EFFECT OF NITROGEN RATES ON THE NUTRIENT BALANCES OF GRAIN SORGHUM

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Abstract. *The effect of nitrogen fertilization in rates 0, 60, 120, 180, 240 and 300 kg N.ha^{-1} on the mineral balances of nitrogen, phosphorus and potassium was studied in the experimental field of Agricultural University of Plovdiv, Bulgaria in 2017-2018 under non-irrigated conditions in grain sorghum hybrid EC Alize. Total nitrogen as NH_4NO_3 was applied as pre-sowing fertilization on the background $P_{50}K_{50}$ fertilization as triple superphosphate and potassium chloride, respectively. The experimental design consisted of a randomized, complete block design with four replications. The size of individual trial plots was 20 m^2. It was found that the grain removed 112.6 kg N.ha^{-1}, 51.1 kg P_2O_5.ha^{-1} and 23.7 kg K_2O.ha^{-1} on average in 2017. In the wet vegetation of 2018, the average quantities of nutrients were higher by 20.4%, 12.5% and 49.4%, respectively for nitrogen, phosphorus and potassium. Nitrogen fertilization proven increased the accumulated nitrogen and potassium in the sorghum grain and it slightly affected the grain phosphorus export. The grain nitrogen removal increased in parallel with the applied nitrogen up to N_{180} in 2017, and up to N_{240} in experimental 2018. The most potassium of the grain 27.6 - 43.5 kg K_2O.ha^{-1} was taken up when sorghum was fertilized with N_{180} and N_{240}. The high N_{300} rate significantly decreased accumulated potassium in the grain, compared to the variants fertilized with $N_{120-240}$. Without nitrogen fertilization sorghum grain annually removed 90.6 – 98.4 kg N.ha^{-1}. The mineral balance of nitrogen was a negative when sorghum received 60 - 120 kg N.ha^{-1} and the soil contained less than 40 mg Nmin.kg^{-1} soil. The phosphorus mineral balance changed from -10.9 kg P_2O_5.ha^{-1} at N_{120} rate up to 2.1 kg P_2O_5.ha^{-1} at the N_0 control. Under $P_{50}K_{50}$ background fertilization the mineral balance of phosphorus was a negative in all nitrogen fertilized variants in 2018, and it was a negative at fertilization rates 60, 120 and 180 kg of N.ha^{-1} in 2017. The mineral balance of potassium was a positive at all studied nitrogen levels $N_0 – N_{300}$. After sorghum harvesting, 14.4 - 27.2 kg K_2O.ha^{-1} on average remained in the soil.*

Keywords: *nitrogen, phosphorus, potassium, balance, fertilization, grain sorghum*

