sciendo

Polish Journal of Agronomy
2023, 52, 71–78

doi: 10.26114/pja.iung.514.2023.52.08

Effect of cultivar and nitrogen fertilisation on grain and protein yield in sorghum

Marcin Różewicz

Department of Cereal Crops
Institute of Soil Science and Plant Cultivation – State Research Institute
ul. Czartoryskich 8, 24-100 Puławy, POLAND

Abstract. Sorghum is a cereal crop of major importance in global production. It is grown in hot and dry regions of the world. In Poland, this species has so far not been cultivated for grain due to unfavourable climatic conditions. Currently, climate warming and the extension of the growing season provide an opportunity to introduce sorghum into grain cultivation. Three grain sorghum cultivars Albanus, Anggy, GK Emese were used in the ongoing microplot trials and three different nitrogen rates were applied: 80, 100 and 120 kg ha^{-1}. The research was conducted over two growing seasons. The aim of the study was to determine the effect of cultivar and level of nitrogen fertilisation on the yield, yield structure and grain protein content of sorghum. A differentiated response of cultivars to nitrogen fertilisation was shown. Albanus and Anggy cultivars have similar yield potential and reaction to nitrogen fertilisation, and the optimum nitrogen dose for the cultivars is 100 kg of nitrogen per hectare, and an increased dose does not significantly increase the yield. Regardless of the level of nitrogen fertilization, the GK Emese variety always showed a higher protein yield compared to the other tested sorghum varieties. The cultivar GK Emese showed the highest yield potential. In 2020 it exhibited the highest increase in grain and protein yield along to increase of nitrogen fertilisation.

Keywords: sorghum grain, sorghum cultivar, nitrogen fertilisation, protein yield

INTRODUCTION

Sorghum is a cereal crop that makes a significant contribution to the food and feed production in rain-scarce areas. It is mainly grown in countries where the cultivation of rainfed cereals is difficult or impossible. Globally, sorghum ranks 5th in terms of cultivated area, after maize, rice, wheat and barley (FAOSTAT, 2023). In 2022, globally, the area under grain sorghum was about 40 million hectares, and in Europe grain sorghum was grown on 183 thousands of hectares with a steady increase in area (https://european-seed.com). The balance of grain sorghum, i.e. its total use versus demand in the European Union countries, is still negative, and in the 2022/2023 season it could be -345 thousand tonnes (Stachowiak et al., 2023). This indicates that sorghum acreage in Europe has potential for growth. A slight trend of increasing popularity of sorghum cultivation is apparent, which is related to its high tolerance to drought and high temperatures and low soil requirements. This makes southern countries such as: Spain, Italy, France (Wolska, 2021), but also Hungary and Romania (Popescu, 2020b). In Poland, the area under sorghum cultivation is estimated to be about 200 ha (Stachowiak et al., 2023). In Poland, due to the sufficient supply of consumer and fodder grain of the main cereals (wheat, triticale, rye, oats and barley), there has been little interest from growers in sorghum cultivation. Another problem for the popularisation of sorghum production is the small number of scientific studies on the cultivation of this cereal under Polish climate conditions. Scientific studies indicate that its cultivation could be popularised. This may contribute to a higher supply of sorghum grain on the market and thus to its wider use. However, the increase in sorghum cultivation in Poland requires the dissemination of knowledge on its production. Therefore, a number of scientific researches focusing on proper agrotechnics and cultivation of this crop in Poland are being conducted (Sowiński, Szydełko-Rabska, 2013; Gierasimiuk et al., 2023). The results of field experiments on the possibility of sorghum cultivation have shown that this cereal can be successfully grown in Poland. However, it is necessary to properly select a cultivar that will be suitable for cultivation in Poland. A problem in the selection of cultivars is the lack of sorghum cultivars recommended for cultivation in the National Register of Plant Varieties (Sowiński, Szydełko-Rabska, 2013). However, the Community Catalogue of Agricultural Crops (CCA) offers more than 200 cultivars of sorghum authorised in the EU (Ka-

