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IMPACT OF DIFFERENT FORMS OF NITROGEN FERTILIZER ON THE CONTENT AND UPTAKE OF MICROELEMENTS IN SORGHUM

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Abstract

The aims of the study were to determine the impact of various forms of nitrogen on the content and uptake of cooper, iron, manganese and zinc by sweet sorghum and to check what remains in the bagasse after extracting the plant juice.

In 201-2011, field experiments were conducted on sweet sorghum (cv. Sucrosorgo 304) fertilized with different forms of nitrogen (nitrate, ammonium and urea).

The fertilizer containing ammonia nitrogen markedly increased the amount of Mn in both years of the study and raised the amount of Zn in 2010. On average, significantly more Fe was found after fertilizing with nitrates (calcium nitrate), and more Zn was found after fertilizing with the form of ammonium (ammonium chloride). In 2010, there were significantly higher increments in the content of all the microelements. A lower content of microelements was found in the bagasse than in the whole plants. On average, throughout the whole study, a significant impact of the fertilization variants on the Zn content appeared. The highest uptake of Cu was found in plants which had been fertilized with nitrate and ammonium forms of nitrogen (ammonium nitrate), whereas Mn and Zn increased when fertilization included ammonium in the form of ammonium sulphate. After fertilizing with ammonium chloride, the uptake was slightly lower. On average for 2010-2011, the highest level of Cu, Mn and Zn occurred in the bagasse from plants that had been fertilized with ammonium chloride.

Keywords: sweet sorghum, nitrogen fertilization, microelements, biomass, bagasse.

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WPŁYW NAWOŻENIA RÓŻNYMI FORMAMI AZOTU NA ZAWARTOŚĆ I POBRANIE MIKROELEMENTÓW PRZEZ SORGO

Abstrakt

Celem badań było określenie wpływu różnych form azotu na zawartość i pobranie miedzi, żelaza, manganu i cynku przez sorgo cukrowe oraz powstałe po tłoczeniu soku wytłoki.

W doświadczeniu polowym w latach 2010-2011 uprawiano sorgo cukrowe (odmiana Sucrosorgo 304), które nawożono nawozami azotowymi zawierającymi różne formy azotu (amonową, azotanową oraz amidową).

Nawozy zawierające formę amonową azotu w obydwu latach badań istotnie wpłynęły na zwiększenie zawartości Mn, a w 2010 r. również Zn. Średnio istotnie więcej Fe stwierdzono w warunkach nawożenia formą azotanową (saletra wapniowa), a Zn – po nawożeniu formą amonową (chlorek amonu). W sorgu zebranym w 2010 r. oznaczono istotnie większą zawartość wszystkich badanych mikroelementów. W wytłokach stwierdzono mniejszą zawartość badanych mikroelementów niż w całych roślinach. Średnio w okresie badań istotny był wpływ stosowanych nawozów na zawartość Zn. Najwięcej Cu pobrały rośliny nawożone nawozem zawierającym obie formy azotu – azotanową i amonową (saletra amonowa), zaś Mn i Zn – formą amonową w postaci siarczanu amonu. Po nawożeniu chlorkiem amonu pobranie było nieznacznie mniejsze. Średnio w latach 2010-2011 największą ilość Cu, Mn i Zn stwierdzono w wytłokach z roślin nawożonych chlorkiem amonu.

Słowa kluczowe: sorgo cukrowe, nawożenie azotem, mikroelementy.

INTRODUCTION

Sweet sorghum belongs to the *Poacea*, family, thus it is a plant with the C_4 pathway of photosynthesis characterized by highly efficient photosynthesis and a better use of water and nitrogen than most plants with the C_3 pathway (Zhao et al. 2005). The plant is grown in semi-arid and arid regions of the world, mainly in areas unsuitable for corn (Kaczmarek et al. 2008). Although sorghum uses nitrogen more efficiently than most plants with the C_3 cycle, nitrogen is the main factor responsible for reduced yields (Young, Long, 2000).

