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THE EFFECT OF YARAREGA FERTILIZATION ON THE NITROGEN EFFECTIVENESS AND YIELD OF SWEET SORGHUM (*Sorghum bicolor* (L.) MOENCH)

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ABSTRACT

Background. The sorghum (C4) species has a high potential for accumulation of photosynthetic radiation. It is possible to obtain a high biomass yield after meeting the fertilization needs of plants, especially as regards nitrogen.
Material and methods. In 2013–2015 at the Experimental Station Pawłowice, which belongs to the Department of Crop Production, a field experiment was conducted that aimed to assess the usefulness of the fertilizer YaraRega to fertilize sweet sorghum. Two methods of using the fertilizer were used: broadcasting application and fertigation, using two rates (40 and 80 kg N per ha), and were compared with the control (without fertilization). The fertilizer in the foliar form was applied in two solutions: 0.20 and 0.40%, respectively, for rates of 40 and 80 kg N per ha. The study estimated the effect of fertilization on the productivity of fresh and dry matter and the effectiveness of these treatments.
Results. The statistically significant increase in the fresh matter yield obtained under the influence of nitrogen rates was about 25% (after fertilization with 40 kg N per ha) and 32% (after the application of 80 kg N per ha). Taking into account also the dry matter yield, only fertilization with 40 kg N per ha caused a significant increase in the yield compared with the control. Fertilization with a rate of 40 kg N per ha caused an increase in the fresh matter yield of about 300 and 334 kg per 1 kg of nitrogen used after of broadcasting and fertigation application methods respectively. Agronomic efficiency expressed in dry matter yield amounted to 75 and 76 kg per 1 kg of nitrogen used.
Conclusion. YaraRega is recommended to be applied to sorghum with the fertigation method. No toxic effect on sorghum plants was observed after an application of the 0.4% solution.

Key words: fertigation, mineral nitrogen, multi-nutrient fertilizer, plant nutrition, yield

INTRODUCTION

Changing climatic conditions, characterized by an intensification of extreme atmospheric phenomena, contribute to the search for species of crop plants that are better adapted to stress conditions. Sorghum, and primarily its cultivars grown for grain, are of great importance in the world, especially in African and Asian countries, but also in the United States of America (Tari *et al*., 2013; FAO, 2014). The high functional value of sorghum is not only due to its widespread application in the food economy (similar

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to other cereal crops), but also to its high tolerance to high air temperatures, resistance to periodic water shortages and suitability for growing in different soils (Tari *et al*., 2013). In Poland, sorghum is an alternative species to maize and its cultivation should be carried out under conditions where the maize yield level is highly risky (Sowiński and Liszka-Podkowa, 2008).

The advantages of sorghum include a high ability to utilize photosynthetic radiation (species from group C4), and thus a high yielding potential (Sowiński and Szydełko-Rabska, 2013; Tari *et al*., 2013). Obtaining high yields is possible after satisfying the fertilization needs of the plants, especially in respect of nitrogen. The results of studies on the effect of nitrogen fertilization technology on the size and quality of biomass obtained from the sorghum above-ground parts are not conclusive (Sowiński and Liszka-Podkowa, 2008; Zielewicz and Kozłowski, 2008; Sowiński, 2009; Kordas *et al*., 2012; Księżak *et al*., 2012; Kruczek, 2014). In the literature the proposed rates of nitrogen vary within a wide range from 40 to 250 $kg \cdot ha^{-1}$ N (Pal *et al*., 1982; Kruczek, 2014). The rate is determined by the expected yield level, the type of a previous crop and the amount of existing nitrogen forms in the soil, as well as the requirements of specific cultivars and the course of the weather (Turgut *et al*., 2005; Almodares *et al*., 2007; 2009; Wortmann *et al*., 2010). Buxton *et al.* (1999) after an application of 140 $kg \cdot ha^{-1}$ N, obtained a slight increase in dry matter (0.8 $Mg \cdot ha^{-1}$) as compared with a rate of 70 $kg \cdot ha^{-1}$ N, while fertilization with rates higher than 140 $kg \cdot ha^{-1}$ N contributed to a reduction in yield. Similar results were obtained by Geng *et al*. (1989). In their study, nitrogen rates above 100 $kg \cdot ha^{-1}$ did not cause an increase in sorghum yield. Increasing the efficiency of nitrogen fertilization can be achieved by dividing the nitrogen rate, using slow-release fertilizers, and also by the use of foliar fertilization or fertigation (Addy *et al*., 2010; Deshmukh *et al*., 2014; Kumar and Chopra, 2013).

