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Concentration of Nitrogen, Phosphorus and Potassium in Sorghum Plants Grown at Different Levels of Nitrogen Nutrition

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Abstract

The pot experiment was conducted in a greenhouse to study the effect of nitrogen nutrition of 0, 200, 400, 600 and 800 mg N.kg^{-1} soil on the concentration of nitrogen, phosphorus and potassium in sorghum plants. The plants were analyzed in 4-5 leaves growth stage by dividing the leaves, stems and roots. It was established that the sorghum plants formed the largest amount of dry biomass when grown at N_{600} level. Higher levels (N_{600} and N_{800}) increased the nitrogen content of stems and roots and phosphorus in all plant parts, but they significantly reduced the nitrogen concentration in the leaves. The concentration of potassium in the leaves and stems increased in parallel with the levels of nitrogen from 3.64% K_2O and 4.02% K_2O at N_0 to 4.42% K_2O and 5.03% K_2O at N_{800}, respectively. The nitrogen level very strongly positively correlated with the nitrogen concentration of roots (r = 0.927**) and the potassium concentration of leaves (r = 0.993**) and stems (r = 0.985**). The relationship between nitrogen fertilization and the nitrogen concentration of leaves was negative (r = - 0.535*). The positive and proven relationship was established between the nitrogen level and the phosphorus concentration of plant organs.

Key words: nitrogen nutrition, phosphorus, potassium, sorghum

Introduction

Sorghum (*Sorghum bicolor* L. Moench) 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). It is one of the five major crops in the world and 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). In the European Union, the production is mainly concentrated in France, Italy and Spain and the total consumption of 850,000 tons in Europe exceeds production (Ivanov, 2006). 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 (Bulgarian Ministry of Agriculture and Foods, Agrostatistics, 2016).

The modern varieties are hybrids with high productivity potential appropriate for application of intensive forage grain production technologies (Kertikov, 2007; Kikindonov et al., 2008). Many agricultural soils have a limited ability to supply available nitrogen for target yields and nitrogen is the most limiting nutrient for cereal crops, including sorghum production (Gerik et al., 2014). The level of nitrogen nutrition has greater effect on growth and yield of sorghum plants than any other essential plant nutrient (Enchev & Kikindonov, 2015). Proper nitrogen nutrition is critical to meet crop needs and indicate considerable opportunities for improving nitrogen use efficiency (Murrel, 2011). The objective of the present study was to establish the effect of different levels of nitrogen nutrition on the dry biomass and concentration of main nutrients - nitrogen, phosphorus and potassium in sorghum plants at 4–5 leaves growth stage.

Material and Methods

The pot experiment was conducted in greenhouse conditions to study the effect of nitrogen nutrition level at 0, 200, 400, 600 and 800 mg $N.kg^{-1}$ soil on the concentration of nitrogen, phosphorus and potassium in sorghum plants. The levels of nitrogen were made by adding of ammonium nitrate dissolved in water. Five plants per pot of hybrid EC Alize were grown under optimal water regime in plastic 5L pots. Each pot contained 3.8 kg air-dry soil and drainage. The soil had slight alkaline reaction (pH = 7.80), low content of mineral nitrogen (13.8 mg $Nmin.kg^{-1}$ soil) and it was well supplied with available phosphorus (178 mg $P_2O_5.kg^{-1}$ soil) and potassium (240 mg $K_2O.kg^{-1}$ soil). The plants were analyzed in 4-5 leaves growth stage by separating them as leaves, stems and roots.

The dry weight of all plant parts was determined after drying for 48 hours at 60 °C. The concentration of nitrogen, phosphorus and potassium was analyzed in each plant part. The sub-samples of 0.5 g ground and dry plant material were mineralized using a wet digestion by H_2SO_4 and H_2O_2 as a catalyst (Mineev, 2001). The concentration of nitrogen and phosphorus in plant samples were determined by colorimetric methods and potassium concentration was analyzed by the flame photometer model PFP-7 (Tomov et al, 2009). An overall analysis of variance (ANOVA) was performed to evaluate the effect of experimental treatments on the referred variables, and the Duncan (1955) multiple range test (p = 0.95) was used in order to determine the difference among the means.

