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REGULAR ARTICLE

The effect of nitrogen fertilization on morphology traits of sweet sorghum cultivated on sandy soil

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ABSTRACT

The paper presents results of the experiment conducted in 2010-2012 on the influence of nitrogen fertilizer type (ammonium sulfate, calcium nitrate, ammonium nitrate and urea) on sweet sorghum cultivated on sandy soil. Selected morphological traits and fresh and dry matter biomass were analyzed. Although fertilization significantly increased fresh and dry aboveground biomass, it did not affect sweet sorghum yield. Fresh aboveground biomass was highest under fertilization with ammonium nitrate (59.3 t ha^{-1}). Fertilization influenced also yield growth rate, which ranged from 23.3 t ha^{-1} (under fertilization with urea) to 26.5 t ha^{-1} (under fertilization with ammonium nitrate). The highest dry matter content (26.1%) and dry matter yield (15.3 t ha^{-1}) were obtained under ammonium sulfate. Nitrogen efficiency was affected by nitrogen fertilization and ranged from 40.4 (under fertilization with urea) to 52.4 kg D.M. kg^{-1} N (under fertilization with ammonium sulfate). On the contrary, nitrogen physiological efficiency was not affected.

Key Words: *sorghum; nitrogen fertilizers; biometrical measurements; biomass productivity.*

INTRODUCTION

Sweet sorghum (*Sorghum bicolor* (L.) Moench) belongs to *Poacea* family. It is characterized by efficient C4 photosynthesis and better use of water and nitrogen than most C3 plants (Zhao et al. 2005). Its valuable traits are high green matter yield (up to 65 t ha^{-1}), large lodging resistance, high content of soluble sugars, and drought tolerance (Sowiński and Liszka-Podkowa 2008).

Sweet sorghum is one of the most important cereals for global agriculture (Nadir et al. 2009). Considering crop area, it is the fifth cereal species after wheat, rice, maize and barley, but is mainly cultivated in semi-arid and arid regions of the world (Borghi et al. 2013). It is used for seed, green matter (for both direct feeding animals and silage) and industrial purposes (paper, starch and spirits) (Rego et al. 2003). In Poland, however, sweet sorghum is of lesser economic importance. Kański et al. (2008) studied possibilities of its introduction in Polish agricultural conditions as an alternative species for maize as silage feedstock. They recommended cultivation of sweet sorghum on light soils under water shortage, conditions poor for maize.

Among the three basic macroelements commonly applied in fertilization, nitrogen has the quickest and greatest effect on plant yielding (Kucharzewski and Nowak 2008). Despite that, the effect of nitrogen fertilizer type on sorghum plant morphology and biomass yielding on sandy soil has seldom been studied (Barbanti et al. 2006, Sowiński and Liszka-Podkowa 2008). This research, thus, aimed to study the sweet sorghum yielding in soil and climate conditions of south-west Poland under various schemes of nitrogen fertilization. We hypothesized that a type of nitrogen fertilizer affects fresh and dry matter yield, morphological traits, as well as efficiency of nitrogen use.

MATERIALS AND METHODS

The experiment was carried out in 2010-2012 in the experimental fields in Pawłowice, belonging to the Department of Crop Production at the Wrocław University of Environmental and Life Sciences (51°09′N and 17°06′E, 120 m a.s.l.). The one-way experiment was arranged in a randomized block design with four replications, on a sandy soil, classified as V soil class belonging to brunic arenosols (IUSS Working Group WRB 2014). Soil chemical composition was close to optimal for sorghum, with macronutrient content on average or high level, covering sorghum needs (Table 1). High macronutrients content resulted from intensive crop production in this area. The field have been used for experiments for over 20 years. Sweet sorghum is well adapted to varying soil pH, with its optimum from 5.8 to 8.5; the soil pH in this experiment was within this range (Table 1). Sorghum can be cultivated on a wide range of soils, thus being an alternative crop to other grain crops mostly on poor acid soils.