The effect of nitrogen fertilization on plant yields is widely known. Among the three basic macroelements used in fertilization, the impact of nitrogen is the most immediate (Fageria, Moreira 2011). However, large doses of nitrogen raise production costs and affect the environment (Sainju et al. 2006, Marsalis et al. 2010). A way to control the adverse effects of fertilization on nature is to adjust the dose of a mineral fertilizer to the nutritional needs of a given crop and to slow down the mineral uptake by applying a fertilizer with a more controlled or slower nutrient release. Slow-acting fertilizers are characterized by a delay between the time of application and nutrient availability, as well as a slower release of nutrients into soil compared to conventional fertilizers (Korzeniowska 2009).

The level of microelements in the biomass depends mainly on the content of elements in the soil, the dose of fertilization, and the growth stage of plants (BUJANOWICZ et al. 2000). The antagonistic and synergistic effects of different microelements along with the soil condition can lead to a deficiency or excess in the concentration of elements in crop yields (SPOSITO 2008).

MATERIAL AND METHODS

Field experiments were set up according to the random block method. They were carried out in 2010 and 2011, in experimental fields at Pawlowice, which belong to the Department of Crop Production, Wroclaw University of Environmental and Life Sciences

The field trials, with four replicates, were established on sandy soil, which belonged to the Polish soil valuation class V, identified as rusty gley soil. Each plot covered 14.7 m^2 (7 m long and 2.1 m wide). Before sowing, mineral fertilizers were applied in the following doses: 30.5 kg P ha^{-1} in the form of triple superphosphate, 100 K ha^{-1} in the form of potassium salt, and 120 kg N ha^{-1} (in the form shown below). Various forms of nitrogen in nitrogen fertilizers were studied in the context of their impact on the content and uptake of microelements in sorghum plants and accumulation in bagasse, such as ammonium sulphate, ammonium chloride, calcium nitrate, ammonium nitrate, urea and slow-release urea under commercial name of Meister. For comparison of the effects of these fertilizers on the level of microelements, a control group was created (no nitrogen fertilizer). The study evaluated the Sucrosorgo 304 variety from Sorghum Partners LLC, which was sown in the first half of May, using 20 seeds with full germination ability per 1 m^2. Plants were harvested at the milky dough stage, ground and sampled for chemical analysis to determine the level of microelements. Next, some of the ground plant material was put into a press set at the pressure of under 30 bars to obtain plant juice for biotechnological purposes. Samples of the bagasse were collected, dried and ground for analyses of the content of microelements. From the plant material obtained the level of Cu, Fe, Mn and Zn was determined using the method of atomic absorption spectrometry after the mineralization of dry ash dissolved in a solution of 1 mol HNO_3 dm^{-3}. The results on the biomass yields and content of microelements were used to calculate the mineral uptake by sorghum plants and the accumulation of micronutrients in the bagasse of sorghum plants. The content of iron was excluded from analyses due to the fact that the laboratory equipment was made of stainless steel and iron.

Variance analysis was applied to the results with a Statistica 9 software package. Confidence intervals were tested with the Duncan's test at the significance level of (α = 0.05).

RESULTS AND DISCUSSION

Nitrogen fertilizers used in the study significantly influenced the content of Mn and Zn in sweet sorghum plants (Table 1). The fertilizer containing ammonium nitrogen significantly increased the level of Mn in both years and the level of Zn in 2010. The plants harvested in 2010 had significantly higher levels of all of the micronutrients. LEHMANN et al. (1999) reported that the content of Zn after fertilizing with ammonium sulphate was 24.1±4.9 mg kg^{-1} d.m., versus 22.4±8.5 mg kg^{-1} d.m. without nitrogen fertilization. For comparison, our research showed that the level of Zn was lower by 43.5 mg kg^{-1} d.m. (after fertilizing with ammonium sulphate) to 37.9 mg kg^{-1} d.m. (without nitrogen fertilization). In the research of PING et al. (2009), there was a higher concentration of Zn and Cu in the leaves than in the stalks of sweet sorghum plants. The stems of plants fertilized with ammonium sulphate had a lower content of Zn than after fertilization

Table 1

The content of microelements in sorghum plants at milk dough stage (mg kg^{-1} d.m.)