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is one of the top ten grown crops in Bulgaria and the modern varieties are hybrids with high productivity potential (KERTIKOV, 2007; KIKINDONOV *ET AL*., 2008). Sorghum has better ability to tolerate drought stress compared with other crops and it is known as an index for drought resistance of agronomic crops (KEBEDE, 2001; WENZEL, 2001). Mineral fertilization is a common practice for crops yield stability in sustainable crop production (FIXEN, 2009). Nitrogen is the main nutrient for the growth and productivity of sorghum and, in the absence of another limiting factor, most strongly limits yields (GERIK *ET AL*., 2014). It involves high energy and production costs in agriculture, it is easily mobile and, its inappropriate use can cause environmental pollution. Effective use of nitrogen is important from an economic and environmental point of view, and must be taken into account in good agricultural practices (DOBERMANN *ET AL*., 2005). The current average nitrogen utilization index of fertilizers for cereal crops, including sorghum, is 30-50% (FIXEN 2009). Rates of nitrogen fertilization for grain sorghum vary and they are most often in the range of 60 to 320 kg N.ha^{-1}, depending on the region and the growing conditions. In dry conditions of Africa and lack of irrigation ability, the fertilization doses are 50-80 kg N.ha^{-1} (STOORVOGEL AND SMALING, 1990). Most often fertilization rates of sorghum grown in non-irrigated conditions are 100-120 kg N.ha^{-1}, but under irrigation or humid conditions fertilization norms are 150-240 kg N.ha^{-1} (GORBANOV, 2010). According to KISSEL (2008), yields higher than 6700 kg N.ha^{-1} requires nitrogen fertilization higher than 150 kg N.ha^{-1}. In the United States, grain sorghum fertilization rates are typically 90-120 kg N.ha^{-1} (DIAZ, 2014, CIAMPITTI *ET AL*., 2014). The yield difference of properly fertilized and unfertilized sorghum may be more than 50% (PAUL, 2009). A key factor for sustainable agricultural production, the obtaining of high and stable yields and preservation of soil fertility is the maintenance of a non-deficit balance of nutrients in the soil (BLAYLOCK *ET AL*., 2005; LADHA *ET AL*., 2005). Studies of nitrogen, phosphorus and potassium balances in Germany for 25 years period showed that phosphorus and potassium surpluses in agriculture declined by 60% since 1980, and the nitrogen surplus has decreased by 23% since 1987 (BACH *ET AL.*, 1998). Results of eighty eight nutrient budgets of nitrogen, phosphorus and potassium in crop rotations of United Kingdom point out nitrogen surplus 83.2 kg N ha^{-1} $year^{-1}$ on average (BERRY *ET AL.*, 2003). The balances of phosphorus and potassium in the same study demonstrate both surpluses and deficits 3.6 kg P ha^{-1} $year^{-1}$, 14.2 kg K ha^{-1} $year^{-1}$ on average. Horticultural systems with manure application show higher surpluses. The studies with wheat, barley and maize on different soil types, demonstrate that the applied fertilizers provide a deficient nitrogen and phosphorus balance except for the higher levels of fertilization (GORBANOV *ET AL.*, 2000; GORBANOV *ET AL.*, 1997; IVANOV *ET AL.*, 1989). In Bulgaria there are insufficient scientific information related to the grain sorghum fertilization and the mineral balances of the main nutrients. The objective of this study was to determine the effect of nitrogen fertilization rates of grain sorghum on the mineral balances of nitrogen, phosphorus and potassium.

MATERIAL AND METHODS

Mineral balances of nitrogen, phosphorus and potassium were studied in the field experiment conducted during the period 2017-2018 on the experimental field of Agricultural University of Plovdiv, Bulgaria. Grain sorghum hybrid EC Alize was grown under non-irrigated conditions. The applied nitrogen fertilization was in rates 0, 60, 120, 180, 240 and 300 kg $N.ha^{-1}$. Total nitrogen as NH_4NO_3 was applied as pre-sowing fertilization on the background $P_{50}K_{50}$ fertilization as triple superphosphate and potassium chloride, respectively. The experimental design was a randomized, complete block design with four replications and a size of experimental plots of 20 m^2 after wheat as predecessor. Standard farming practices for the region of Southern Bulgaria were applied.

Table 1

Content of available nitrogen, phosphorus and potassium in the soil.

Year	Soil depth, cm	Nmin, $mg.kg^{-1}$	P_2O_5, mg.100 g^{-1}	K_2O, mg.100 g^{-1}
2017	0-30	27.6	15.8	21,0
	30-60	22.1	13.9	24.0
2018	0-30	33.8	17.3	23.1
	30-60	20.4	14.1	22.9

The soil type of the experimental field is alluvial-meadow *Mollic Fluvisols* (FAO, 2006) with slightly alkaline reaction pH_{H2O}=7.80. The content of available nutrients in the soil before sowing of the sorghum was determined in soil layers 0-30 and 30-60 cm and pointed out in Table 1. The soil had low content of mineral nitrogen and it was good supplied with available phosphorus (Egner-Ream method) and exchangeable potassium (extracted by 2N HCL).

Meteorological conditions during vegetation period of sorghum were recorded daily in the experimental area and are given in Table 2, together with the long-term average of temperature and precipitations. The values of temperature and precipitations during the vegetation period of sorghum characterized hydro-thermal conditions of 2017 as warm and dry. In contrast, the months of May, June and July of 2018 were characterized as extremely humid. The amount of precipitation exceeded nearly twice the values of long-term norm for the region.

Table 2

Hydro-thermal conditions during sorghum vegetation period.