Table 1. Soil characteristics of the experimental field

Year	pH	P	K	Mg
	1 M KCl	mg kg^{-1}		
2010	6.3	45.7	55.9	15.1
2011	6.7	302.0	236.0	34.9
2012	5.6	152.9	62.2	14.3

The plot area was 14.7 m^2 (7 m long and 2.1 m wide). Plots without nitrogen fertilization represented the control treatment. Before sowing, mineral fertilization was applied in the following doses: 70 kg P_2O_5 ha^{-1} in the form of triple superphosphate, 120 K_2O ha^{-1} in the form of potassium salt, and 120 kg N ha^{-1} in the form determined by the treatment (ammonium sulfate, calcium nitrate, ammonium nitrate and urea). Sucrosorghum 304 hybrid (SS304), produced by Sorghum Partners® company, the USA, with high content of soluble carbohydrates, was sown in the first half of May, in the density of 20 germinating seeds 1 m^{-2}. Sorghum was harvested at the end of September, when plants, depending on weather conditions, were in stages from formation of grain to milk-dough. The number of plants per unit area was determined twice (at the beginning and at the end of a growing season). In the period of stem growth, its dynamics was measured every two weeks. After harvest the sample was collected to measure number of leaves, number of nodes, and node diameter, and to determine dry matter content. Dry matter yield was estimated as a product of aboveground biomass and dry matter content.

Fertilization efficiency was expressed as nitrogen efficiency (which determines yield growth rate per nitrogen unit used in fertilizers) and nitrogen physiological efficiency. These indices were determined as (Sosnowski 2012):

$$AE = \frac{YN - Y0}{N} \quad (1)$$

$$PE = \frac{YN - Y0}{UN - U0} \quad (2)$$

where AE is the nitrogen efficiency, PE is the nitrogen physiological efficiency, YN is yield from the fertilized treatment with the nitrogen dose applied (120 kg N ha^{-1}), Y0 is yield from the control treatment (without nitrogen fertilization), N is the nitrogen dose provided to the YN treatment (N=120 kg ha^{-1}), UN is nitrogen uptake obtained from YN treatment, and U0 is nitrogen uptake obtained from Y0 control treatment.

A two-way analysis of variance was carried out to estimate the main effects of fertilizer type and year and their interaction on the variability of the studied parameters. We used Statistica 10 (StatSoft 2011) for statistical analyses. The significance level was 0.05.

RESULTS AND DISCUSSION

During the vegetation seasons, average air temperature and rainfall were higher than the multiyear average from 1981-2010 (Table 2). Three months' average temperature (May 2010, September 2010 and July 2011) was smaller than the long-term average. Water deficit, noted at the beginning of the 2011 growing season (Table 2), did not affect dry matter yield, which was highest in the three years studied.

Table 2. Weather characteristics during 2010-2012

Month	Temperature				Rainfall			
	Differences from multiyear's average			Multiyear's average	Differences from multiyear's average			Multiyear's average
	2010	2011	2012	1981-2010	2010	2011	2012	1981-2010
Apr	1.0	3.0	1.2	8.6	14.9	-3.5	-2.9	30.5
May	-1.4	0.4	1.5	14.3	89.4	-1.9	12.4	51.3
Jun	1.0	2.0	0.3	17.0	-26.6	36.2	35.2	59.5
Jul	2.7	-1.1	1.0	19.0	-0.3	92.0	29.1	78.9
Aug	1.0	1.0	1.2	18.1	47.4	17.2	11.5	61.7
Sep	-0.8	1.9	1.1	13.5	88.8	-14.9	7.3	45.3
Average/ sum	0.6	1.2	1.0	15.1	213.6	125.1	92.6	327.2