The aim of the study was to determine the response of sweet sorghum to fertilization with a multicomponent fertilizer (YaraRega – N 20%, P_2O_5 5%, K_2O 18%, S 2% + Zn + B) applied through broadcasting and fertigation.

MATERIAL AND METHODS

The experiment with sweet sorghum was conducted in 2013–2015 in Pawłowice near Wrocław (51°09’ N; 17°06’ E) in fields belonging to the Department of Crop Production of the Wroclaw University of Environmental and Life Sciences. It was established in light soil with a soil quality of class V.

The two-factorial experiment comprised of two methods of application of the YaraRega fertilizer and of two rates of the fertilizer mass as compared with the control (without nitrogen fertilization).

The layout of the experiment was as follows:

- factor I: the fertilization method: top-dressing – broadcasting, top-dressing by fertigation using the sprinkler method,
- factor II: the rate of fertilizer mass (YaraRega): 0, 90 and 180 $kg \cdot ha^{-1}$ (which corresponded to 40 and 80 $kg \cdot ha^{-1}$ N).

The fertilizer application was conducted during sorghum growth (about 60 days after sowing), and was aimed at fertilization by the traditional method (broadcasting) and fertigation. Therefore, the applied nitrogen rates were lower as compared with those given in the literature. No other fertilization was used in the present study.

Each variant of the experiment was repeated three times, and the size of a single plot was 21 m^2 (10 m in length, 2.1 m in width). Sorghum was sown after winter rye each year. The study was aimed at assessing the effect of fertilization on the sweet sorghum cultivar Róna1 bred by the Hungarian seed company Gabonakutató Nonprofit Közhasznu KFT. The experimental sowing was performed with a plot drill Wintersteiger in the first half of May in 2014 and 2015 (in 2013, for organizational reasons, the sowing of the experiment was performed after the 20th of May). Weeds were controlled chemically with the herbicide Lumax 537.5 SE in a dose of 2 $dm^3 \cdot ha^{-1}$, which was used directly after sowing, on a wide spectrum of weeds including dicot and monocot species. During the growth period, additional care was applied by manually removing weeds. Broadcasting of fertilizers and fertigation was performed at the 10--leaf stage, i.e.: on 16th July 2014, 7th July 2015 (in 2013 due to the later sowing time this was performed later – 22th July). The fertilizer was applied in the late morning and the mean daily air temperature was:

22.2; 22.4; 23.6°C, respectively, in 2013, 2014, 2015. In all years, there was no rainfall on the day before and on the day of application of the fertilizer. 100 m^3 of water per ha was used in the fertilization by fertigation and the solution concentration was 0.20 and 0.40% of the (for a rate of 90 and 180 $kg·ha^{-1}$ of fertilizer mass, respectively).

Observations of plant growth and development were conducted during the growth. During the study the following determinations and measurements were made: the number of plants after emergence and the number of stems before harvest, necrotic damage 7 days after fertilization (percentage of leaf blades with necrosis), measurement of leaf greenness index (SPAD) with an N-tester at two dates: before fertilization and 60 days after fertilization. During harvest, the yield of the above-ground parts was determined, as well as the dry matter content using the drier method, and a botanical analysis of the above-ground parts of the sorghum was performed.

In the field study, the effect of the new formulation of the multi-component fertilizer YaraRega (N:P:K – 27:5:5), produced in the solid form, on sweet sorghum yield and fertilization efficiency was determined. Nitrogen in the fertilizer was in the form of ammonium nitrate with a small amount of ammonium chloride (<1%), (European Commission, 2010).

On the basis of the measurements and analyses carried out, calculations of the agricultural and physiological effectiveness of nitrogen were made (for a rate of 40 and 80 $kg·ha^{-1}$ N).