Year	Fertilizer type	Cu	Fe	Mn	Zn
2010	ammonium sulphate	3.263	61.46	56.15	75.81
	ammonium chloride	3.550	78.48	61.88	70.37
	calcium nitrate	3.175	79.01	30.96	62.87
	amonium nitrate	4.250	45.17	49.70	58.58
	urea	3.200	65.23	35.97	74.92
	slow-release urea -Meister	3.100	58.25	38.88	51.13
	control	3.575	73.68	33.40	51.75
LSD α = 0.05		n.s.	15.53	19.66	17.25
2011	ammonium sulphate	2.088	53.25	19.49	59.31
	ammonium chloride	2.225	53.76	16.26	66.13
	calcium nitrate	2.075	57.31	14.21	58.13
	amonium nitrate	2.025	48.53	11.84	49.63
	urea	2.250	55.93	12.45	38.25
	slow-release urea -Meister	2.063	53.00	10.85	31.69
	control	2.425	57.23	14.53	68.88
LSD α = 0.05		0.165	n.s.	4.59	16.04
Means from years 2010 and 2011	ammonium sulphate	2.675	57.36	37.81	67.56
	ammonium chloride	2.888	66.13	39.08	68.25
	calcium nitrate	2.625	68.16	22.59	60.50
	amonium nitrate	2.979	47.09	28.06	53.46
	urea	2.657	59.91	22.53	53.96
	slow-release urea -Meister	2.581	55.63	24.96	41.41
	control	3.000	65.45	23.96	60.31
LSD α = 0.05		n.s.	12.09	n.s.	14.88
2010	–	3.410	66.14	44.80	64.36
2011	–	2.144	53.91	14.21	51.93
LSD α = 0.05		0.254	6.19	6.31	8.25

with either of the two ammonium nitrate forms. The levels of Cu in leaves and stems were similar. MARCHIOL et al. (2007), after fertilizing sorghum with urea in a dose of 150 kg ha^{-1} reported 29.6 ± 6.3 mg Cu kg^{-1} d.m. and 55.5 ± 3.6 mg Zn kg^{-1} d.m. in thee stems, while the plants not fertilized with nitrogen had 28.6 ± 4.5 Cu and 86.4 ± 19 mg Zn kg^{-1} d.m., respectively.

The bagasse had a lower level of the micronutrients than the complete plant matter. In both years, there were significant differences between the types of nitrogen fertilizer and the resulting levels of Mn and Zn, and the level of Cu in 2010 (Table 2). The means from both years were significantly higher for Zn after fertilization with ammonium chloride (60.8 mg Zn kg^{-1} d.m.) and ammonium sulphate (51.8 mg Zn kg^{-1} d.m.) than with Meister (34.6 mg Zn kg^{-1} d.m.). The bagasse obtained from plants collected in 2010 had much higher concentrations of all the microelements. The difference in the level of manganese was particularly noteworthy.

Table 2

The content of microelements in sorghum bagasse (mg kg^{-1} d.m.)

Year	Fertilizer type	Cu	Fe	Mn	Zn
2010	ammonium sulphate	3.217	127.1	38.88	66.92
	ammonium chloride	3.513	65.94	49.20	63.38
	calcium nitrate	3.038	82.73	23.66	47.63
	amonium nitrate	3.400	64.95	33.90	46.75
	urea	2.725	63.89	37.74	55.06
	slow-release urea -Meister	2.717	67.12	29.20	43.42
	control	3.100	67.88	23.84	43.50
LSD $\alpha = 0.05$		0.389	n.s.	4.59	11.48
2011	ammonium sulphate	2.163	58.23	16.84	40.50
	ammonium chloride	2.188	59.46	13.64	58.25
	calcium nitrate	1.988	63.14	11.64	35.63
	amonium nitrate	1.325	53.23	9.188	32.44
	urea	2.050	61.39	11.08	31.25
	slow-release urea -Meister	2.038	100.2	9.113	28.00
	control	2.200	65.73	11.80	31.80
LSD $\alpha = 0.05$		n.s.	24.16	4.57	10.47
Means from years 2010 and 2011	ammonium sulphate	2.614	87.72	26.29	51.82
	ammonium chloride	2.850	62.70	31.42	60.81
	calcium nitrate	2.513	72.93	17.64	41.63
	amonium nitrate	2.017	57.13	17.43	37.21
	urea	2.388	62.64	24.41	43.26
	slow-release urea -Meister	2.329	86.02	17.72	34.61
	control	2.650	66.80	17.81	37.63
LSD $\alpha = 0.05$		n.s.	n.s.	n.s.	12.31
2010	means for fertilizers	3.086	78.13	34.64	54.44
2011		1.977	65.94	11.90	37.22
LSD $\alpha = 0.05$		0.235	n.s.	4.02	6.43