Corresponding author:
Marcin Różewicz
e-mail: mrozewicz@iung.pulawy.pl
phone: +48 81 4786 818

czorek, 2020). The grain has multidirectional uses. It can be used for milling into flour, but the qualitative requirement is a minimum of 11.5% protein content in the grain (Sobolewska, Bury, 2020). The protein content and quality of the flour obtained from sorghum are also influenced by the cultivar as well as nitrogen fertilisation (Sobolewska et al., 2018). Another positive that may contribute to the growing interest in sorghum is that it does not contain gluten, as well as contains numerous bioactive compounds with positive effects on human health (Frankowski, 2017). A new direction of sorghum utilisation in Poland may also be its use in the production of beer, which has a lower alcohol content (Gasiński et al., 2023). In addition to the food use of sorghum grain, it has applications in animal nutrition, especially for various poultry species (Różewicz, 2020). The protein content of sorghum grain is an equally important quality parameter for use in human nutrition as it is for use in livestock feed. Cereal protein is important in both animal and human nutrition (Boczar, 2018). An additional aspect of great importance for the efficient use of the available arable land and feed base on the farm is the protein yield obtained per hectare of cropped area. The aim of the research was to determine the effect of variety and nitrogen fertilization on grain and protein yield of sorghum.

MATERIAL AND METHODS

In two growing seasons of 2020 and 2021, a microplot two-factor experiment was conducted on experimental plots (51°41’ N, 21°95’ E) belonging to the Institute of Soil Science and Plant Cultivation in Puławy. In 2020 the forecrop was maize, while in 2021 the forecrop was winter wheat. Three grain sorghum cultivars were used, two with typical grain use Albanus and Anggy, and one cultivar with a two-way type of use GK Emese – for the production of grain and silage (Table 1). The seed of the cultivars used in the experiment was obtained from the Sorgo Polska Janusz Sus company. The conducted experiment had a randomised design in four replications, each plot had an area of 1 m^2. The first experimental factor was the cultivar and the second experimental factor was the level of nitrogen fertilisation. Sowing was done manually in the second decade of May. Weather conditions (average temperatures and precipitation) during the growing seasons are presented in Table 2. The experiment was established on brown soil classified as good wheat complex. Pre-sowing fertilisation was applied in the following amounts: with 70 kg P_2O_5 ha^{-1} (triple superphosphate) and 100 kg K_2O ha^{-1} (potassium salt). Mineral fertilisation with nitrogen in the form of urea was applied pre-sowing at three different doses for each cultivar 80, 100 and 120 kg ha^{-1}. The inter-row spacing was 0.5 m and the sowing norm applied was 24 plants per m^2. Weeding was carried out manually, throughout the season when weeds were appeared. The panicles were harvested at full maturity in the third decade of October. During harvesting, yield structure analysis was carried out by calculating plant density, tillering coefficient, number of panicles. Then, grain from panicles was threshed and dried in a drying chamber at 55 °C for 48 hours with forced air circulation. After re-drying, the grain was weighed and the yield per hectare of area was calculated. In addition, the thousand grain weight was calculated and representa-

Table 1. Characteristics of sorghum cultivars.

Cultivar	Thousand-grain weight [g]	Grain colour	Plant height	Declared grain yield [t ha^{-1}]	Protein content [%]
Albanus	30	White 	120–140	8.6	10.0–11.0
Anggy	-	Bright orange 	120–130	6.0–8.0	-
GK Emese	30–32	Brown 	140–150	9.0–9.5	10.5–12.5

- no information

Source: https://lidea-seeds.com/products/albanus, https://ragt-saaten.at/de-at/nos-varietes/rgt-anggy-sorghum, https://energiepflanzen.jimdo.com/sorghum/sortenbeschreibungen/gk-emese/

Table 2. Characteristics of weather conditions during the years of the study.

Month	Air temperature [°C]			Precipitation [mm]		
	Year					
	2020	2021	Multi-year# average	2020	2021	Multi-year# average
V	11.9	12.9	14.5	93.9	61	58
VI	19.1	20.0	17.2	159	53	65
VII	19.3	22.2	19.5	31.9	110	80
VIII	20.3	17.1	17.8	95.5	219	87
IX	14.9	12.9	13.3	102	77.6	55
X	10.4	8.7	8.0	90	5.0	44

1981–2010

tive grain samples from each plot of two (a total of 8 for each experimental site) were analysed for total protein content using, the Kjeldahl method (protein conversion factor 6.25). On the basis of the grain yield obtained and the results of the protein analyses, the protein yield per hectare of the plot was calculated according to the formula:
grain yield × protein content in grain = protein yield.