Results and Discussion

Young sorghum plants accumulated 2.39 g DM.pot^{-1} an average when grown under conditions of good water supply and nitrogen fertilization levels 0 – 800 mg N.kg^{-1} soil (Table 1). The largest share from the total dry biomass of plants was distributed to dry mass of roots (41.8 %), followed by the leaf dry biomass (33.9%), and stem dry biomass was the lowest share (24.3%). The nitrogen level had a positive effect on the accumulation of dry biomass in the sorghum organs (Table 1 and Figure 1). Plants formed the largest amount of dry biomass when grown at N_{600} level. The dry mass of roots at this level exceeded twofold the dry mass of unfertilized root at N_0. The accumulation of dry mass in the leaves and stems of sorghum plants grown at N_{600} level exceeded the dry mass of the same parts of sorghum without nitrogen N_0 by 65.2% and 21.8%, respectively (Table 1).

Tab. 1. Effect of nitrogen level on the leaf, stem and root dry biomass of sorghum, g DM.pot^{-1}

Утицај нивоа ђубрења азотом на суву масу листова, стабла и корјена сирка, у g суве масе по саксији

Nitrogen level	Leaves	% to N_0	Stems	% to N_0	Roots	% to N_0	Plants	% to N_0
N_0	0.63 ^{c}	100	0.43 ^{b}	100	0.96 ^{ab}	100	2.02 ^{c}	100
N_{200}	0.70 ^{c}	110.3	0.45 ^{b}	104.8	1.03 ^{a}	107.2	2.17 ^{bc}	107.7
N_{400}	0.93 ^{ab}	148.0	0.68 ^{ab}	157.3	1.08 ^{a}	112.8	2.69 ^{ab}	133.2
N_{600}	1.04 ^{a}	165.2	0.88 ^{a}	205.5	1.17 ^{a}	121.8	3.09 ^{a}	153.1
N_{800}	0.74 ^{bc}	117.7	0.47 ^{b}	108.8	0.75 ^{b}	77.9	1.96 ^{c}	96.9
Average	*0.81*	-	*0.58*	-	*1.00*	-	*2.39*	-

**Values in each column followed by the same letters are not significantly different at p<0.05 according to Duncan's multiple range test.*

The dry biomass of the aerial plant parts (leaves + stems) increased from 1.05 g DM.pot^{-1} at N_0 level to 1.92 g DM.pot^{-1} at N_{600} level, or the increase was by 83.3%. The positive effect of the level of nitrogen nutrition on the root dry mass was established as a trend without proven significant differences.

The influence of low N_{200} fertilization on the accumulated leaf and stem dry mass of sorghum was insignificant compared to unfertilized control.

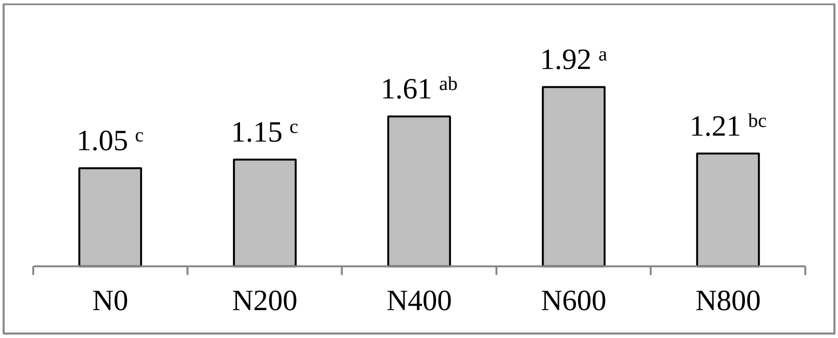

Fig. 1. Effect of nitrogen level on leaf + stem dry biomass of sorghum, g DM.pot^{-1}
Утицај нивоа ђубрења азотом на суву масу лишћа+стабла сирка, у g суве масе по саксији

The growing of sorghum plants at nitrogen levels exceeding N_{600} resulted in significantly less dry mass accumulation and of individual organs, namely leaves, stems and roots.