Effectiveness indices were established based on the method developed by Fotyma and Mercik (1995):

$$Er = (YN - Y0)/N$$

$$Ef = (YN - Y0)/(PN - P0)$$

where:

- Er – agricultural effectiveness,
- Ef – physiological effectiveness,
- YN – yield from the treatment with applied nitrogen rate,
- Y0 – yield from the control treatment without nitrogen,
- N – nitrogen rate applied to treatment YN,
- PN – nitrogen uptake with plant yield from treatment YN,
- P0 – nitrogen uptake with plant yield from the control Y0.

Harvest of the above-ground parts was made on 29, 29 and 9 of September, respectively, in 2013, 2014 and 2015. In 2015, due to high temperatures and a long drought period, the harvest was carried out earlier than in the other years.

The results of field measurements and calculated parameters characterizing the yield were compared with an analysis of variance at the significance level $P < 0.05$ using ANOVA/MANOVA software (Statistica 10). For the statistical analysis of both the agricultural and physiological effectiveness of fertilization, α value was given.

Description of site conditions

The soil was classified into the rusty gley soils with the granulometric composition of loose sand (percentage of fractions): 2.0–0.05 mm ÷ 82–84%, 0.05–0.002 mm ÷ 12–16%, <0.002 mm ÷ 2–4%. The soil had a slightly acidic reaction (pH within 5.6–5.7), with a high content of phosphorus (70.7–87.3 $mg·kg^{-1}$ soil), a medium content of potassium (121.6–127.3 $mg·kg^{-1}$ soil) and a very high content of magnesium (124.5–151.6 $mg·kg^{-1}$ soil). The range of percentages of granulometric fractions and chemical compositions resulted from measurements made at different locations on the field.

Meteorological data was obtained from the AsterGate weather station, which is part of the equipment of the station in Pawłowice owned by the Department of Crop Production. Measurements were recorded at 10-minute intervals, based on which daily values were calculated: average (temperature) and total (rainfall). The values of temperature and rainfall from the multi-year period (1981–2010) are derived from the data collected at the Wrocław University meteorological station.

The total rainfall during sorghum growth was highly varied in the years of the study (Table 1). In 2013 the total rainfall for the period from April to September amounted to 560.6 mm and was higher by 233.4 mm than the multi-year average. The year 2015 was marked by a strong rainfall deficit and in the period from April to September the total rainfall was only 171.3 mm and was lower by 112.3 mm than the multi-year average.

Table 1. Weather conditions during sweet sorghum growth

Year	Month						Total/Average
	April	May	June	July	August	September	
Rainfall, mm							
2013	42.7	135.9	171.7	36.3	68.2	105.8	560.6
2014	55.2	101.4	40.2	52.9	75.0	72.2	396.9
2015	15.8	21.0	73.3	55.6	5.6	23.2	194.5
Multi-year average	30.5	51.3	59.5	78.9	61.7	45.3	327.2
Average air temperature, °C							
2013	9.15	14.61	17.68	20.48	19.02	12.86	15.6
2014	10.58	13.32	16.57	21.24	17.29	15.49	15.7
2015	8.89	13.46	16.63	20.27	22.65	15.07	16.2
Multi-year average	8.9	14.4	17.1	19.3	18.3	13.6	15.3

The average air temperature during sorghum growth in 2013 and 2014 was higher than the multi-year average by 0.3 and 0.4°C, respectively. In 2015, from April to June, air temperatures were at the level of the multi-year average. In July of this year the temperature was higher by 1°C, and in August by 4.3°C. The higher average air temperature and lower total rainfall in 2015 did not affect the growth and yield of sorghum. There was only an acceleration of growth and the harvest was made about 3 weeks earlier. A high tolerance to stress is a basic characteristic of sorghum (Tari *et al*., 2013).

RESULTS

The weather patterns (both temperature and rainfall) in the early sorghum growth period determined the emergence of plants. In 2013, plant emergence was recorded after 9 days, in the other years after 14 days from sowing.