There are few studies on the content of microelements in the bagasse of sorghum. SESHAIAH et al. (2012) reported a higher content of copper (57.4 mg Cu kg^{-1} d.m.) and a similarly higher result level of zinc (48.8 mg Zn kg^{-1} d.m.).

Our study revealed a diverse impact of fertilization on the uptake of micronutrients in the plant biomass of sweet sorghum. Fertilizing with nitrogen as a nitrate (calcium nitrate) significantly increased the uptake of iron in both years (Table 3). In 2010, plants fertilized with ammonium nitrate had a much higher uptake of Cu, while plants fertilized with ammonium sulphate had a higher uptake of Zn and Mn. In 2011, sorghum fertilized with ammonium chloride had a much higher level of Zn, and plants fertilized with ammonium sulphate had a much higher level of Mn. The highest average level of Cu for both years 2010-2011 was determined in plants fertilized with ammonium nitrate; the highest level of Fe was in plants fertilized with calcium nitrate, and the highest levels of Mn and Zn occurred in plants fertilized with ammonium sulphate. There was a much higher uptake of

Table 3

The uptake of microelements by sorghum plants (g ha^{-1})

Year	Fertilizer type	Cu	Fe	Mn	Zn
2010	ammonium sulphate	39.47	743.8	679.3	916.1
	ammonium chloride	37.15	816.6	653.0	736.1
	calcium nitrate	35.74	890.3	348.2	709.4
	amonium nitrate	55.91	516.1	601.2	731.3
	urea	39.59	806.3	492.6	898.0
	slow-release urea -Meister	32.10	603.5	409.1	532.9
	control	20.53	423.1	191.8	297.2
LSD $\alpha = 0.05$		8.96	173.2	132.6	169.1
2011	ammonium sulphate	39.45	1006	368.9	1121.2
	ammonium chloride	40.71	982.7	297.2	1211.9
	calcium nitrate	37.92	1029	255.6	1050.9
	amonium nitrate	36.60	876.6	213.6	899.8
	urea	37.49	926.4	206.9	643.3
	slow-release urea -Meister	36.54	942.1	192.8	563.5
	control	33.68	794.9	201.8	956.7
LSD $\alpha = 0.05$		n.s.	126.4	55.8	186.3
Means for years 2010 and 2011	ammonium sulphate	39.46	874.9	524.1	1018.7
	ammonium chloride	38.93	899.6	475.1	974.0
	calcium nitrate	36.83	960.0	301.9	880.2
	amonium nitrate	46.26	696.4	407.4	815.5
	urea	38.54	866.3	349.7	770.7
	slow-release urea -Meister	34.32	772.8	300.9	547.7
	control	24.92	547.0	195.1	517.0
LSD $\alpha = 0.05$		5.86	141.9	124.0	172.2
2010	means for fertilizers	37.21	685.7	482.2	688.6
2011	means for fertilizers	37.78	947.8	252.7	918.3
LSD $\alpha = 0.05$		n.s.	71.9	60.8	103.2

Fe and Zn in the plant material from sorghum sown in 2011, and a higher uptake of Mn in 2010.