The results obtained were statistically elaborated by means of analysis of variance, assessing the significance of differences with the t-Tukey test at $\alpha = 0.05$. Statistica v.13.1 was used for this purpose.

RESULTS AND DISCUSSION

In the study conducted with uniform inter-row spacing and sowing date applied, it was found that plant density was shaped by nitrogen fertilisation and cultivar (Table 3). The cultivar Albanus showed no significant increase in plant number with increasing nitrogen fertilisation. There was a slight tendency for this cultivar to have higher plant numbers when nitrogen fertilisation was 100, and increasing fertilisation levels resulted in lower plant density. The cultivar Anggy showed a significant increase in plant density at a dose of 100 kg N ha^{-1}, while increasing fertilisation by 20 N ha^{-1} reduced plant density (by 2 pc m^{-2} in 2020 and by 1.3 pc m^{-2} in 2021). The cultivar GK Emese responded most to nitrogen fertilisation to increase plant density. At the same time, this response was differentiated by year. In 2020, there was a slight tendency for the number of plants in this cultivar to decrease with increasing fertilisation, but these differences were not statistically significant. In 2021, on the other hand, the cultivar responded with a clear increase in the number of plants per unit area with increasing levels of nitrogen fertilisation. When comparing main effects, there was no significant effect of nitrogen fertilisation on plant number, but a greater effect of years was found. In 2021, a lower nitrogen rate (80 kg ha^{-1}) was found to significantly reduce the number of plants per unit area (Table 4). There was no effect of cultivar on plant density, but the effect of years was found regarding to cultivar. Optimum plant density is one of the factors determining yield. It allows maximum utilisation of the area and maximisation of the yield from it. The type of yield and the specific cultivar must be taken into account. In the case of sorghum grown for green matter, the optimum plant density makes it possible to maximise the yield of green matter silage or panicles for grain. The plant density of sorghum is sometimes determined by the sowing date and the spacing between rows (Kruczek et al., 2014). The most important element of grain sorghum yield structure is the number of panicles formed by the plants (Alikhani et al., 2012).

Plant tillering and the number of panicles per unit area also affected the yield structure. Own research showed that the grain sorghum studied reacted with a decrease in tillering to increasing nitrogen fertilisation (Table 3). The response of the cultivar tillering was also related to the years of cultivation. In 2020, the decrease in tillering was similar in 2021 (Table 4). A study by Szumiło and Rachoń

Table 3. Yield structure of grain sorghum depending on cultivar and nitrogen fertilisation level.

N dose	Cultivar	Plant density [pc m^{-2}]		Number of panicles per m^2		Tillering index	
		Year					
		2020	2021	2020	2021	2020	2021
80 kg ha^{-1}	Albanus	20.0 b	18.6 bc	38.0 b	39.0 a	1.9 ab	2.1 a
	Anggy	18.0 c	16.5 c	30.6 d	29.7 c	1.7 bc	1.8 b
	GK Emese	22.0 ab	18.5 bc	44.0 a	40.7 a	2.0 a	2.2 a
100 kg ha^{-1}	Albanus	20.5 b	19.1 b	34.0 c	32.5 bc	1.7 bc	1.7 bc
	Anggy	23.0 a	20.3 ab	34.5 c	36.5 b	1.5 cd	1.8 b
	GK Emese	20.5 b	21.5 a	28.7 d	40.8 a	1.4 d	1.9 b
120 kg ha^{-1}	Albanus	19.5 bc	18.4 b	39.0 b	35.0 b	2.0 a	1.9 b
	Anggy	21.0 ab	19.0 b	21.0 e	28.5 c	1.0 e	1.5 c
	GK Emese	21.5 ab	22.5 a	32.3 cd	33.7 b	1.5 cd	1.5 c

Values in columns signed with different letters (a-e) are significantly different ($\alpha = 0.05$).

Table 4. Average yield structure values for nitrogen fertilisation rate and cultivar.

