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EFFECT OF NITROGEN RATES ON CONCENTRATRION OF NITROGEN, PHOSPHORUS AND POTASSIUM IN SORGHUM

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Abstract

The response of nitrogen, phosphorus and potassium concentration of grain sorghum to nitrogen fertilization in rates 0, 60, 120, 180, 240 and 300 kg N·ha^{-1} was studied in the experimental field of Agricultural University of Plovdiv, Bulgaria in 2017-2019 under non-irrigated conditions. It was established proven effect of nitrogen fertilization on the concentration of nitrogen, phosphorus and potassium in the sorghum straw. The average grain nitrogen concentration ranged from 1.96% N at N_0 to 2.35% at N_{300}. The applying of higher $N_{180-300}$ rates proven increased the concentration of grain nitrogen. The increase of grain phosphorus concentration was up to N_{120} and higher nitrogen rates decreased its value. The hydro-thermal conditions during the sorghum vegetation slightly affected the concentration of nitrogen and phosphorus in plant parts, but the drought conditions in 2017 significantly decreased the grain potassium concentration.

***Key words**: nitrogen, phosphorus, potassium, concentration, sorghum.*

INTRODUCTION

Sorghum (*Sorghum bicolor* (L.) Moench) is the fifth leading cereal grain produced worldwide after wheat, corn, rice, and barley (FAO, 2013). In Bulgaria the production of grain sorghum has increased in recent years and sorghum is one of the top ten grown crops in the country. It can be used as food (grain), feed (grain and biomass), fuel (ethanol production), fiber (paper), fermentation (methane production) and organic by-products (Fernandes et al., 2013). This crop has better abilityto tolerate drought stress compared with other crops andis known as an index for drought resistance ofagronomic crops (Kebede, 2001; Wenzel, 2001). Nutrient uptake of sorghum precedes dry matter accumulation because nutrients are required for growth and dry matter accumulation (Soleymani et al., 2011). Sorghum is mainly grown under non-irrigated fields where stressful conditions during grain filling can limit productivity and increase the dependence of the yield of spare assimilations (Kaye et al., 2007). It is a multipurpose crop belonging to the Poaceae family, which are C_4 carbon cycle plants with high photosynthetic efficiency and productivity (Tari et al., 2012).
Nitrogen is the main nutrient for C_4 plant productivity (Hao et al., 2014). It plays a critical role in cell division during the plant growth (Stals and Inzé, 2001) and the deficit of soil nitrogen leads to lower sorghum biomass due to reductions in leaf area, chlorophyll index, and photosynthetic rate (Zhao et al., 2005; Hirel et al., 2007; Mahama et al., 2014). Nitrogen fertilizer is known to boost the aboveground biomass yield (Amaducci et al., 2004; Anderson et al., 2013). Nitrogen fertilization had a significant impact on the concentration of protein in the grain and grain protein yield (Anfinrud et al., 2013). Application of nitrogen in rates 120-240 kg N·ha^{-1} increase crude protein content to higher levels to support rapid weight gains and milk yields (Hoffman et al., 2001; Kaufman et al., 2013). The nitrogen doses 50-200 kg ha^{-1} contributed to an increase in the crude protein together with an increase in dry matter and/or protein concentration and crude protein increased 59.5-312.9% (Melo et al., 2017). The phosphorus and potassium fertilization slightly affected grain protein yield of sorghum grown under good phosphorus and potassium soil availability (Franco et al., 2017). Improper nitrogen fertilization and excess nitrogen resulted in environmental impacts, such as the pollution by nitrate (NO_3-N) leaching and nitrous oxide emissions (Miller and Cramer, 2004; Ramu et al., 2012), as well as increasing production costs (Marsalis et al., 2010). Thus, coordination of sorghum N demand with N supply is critically important to maximize economic efficiency, optimize biomass quality,

and minimize loss of soil NO_3-N and environmental pollution (Schroder et al., 2000; Zhu et al., 2000; Rooney et al., 2007; Cui et al., 2008; Meki et al., 2017).

The objective of this study was to determine the effect of nitrogen fertilization rates on the concentration of protein in the grain and grain protein yield of sorghum grown under non-irrigated conditions.

