Original Scientific paper
10.7251/AGRENG2001046T
UDC 633.17:631.84

UPTAKE AND EXPENSE OF NITROGEN, PHOSPHORUS AND POTASSIUM IN GRAIN SORGHUM DEPENDS ON NITROGEN FERTILIZATION

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ABSTRACT

The uptake and expense of nitrogen, phosphorus and potassium in grain sorghum was studied in a field experiment during the period 2017-2018. Hybrid EC Alize was grown under non-irrigated conditions. The applied nitrogen fertilization was in rates 0, 60, 120, 180, 240 and 300 kg $N.ha^{-1}$. It was established that application of N_{240} and N_{300} let to high average uptake of nitrogen (212.0 kg $N.ha^{-1}$) and phosphorus (125.2 kg $P_2O_5.ha^{-1}$) in maturity. The higher removal of 159.9 kg $K_2O.ha^{-1}$ on average was observed at N_{180} rate. The expense of nitrogen for production of 1 t of grain increased in parallel with the nitrogen fertilization. The highest nitrogen expense of 39.7 - 45.3 kg $N.t^{-1}$ grain was established when sorghum received 300 kg $N.ha^{-1}$ and it exceeded the control by 38.8 in 2017 and by 53.6% in 2018. Sorghum plants used 15.5 - 16.6 kg P_2O_5 an average to form 1 t of grain and nitrogen fertilization in rates N_{60}-N_{300} slightly affected the phosphorus expense. Nitrogen fertilization proven increased the expense of potassium for production of 1 t of grain compared to N_0 control plants. The increase was by 8.3 - 20.0% in 2017 and by 8.0 - 34.0% in 2018. Sorghum plants expensed 23.2 - 24.2 kg K_2O on average to form 1 t of grain at nitrogen rates N_{180}-N_{300}. The strong positive correlation was established between nitrogen fertilization with N uptake (0.966**) and N expense (0.997**) and K uptake (0.820*) and K expense (0.870*).

Keywords: *Uptake, Expense, Nutrients, Grain sorghum.*

INTRODUCTION

Nitrogen is the main nutrient for the growth and productivity of sorghum and, in the absence of another limiting factor, most strongly affected the 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 $N.ha^{-1}$ require 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 the preservation of soil fertility is the maintenance of a non-deficit balance of the nutrients in the soil (Fixen, 2009). Nutrients uptake of sorghum is the main source of information for optimization of the fertilization and depends on various factors: weather conditions, soil reserves, nitrogen rates, the amount of dry biomass formed, and others (Ladha et al., 2005). Average removal of main nutrients of sorghum crop is within limits 40–250 kg $N.ha^{-1}$, 20-60 kg $P_2O_5.ha^{-1}$, and 40-250 kg $K_2O.ha^{-1}$ for one vegetation period (Stewart, 2012). The consumption of nitrogen, phosphorus and potassium to form one tone of grain and the corresponding side production is a basic indicator for the efficiency of mineral nutrition. In Bulgaria there is insufficient scientific information related to the total uptake of nutrients of different grain sorghum hybrids. The objective of this study was to investigate the effect of nitrogen rates on the uptake and expense of nitrogen, phosphorus and potassium in grain sorghum.

MATERIAL AND METHODS

The field experiment was 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 layers 0-30 and 30-60 cm.

Year	Nmin, $mg.kg^{-1}$		P_2O_5, $mg.100\ g^{-1}$		K_2O, $mg.100\ g^{-1}$	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
2017	27.6	22.1	15.8	13.9	21.0	24.0
2018	33.8	20.4	17.3	14.1	23.1	22.9

The soil type of the experimental field is alluvial-meadow *Mollic Fluvisols* (FAO, 2006) with slightly alkaline reaction pH_{H2O}=7.80 and content of organic matter 1.3% (Popova et al., 2012). The content of available nutrients in the soil before sowing of the sorghum was determined in soil layers 0-30 and 30-60 cm (Table 1). The soil had low content of mineral nitrogen and it was good supplied with available phosphorus according (Egner-Ream method) and exchangeable potassium (extracted by 2N HCL).

Table 1. Hydro-thermal conditions during sorghum vegetation period.