Tab. 2. Effect of nitrogen level on the concentration of nitrogen (N %) in sorghum plants
Утицај нивоа ђубрења азотом на концентрацију азота (N %) у биљкама сирка

Nitrogen level	Leaves	% to N_0	Stems	% to N_0	Roots	% to N_0
N_0	5.01 ^{a}	100	3.72 ^{b}	100	1.78 ^{d}	100
N_{200}	4.91 ^{ab}	98.0	3.75 ^{b}	100.9	2.22 ^{c}	124.9
N_{400}	4.85 ^{ab}	96.8	3.87 ^{ab}	104.0	2.23 ^{c}	125.3
N_{600}	4.66 ^{b}	93.0	4.07 ^{a}	109.4	2.48 ^{b}	139.2
N_{800}	4.62 ^{b}	92.2	4.06 ^{a}	109.1	2.95 ^{a}	165.9
Average	*4.81*	-	*3.89*	-	*2.33*	-

**Values in each column followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test.*

The average nitrogen concentration of sorghum plant organs in 4-5 leaf stage was 4.81 % N in the leaves, 3.89% N in the stems and 2.33% N in the roots (Table 2). The plant leaves grown without nitrogen fertilization contained 5.01% N. The effect of nitrogen level on the nitrogen concentration of different plant organs was unidirectional. The percentage of leaf nitrogen changed from 4.62% N in the plants grown at N_{800} level to 5.01% N in the leaves of control plants N_0. No proven differences were found in the leaf nitrogen concentration in the plants grown using N_{200} – N_{800} fertilization levels. The results demonstrated that higher levels of nitrogen, N_{600} and $N_{800,}$ led to significantly lower leaf nitrogen concentration compared to the control leaves at the N_0 level. This was probably due to the "dilution effect" established for other crops, when leaf growth and dry mass accumulation exceed the nitrogen absorption per unit of dry mass. Unlike leaves, nitrogen fertilization increased the percentage of nitrogen in the stems and the differences were significant at higher N_{600} and N_{800} levels compared to the non-fertilized plants.

The root nitrogen content increased in parallel with the increasing of nitrogen level and ranged from 1.78% N at N_0 to 2.95% N at N_{800}. The differences between the investigated nitrogen levels were mathematically proven, with the exception of the difference relating to the root nitrogen concentration between the N_{200} and N_{400} levels.

Tab. 3. Effect of the nitrogen level on the concentration of phosphorus (P_2O_5%) in sorghum plants
Утицај нивоа ђубрења азотом на концентрацију фосфора (P_2O_5 %) у биљкама сирка

Nitrogen level	Leaves	% to N_0	Stems	% to N_0	Roots	% to N_0
N_0	0.558 ^{c}	100	0.634 ^{b}	100	0.528 ^{b}	100
N_{200}	0.589 ^{b}	105.6	0.631 ^{b}	99.6	0.506 ^{b}	95.8
N_{400}	0.633 ^{a}	113.5	0.661 ^{b}	104.2	0.560 ^{ab}	106.0
N_{600}	0.655 ^{a}	117.4	0.762 ^{a}	120.1	0.628 ^{a}	118.9
N_{800}	0.632 ^{a}	113.2	0.751 ^{a}	118.4	0.601 ^{a}	113.8
Average	*0.613*	-	*0.688*	-	*0.565*	-

**Values in each column followed by the same letters are not significantly different at p<0.05 according to Duncan's multiple range test.*

The average concentration of phosphorus in the sorghum plants was of similar value - 0.613% P_2O_5 in the leaves, 0.688% P_2O_5 in the stems, and 0.565% P_2O_5 in the roots (Table 3). Growing plants at higher level (N_{600} and N_{800}) resulted in significantly higher P_2O_5 content of the sorghum organs.