After plant emergence, there were no significant differences in the number of plants per area unit within each of the years of the study (Table 2). Significant differences were only found between the years of the study. In 2014, the weather conditions immediately after sowing (heavy rainfall with 33 mm falling during the week after sowing and low temperature, only 12.2°C) were the least favourable for the sorghum emergence and the number of plants was significantly lower in this year. It was shown that the applied nitrogen rate had a significant effect on the number of sorghum stems before harvest. The application of 40 $kg \cdot ha^{-1}$ N as compared with the control (without nitrogen fertilization) caused a significant increase in the number of stems per unit area. Increasing the rate to 80 $kg \cdot ha^{-1}$ N increased competition between the stems and the weakest halted their growth. Significant differences in the number of stems were observed in the years of the study. This figure was significantly the smallest in 2013. The initial density was strongly negatively correlated ($r = -0.720$) with the tillering index and was statistically significant. In 2014, where the smallest number of plants was obtained after emergence, the tillering index amounted to 2.3 and was significantly higher than in the other years.

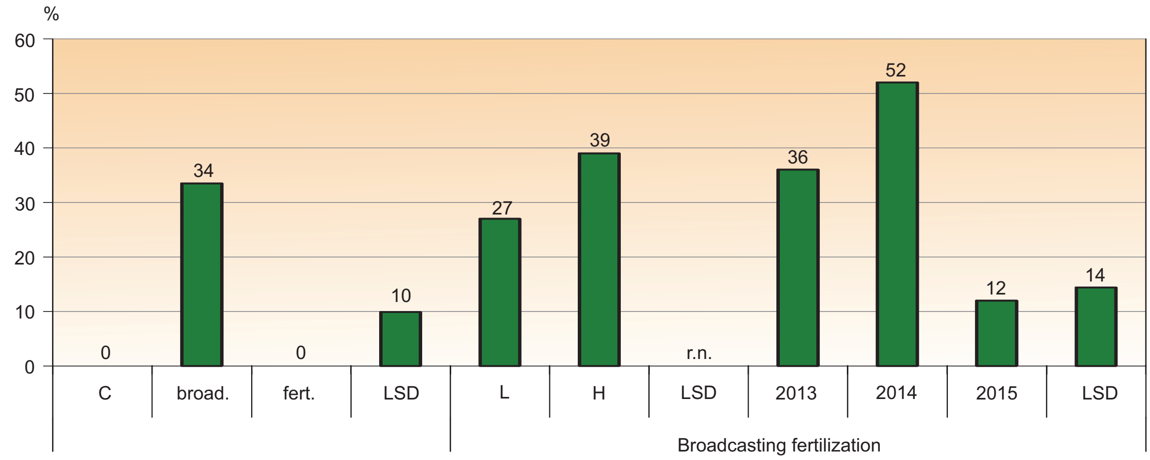
Broadcasting with the fertilizer YaraRega resulted in necrotic lesions on leaf blades (Fig. 1). On average over the three years of the study, significantly high damage was found on 34% of leaves forming the field surface. The amount of damage was differentiated by the rate of fertilizer and by the year of the study. Only the differences between the years were statistically significant. Despite weather conditions that were favourable for fertilization, the damage caused by the surface applied fertilizer was the result of the residue dissolving on the surface of leaf blades in water gathering on their surface in the cool time of the day in the form of dew. The application of the fertilizer YaraRega by fertigation did not cause damage to sorghum leaves.

Before fertilizer application no significant differences were found between the factors tested for in the values of the leaf greenness index (SPAD) (Table 3). In the years of the study, the SPAD values were statistically different and ranged from 438 (2013) to 633 (2014). Readings made 60 days after fertilization showed the significant effect of the nitrogen rate on the SPAD. Without nitrogen fertilization (control), the average value was significantly lower (415) than after fertilization with a rate of 40 (566) and 80 kg·ha^{-1} N (587). Fertilization method did not affect the value of this index. The high solubility of the fertilizer in soil water and the easy absorption through the sorghum root system influenced the lack of difference between the fertilization methods. On average from the multi-year period, after 60 days from fertilization, similar relationships were observed in leaf greenness index values as at the earlier time.