Specification	Plant density [pc m^{-2}]		Number of panicles per m^2		Tillering index	
	Year					
	2020	2021	2020	2021	2020	2021
Nitrogen dose						
80 kg ha^{-1}	20.0 a	17.9 b	37.5 a	36.5 a	1.9 a	2.0 a
100 kg ha^{-1}	21.3 a	20.3 a	32.4 ab	36.6 a	1.5 b	1.8 ab
120 kg ha^{-1}	20.7 a	20.0 a	30.8 b	32.4 b	1.5 b	1.6 c
Cultivar						
Albanus	20.0 a	18.7 a	37.0 a	35.5 a	1.9 a	1.9 a
Anggy	20.7 a	18.6 a	28.7 b	31.6 b	1.4 b	1.7 b
GK Emese	21.3 a	20.8 a	35.0 a	38.4 a	1.6 b	1.9 a

Values in columns signed with different letters (a-c) are significantly different ($\alpha = 0.05$).

Table 5. Sorghum yield composition and yield in relation to nitrogen dose and cultivar.

Nitrogen dose	Cultivar	Grain weight per panicle [g]		Yield calculated [t ha^{-1}]		Thousand grain weight [g]	
		Year					
		2020	2021	2020	2021	2020	2021
80 kg ha^{-1}	Albanus	12.90 d	16.41 d	4.9 d	6.4 b	26.2 ab	25.9 bc
	Anggy	17.32 c	18.86 c	5.3 cd	5.6 b	24.8 b	24.9 c
	GK Emese	17.96 c	19.41 bc	7.8 b	7.9 a	27.4 ab	27.0 ab
100 kg ha^{-1}	Albanus	16.47 c	20.93 b	5.6 cd	6.8 b	27.8 a	27.1 ab
	Anggy	17.11 c	18.36 c	5.9 cd	6.7 b	25.5 b	25.2 bc
	GK Emese	29.08 b	17.48 cd	8.2 b	7.1 ab	28.7 a	28.2 a
120 kg ha^{-1}	Albanus	15.65 c	20.86 b	6.1 c	7.3 a	27.8 a	27.8 ab
	Anggy	27.62 b	22.81 a	5.8 cd	6.5 b	25.4 b	25.7 bc
	GK Emese	33.64 a	19.15 bc	10.5 a	6.5 b	28.6 a	27.8 ab

Values in columns signed with different letters (a-d) are significantly different ($\alpha = 0.05$).

Table 6. Sorghum yield composition and yield averages as a function of nitrogen dose and cultivar.

Specification	Grain weight per panicle [g]		Yield calculated [t ha^{-1}]		Thousand grain weight [g]	
	Year					
	2020	2021	2020	2021	2020	2021
Nitrogen dose						
80 kg ha^{-1}	16.06 c	18.23 b	6.0 b	6.6 a	26.1 b	25.9 a
100 kg ha^{-1}	20.89 b	18.93 ab	6.6 b	6.9 a	27.3 a	26.8 a
120 kg ha^{-1}	25.64 a	20.94 a	7.5 a	6.8 a	27.3 a	27.1 a
Cultivar						
Albanus	15.1 c	19.40 b	5.5 b	6.8 ab	27.3 ab	26.9 ab
Anggy	20.69 b	20.01 a	5.7 b	6.3 b	25.3 b	25.3 b
GK Emese	26.90 a	18.68 c	8.8 a	7.2 a	28.2 a	27.7 a

Values in columns signed with different letters (a-c) are significantly different ($\alpha = 0.05$).

(2014) confirms that the course of weather in the years of the experiments conducted significantly differentiated panicle density per unit area in grain type sorghum. Yang et al. (2021) indicate that in sorghum cultivation and yield maximisation, it is important to select the sowing density and expected plant density for nitrogen fertilisation and to divide the nitrogen dose into two parts with pre-sowing application of 1/3 of the whole dose. In our study, the entire nitrogen dose was applied pre-sowing, which may have influenced plant density. Plant density also affects nitrogen use efficiency. According to the study by Zand et al. (2014), the highest nitrogen use efficiency occurs at a grain sorghum plant density of 20 pc m^{-2} and fertilisation of 80 kg ha^{-1}.

Thousand grain weight and grain weight per panicle also have a significant effect on grain yield of sorghum (Khandelwal et al., 2015). The cultivar GK Emese showed the greatest response to increasing nitrogen in terms of grain weight per panicle. Only in 2021, a reduction in panicle grain weight was recorded for this cultivar when fertilised with nitrogen at 100 and 120 kg N ha^{-1}, but there was no statistical difference. The Anggy cultivar significantly increased yield per panicle when fertilised with 120 kg N ha^{-1}. The cultivar Albanus showed an increase in grain weight per panicle up to 100 kg N ha^{-1} while increasing the dose by a further 20 kg had no significant effect on this trait (Table 5).