The highest average potassium concentration of 4.59% K_2O in a 4-5 leaf growth stage was found in the stems, followed by the potassium content in the leaves - 4.00% (Table 4).

Tab. 4. Effect of nitrogen level on the concentration of potassium (K_2O%) in sorghum plants
Утицај нивоа ђубрења азотом на концентрацију калијума (K_2O %) у биљкама сирка

Nitrogen level	Leaves	% to N_0	Stems	% to N_0	Roots	% to N_0
N_0	3.64 ^{d}	100	4.02 ^{e}	100	1.72 ^{ns}	100
N_{200}	3.79 ^{d}	103.9	4.39 ^{d}	109.2	1.78	103.5
N_{400}	3.97 ^{c}	109.1	4.64 ^{c}	115.4	1.84	107.0
N_{600}	4.20 ^{b}	115.4	4.87 ^{b}	121.1	1.82	105.8
N_{800}	4.42 a	121.4	5.03 ^{a}	125.1	1.79	104.1
Average	*4.00*	-	*4.59*	-	*1.79*	-

**Values in each column followed by the same letters are not significantly different at $p<0.05$ according to Duncan's multiple range test.*

The roots contained 1.79% K_2O on average and the level of nitrogen nutrition slightly affected this concentration. The concentration of potassium in leaves and stems increased in parallel with the level of nitrogen. With no nitrogen fertilization the leaves and stems contained 3.64% K_2O and 4.02% K_2O, respectively. As a result of applied N_{800} fertilization, the potassium concentration in these organs increased by 21.4% and 25.1%, respectively.

The performed correlation analysis did not demonstrate a definite relationship between studied nitrogen level in a range from N_0 to N_{800} and the dry mass of the plants (Table 5).

Tab. 5. Correlation between nitrogen nutrition and dry biomass in sorghum plants
Корелација између исхране азотом и суве биомасе биљака сирка

Parameters	Leaves	Stems	Roots	Leaves+ Stems	Plants
N level	0.283	0.382	0.437	0.346	0.398
Leaves		0.832**	0.431	0.961**	0.921*
Stems			0.612**	0.953**	0.957**
Roots				0.541*	0.698*
Leaves+Stems					0.980**

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

The correlation analysis did not demonstrate a definite relationship between the studied nitrogen level ranging from N_0 to N_{800} and the plant dry mass (Table 5). Dry mass of aboveground plant parts strongly correlated with leaf dry mass (r = 0.961 **) and stem dry mass (r = 0.953**).

The nitrogen level very highly and positively correlated with the root nitrogen concentration (r = 0.927**) and the leaf (r = 0.993**) and stem (r = 0.985**) potassium concentration (Table 6).

Tab. 6. Correlation between nitrogen nutrition, concentration of nitrogen, phosphorus and potassium in sorghum plants
Корелација између исхране азотом, те концентрације азота, фосфора и калијума и биљкама сирка

Parameters	N leaves	N stems	N roots	P_2O_5 leaves	P_2O_5 stems	P_2O_5 roots	K_2O leaves	K_2O stems	K_2O roots
Nitrogen level	-0.535*	0.556*	0.927**	0.771**	0.796**	0.643**	0.993**	0.985**	0.535*
N leaves		-0.374	-0.531*	-0.242	-0.454*	-0.286	-0.477	-0.527	-0.057
N stems			0.526*	0.502*	0.774**	0.569**	0.555*	0.601**	0.042
N roots				0.537*	0.704**	0.489*	0.931**	0.906**	0.440
P_2O_5 leaves					0.719**	0.732**	0.744**	0.831**	0.683**
P_2O_5 stems						0.894**	0.819**	0.800**	0.301
P_2O_5 roots							0.659**	0.669**	0.408
K_2O leaves								0.966**	0.510
K_2O stems									0.601**