Table 2. Plant density after emergence and the effect of nitrogen fertilization on stem number before harvest (per m^2) and tillering index; average from years 2013–2015

Treatment	Number of plants after emergence	Number of stems before harvest	Tillering index
Interaction of fertilization methods and nitrogen rates			
Broadcasting 40 kg·ha^{-1} N	11.5	15.3	0.9
Broadcasting 80 kg·ha^{-1} N	10.9	12.7	0.4
Fertigation 40 kg·ha^{-1} N	10.0	15.7	1.6
Fertigation 80 kg·ha^{-1} N	11.7	15.9	0.8
$LSD_{0.05}$	ns	ns	ns
Average for fertilization methods			
Broadcasting	11.2	14.0	0.6
Fertigation	10.8	15.8	1.2
$LSD_{0.05}$	ns	ns	ns
Average for nitrogen rates			
0N(control)	14.0	12.7b	0.5
40 kg·ha^{-1} N	15.1	15.5a	1.2
80 kg·ha^{-1} N	15.8	14.3ab	0.6
$LSD_{0.05}$	ns	2.5	ns
Average for years			
2013	14.6a	12.4b	0.09b
2014	5.5b	14.5ab	2.3a
2015	13.2a	15.4a	0.3b
$LSD_{0.05}$	2.6	2.5	0.08

ns – non-significant difference



C – control, broad. – broadcasting, fert. – fertigation; L – a rate of 40 kg·ha^{-1} N, H – a rate of 80 kg·ha^{-1} N

Fig. 1. Sweet sorghum leaf blade damage one week after fertilizer application (% of leaf blades with necrosis); average from years 2013-2015

Table 3. SPAD value. Average from years 2013-2015

Treatment	SPAD value	
	before fertilizer application	60 days after fertilizer application
Interaction of fertilization methods and nitrogen rates		
Broadcasting 40 kg·ha^{-1} N	537	576
Broadcasting 80 kg·ha^{-1} N	540	583
Fertigation 40 kg·ha^{-1} N	546	556
Fertigation 80 kg·ha^{-1} N	559	590
$LSD_{0.05}$	ns	ns
Average for fertilization methods		
Broadcasting	538	580
Fertigation	553	573
$LSD_{0.05}$	ns	ns
Average for nitrogen rates		
0N (control)	540	480a
40 kg·ha^{-1} N	542	566b
80 kg·ha^{-1} N	549	587b
$LSD_{0.05}$	ns	84
Average for years		
2013	438a	415a
2014	633c	675c
2015	562b	553b
$LSD_{0.05}$	24	55

ns – non-significant difference

Neither the interaction of fertilization method and nitrogen rate nor the fertilization method showed statistically significant differences in the fresh and dry matter yield of sorghum above-ground parts (Table 4). The fresh and dry matter yield of the above-ground parts of sorghum without nitrogen fertilization was high and on average for the three years of the study it was 38.2 and 9.2 $Mg \cdot ha^{-1}$, respectively. Fertilization resulted in a statistically significant increase in the fresh matter yield by 25% (after fertilization with 40 $kg \cdot ha^{-1}$ N) and by 32% (after the application of 80 $kg \cdot ha^{-1}$ N). Fertilization with a rate of 80 $kg \cdot ha^{-1}$ N did not cause a significant increase in dry matter yield as compared with that obtained after the application of the lower rate. In this experiment, the weather conditions during the years of the study had a significant influence on the dry matter yield of sweet sorghum.

There was no significant effect of the fertilization method and nitrogen rate on the yield fraction percentage. The application of the higher rate in both application methods resulted in a non-significant decrease in the percentage of panicles by 1.3 percentage points (ppt.) (broadcasting) and by 2.9 ppt. (fertigation). On average, for a dose of 40 $kg \cdot ha^{-1}$ of nitrogen, the percentage of panicles compared with the unfertilized variant decreased non-significantly by 4.2 ppt. and by 7.1 ppt. when the nitrogen rate was increased to 80 $kg \cdot ha^{-1}$ N. The weather conditions in the years of the study significantly differentiated the botanical composition of the harvested biomass.

