{N_i}{\Delta Y}$$

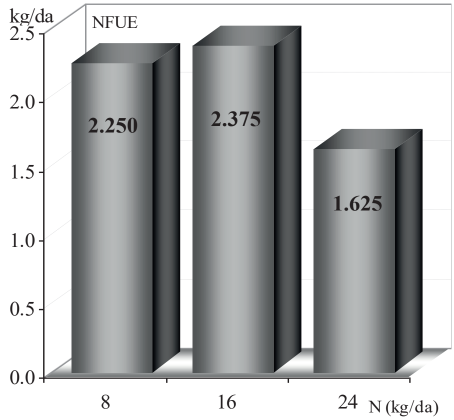

Figure 4. NFUE (1) - average for 2004-2007

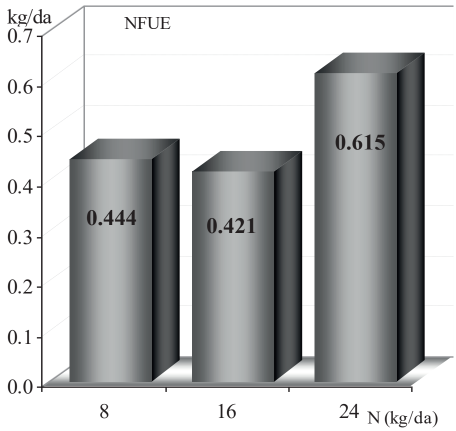

Figure 5. NFUE (2) - average for 2004-2007

As a measure of yield and nitrogen rates is kg/da, the NFUE is obtained and presented as a coefficient.

The results regarding the nitrogen fertilization efficiency are illustrated in Figures 4 and 5. Both graphs show clearly that the highest NFUE is at N_{16}, with an average additional yield of 2.375 kg/da for each 1 kg/da of nitrogen and 0.4211 kg/da of nitrogen is required to obtain 1 kg/da of additional yield. Slightly lower (5.5%) is the fertilization efficiency with N_8, while at N_{24} the difference is more significant (average 46.1%) than that at N_{16}. These results suggest that, under the conditions of the experiment, grain corn under non-irrigation conditions should not be fertilized at rates higher than N_{16}.

The 1000 seeds weight

Table 2. 1000 seeds weight depending on nitrogen rate

Var.	1000 s weight g	to N_0 ±Y /g/	to N_0 %	to N_0 w	to N_{24} ±Y /g/	to N_{24} %	to N_{24} w
2004							
N_0	321	St.	100.0	St.	-24	93.0	b
N_8	323	2	100.6	n.s.	-22	93.6	b
N_{16}	340	19	105.9	b	-5	98.6	n.s.
N_{24}	345	24	107.5	b	St.	100.0	St.
LSD (g) 5% = 12 1% = 19 0.1% = 30							
2005							
N_0	338	St.	100.0	St.	-3	99.1	n.s.
N_8	332	-6	98.2	n.s.	-9	97.4	n.s.
N_{16}	357	19	105.6	n.s.	16	104.7	n.s.
N_{24}	341	3	100.9	n.s.	St.	100.0	St.
LSD (g) 5% = 47 1% = 71 0.1% = 114							
2006							
N_0	320	St.	100.0	St.	34	111.9	n.s.
N_8	289	-31	90.3	n.s.	3	101.0	n.s.
N_{16}	270	-50	84.4	n.s.	-16	94.4	n.s.
N_{24}	286	-34	89.4	n.s.	St.	100.0	St.
LSD (g) 5% = 59 1% = 89 0.1% = 143							
2007							
N_0	225	St.	100.0	St.	-25	90.0	a
N_8	233	8	103.6	n.s.	-17	93.2	n.s.
N_{16}	218	-7	96.9	n.s.	-32	87.2	a
N_{24}	250	25	111.1	a	St.	100.0	St.
LSD (g) 5% = 23 1% = 35 0.1% = 57							
Average for 2004-2007 period							
N_0	301	St.	100.0	St.	-5	98.4	n.s.
N_8	294	-7	97.7	n.s.	-12	96.1	n.s.
N_{16}	296	-5	98.3	n.s.	-10	96.7	n.s.
N_{24}	306	5	101.7	n.s.	St.	100.0	St.
LSD (g) 5% = 27 1% = 40 0.1% = 65							
Y - weight; W – warranty							

The absolute weight of maize seeds under non-irrigation conditions is more influenced by the conditions of the year and, regardless of the nitrogen fertilization rate, values during the more favorable years are within the range characteristic of the hybrid used for the purposes of the study. Significantly smaller absolute weight of seeds is obtained during the extreme 2007 (Table 2).