MATERIALS AND METHODS

The investigation was carried out during the period 2017-2019 on the experimental field of Agricultural University of Plovdiv, Bulgaria, under non-irrigated conditions after wheat as predecessor. The effect of nitrogen fertilization in rates 0, 60, 120, 180, 240 and 300 kg N·ha^{-1} on the concentration of nitrogen, phosphorus and potassium in the grain and stover was studied at grain sorghum hybrid EC Alize. The experimental design consisted of a randomized, complete block design with four replications. The size of individual trial plots was 20 m^2. 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. 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
2019	0-30	31.8	16.9	24.1
	30-60	24.2	12.8	24.4

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.

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
2019	12.6	18.2	23.4	23.5	24.6
Long-term norm	12.2	17.2	20.9	23.2	22.7
Year	Precipitation (L·m^{-1})				
2017	26.1	52.7	15.4	29.8	9.2
2018	25	112.3	118.9	94.7	35.1
2019	76.5	21.3	196.7	67.5	30.6
Long-term norm	45	65	63	49	31

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. The amount of rainfall during the sorghum vegetation period in 2019 differed sharply from the long-standing value. In May, when sorghum was sown, 3 times less rainfall or 43.7 mm less fell compared to the long-term value of the month.

The concentration of nitrogen, phosphorus and potassium were analyzed in sorghum grain and stover after wet digestion by H_2SO_4 and H_2O_2 as a catalyst (Tomov et al., 2009).

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.

RESULTS AND DISCUSSIONS

Nitrogen fertilization had a positive effect on the percentage of nitrogen in the grain (Table 3). The average nitrogen concentration in sorghum grains varied from 1.96 % N at N_0 and up to 2.35% at N_{300}. The increase in the average concentration of nitrogen in the grain was up to the N_{18}rate, differences between this norm and the increased fertilization variants N_{240} and N_{300} were insignificant. Plants grown without nitrogen fertilization contained least nitrogen in the range of 1.95 and 1.98% N, except in 2017, where the difference between the control and N_{60} was not proven.

Table 3. Grain nitrogen concentration (N, %) depending on nitrogen fertilization

N rate	2017	2018	2019	2017-2019
N_0	1.98^{d}	1.96^{e}	1.95^{e}	1.96^{d}
N_{60}	2.03^{d}	2.11^{d}	2.13^{d}	2.09^{c}
N_{120}	2.16^{c}	2.21^{c}	2.25^{c}	2.21^{b}
N_{180}	2.20^{ab}	2.29^{b}	2.31^{b}	2.27^{ab}
N_{240}	2.22^{ab}	2.33^{b}	2.35^{ab}	2.30^{ab}
N_{300}	2.28^{a}	2.39^{a}	2.39^{a}	2.35^{a}
Year	**2.14^{ns}**	**2.22**	**2.23**	

The conditions of the year did not affect the concentration of nitrogen in the grain and the mean values obtained by year were close to each other. During the drought 2017, the differences between nitrogen concentrations at moderate and higher (N_{180}, N_{240}, N_{300}) rates were unproven and their values did not differ significantly from one another. The results show that the application of the higher N_{300} nitrogen in 2018 and 2019 experimental years resulted in a significantly higher grain nitrogen concentration as well as the highest obtained during the experimental period. Differences between the values of nitrogen concentration in sorghum grain at fertilizer rate N_{180} and N_{240} were not demonstrated on average over the period and separately over the three years of the study.

Nitrogen fertilization raised the average nitrogen content of sorghum stover from 0.67% N at N_0 to 1.17% at N_{300} (Table 4). The effect of nitrogen fertilization had been demonstrated compared to the control over the three years. The lowest concentrations of nitrogen in sorghum stover during the three-year experimental period were obtained in plants that were not fertilized with nitrogen. The nitrogen concentration in the stove was the lowest at $N_{60}$of the nitrogen fertilized variants. Effect of applied high nitrogen N_{240} and N_{300} rates proven to lead to the straw with the highest nitrogen content 1.16-1.17% N, but differences between the averages values were not significance. The nitrogen content of sorghum stover at fertilizer rates N_{120} and N_{180} was not demonstrated on average over the period and separately over the three years of the study. The highest concentrations of nitrogen were obtained during the humid 2018 and 2019 at fertilizer rates of N_{300} and N_{240}. The conditions of the year did not have a significant effect on the nitrogen concentration in the sorghum stover and the obtained average annual values were close.