Year	April	May	June	July	August
	Temperature, ^oC				
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 values of temperature and precipitations during the vegetation period of sorghum characterized hydro-thermal conditions of 2017 as warm and dry (Table 1). 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 the long-term norm for the region. The concentrations of nitrogen, phosphorus and potassium were analyzed in sorghum aboveground parts in maturity 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 uptake of nitrogen, phosphorus and potassium was obtained by multiplying the dry mass of aboveground parts of sorghum ($kg.ha^{-1}$) by the concentration (%) of each nutrient and divided by 100. 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 DISCUSSION

In maturity sorghum plants removed in its above-ground dry biomass an average of 180.7 kg $N.ha^{-1}$ in 2017 and 227.5 kg of $N.ha^{-1}$ in 2018 (Table 2). The average uptake of phosphorus and potassium during the two experimental years was within limits 79.9 - 99.9 kg $P_2O_5.ha^{-1}$ and 106.8 - 146.8 kg $K_2O.ha^{-1}$, respectively.

Table 2. Effect of nitrogen fertilization on the uptake of nitrogen, phosphorus and potassium in sorghum grain and stover.

Fertilization	2017	% to N_0	2018	% to N_0	2017-2018	% to N_0
			kg $N.ha^{-1}$			
N_0	130.9 e	100	148.0 e	100	119.7	100
N_{60}	147.6 d	112.8	175.0 d	118.2	138.4	115.6
N_{120}	182.4 c	139.3	218.1 c	147.4	171.8	143.5
N_{180}	202.9 b	155.0	256.5 b	173.3	196.9	164.5
N_{240}	207.7 ab	158.7	287.4 a	194.2	212.0	177.1
N_{300}	212.5 a	162.3	279.7 a	189.0	210.9	176.2
Average	*180.7*		*227.5*		*175.0*	
			kg $P_2O_5.ha^{-1}$			
N_0	65.4 b	100	72.6 c	100	84.5	100
N_{60}	77.8 ab	119.0	86.5 c	119.1	100.6	119.1
N_{120}	87.2 a	133.3	102.9 b	141.7	116.3	137.6
N_{180}	85.6 a	130.9	109.2 b	150.4	119.0	140.9
N_{240}	80.5 a	123.1	125.0 a	172.2	125.2	148.2
N_{300}	82.8 a	126.6	103.1 b	142.0	113.6	134.5
Average	*79.9*		*99.9*		*109.9*	
			kg $K_2O.ha^{-1}$			
N_0	82.5 e	100	100.3 e	100	95.7	100
N_{60}	95.5 d	115.8	117.5 d	117.1	111.5	116.5
N_{120}	106.9 c	129.6	144.9 c	144.5	131.5	137.4
N_{180}	124.4 a	150.8	182.5 a	182.0	159.9	167.1
N_{240}	117.6 ab	142.5	180.6 a	180.1	155.2	162.2
N_{300}	114.1 bc	138.3	155.2 b	154.7	140.6	146.9
Average	*106.8*		*146.8*		*132.4*	

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

The total removal of the three nutrients depended on the hydro-thermal conditions of the sorghum growing period and the obtained yields of grain and stover. As a result of the wet growing conditions of 2018 and higher productivity of grain and stover, the average uptake of nutrients exceeded by 46.8 kg N.ha-1, 20.0 kg P_2O_5.ha-1 and 40.0 kg K_2O.ha-1 their average values in experimental 2017. Expressed as a percentage, this increase was by 25.9% for nitrogen, 20.0% for phosphorus and 37.4% for potassium. Applied nitrogen in rates 0-300 kg N.ha-1 increased the total removal of nitrogen in maturity by 12.8 - 62.3% in 2017 and by 18.2 - 94.2% in 2018. The established differences were mathematically proven compared to the control without nitrogen. In 2017, the amount of nitrogen accumulated in the above-ground plant parts in maturity increased along with the amount of applied nitrogen fertilization up to N300 rate. In 2018, the greatest nitrogen removal was established at the higher N_{240} and N_{300} rates and it reached 279.7 - 287.4 kg $N.ha^{-1}$.