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

There was a positive correlation between the nitrogen level and the stem nitrogen content, whereas the relationship between nitrogen fertilization and the leaf nitrogen concentration was negative (r = 0.535*). According to Almaliev et al. (2013), the concentration of phosphorus in durum wheat genotypes in tillering was slightly dependent on nitrogen fertilization. The positive and proven relationship was established in this study for sorghum plants between the nitrogen level and the phosphorus concentration in plant organs. A positive relationship between nitrogen and phosphorus (r = 0.774**), nitrogen and potassium (r = 0.601**), and phosphorus and potassium (r = 0.985**) was proven in the sorghum leaves. Similar results were obtained for young genotypes of durum wheat in tillering (Almaliev et al., 2013).

Conclusion

Sorghum plants formed the largest amount of dry biomass when grown at the N_{600} level. The leaf + stem dry mass increased from 1.05 g DM.pot^{-1} at N_0 level to 1.92 g DM.pot^{-1} at N_{600} level, or the increase was by 83.3%. Nitrogen levels exceeding N_{600} resulted in significantly less dry mass accumulation. Higher levels, N_{600} and N_{800}, led to significantly lower nitrogen concentration in the leaves compared to the N_0 control, but the same level increased the stem and root nitrogen content. The average concentration of phosphorus in sorghum organs was of similar value - 0.613% P_2O_5 in the leaves, 0.688% P_2O_5 in the stems, and 0.565% P_2O_5 in the roots. Growing plants at higher levels (N_{600} and N_{800}) resulted in significantly higher phosphorus content in the sorghum organs.

The concentration of potassium in the leaves and stems increased in parallel with the levels of nitrogen from 3.64% K_2O and 4.02% K_2O at N_0 to 4.42% K_2O and 5.03% K_2O at N_{800}, respectively. The nitrogen level very strongly and positively correlated with the root nitrogen concentration (r = 0.927**) and the leaf (r = 0.993**) and stem (r = 0.985**) potassium concentration. The relationship between nitrogen fertilization and the leaf nitrogen concentration was negative (r = 0.535*). The positive and proven relationship was established between the nitrogen level and the phosphorus concentration in plant organs.

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Концентрација азота, фосфора и калијума у биљкама сирка, гајеним у условима ђубрења различитим дозама азота

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Сажетак

Експеримент је спроведен у стакленику, у циљу проучавања утицаја ђубрења азотом у третманима од 0, 200, 400, 600 и 800 mg N/kg на концентрацију азота, фосфора и калијума у биљкама сирка. Биљке су анализиране у фази 4-5 листова, посебно за листове, стабло и корјен. Утврђено је да су биљке сирка имале највећу масу суве биљке у третману ђубрења са азотом N_{600}. Виши нивои ђубрења азотом (N_{600} и N_{800}) утицали су на повећање садржаја азота у стаблу и корјену, као и фосфора у свим биљним органима, али су значајно смањили концентрацију азота у листовима. Концентрација калијума у листовима и стаблу повећавала се истовријемено са повећањем нивоа ђубрења азотом, од 3.64 % K_2O и 4.02 % K_2O у третману N_0 до 4.42 % K_2O и 5.03 % K_2O у третману N_{800}. Ниво ђубрења азотом је имао веома јаку позитивну корелацију са концентрацијом азота у корјену (r = 0.927**) и концентрацијом калијума у листовима (r = 0.993**) и стаблу (r = 0.985**). Утврђена је негативна корелација (r = - 0.535*) између нивоа ђубрења азотом и концентрације азота у листовима. Позитивна корелација постојала је између нивоа ђубрења азотом и концентрације фосфора у биљним органима.

Кључне ријечи: исхрана азотом, фосфор, калијум, сирак

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