Nitrogen fertilisation had a significant effect on total grain weight per panicle with differences becoming apparent between years. In 2020, a significant increase in grain weight per panicle was found as the fertilisation rate increased, while in 2021 only the application of the highest nitrogen rate of 120 kg ha^{-1} affected the increase in grain weight per panicle compared to 80 kg N ha^{-1} (Table 6). Cultivar was found to have a significant effect on grain weight per panicle, but this trait was influenced by the years of study. The Anggy cultivar had the most stable grain weight per panicle over the years studied. In contrast, the other two cultivars showed variable grain weight per panicle over the years (Table 6).

There was significant effect of nitrogen fertilisation level on thousand grain weight but only in 2020 between dose 80 kg N ha^{-1} and 100, 120 kg N ha^{-1}. Thousand grain weight is a varietal trait and is only slightly influenced by agrotechnic (Amare et al., 2015).

The applied nitrogen fertilisation rates influenced the obtained grain yield in the cultivars tested, although the individual cultivars responded with different yield increases. Among the cultivars tested, the highest grain yield was obtained from the GK Emese cultivar at the highest nitrogen fertilisation rate of 120 kg ha^{-1}. This cultivar achieved a yield above 10 t ha^{-1} only in 2020 (Table 5). Akinseye et al. (2020) using different nitrogen rates in sorghum cultivation, found that a level of 100 kg N ha^{-1} was optimal for obtaining high grain yield in sorghum. In our study, in 2020 the average yield was the highest when the highest nitrogen fertilisation was applied. In 2021 an increase of fertilisation dose from 100 to 120 kg ha^{-1} caused a decrease in yield, but it was not significant. The average yield of the Albanus and Anggy cultivars did not differ significantly, only the GK Emese cultivar showed a higher average yield in both years studied (Table 6). Grain yield is the final result of the number of grains per panicle and thousand grain weight (Baye et al., 2022). As shown by Jabereldar et al. (2017), 1000 grain weight is a yield component that reflects the relationship of photosynthetic intensity at the seed-filling stage, and water deficit during this period reduces grain weight. In our study, water deficit was not found to affect thousand-grain weight. In July, 2020 when the plant flowering and seed-filling stage began, was characterised by significantly less rainfall than the multi-year average, and in July 2021 by above-average rainfall which did not differentiate thousand grain weight.

Cultivars, on the other hand, showed varied yield which may indicate their differential response to weather conditions during flowering and grain filling. Romana et al. (2018) and Menezes et al. (2015) point to significant genetic variation in sorghum cultivars and their different responses to weather conditions, indicating that certain cultivars respond much better to drought stress than to excess rainfall. In our study, two tested cultivars Albanus and Anggy showed an increase in grain yield in 2021 when precipitation was more than double in July and August that of the multi-year period. The study by Szumiło and Rachoń (2014) showed that the most favourable weather conditions in Poland for high grain yield of sorghum should be characterised by a deficit of precipitation and higher air temperature in June and August, and a marked excess of precipitation and slightly lower temperature in May and September. In the years of the study, higher precipitation was recorded in May 2020 than in the multi-year period, but lower air temperature which, due to the thermal requirements of sorghum during emergence, may have influenced the lower grain yield compared to 2021. As shown by Patanè et al. (2016), sorghum cultivars may show different responses in germination to temperature and moisture during emergence. According to Gao et al. (2022), weather conditions occurring at the grain-filling stage have a much greater effect on grain yield than those occurring at the emergence stage. Bell et al. (2018) also point out the great importance of water conditions during the flowering period of sorghum in ensuring higher yield, especially its important component which is grain weight per panicle. Güler et al. (2008) conclude that yield and thousand grain weight are more influenced by cultivar than nitrogen fertilisation. In contrast, Dembele et al. (2021) indicate that thousand grain weight influenced grain yield of sorghum cultivars, but that the response to nitrogen doses in terms of this trait is cultivar dependent. The grain yields of the different cultivars achieved in our study varied but the cultivar GK Emese

Table 7. Protein content and protein yield as a function of nitrogen dose and cultivar.