Without nitrogen fertilization, sorghum plants accumulated in the above-ground dry mass 65.4 - 72.6 kg $P_2O_5.ha^{-1}$. Our results showed no proven differences in the phosphorus uptake between the control variant and the low N_{60} fertilizer variant. In 2017, nitrogen-fertilized plants exported from 19.0 to 33.3% more phosphorus than the control plants. There was a slight effect of nitrogen fertilization in rates N_{60}-N_{300} on the total accumulated phosphorus of sorghum. The values varied from 77.8 kg $P_2O_5.ha^{-1}$ at N_{60} to 87.2 kg $P_2O_5.ha^{-1}$ at N_{120}.

The application of 120-300 kg $N.ha^{-1}$ increased the phosphorus removal with 41.7 to 72.2% compared to the nitrogen-free control in 2018. During the same experimental year, sorghum exported the highest amount of phosphorus 125.0 kg $P_2O_5.ha^{-1}$ when plants were fertilized with 240 kg $N.ha^{-1}$, and the differences were proven against all other variants in the study.

Total potassium uptake of sorghum was higher in the wet vegetation period of 2018 experimental year. This was observed in regard to the control and to all studied nitrogen rates. The influence of applied nitrogen in rates 60-300 kg $N.ha^{-1}$ on the total potassium absorption in maturity was positive and proven against the control variant in both experimental years. Nitrogen fertilization increased the potassium removal by 15.8-50.8% in 2017 and by 17.1-82.0% in 2018. Sorghum accumulated most potassium in the above-ground biomass when plants received 180 and 240 kg $N.ha^{-1}$. The highest rate of N_{300} reduced potassium uptake, compared to variants fertilized with N_{180}-N_{240}.

On average for the period 2017-2018, the application of N_{60} rate increased the amount of nutrients of the above-ground dry biomass in maturity by 15.6% for nitrogen, 19.1% for phosphorus and 16.5% for potassium. The fertilization of the sorghum with higher levels of N_{240} and N_{300} resulted in high average nitrogen and phosphorus removal which reached 212.0 kg $N.ha^{-1}$ and 125.2 kg $P_2O_5.ha^{-1}$, respectively. The application of N_{180} to sorghum let to a high potassium intake of 159.9 kg $K_2O.ha^{-1}$ on average over the studied period.

The expense of nutrients to form 1 t of sorghum grain and the corresponding additional production was higher in all studied variants during the wet 2018 year (Table 3). The average expense of the nutrients in 2018 exceeded the expense in 2017 by 7.9% for nitrogen, 8.0% for phosphorus and 17.4% for potassium. At a unit phosphorus used for grain formation and corresponding additional production, sorghum plants consumed 2.26 units of nitrogen and 1.34 - 1.46 units of potassium. The amount of nitrogen to form 1 t of sorghum grain increased in parallel with the magnitude of the nitrogen rate. This was established over the period 2017 - 2018. The expense of nitrogen for producing 1 t of grain at the high N_{300} rate was 39.7 kg N in experimental 2017 and 45.3 kg N in 2018. These values exceeded the control plants by 38.8% and 53.6%, respectively. Fertilization rates N_{240} and N_{300} showed higher nitrogen consumption to form 1 t of grain and they were less efficient from an agrochemical point of view. The slight effect of nitrogen fertilization on the expense of phosphorus was obtained in 2017. In 2018, a proven difference was established only between the control plants and the plants received N_{240}.

Table 3. Expense of nitrogen, phosphorus and potassium for formation of one ton of sorghum grain and corresponding additional production depends on nitrogen fertilization.