Year	April	May	June	July	August
	Temperature (°C)				
2017	12.7	17.6	23.7	25.1	25.4
2018	16.4	19.2	28.8	30.5	24.2
Long-term norm	12.2	17.2	20.9	23.2	22.7
	Precipitation ($L.m^{-1}$)				
2017	26.1	52.7	15.4	29.8	9.2
2018	25.0	112.3	118.9	94.7	35.1
Long-term norm	45.0	65.0	63.0	49.0	31.0

The concentrations of nitrogen, phosphorus and potassium were analyzed in sorghum grain after wet digestion by H_2SO_4 and H_2O_2 as a catalyst (MINEEV, 2001). The concentrations of nitrogen and phosphorus were determined by colorimetric methods and potassium concentration was analyzed by the flame photometer model PFP-7. The content of accumulated nitrogen, phosphorus and potassium was obtained by multiplying the dry mass of sorghum grain by the concentration of each nutrient. The mineral balances of nutrients (kg.ha^{-1}) were calculated as the difference between the applied fertilizing element (N, P_2O_5, K_2O) and the removal of nitrogen, phosphorus and potassium by sorghum grain. An overall analysis of variance (ANOVA) was performed to evaluate the effect of the experimental treatments on the referred variables. In order to establish the difference among the means Duncan's multiple range test at level of significance $p \leq 0.05$ was used. Correlation test with significance level reported ($p < 0.05$ or $p< 0.01$) was based on Pearson's correlation coefficient.

RESULTS AND DISCUSSIONS

During the comparatively dry 2017 experimental year, the average grain yield was 5234 kg.ha^{-1}, and under the meteorologically favorable year of 2018, average grain yield was 6803 kg.ha^{-1} (Table 3). Regarding the grain yield of sorghum, the strong proven effect of the nitrogen fertilization of a dose N_{180} was established in 2017. The yield increase was by 25.8% above the control plants. In 2017, the application of N_{120}, N_{240} and N_{300} resulted in similar grain yields 5355 – 5455 kg.ha^{-1}. Higher grain yields of sorghum in 2018 were found at rates N_{240} and N_{180}, which exceeded the N_0 control by 38.4 and 35.7%, respectively.

Table 3.

Productivity of sorghum depending on nitrogen fertilization rates, kg.ha^{-1}

Fertilization	2017		2018	
	Grain	% to N_0	Grain	% to N_0
N_0	4572 ^{d*}	100	5023 ^{d}	100
N_{60}	4897 ^{c}	107.2	5441 ^{c}	108.7
N_{120}	5378 ^{b}	117.7	6090 ^{b}	116.6
N_{180}	5750 ^{a}	125.8	6812 ^{a}	126.6
N_{240}	5455 ^{b}	119.3	6951 ^{a}	124.9
N_{300}	5355 ^{b}	117.3	6180 ^{b}	126.4
Average	5234		6803	

*Values with identical letters within each column are not significantly different at p<0.05 according to Duncan's multiple range test.

Nitrogen removal is the main source of information for optimization of nitrogen fertilization. It depends on various factors as weather conditions, soil reserves, nitrogen doses, amount of biomass formed, and so on. The uptake of nutrients depended on the concentration of the elements in the grain, on the grain yield and on the climatic conditions during the sorghum vegetation period. According to STEWART (2012) sorghum grain uptakes and removes on average 110 kg N, 62 kg P_2O_5 and 45 kg K_2O per hectare area. At the studied nitrogen rates 0-300 kg N.ha^{-1}, sorghum grain accumulated 112.6 kg N.ha^{-1} in 2017 and 135.6 kg N.ha^{-1} in 2018 on average (Table 4). The average export of phosphorus and potassium was 51.1 - 57.5 kg P_2O_5.ha^{-1} and 23.7 - 35.4 kg K_2O.ha^{-1} over the two experimental years.

Table 4.