With regard to fertilization rates, there is little and is not unidirectional impact, without statistical warranty. An exception is the results of the first test year, which show a statistically warranted gradual increase in values with increasing of nitrogen rates. On average over the four experimental years, all differences are not statistically warranted. This gives reason to believe that, under irrigation conditions, the fertilization of maize does not affect the absolute weight of the seeds. These results are confirmed by Wajid et al. (2007) and Siam et al. (2008).

Test weight of the seeds depending on nitrogen rate

Table 3. Test weight of the seeds depending on nitrogen rate

var.	test weight kg/m³	to N_0 ±Y kg/m³	to N_0 %	to N_0 w	to N_{24} ±Y kg/m³	to N_{24} %	to N_{24} w
2004							
N_0	671	St.	100.0	St.	-32	95.4	a
N_8	679	8	101.2	n.s.	-24	96.6	n.s.
N_{16}	706	35	105.2	a	3	100.4	n.s.
N_{24}	703	32	104.8	a	St.	100.0	St.
LSD (kg/m³) 5% = 31 1% = 47 0.1% = 76							
2005							
N_0	708	St.	100.0	St.	3	100.4	n.s.
N_8	700	-8	98.9	n.s.	-5	99.3	n.s.
N_{16}	710	2	100.3	n.s.	5	100.7	n.s.
N_{24}	705	-3	99.6	n.s.	St.	100.0	St.
LSD (kg/da) 5% = 25 1% = 37 0.1% = 59							
2006							
N_0	889	St.	100.0	St.	-42	95.5	n.s.
N_8	928	39	104.4	n.s.	-3	99.7	n.s.
N_{16}	959	70	107.9	n.s.	28	103.0	n.s.
N_{24}	931	42	104.7	n.s.	St.	100.0	St.
LSD (kg/m³) 5% = 79 1% = 120 0.1% = 193							
2007							
N_0	710	St.	100.0	St.	-7	99.0	n.s.
N_8	711	1	100.1	n.s.	-6	99.2	n.s.
N_{16}	721	11	101.5	n.s.	4	100.6	n.s.
N_{24}	717	7	101.0	n.s.	St.	100.0	St.
LSD (kg/m³) 5% = 19 1% = 28 0.1% = 46							
Average for 2004-2007 period							
N_0	745	St.	100.0	St.	-19	97.5	a
N_8	755	10	101.3	n.s.	-9	98.8	n.s.
N_{16}	774	29	103.9	b	10	101.3	n.s.
N_{24}	764	19	102.6	a	St.	100.0	St.
LSD (kg/m³) 5% = 18 1% = 27 0.1% = 43							
Y – test weight; W – warranty							

The data for the effect of nitrogen fertilization on the test weight are presented in Table 3.

With respect to this indicator, the variation by year is more significant than that is accounted over the year when fertilizing with different rates of nitrogen. However, the same trend has been observed here in all the experimental years, namely - the highest test weight of seeds from plants fertilized with N_{16}, despite the fact that the differences are not statistically warranted in three of the experimental years. On average over the experimental period, there is a statistically warranted increase in test weight at N_{16} and N_{24} compared to N_0. The differences between N_8, N_{16} and N_{24} are below 2% and are not statistically warranted. The results in Table 3 give reason to believe that nitrogen fertilization has a relatively small effect on the test weight of maize seed grown under non-irrigation conditions, with the increase in norm in the N_8-N_{24} range practically not changing the values.

Economical analysis

The costs of growing corn are valid for Bulgaria to 2019 and include all the major agricultural activities (tillage, sowing, plant protection and fertilization, harvesting and labor costs). Prices are valid in the presence of own equipment (tractors, combines, sowing machines and more). Revenue is determined on the basis of the exchange rate of the grain in 2019 (577 BGN/t or 0.577 BGN/kg). The summarized results of the economic analysis show that total production (revenue from the sale of production) increases steadily with an increase in the rate of nitrogen fertilization, with the absolute difference between N_0 and N_{24} being 22.5 BGN/da or 4.5% (Table 4). In terms of this indicator, the results at N_{16} and N_{24} are comparable. Production costs also increase steadily with the increase in the nitrogen rate, in which case the rate of increase is the same (11 BGN/da). As a result, an increase in the rate of fertilization increases the cost price of production. It turns out that it is lowest in the variant without fertilization (0.07 BGN/kg) and highest at N_{24} (0.10 BGN/kg). The non-fertilizing variant has a significantly higher rate of profitability than the fertilized variants, with an average difference of 57% over, compared to N_{24}. Of all included economic indicators, the most important for farmers is net income (profit). It is practically the same at fertilization with N_{16} and without fertilization (N_0). Upon fertilization with N_8 and N_{24} net income is lower by 5 to 10 BGN/da. These results suggest that fertilizing maize with nitrogen (using NH_4NO_3) is an economically inefficient activity when it is grown for grain in non-irrigated conditions.