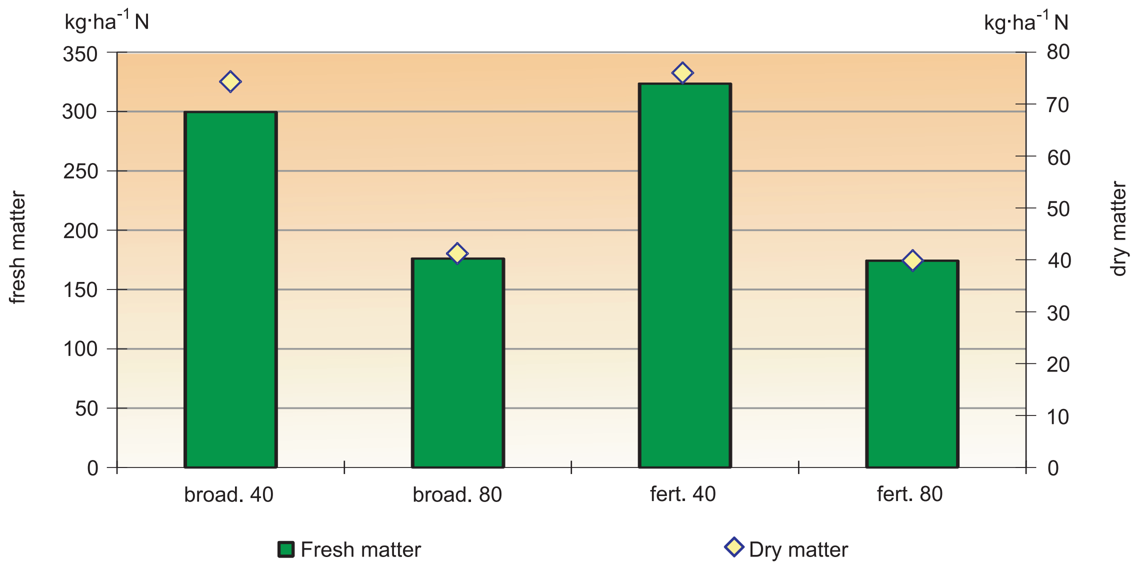
Table 4. Fresh and dry matter yield ($Mg \cdot ha^{-1}$) and their structure (%); average from years 2013-2015

Treatment	Aboveground biomass yield		Percentage		
	fresh	dry	stem	leaf	panicle
Interaction of fertilization methods and nitrogen rates					
Broadcasting 40 $kg \cdot ha^{-1}$ N	47.5	11.4	66.9	18.1	15.0
Broadcasting 80 $kg \cdot ha^{-1}$ N	50.3	11.8	67.1	19.2	13.7
Fertigation 40 $kg \cdot ha^{-1}$ N	47.7	11.2	69.0	16.0	15.0
Fertigation 80 $kg \cdot ha^{-1}$ N	50.7	11.8	69.3	18.6	12.1
$LSD_{0.05}$	ns	ns	ns	ns	ns
Average for fertilization methods					
Broadcasting	48.9	11.6	67.0	18.6	14.4
Fertigation	49.2	11.6	69.1	17.2	13.6
$LSD_{0.05}$	ns	ns	ns	ns	ns
Average for nitrogen rates					
0N (control)	38.2b	9.2b	60.4	19.2	20.4
40 $kg \cdot ha^{-1}$ N	47.6a	11.3a	66.1	17.6	16.2
80 $kg \cdot ha^{-1}$ N	50.5a	11.9a	67.7	18.9	13.3
$LSD_{0.05}$	5.1	1.5	ns	ns	ns
Average for years					
2013	48.6a	8.8c	61.2	35.8	3.0
2014	50.5a	12.9a	68.5	12.9	18.7
2015	38.9b	10.7b	68.2	12.0	19.7
$LSD_{0.05}$	5.0	1.2	3.7	3.0	3.7

ns – non-significant difference

Regardless of the fertilizer application, the agronomic effectiveness of sorghum fertilization expressed in kg of fresh and dry matter per 1 kg of nitrogen was at a similar level (Fig. 2). Fertilization with a rate of 40 kg·ha^{-1} N caused an increase in fresh matter by 300 and 334 kg·kg^{-1} N, respectively, after the use of broadcasting and fertigation. In dry matter, the index value amounted to 75 and 76 kg·kg^{-1} N, respectively, after the use of broadcasting and fertigation. Increasing the nitrogen rate to 80 kg caused a significant decrease in agronomic effectiveness by 41–46% depending on the fertilization method and by 45 and 48%, respectively, for broadcasting and fertigation (when the indices were calculated for dry matter yield).