Effect of nitrogen fertilization on the nitrogen, phosphorus and potassium uptake of sorghum grain

Fertilization	2017		2018	
	kg $N.ha^{-1}$	% to N_0	kg $N.ha^{-1}$	% to N_0
N_0	90.6 ^{d}	100	98.4 ^{f}	100
N_{60}	99.1 ^{c}	109.4	114.8 ^{e}	116.7
N_{120}	116.3 ^{b}	128.4	134.6 ^{d}	136.8
N_{180}	126.5 ^{a}	139.6	155.9 ^{b}	158.5
N_{240}	120.9 ^{ab}	133.5	161.8 ^{a}	164.5
N_{300}	122.1 ^{ab}	134.8	147.9 ^{c}	150.4
Average	*112.6*		*135.6*	
	kg $P_2O_5.ha^{-1}$	% to N_0	kg $P_2O_5.ha^{-1}$	% to N_0
N_0	47.4 ^{ns}	100	48.5 ^{b}	100
N_{60}	53.0	111.9	54.8 ^{b}	113.0
N_{120}	59.3	125.0	62.5 ^{ab}	128.9
N_{180}	53.4	112.6	58.7 ^{ab}	121.1
N_{240}	46.1	97.3	69.2 ^{a}	142.8
N_{300}	47.6	100.4	51.1 ^{b}	105.3
Average	*51.1*		*57.5*	
	kg $K_2O.ha^{-1}$	% to N_0	kg $K_2O.ha^{-1}$	% to N_0
N_0	19.7 ^{d}	100	26.0 ^{d}	100
N_{60}	21.8 ^{c}	110.4	31.4 ^{c}	120.9
N_{120}	24.9 ^{b}	126.3	36.6 ^{b}	140.8
N_{180}	27.6 ^{a}	140.2	43.5 ^{a}	167.4
N_{240}	25.5 ^{b}	129.4	43.5 ^{a}	167.4
N_{300}	22.5 ^{c}	114.2	31.1 ^{c}	119.7
Average	*23.7*		*35.4*	

*Values with identical letters within each column and nutrient are not significantly different at $p<0.05$ according to Duncan's multiple range test.

Under more favorable hydro-thermal conditions in 2018 and higher obtained yields, grain uptook 23.0 kg $N.ha^{-1}$, 6.4 kg $P_2O_5.ha^{-1}$ and 11.7 kg $K_2O.ha^{-1}$ more nutrients compared to their quantities in 2017. The increasing was by 20.4% for nitrogen, by 12.5% for phosphorus and by 49.4% for potassium. The highest nitrogen removal of grain 90.6 - 98.4 kg $N.ha^{-1}$ was observed when sorghum grown without nitrogen fertilization. Nitrogen uptake of the grain increased in nitrogen fertilized plants during both harvested years. The established differences were mathematically proven against to the control plants. As a result of nitrogen fertilization, sorghum grain contained 9.4% - 39.6% more nitrogen in 2017 and 16.7% - 64.5% more in 2018. The amount of nitrogen accumulated in the grain increased with the increasing of applied nitrogen rate up to N_{180} in 2017. At this rate, grain nitrogen was 126.5 kg $N.ha^{-1}$ and exceeded by 39.6% that of the nitrogen-free control plants. The results indicated a tendency of lower amounts of absorbed nitrogen in the treatments with higher N_{240} and N_{300} rates, but the differences with the variant N_{180} were not mathematically proven. In 2017 effect of N_{240} and N_{300} rates on the accumulated grain nitrogen was not proven also with respect to variant N_{120}. During the wet experimental 2018, the positive influence of the studied fertilization N_{60}-N_{300} on the amount of grain nitrogen was significant. The grain of nitrogen received plants contented 16.4 – 63.4 kg $N.ha^{-1}$ more nitrogen, compared to the nitrogen-free control. The nitrogen uptook of grain simultaneously enhanced with of the applied nitrogen doses. The highest amount of grain nitrogen 161.8 kg $N.ha^{-1}$ was obtained with the application of 240 kg $N.ha^{-1}$. The use of a high N_{300} rate significantly reduced the absorbed nitrogen of sorghum grain by 13.9 kg $N.ha^{-1}$.

Table 5.

Mineral balances of nitrogen, phosphorus and potassium depending on nitrogen fertilization.