Nitrogen fertilization affected plant height, starting from the third measurement period (Table 3). Mean (within the three-year period) maximum height of the fertilized plants in the last term ranged from 241.2 cm (fertilized with urea) to 250.4 cm (fertilized with ammonium sulfate). Non-fertilized plants were significantly lower, with mean height of 198.3 cm. In 2010, the highest number of leaves was noted after application of ammonium nitrate, in 2011, without fertilization, and in 2012, after fertilization of calcium nitrate and ammonium sulfate. On average across years, fertilization did not differentiate number of leaves (Table 4). In 2010, fertilization with ammonium nitrate application provided the highest number of nodes; in 2011, it did not influence number of nodes; in 2012, however, fertilization with ammonium nitrate led to the highest number of nodes. Fertilization with calcium nitrate and ammonium sulfate led to the largest mean shoot diameter (20.6 and 20.5 mm, respectively). In the study by El-Lattief (2011), application of ammonium nitrate in three doses provided the highest plants (315.8 cm) with the largest shoot diameter (2.33 cm); the highest number of nodes was observed after fertilization with ammonium sulfate in three doses. Ahmed et al. (2007)

reported that mean plant height of sorghum fertilized with ammonium sulfate and urea was similar (147 cm) while plants fertilized with ammonium nitrate were significantly higher (mean of 158 cm). The authors observed the highest numbers of leaves and internodes after application of ammonium nitrate (8.5 and 7.1, respectively).

Table 3. The effect of fertilizer type on sorghum growth dynamic. . Average from years 2010-2012

Fertilizer type	Stem height (cm) - measurement				
	First	Second	Third	Fourth	Fifth
	Means from 2010-2012				
Without fertilization	47.1a	87.2a	120.3a	163.9a	198.3a
Amonium sulfate	57.9a	104.2a	166.7b	214.6b	250.4b
Calcium nitrate	55.0a	107.7a	158.7b	210.9b	246.8b
Amonium nitrate	62.4a	116.1a	161.5b	212.9b	248.1b
Urea	58.6a	104.5a	159.1b	214.1b	241.2b
P-value	0.381	0.070	0.001	<0.001	<0.001
	Means from the fertilization forms				
2010	34.4a	88.1a	132.3a	194.0a	215.9a
2011	64.6b	105.2b	166.1b	211.4a	256.1b
2012	69.6b	118.5b	161.4b	204.5a	238.9b
P-value	<0.001	<0.001	0.001	0.198	0.001
	Interaction fertilization × years (FxY)				
P-value	0.833	0.846	0.928	0.585	0.533

Table 4. The effect of fertilizer type on number of leaves and node, stem diameter (mm). Average from years 2010-2012

Fertilizer type	No. of leaves	Node number	Stem diameter
	Means from 2010-2012		
Without fertilization	10.6a	8.9a	20.2a
Amonium sulfate	10.4a	8.8a	20.5a
Calcium nitrate	10.5a	9.5a	20.6a
Amonium nitrate	10.6a	10.0a	19.8a
Urea	10.1a	9.7a	19.2a
P-value	0.789	0.107	0.403
	Means from the fertilization forms		
2010	10.7b	9.3b	20.2b
2011	9.8a	8.6a	19.0a
2012	10.9b	10.3c	21.0b
P-value	0.001	<0.001	0.003
	Interaction: fertilization × years (FxY)		
P-value	0.001	<0.001	0.227

Fertilization affected aboveground mass and dry matter yield. The various fertilizers, however, did not differentiate sorghum yield (Table 5). The highest aboveground biomass (59.3 t ha^{-1}) was obtained after application of ammonium nitrate and was 26.5 t ha^{-1} higher than control . Sorghum fertilized with ammonium sulfate had the highest dry matter content (26.1% fresh matter) and dry matter yield (15.3 t ha^{-1}). Plants from the control treatment had the lowest dry matter content (24.2% fresh matter).

Mean dry matter yield ranged from 6.0 t ha^{-1} (under fertilization with urea) to 7.4 t ha^{-1} (under fertilization with ammonium sulfate). El-Lattief (2011) reported the highest mean dry matter yield rate of 28 t ha^{-1}; the highest yield (40.8 t ha^{-1}) was obtained after fertilizing sorghum with ammonium nitrate in three doses while the lowest yield (lower by 12.8 t ha^{-1}) after fertilization with ammonium sulfate in two doses.