The physiological effectiveness of sweet sorghum fertilization was the highest – 302 kg of fresh matter per 1 kg N, when the fertilizer YaraRega was applied at a rate of 40 kg·ha^{-1} N by fertigation (Fig. 3). These differences were not statistically confirmed. Fertilization with the higher rate by fertigation (80 kg·ha^{-1} N) as well as by broadcasting (regardless of the rate) had a similar effect on the physiological effectiveness of this treatment. Significant differences were only observed between the years in which the study was conducted.



broad. 40 – broadcasting (40 kg·ha^{-1} N), broad. 80 – broadcasting (80 kg·ha^{-1} N)
fert. 40 – fertigation (40 kg·ha^{-1} N), fert. 80 – fertigation (80 kg·ha^{-1} N)

Statistical analysis of agronomic efficiency (α–value)

	Degree of freedom	Agronomic efficiency	
		Fresh matter	Dry matter
Fertilization methods vs rates	1	0.69	0.54
Fertilization methods	1	0.88	0.96
Rates	1	0.003	0.001
Years	2	0.27	0.45

Fig. 2. The effect of fertilization methods and nitrogen rates on fertilization agronomic efficiency; average from years 2013–2015

Description under Fig. 2

Statistical analysis of physiological efficiency (α–value)

	Degree of freedom	Physiological efficiency	
		Fresh matter	Dry matter
Fertilization methods vs rates	1	0.52	0.70
Fertilization methods	1	0.37	0.56
Rates	1	0.41	0.27
Years	2	0.004	0.003

Fig. 3. The effect of fertilization methods and nitrogen rates on fertilization physiological efficiency; average from years 2013–2015

DISCUSSION

Obtaining the optimal plant density is one of the main determinants of successful crop cultivation and yield. Hołubowicz-Kliza (2007) reports that low plant density after emergence causes greater tillering of sorghum plants. The results obtained in the present study confirm previous reports concerning the high capacity for self-regulation and density compensation of sorghum depending on cultivation conditions (Hołubowicz-Kliza, 2007; Sowiński and Szydełko--Rabska, 2011). In the unfavourable year of 2014, sorghum plants formed on average 2.3 stems, i.e. considerably more than in 2013. The capacity for strong tillering and self-regulation of density should be taken into account when deciding whether to liquidate a plantation due to an unsatisfactory number of plants after emergence.

Soil conditions, especially organic matter mineralization and weather patterns, determine the availability of nitrogen and affect the value of the SPAD. Prior to application of the fertilizer YaraRega, statistically significant differences in the SPAD were found between the years of the study. 60 days after fertilization with a rate of 40 kg·ha^{-1} N, on average the SPAD value had increased by 18% as compared with the index value recorded in plants without fertilization. After fertilization with a rate of 80 kg·ha^{-1} N, this difference in relation to the control was 22%. Mahama *et al.* (2014) obtained similar increases in the SPAD values during sorghum flowering and maturation. They reported an increase in the SPAD value compared with the control that was 23% (after fertilization with a rate of 45 kg·ha^{-1} N) and 29% when the rate was increased to 90 kg·ha^{-1} N.

On average, over the three-year study period, a high yield of sorghum fresh and dry matter was obtained without nitrogen fertilization. This was due to the high fertility of the soil in which the experiment was conducted. Nevertheless, the application of fertilizer significantly affected the fresh and dry matter yield of the sorghum above-ground parts. However, the method of fertilization used did not differentiate this effect. YaraRega applied both by broadcasting and by fertigation caused a similar increase in the fresh and dry matter yield. Under conditions found in Poland, an increase in yield has been obtained after application of up to 250 kg·ha^{-1} N (Kruczek, 2014). Mosali *et al.* (2010) showed that the effect of nitrogen fertilization, regardless of the method and nitrogen rate, depends on the course of the weather during the growing season. In the present study the maximal difference in the fresh matter yield between the years was 30%, whereas in the dry matter yield it was 47%.