Table 4. Stover nitrogen concentration (N, %) depending on nitrogen fertilization

N rate	2017	2018	2019	2017-2019
N_0	0.69^{d}	0.69^{e}	0.62^{e}	0.67^{d}
N_{60}	0.76^{c}	0.81^{d}	0.74^{d}	0.77^{c}
N_{120}	0.98^{b}	0.94^{c}	0.98^{c}	0.97^{b}
N_{180}	1.03^{b}	0.95^{c}	0.93^{c}	0.97^{b}
N_{240}	1.15^{a}	1.13^{b}	1.19^{a}	1.16^{a}
N_{300}	1.16^{a}	1.26^{a}	1.10^{b}	1.17^{a}
Year	**0.96^{ns}**	**0.96**	**0.93**	

The average concentration of phosphorus in sorghum grain varied between 1.01% P_2O_5 at N_0 and 0.86% at N_{300} (Table 5). Plants grown without nitrogen fertilization and under conditions of lower fertilizer norms contained the most phosphorus in the range 1.01 and 1.08% of P_2O_5. The increase in the average concentration of phosphorus in the grain was up to N_{120}, with insignificant differences between N_0, N_{60} and N_{120} both on average over the period and in 2019. Fertilizer norms higher than N_{120} leaded to a decrease in the percentage of phosphorus in the grain of sorghum. Differences in the concentration of phosphorus in sorghum grain in 2019 and the average over the period at elevated fertilizer rates N_{180}, N_{240} and N_{30} were insignificant. The conditions of the year did not affect the concentration of phosphorus in the grain and the mean values obtained over the years were very close to each other. In 2017 and 2018, the concentration of phosphorus in the sorghum grain in the all studied variants was slightly influenced by nitrogen fertilization and the differences were insignificant.

Table 5. Grain phosphorus concentration (P_2O_5, %) depending on nitrogen fertilization

N rate	2017	2018	2019	2017-2019
N_0	1.04 ns	0.97 ns	1.02^{b}	1.01^{ab}
N_{60}	1.08	1.01	1.07^{ab}	1.05^{a}
N_{120}	1.10	1.03	1.11^{a}	1.08^{a}
N_{180}	0.93	0.86	0.97^{c}	0.92^{bc}
N_{240}	0.85	1.00	0.93^{c}	0.93^{bc}
N_{300}	0.89	0.83	0.85^{d}	0.86^{c}
Year	**0.98^{ns}**	**0.95**	**0.99**	

Nitrogen fertilization raised the average phosphorus content of sorghum stover from 0.33% P_2O_5 at N_0 to 0.49% P_2O_5 at N_{300} (Table 6). The effect of nitrogen fertilization had been demonstrated compared to the control over the three experimental years. The lowest concentrations of phosphorus in sorghum stover during the three-year experimental period were obtained in non-fertilized plants.

Table 6. Stover phosphorus concentration (P_2O_5, %) depending on nitrogen fertilization

N rate	2017	2018	2019	2017-2019
N_0	0.31^{b}	0.34^{b}	0.33^{d}	0.33^{c}
N_{60}	0.39^{a}	0.43^{a}	0.42^{c}	0.41^{b}
N_{120}	0.41^{a}	0.46^{a}	0.43^{bc}	0.43^{b}
N_{180}	0.43^{a}	0.48^{a}	0.45^{b}	0.45^{ab}
N_{240}	0.46^{a}	0.50^{a}	0.49^{ab}	0.48^{a}
N_{300}	0.45^{a}	0.50^{a}	0.51^{a}	0.49^{a}
Year	**0.41^{ns}**	**0.45**	**0.44**	

Fertilization with moderate and elevated nitrogen levels N_{180}, N_{240} and N_{300}were proven to accumulate the stover with the highest phosphorus content, but differences between their values were not proven.

The concentration of phosphorus in stover in 2017 and 2018 among all fertilized variants were close to each other and the differences were not significant. In 2019, the phosphorus content of sorghum stover increased in parallel and was highest at the N_{240} and N_{300} fertilizer rates. The conditions of the year did not have a significant effect on the phosphorus concentration in the sorghum stover, with the average annual values obtained were close.

The obtained average values for the period 2017-2019 did not indicate a proven effect of nitrogen fertilization on the concentration of potassium in the sorghum grain, despite a tendency for higher values with increasing fertilization up to N_{240} (Table 7). The effect of the more favorable rainfall in 2018 and 2019 on the concentration of potassium in sorghum grains on average from the nitrogen fertilizer rates tested was proven to the dried 2017.

The highest concentrations of potassium in the grain were obtained in variants N_{120}, N_{180} and N_{240}. The differences between these three rates were unproven except for N_{120} in 2018.