Table 5. Fresh and dry matter biomass (t per ha) and dry matter content (%). Average from years 2010-2012

Fertilizer type	Aboveground biomass	Dry matter content %	Dry matter yield
	Means from 2010-2012		
Without fertilization	32.8a	24.2	7.9a
Amonium sulfate	58.5b	26.1	15.3b
Calcium nitrate	56.9b	25.3	14.5b
Amonium nitrate	59.3b	25.2	15.0b
Urea	55.0b	25.2	13.9b
P-value	<0.001	N/A.	<0.001
	Means from the fertilization forms		
2010	43.5a	23.2	10.1a
2011	57.3a	29.5	16.9b
2012	54.5a	23.3	12.7a
P-value	0.054	N/A.	<0.001
	Interaction: fertilization × years (FxY)		
P-value	0.444	N/A	0.482

N/A - Not available, because dry matter content was estimated based on a common sample from all replications for the given treatment

Table 6. Nitrogen efficiency (kg D.M. per kg N) and nitrogen physiological efficiency (kg D.M. per kg uptaked N)

Fertilizer type	Efficiency	
	Nitrogen	Nitrogen physiological
	Means from 2010-2012	
Amonium sulfate	52.4a	120.8a
Calcium nitrate	45.3a	96.5a
Amonium nitrate	49.9a	91.6a
Urea	40.4a	91.2a
P-value	0.804	0.692
	Means from the fertilization forms	
2010	54.4b	76.9a
2011	31.2a	114.3a
2012	55.4b	108.9a
P-value	0.008	0.212
	Interaction: fertilization × years (FxY)	
P-value	<0.001	<0.001

The best year for sorghum cultivation was 2011, with high aboveground biomass (57.3 t ha^{-1}) and dry matter yield (16.9 t ha^{-1}). This year, sorghum was harvested in milk-dough maturity stage of grain and dry matter content was high (29.5%). It was due to favorable weather: water deficit at the beginning of the growing season, high temperature, and high rainfall in June, July and August. Marsalis at al. (2010) also reported that forage sorghum yielded at a similar level as maize (24.4 D.M. t ha^{-1}) and had similar dry matter content; they conducted their experiment, however, in different climatic conditions and after application of 123 kg N ha^{-1} (Marsalis at al. 2010).

Fertilization affected neither nitrogen efficiency nor nitrogen physiological efficiency (Table 6). The differences among fertilization types in nitrogen physiological efficiency were biologically but not statistically meaningful. It was likely due to large within-treatment variation. Nitrogen efficiency was affected by environmental conditions. The lowest mean efficiency was recorded in 2011 (31.2 kg D.M. kg^{-1} N; Table 6). In Polish conditions, under nitrogen fertilization ranging from 80 to 120 kg N ha^{-1}, it is possible to receive nitrogen physiological efficiency from 15.1 to 67.9 kg D.M. kg^{-1} N and nitrogen efficiency from 7.5 to 47.5 kg D.M. kg^{-1} N (Księżak et al. 2012). In other conditions and under optimal N doses (183 in 2010 and 148 kg N $\cdot ha^{-1}$ in 2011), Hao et al. (2014) reported higher nitrogen use efficiency, ranging from 78 and 90 kg D.M. kg^{-1} N.

CONCLUSIONS

1. Sweet sorghum can be fertilized with different forms of nitrogen. No differences among those applied in this research (ammonium sulfate, calcium nitrate, ammonium nitrate and urea) were observed for morphological traits and yield.
2. Nitrogen fertilization of sweet sorghum with nitrogen was effective. Nonetheless, the form of fertilization did not affect nitrogen efficiency and nitrogen physiological efficiency.
3. In south-western Poland, on sandy soils and in favorable weather conditions, it is possible to obtain high dry matter yield of sweet sorghum, even over 15 t ha^{-1}.

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