Table 4. Indicators of economic efficiency depending on the rate of nitrogen fertilization

Nitrogen rates (kg/da)			
N_0	N_8	N_{16}	N_{24}
Grain Yield (kg/da)			
871.0	881.0	909.0	910.0
Production cost BGN/kg			
0.577	0.577	0.577	0.577
Total production (sale production revenue) BGN/da			
502.57	508.34	524.49	525.07
Production costs BGN/da			
62	73	84	95
Cost price BGN/kg			
0.07	0.08	0.09	0.10
Rate of profitability %			
710.59	596.35	524.40	452.71
Net income (profit) BGN/da			
440.57	435.34	440.49	430.07

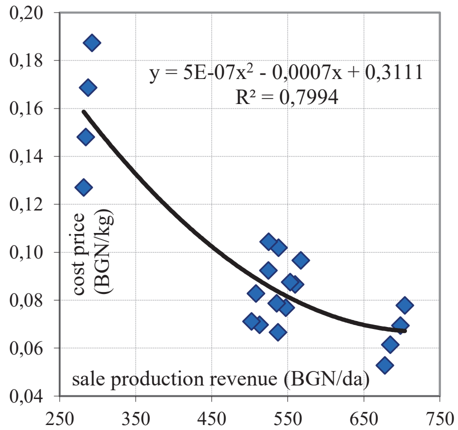

Figure 6. Relationship between sale production revenue and cost price for non-irrigated grain

Based on the economic parameters obtained in all variants and experimental years, some useful for science and practice relationships have been established. Figure 6 shows the relationship between revenue from the sale of production and its cost price, according to which, with the increase in revenue, the cost price gradually decreases and reaches minimum values (0.66 BGN/kg) in the range 695-705 BGN/da. The relationship is squire and is graphically expressed by the concave parabola at $R^2 = 0.799$.

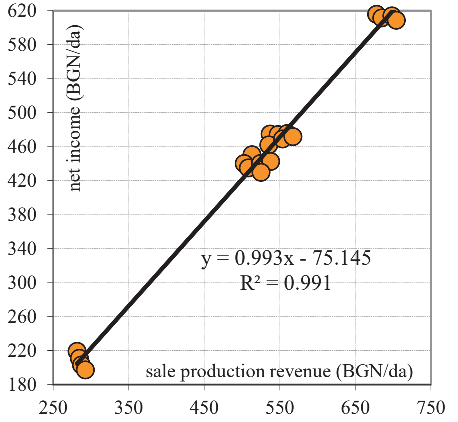

Figure 7. Relationship between sale production revenue and net income for non-irrigated grain

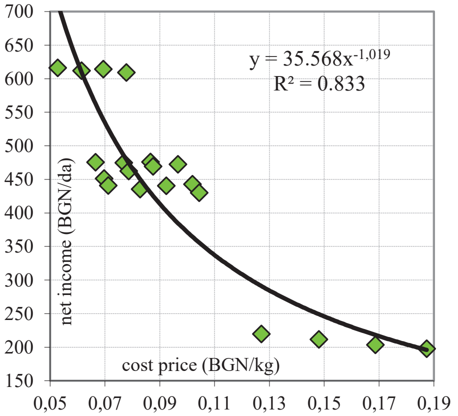

Figure 8. Relationship between cost price and net income for non-irrigated grain

Figure 7 shows the relationship between revenue and net income. It is linear at R^2 = 0.991. There is also a close mathematical relationship between production cost price and net income. It is most accurately expressed as power equation: $Y = 35.568x^{-1.019}$, where Y is the net income and x is the cost price. Graphically, this dependence is a concave curve that approximates the empirical points at $R^2 = 0.833$ (Figure 8).

CONCLUSIONS

The fertilization of non-irrigated corn has a relatively small effect on its productivity and differences from the non-fertilized variant are not statistically warranted. Fertilization with N_8 increases yield by an average of 10 kg/da or 1.1% over the non-fertilized control. With N_{16} fertilization, the yield increase is in the range of 3-8% in the more favorable years and only 2% in the dry years. Average for the four years, the application of N_{16} increases yields by 4.4% or 38 kg/da. Compared to N_8, at N_{16} the yield is on average 28 kg/da or just over 1% and is not statistically warranted. The further increase of the nitrogen rate to N_{24} has practically no effect on the yield, and compared to N_{16} the difference is only 1 kg (0.1%) and is not warranted.

There is a squire relationship between relative yield and relative nitrogen rate at $R^2 = 0.732$. It can be used to solve optimization tasks.

Fertilization rates have little or no impact on the 1000 seeds weight and their test weight.

From an economic perspective, the best results are obtained by N_0 and N_{16}, which gives reason to believe that for the region of Plovdiv, fertilization of grain corn under non-irrigation conditions is ineffective activity.

ACKNOWLEDGEMENTS

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