Nitrogen dose	Cultivar	Protein content [%]		Protein yield [kg ha^{-1}]	
		Year			
		2020	2021	2020	2021
80 kg ha^{-1}	Albanus	9.9 c	9.3 c	485.1 e	595.2 d
	Anggy	9.1 c	9.5 c	482.3 e	532.0 e
	GK Emese	10.5 b	10.9 b	819.0 c	861.1 a
100 kg ha^{-1}	Albanus	10.3 bc	10.5 bc	576.8 e	714.0 c
	Anggy	10.5 b	10.4 bc	619.5 d	696.8 c
	GK Emese	11.3 ab	12.2 a	926.6 b	866.2 a
120 kg ha^{-1}	Albanus	10.6 b	10.4 bc	646.6 d	759.2 b
	Anggy	10.8 ab	10.5 bc	626.4 d	682.5 c
	GK Emese	11.7 a	12.5 a	1228.5 a	812.5 ab

Values in columns signed with different letters (a-e) are significantly different ($\alpha = 0.05$).

Table 8. Average protein content and protein yield as a function of nitrogen dose and cultivar.

Specification	Protein content [%]		Protein yield [kg ha^{-1}]	
	Year			
	2020	2021	2020	2021
Nitrogen dose				
80 kg ha^{-1}	9.8 a	9.9 a	595 c	662.8 a
100 kg ha^{-1}	10.7 a	11.0 a	707.6 b	759.0 a
120 kg ha^{-1}	11.00 a	11.1 a	833.8 a	751.4 a
Cultivar				
Albanus	10.3 a	10.1 a	569.5 b	689.5 b
Anggy	10.1 a	10.1 a	576.1 b	637.1 b
GK Emese	11.2 a	11.8 b	991.4 a	846.6 a

Values in columns signed with different letters (a-c) are significantly different ($\alpha = 0.05$).

achieved grain yield above 10 t ha^{-1} in 2020 at the highest fertilisation level, with is comparable to the yields obtained in different grain sorghum cultivars by Manole et al. (2020). Considering that the average grain sorghum yield in the European Union countries is 5.2 t ha^{-1} (Popescu, 2020a), it can be concluded that the yields obtained in our study exceeded this value, except for the yield value obtained by the Albanus cultivar (4.9 t ha^{-1}).

The highest protein content characterised the GK Emese cultivar, it was also translated into a high protein yield (Table 7, 8). Only the GK Emese variety met the minimum quality requirements with a protein content in grain of up to 11.5%, intended for baking purposes, but only at the highest fertilization dose in both test frames and at a dose of 100 N ha^{-1} in 2021. Also in the study by Sobolewska and Bury (2020), the GK Emese cultivar had the highest grain protein content compared to other grain sorghum cultivars (Sweet Caroline and Sweet Susanna). Higher yield and protein content showed that this cultivar was more predisposed to intensive cultivation. The years had a strong influence on the protein grain content and protein yield. The GK Emese cultivar achieved an even higher protein yield in 2020 with the highest fertilisation level than in 2021. Compared to other cereals grown in Poland, the protein yield of sorghum cultivars Albanus and Anggy was comparable or higher. The GK Emese cultivar showed an outstanding ability to achieve a high protein yield per area, but only in one year of research, 2020. This is very important for feed grains and farms with weaker soils. In comparison, replacing rye which yields protein is around 250 kg t ha^{-1} (Różewicz, 2019) with sorghum cultivation increases protein yield per ha by twofold (for the Albanus and Anggy cultivars) or even fourfold (for the GK Emese cultivar). Differences in protein content can be caused by both genetic factors and the impact of weather conditions. Drought stress reduces the protein and starch content of the grain as well as the cultivar affects this trait (Hosain et al., 2016). Very important in the context of drought tolerance and grain quality are advances in genotype-environment (G×E) interactions provide ample opportunities to improve grain quality through balanced fertilisation under water-limited conditions. Sarshad et al. (2021) showed that drought stress can even have a beneficial effect on some grain quality traits in sorghum, including protein content. Soleymani et al. (2011) showed that increasing the nitrogen fertilization dose above 80 kg N ha^{-1} does not have a significant impact on increase in protein content in sorghum grain. Own research also showed that the tested Albanus and Anggy varieties responded with growth of grain protein content to increase of N dose from 80 to 120 kg ha^{-1} (Table 7). The GK Emese cultivar had a significant increase of protein yield only when the dose of nitrogen was increased to 100 kg N ha^{-1}, and in the case of 120 kg N ha^{-1} there was no significant difference. As indicated by Ostmeyer et al. (2022) in grain sorghum cultivars, an important marker for genetic breeding of new cultivars is to increase the conversion of nitrogen into protein in the grain which will increase nitrogen use efficiency. Also Nguluu et al. (2023) confirm the differential response of cultivars and nitrogen use coefficient indicating the importance of genotype.