Taking care of the environment is currently becoming more important and thus much attention is being paid to the effective use of the means of production, including the energy-intensive (in the process of production) fertilizers. The indicators used for this purpose are agronomic and physiological effectiveness. After fertilization with a rate of 40 kg·ha^{-1} N, regardless of the application method, a high agronomic and physiological effectiveness was obtained. Increasing the nitrogen rate to 80 kg·ha^{-1} N caused a decrease in the values of these indices. In the study carried out by Szydełko-Rabska and Sowiński (2014) the agronomic effectiveness of nitrogen fertilization ranged (depending on the fertilizer) from 40.4 to 52.0 kg d.m.·kg^{-1} N, and the physiological effectiveness – from 91.2 to 102.8 kg d.m.·kg^{-1} of nitrogen.

CONCLUSIONS

1. YaraRega is a fertilizer which can be recommended for foliar plant application. After its application in the form of a 0.4% solution, no toxic effects on the plants were observed.
2. Top-dressing (broadcasting) with the fertilizer YaraRega during sweet sorghum growth may cause damage to the leaf blades of plants even if the fertilizer is applied on dry leaves. The fertilizer left on the leaf blades can be dissolved in water settling on the surface of the plants in the cool time of the day.
3. Fertilization performed in the form of foliar application during sweet sorghum growth caused an increase in fresh matter yield by 25-32% as compared with the yield obtained from sorghum without fertilization.
4. The application method of the fertilizer YaraRega had no effect on the sweet sorghum yield. Leaf blade damage after application by broadcasting did not contribute to a decrease in the fresh and dry matter yield of the above-ground parts.

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WPŁYW RÓŻNEGO SPOSOBU APLIKACJI NAWOZU YARAREGA NA EFEKTYWNOŚĆ NAWOŻENIA I PLONOWANIE SORGA CUKROWEGO (*Sorghum bicolor* (L.) Moench)

Streszczenie

W latach 2013–2015 przeprowadzono badania mające na celu ocenę wpływu nawozu YaraRega na plon, cechy morfologiczne i właściwości chemiczne sorga cukrowego. YaraRega jest nową formulacją nawozów zalecaną do stosowania łącznie z nawadnianiem. Nawóz stosowano dwiema metodami, w tym samym terminie, w dwóch dawkach: poprzez aplikację powierzchniową oraz fertygację, w dawce 90 i 180 kg·ha^{-1} masy nawozowej (co odpowiadało 40 i 80 kg·ha^{-1} N) w porównaniu z kontrolą (bez nawożenia). Nawóz w formie roztworu zastosowano w dwóch stężeniach 0.20 i 0.40% (odpowiednio dla dawki 90 i 180 kg·ha^{-1} masy nawozowej). Określono wpływ nawożenia na wielkość plonu świeżej i suchej masy oraz efektywność tego zabiegu. Pod wpływem nawożenia uzyskano statystycznie istotny większy plonu świeżej masy o 25% (po nawożeniu 90 $kg \cdot ha^{-1}$) i o 32% (po zastosowaniu 180 $kg \cdot ha^{-1}$ masy nawozowej). Nawożenie dawką 40 $kg \cdot ha^{-1}$ N spowodowało istotny wzrost plonu suchej masy o 300 kg (powierzchniowe nawożenie) i o 334 kg (fertygacja) na kg zastosowanego azotu. Efektywność agronomiczna wyrażona w kg suchej masy na kg azotu wynosiła odpowiednio dla obiektów nawożonych powierzchniowo i poprzez fertygację 75 i 76 $kg \cdot kg^{-1}$ N.

Słowa kluczowe: azot mineralny, efektywność, fertygacja, nawóz wieloskładnikowy, plon