Fertilization	2017	2018	2017-2018
± kg $N.ha^{-1}$			
N_0	-90.6	-98.4	-94.5
N_{60}	-39.1	-54.8	-47.0
N_{120}	3.7	-14.6	-5.5
N_{180}	53.5	24.1	38.8
N_{240}	119.1	78.2	98.6
N_{300}	177.9	152.1	165.0
Average	*37.4*	*14.4*	
± kg $P_2O_5.ha^{-1}$			
N_0	2.6	1.5	2.1
N_{60}	-3.0	-4.8	-3.9
N_{120}	-9.3	-12.5	-10.9
N_{180}	-3.4	-8.7	-6.0
N_{240}	3.9	-19.2	-7.7
N_{300}	2.4	-1.1	0.7
Average	*-1.1*	*-7.5*	
± kg $K_2O.ha^{-1}$			
N_0	30.3	24.0	27.2
N_{60}	28.2	18.6	23.4
N_{120}	25.1	13.4	19.3
N_{180}	22.4	6.5	14.4
N_{240}	24.5	6.5	15.5
N_{300}	27.5	18.9	23.2
Average	*26.3*	*14.6*	

In 2017, the phosphorus uptake of sorghum grain changed from 47.4 kg $P_2O_5.ha^{-1}$ (at N_0) to 59.3 kg $P_2O_5.ha^{-1}$ (at N_{120}), but the effect of nitrogen fertilization was not mathematically proven (Table 4). A tendency showed higher grain phosphorus content when sorghum plants grown under low to moderate nitrogen rates - N_{60}, N_{120} and N_{180}. In experimental 2018, the accumulated grain phosphorus varied depending on the nitrogen levels from 48.5 kg $P_2O_5.ha^{-1}$ (at N_0) to 69.2 kg $P_2O_5.ha^{-1}$ (at N_{240}). Nitrogen fertilized plants removed 5.3% - 42.8% more phosphorus of the grain compared to the control plants, but significant difference was established between variants N_{240} and N_0 only. Application of 240 kg $N.ha^{-1}$ proven increased the accumulated phosphorus in the grain compared to their values at treatments N_{60} and N_{300}.

The potassium uptake of sorghum grain was higher in the wet 2018 year. The results demonstrated a significant effect of the fertilization within rates 60-300 kg $N.ha^{-1}$ on the accumulated potassium of the grain against the N_0 control during both experimental years. In 2017, nitrogen fertilization increased removed with grain potassium from 10.4% at low N_{60} rate up to 40.2% at N_{180}. During harvested 2018, the amount of grain potassium increased in a range 20.9% (at N_{60}) - 67.4% (at N_{180} and N_{240}), compared to nitrogen-free control plants. The application of a high N_{300} rate in sorghum resulted in lower potassium uptake of grain, compared to the variants fertilized with $N_{120-240}$ rates.

The mineral balance of nitrogen showed positive average values in both experimental years (Table 5). Nitrogen balance was strong negative in the nitrogen-free control N_0 and it was equal to the content of nitrogen in the grain. The results demonstrated that 90.6 - 98.4 kg of $N.ha^{-1}$ was removed from the soil per one year when sorghum grown without nitrogen fertilization. Nitrogen balance was negative at low N_{60} rate in 2017. Higher yields of sorghum grain were obtained in wet 2018 and this led to a negative balance of nitrogen at variants N_{60}

and N_{120}. Application of 60 - 120 kg $N.ha^{-1}$ resulted in negative values of the mineral balance of nitrogen when soil contained below 40 mg $Nmin.kg^{-1}$ before sowing of sorghum. Thus, the lower soil fertility would be expected in the long term period. The differences between applied nitrogen in the soil and nitrogen removal by yields at moderate and higher (N_{180}, N_{240}, N_{300}) rates was positive and its values increased in parallel with the applied nitrogen. At these nitrogen doses, the positive nitrogen balance was within the range of 38.8 kg $N.ha^{-1}$ up to 165.0 kg $N.ha^{-1}$. Nitrogen residues at elevated N_{240} and N_{300} levels indicated inefficient use of nitrogen fertilizer, possible nitrogen losses in the environment, and economic losses for the farmers.

Table 6.