CONCLUSIONS

1. Nitrogen fertilisation influenced component and final grain yield, with a maximum nitrogen dose of 100 kg per ha recommended for the cultivars Albanus and Anggy. GK Emese cultivar in favourable environmental conditions showed increase of yield to 120 kg nitrogen per ha.

2. Both nitrogen fertilisation and cultivar had an effect on protein content and yield per area, with the GK Emese cultivar being the most efficient in this respect but it depend from the weather conditions.

3. The obtained grain yield depended to a large extent on plant tillering, number of panicles per m^2 and grain weight per panicle, and these were influenced both by cultivar, nitrogen fertilisation, but also by the weather conditions in the years of the study.

REFERENCES

Akinseye F.M., Ajegbe H.A., Kamara A.Y., Adefisan E.A. Whitbread A.M., 2020. Understanding the response of sorghum cultivars to nitrogen applications in the semi-arid Nigeria using the agricultural production systems simulator. Journal of Plant Nutrition, 27: 1-17, https://doi.org/10.1080/01904167.2020.1711943.

Alikhani M.A., Etemadi F., Ajirlo A.F., 2012. Physiological basic of yield difference in grain sorghum (*Sorghum bicolor* L. Moench) in a semi-arid environment. Journal of Agricultural and Biological Science, 7(7): 488-496.

Amare K., Zeleke H., Bultosa G., 2015. Variability for yield, yield related traits and association among traits of sorghum (Sorghum Bicolor L.) Moench) varieties in Wollo, Ethiopia. Journal of Plant Breeding and Crop Science, 7(5): 125-133, doi: 10.5897/JPBCS2014.0469.

Baye W., Xie Q., Xie P., 2022. Genetic architecture of grain yield-related traits in sorghum and maize. International Journal of Molecular Sciences, 23(5), 2405, https://doi.org/10.3390/ijms23052405.

Bell J.M., Schwartz R., McInnes K.J., Howell T., Morgan C.L., 2018. Deficit irrigation effects on yield and yield components of grain sorghum. Agricultural Water Management, 203: 289-296, https://doi.org/10.1016/j.agwat.2018.03.002.

Boczar P., 2018. Plant protein-sources, production costs and quality. Zeszyty Naukowe SGGW w Warszawie-Problemy Rolnictwa Światowego, 18(4): 122-132. (in Polish + summary in English)

Dembele J.S.B., Gano B., Kouressy M., Dembele L.L., Doumbia M., Ganyo K.K., Sanogo S.B., Togola A., Traore K., Vaksman M., Teme N., Diofu D., Audebert A., 2021. Plant density and nitrogen fertilization optimization on sorghum grain yield in Mali. Agronomy Journal, 113(6): 4705-4720, https://doi.org/10.1002/agj2.20850.

FAOSTAT. Food and Agriculture Organization of the United Nations. 2023. Available online: http://www.fao.org/faostat/en/#data/QC (accessed 26 July 2023).

Frankowski J., 2017. Nutritional and therapeutic properties of sorghum (Sorghum Moench). Advances in Phytotherapy,18(3): 209-214, doi: https://doi.org/10.25121/PF.2017.18.3.209. (in Polish + summary in English)

Gao F.C., Yan H.D., Gao Y., Huang Y., Li M., Song G.L., Ren Y.M., Li Y.H., Jiang Y.X., Tang Y.J., Wang Y.X., Tao L., Fan G.Y., Wang Z.G., Guo R.F., Meng F.H., Han F.X., Jiao S.J., Li G.Y., 2022. Interpretation of genotype-environment-sowing date/plant density interaction in sorghum [Sorghum bicolor (L.) Moench] in early mature regions of China. Frontiers in Plant Science, 13, 1008198, https://doi.org/10.3389/fpls.2022.1008198.