Table 7. Grain potassium concentration (K_2O, %) depending on nitrogen fertilization

N rate	2017	2018	2019	2017-2019
N_0	0.43^{c}	0.52^{d}	0.49^{c}	0.48^{ns}
N_{60}	0.44^{b}	0.58^{c}	0.53^{b}	0.52
N_{120}	0.46^{a}	0.60^{bc}	0.58^{a}	0.55
N_{180}	0.48^{a}	0.64^{a}	0.61^{a}	0.58
N_{240}	0.47^{a}	0.63^{ab}	0.62^{a}	0.57
N_{300}	0.42^{c}	0.50^{d}	0.53^{b}	0.48
Year	**0.45^{b}**	**0.58^{a}**	**0.56^{a}**	

The difference between the control and the nitrogen fertilized plants was only demonstrated in 2019. The results show that the application of the higher N_{300}norm proven reduced the potassium concentration in the grain closed to values of the control plants.

In contrast to the concentration of potassium in the grain, nitrogen fertilization raised the average potassium content of sorghum stover from 1.06% P_2O_5 at N_0 to 1.32% P_2O_5 at N_{180} (Table 8). The effect of nitrogen fertilization was demonstrated compared to the control over the three experimental years and averaged over the period. Without nitrogen fertilization, the sorghum stover contained 1.04-1.08% K_2O. Nitrogen fertilization raised the concentration of potassium in sorghum stover to N_{180}. Higher fertilization rates did not increase the concentration of potassium in stover. No differences between fertilizer rate N_{240} and N_{120} were obtained and the values were close to each other. Fertilizing with the high N_{300} norm led to a concentration of potassium in stover of sorghum close to variant N_{60}. Only the average concentration for the period 2017-2019 was an exception. The conditions of the year did not have a significant effect on the concentration of potassium in the sorghum stover, with the obtained average annual values being close.

Table 8. Stover potassium concentration (K_2O, %) depending on nitrogen fertilization

N rate	2017	2018	2019	2017-2019
N_0	1.08^{d}	1.04^{d}	1.06^{d}	1.06^{e}
N_{60}	1.15^{c}	1.16^{c}	1.12^{c}	1.14^{d}
N_{120}	1.22^{b}	1.22^{b}	1.25^{b}	1.23^{b}
N_{180}	1.30^{a}	1.31^{a}	1.35^{a}	1.32^{a}
N_{240}	1.22^{b}	1.23^{b}	1.26^{b}	1.24^{b}
N_{300}	1.17^{c}	1.18^{c}	1.22^{bc}	1.19^{c}
Year	**1.19^{ns}**	**1.19**	**1.21**	

The obtained results indicated that the nitrogen concentration in the sorghum grain was 2.23-2.40 times higher than the concentration of nitrogen of the stover. Similar results were found for phosphorus, with its concentration in the grain exceeding 2.11-2.39 times the percentage of phosphorus in stover. In contrast to these two elements, the potassium content of stover was higher than that of sorghum grain 2.05-2.64 times on average per year.

CONCLUSIONS

Nitrogen fertilization increased the concentration of nitrogen in sorghum hybrid EC Alize from 1.96% N (at N_0) up to 2.35% (at N_{300}) in the grain, and from 0.67% N (at N_0) to 1.17% N (at N_{30}) in the sorghum stover. The applying of higher $N_{180-300}$ rates proven increased the concentration of grain nitrogen over the period 2017-2019. The increase of grain phosphorus concentration was up to N_{120} and higher nitrogen rates decreased its value, but the higher nitrogen rates N_{240} and N_{300} significantly increased the phosphorus concentration of the stover.

The studied nitrogen rates 0-300 kg N·ha^{-1} slightly affected the potassium concentration of the grain, but the percentage of potassium in sorghum stover proven increased with nitrogen rates up to N_{180} with value of 1.32% K_2O. Nitrogen concentration in the sorghum grain was 2.23-2.40 times higher than the concentration of nitrogen of the stover. Similar results were found for phosphorus, with its concentration in the grain exceeding 2.11-2.39 times the percentage of phosphorus in stover. In contrast to these two elements, the potassium content of stover was higher than that of sorghum grain 2.05-2.64 times on average per year. The hydro-thermal conditions during the sorghum vegetation slightly affected the concentration of nitrogen and phosphorus in the plant parts, but the drought conditions in 2017 significantly decreased the average grain potassium concentration.

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