PING et al. (2009) reported that the uptake of Zn in sorghum plants fertilized with ammonium nitrate ranged from 1.0 to 1.4 kg ha^{-1}, while fertilization with ammonium sulphate slightly decreased the uptake (1.0-1.2 kg ha^{-1}). The Zn uptake by plants with no nitrogen fertilization had a wider range (0.8-1.4 kg ha^{-1}), and the content of Cu ranged from 0.18 to 0.27 kg ha^{-1}. In the research of MARCHIOL et al. (2007), plants fertilized with urea had the uptake of 644 g ha^{-1} of Cu and 1223 g ha^{-1} of Zn, and plants with no nitrogen fertilization absorbed 148 g ha^{-1} of Zn. On the other hand, our research showed a much lower uptake of Cu than cited in other scientific research from various parts of the world. Our results were in the range of 20.5 to 55.9 g ha^{-1}, and available references report a range from 180 (PING et al. 2009) to 644 g ha^{-1} (MARCHIOL et al. 2007)

Fertilization significantly affected the accumulation of micronutrients in bagasse (Table 4). In 2010, the highest increase concerned the level of Cu

Table 4

The accumulation of microelements in sorghum bagasse (g ha^{-1})

Year	Fertlizer type		Cu	Mn	Zn
2010	ammonium sulphate		36.99	546.1	835.1
	ammonium chloride		36.52	577.9	691.8
	calcium nitrate		33.15	293.0	593.8
	amonium nitrate		47.32	494.9	632.8
	urea		35.13	458.8	759.2
	slow-release urea -Meister		29.59	345.0	486.2
	control		19.67	168.2	280.6
LSD $\alpha = 0.05$			6.63	77.5	118.7
2011	ammonium sulphate		36.01	311.0	865.8
	ammonium chloride		37.66	256.4	1070.0
	calcium nitrate		34.65	218.9	804.3
	amonium nitrate		28.45	177.2	698.6
	urea		33.47	182.6	546.7
	slow-release urea -Meister		33.31	163.8	488.4
	control		28.74	164.7	650.1
LSD $\alpha = 0.05$			4.53	46.4	97.8
Means for years 2010 and 2011	ammonium sulphate		33.55	333.0	682.3
	ammonium chloride		35.25	359.2	787.8
	calcium nitrate		30.97	210.1	518.0
	amonium nitrate		29.52	264.7	515.9
	urea		30.05	291.7	535.3
	slow-release urea -Meister		28.57	207.9	426.9
	control		20.48	139.0	290.5
LSD $\alpha = 0.05$			4.75	85.6	90.7
2010		means for fertilizers	30.89	341.8	534.2
2011			29.27	176.7	588.3
LSD $\alpha = 0.05$			n.s.	40.9	n.s.

in the bagasse from plants fertilized with ammonium nitrate (47.3 g ha^{-1} of Cu), but in 2011 the highest Cu concentration in sorghum bagasse appeared after fertilization with ammonium chloride, ammonium sulphate and ammonium nitrate (37.7, 36.0, 34.7 g ha^{-1} of Cu respectively). The two-year average accumulation of Mn and Zn was significantly the highest after fertilization with the form of ammonium, either as ammonium sulphate or ammonium chloride.

CONCLUSIONS

1. Nitrogen fertilization in the form of ammonium resulted in a significantly higher average level of zinc in both the years of the study, whereas nitrogen used either as a nitrate or ammonium (ammonium nitrate) significantly reduced the iron content in sorghum plants relative to the control group.

2. Extracted juice showed the biggest decrease in the level of Zn 10.0-14.2 mg kg^{-1} d.m., and a somewhat smaller decrease in the level of Cu 0.17-0.33 mg kg^{-1} d.m.

3. The accumulation of micronutrients in bagasse was lower than in whole plants and the biggest difference was noted in the accumulation of Zn, which translated into a high level of this microelement in extracted sorghum juice.

4. Different forms of nitrogen fertilization had a significant impact on the uptake of microelements in the plant biomass of sorghum (highest uptake of Cu resulted from the application of ammonium nitrate, Fe – calcium nitrate, Mn and Zn – ammonium sulphate). The accumulation of all these microelements in sorghum bagasse was the highest after the application of ammonium chloride as a fertilizer.

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