Correlation of nitrogen fertilization of sorghum, N, P, K in the grain and N, P, K mineral balances

Parameters	2017					
	N in the grain	P in the grain	K in the grain	N balance	P balance	K balance
N fertilization	0.867*	-0.271	0.519	0.997**	0.271	-0.519
N in the grain		0.12	0.855*	0.829*	-0.12	-0.855*
P in the grain			0.35	-0.322	-1**	-0.350
K in the grain				0.46	-0.35	-1**
N balance					0.322	-0.46
P balance						0.35
Parameters	2018					
	N in the grain	P in the grain	K in the grain	N balance	P balance	K balance
N fertilization	0.884*	0.366	0.514	0.992**	-0.366	-0.514
N in the grain		0.674	0.853*	0.818*	-0.674	-0.853*
P in the grain			0.854*	0.268	-1**	-0.854*
K in the grain				0.401	-0.854*	-1**
N balance					-0.268	-0.401
P balance						0.854*

**Correlation is significant at the 0.01 level
*Correlation is significant at the 0.05 level

On average, for the period 2017-2018, the mineral balance of phosphorus changed to a relatively narrow range from -10.9 kg $P_2O_5.ha^{-1}$ at N_{120} to 2.1 kg $P_2O_5.ha^{-1}$ in the nitrogen-free control. In 2017, the positive phosphorus balance was established at application of higher N_{240} and N_{300} rates. In 2018, which was characterized by higher yields, a negative mineral balance of phosphorus was found in all nitrogen fertilized variants ranging from -1.1 kg $P_2O_5.ha^{-1}$ (at N_{300}) to -19.2 kg $P_2O_5.ha^{-1}$ at N_{240} (Table 5).

The mineral balance of potassium was positive over both experimental years. In the soil remained from 14.4 kg $K_2O.ha^{-1}$ (at N_{180}) to 27.2 kg $K_2O.ha^{-1}$ (at N_0) on average after sorghum harvesting. The positive balance of potassium was higher in 2017, which was related to the lower grain yields of sorghum and less grain potassium uptake.

The correlation analysis presented in Table 6 showed that nitrogen fertilization very strong and positively correlated with grain nitrogen (r = 0.867* in 2017; r = 0.884* in 2018) and nitrogen mineral balance (r = 0.997** in 2017; r = 0.992** in 2018). Very strong negative relationship was found between accumulated nitrogen in the sorghum grain and potassium mineral balance in both experimental years.

CONCLUSIONS

Sorghum grain removed 112.6 kg $N.ha^{-1}$, 51.1 kg $P_2O_5.ha^{-1}$ and 23.7 kg $K_2O.ha^{-1}$ on average in 2017. In the wet vegetation of 2018, the average quantities of nutrients were higher by 20.4%, 12.5% and 49.4%, respectively for nitrogen, phosphorus and potassium. Nitrogen fertilization proven increased the accumulated nitrogen and potassium in the grain and it slightly affected the grain phosphorus export. The grain nitrogen removal increased in parallel with the applied nitrogen up to N_{180} in 2017 and up to N_{240} in experimental 2018. The most potassium of the grain 27.6 - 43.5 kg $K_2O.ha^{-1}$ was taken up when sorghum was fertilized with N_{180}

and N_{240}. The high N_{300} rate significantly decreased accumulated potassium in the grain, compared to the variants fertilized with $N_{120-240}$. Without nitrogen fertilization sorghum grain annually removed 90.6 – 98.4 kg $N.ha^{-1}$. The mineral balance of nitrogen was a negative when sorghum received 60 - 120 kg $N.ha^{-1}$ and the soil contained less than 40 mg $Nmin.kg^{-1}$ soil. The phosphorus mineral balance changed from -10.9 kg $P_2O_5.ha^{-1}$ at N_{120} rate up to 2.1 kg $P_2O_5.ha^{-1}$ at the N_0 control. Under $P_{50}K_{50}$ background fertilization the mineral balance of phosphorus was a negative in all nitrogen fertilized variants in 2018, and it was a negative at fertilization rates 60, 120 and 180 kg of $N.ha^{-1}$ in 2017. The mineral balance of potassium was a positive at all studied nitrogen levels $N_0 – N_{300}$. After sorghum harvesting, 14.4 - 27.2 kg $K_2O.ha^{-1}$ on average remained in the soil.

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