Fertilization	2017	% to N_0	2018	% to N_0	2017-2018	% to N_0
kg $N.t^{-1}$						
N_0	28.6 d	100	29.5 e	100	29.1	100
N_{60}	30.1 cd	105.2	32.2 d	109.2	31.2	107.0
N_{120}	33.9 c	118.5	35.8 cd	121.4	34.9	119.8
N_{180}	35.3 bc	123.4	37.7 c	127.8	36.5	125.4
N_{240}	38.1 ab	133.2	41.4 b	140.3	39.8	136.6
N_{300}	39.7 a	138.8	45.3 a	153.6	42.5	146.0
Average	*34.3*		*37.0*			
kg $P_2O_5.t^{-1}$						
N_0	14.3 ns	100	14.5 b	100	14.4	100
N_{60}	15.9	111.2	15.9 ab	109.7	15.9	110.4
N_{120}	16.2	113.3	16.9 ab	116.6	16.6	114.9
N_{180}	14.9	104.2	16.1 ab	111.0	15.5	107.6
N_{240}	14.7	102.8	18.0 a	124.1	16.4	113.5
N_{300}	15.4	107.7	16.7 ab	115.2	16.1	111.5
Average	*15.2*		*16.4*			
kg $K_2O.t^{-1}$						
N_0	18.0 c	100	20.0 e	100	19.0	100
N_{60}	19.5 b	108.3	21.6 d	108.0	20.6	108.2
N_{120}	19.9 b	110.6	23.8 c	119.1	21.9	115.0
N_{180}	21.6 a	120.0	26.8 a	134.0	24.2	127.4
N_{240}	21.6 a	120.0	26.0 ab	130.0	23.8	125.3
N_{300}	21.3 a	118.3	25.1 bc	125.5	23.2	122.1
Average	*20.3*		*23.9*			

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

Sorghum spent an average of 15.5 – 16.6 kg P_2O_5 to form one ton of grain and corresponding additional production when plants received nitrogen in rates 60-300 kg $N.ha^{-1}$.
Without nitrogen fertilization, sorghum expensed 18.0 - 20.0 kg K_2O to form 1 t of grain. Nitrogen fertilization proven increased the potassium expense by 8.3 - 21.6% in 2017 and by 8.0 - 34.0% in 2018, compared to the control plants. Higher $N_{180-300}$ rates demonstrated higher potassium expense for grain formation 23.2-24.2 kg $K_2O.t^{-1}$ on average for the period 2017-2018.

Table 4. Correlation of nitrogen fertilization, uptake and expense of nitrogen, phosphorus and potassium in grain sorghum average for the period 2017-2018.

Parameters	N uptake	P_2O_5 uptake	K_2O uptake	N expense	P_2O_5 expense	K_2O expense
N fertilization	0.966**	0.801	0.820*	0.997**	0.600	0.870*
N uptake		0.910*	0.934**	0.962**	0.633	0.956*
P_2O_5 uptake			0.942**	0.798	0.801	0.937**
K_2O uptake				0.802	0.567	0.992**
N expense					0.618	0.851*
P_2O_5 expense						0.592

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

Nitrogen fertilization of the sorghum was in a strong positive correlation with N uptake (0.966**) and N expense (0.997**) and K uptake (0.820*) and K expense (0.870*) (Table 4). Proven positive relations were established among uptake of nitrogen, phosphorus and potassium. Expense of nitrogen for formation of one ton of sorghum grain and corresponding additional production strongly and positively correlated with the expense of phosphorus.

CONCLUSIONS

Application of N_{240} and N_{300} rates in grain sorghum let to high average uptake of nitrogen (212.0 kg $N.ha^{-1}$) and phosphorus (125.2 kg $P_2O_5.ha^{-1}$) in maturity. The higher removal of 159.9 kg $K_2O.ha^{-1}$ on average was observed at N_{180} rate. The expense of nitrogen for production of 1 t of grain increased in parallel with the nitrogen fertilization. The highest nitrogen expense of 39.7 - 45.3 kg $N.t^{-1}$ grain was established when sorghum received 300 kg $N.ha^{-1}$ and it was exceeded the control without nitrogen fertilization by 38.8 in 2017 and by 53.6% in 2018. Sorghum plants used 15.5 - 16.6 kg P_2O_5 on average to form 1 t of grain and nitrogen fertilization in rates N_{60}-N_{300} slightly affected the phosphorus expense. Nitrogen fertilization proven increased the expense of potassium for production of 1 t of grain compared to N_0 control plants. The increased was by 8.3 - 20.0% in 2017 and by 8.0 - 34.0% in 2018. Sorghum plants expensed 23.2 - 24.2 kg K_2O on average to form 1 t of grain at nitrogen rates N_{180}-N_{300}. The strong positive correlation was established between nitrogen fertilization with N uptake (0.966**) and N expense (0.997**) and K uptake (0.820*) and K expense (0.870*).

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