Gasiński A., Kawa-Rygielska J., Spychaj R., Opiela E., Sowiński J., 2023. Production of gluten-free beer brewing from sorghum malts mashed without external enzyme preparations. Journal of Cereal Science, 112, 103693, https://doi.org/10.1016/j.jcs.2023.103693.

Gierasimiuk N., Bury M., Jaroszewska A., 2023. Influence of Sowing Date and Level of Nitrogen Fertilization on the Yield of Five Varieties of Grain Sorghum. Available at SSRN: https://ssrn.com/abstract=4669514 or http://dx.doi.org/10.2139/ssrn.4669514.

Güler M., Gül I., Yilmaz Ş., Emeklier H. Y., Akdoğan G., 2008. Nitrogen and plant density effects on sorghum. Journal of Agronomy, 7(3): 220-228, 10.3923/ja.2008.220.228.

Hossain A.K.M.Z., Mahmud M.S., Islam M.S., Tajkia J.E., Sagar A., Khaton M.A., 2016. Effect of moisture stress on morphological and yield attributes of four sorghum varieties. Progressive Agriculture, 27(3): 265-271, https://doi.org/10.3329/pa.v27i3.30806.

https://european-seed.com (accessed 20 July 2023)

Jabereldar A.A., El Naim A.M., Abdalla A.A., Dagash Y.M., 2017. Effect of water stress on yield and water use efficiency of sorghum (Sorghum bicolor L. Moench) in semi-arid environment. International Journal of Agriculture and Forestry, 7(1): 1-6, doi: 10.5923/j.ijaf.20170701.01.

Kaczorek Z., 2020. Sorghum camel among plants. Świętokrzyski Ośrodek Doradztwa Rolniczego in Modliszewice. https://www.sodr.pl/informacje-branzowe/index/Sorgo-wielblad--wsrod-roslin/idn:1389 (accessed 08.06.2020).

Khandelwal V., Shukla M., Jodha B.S., Nathawat V.S., Dashora S.K., 2015. Genetic parameters and character association in sorghum (Sorghum bicolor (L.) Moench). Indian Journal of Science and Technology, 8(22): 2-4.

Kruczek A., Skrzypczak W., Waligóra H., 2014. Response of sorghum to varying plant density and row spacing in relation to sowing date. Science Nature Technology, 8(1), 13. (in Polish + summary in English)

Manole D., Giumba A.M., Ganea L., 2020. Researches and Contributions to Plant Sorghum Crop in the Conditions of Climate Changes. Annals of the Academy of Romanian Scientists Series Agriculture, Silviculture and Veterinary Medicine Sciences (1/2020), Avialiable at https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3699185.

Menezes C.B., Saldanha D.C., Santos C.V., Andrade L.C., Júlio M.M., Portugal A.F., Tardin F.D., 2015. Evaluation of grain yield in sorghum hybrids under water stress. Genetics and Molecular Research, 14(4): 12675-12683, http://dx.doi.org/10.4238/2015.October.19.11.

Ngulu S., Muui C., Muasya R., 2023. Effect of nitrogen fertilizer on nitrogen use efficiency and yield of selected sorghum genotypes in semi-arid regions of Kenya. East African Journal of Science, Technology and Innovation, 4(2), https://doi.org/10.37425/eajsti.v4i2.546.

Ostmeyer T.J., Bahuguna R.N., Kirkham M.B., Bean S., Jagadish S.V., 2022. Enhancing sorghum yield through efficient use of nitrogen – challenges and opportunities. Frontiers in Plant Science, Sec. Crop and Product Physiology, 13, 845443, https://doi.org/10.3389/fpls.2022.845443.

Patanè C., Saita A., Tubeileh A., Cosentino S. L., Cavallaro V., 2016. Modelling seed germination of unprimed and primed seeds of sweet sorghum under PEG-induced water stress through the hydrotime analysis. Acta Physiologiae Plantarum, 38: 1-12, doi: https://doi.org/10.1007/s11738-016-2135-5.

Popescu A., 2020a. Sorghum production in the EU-28 in the period 2008-2019 and its forecast for 2020-2014 horizon. Scientific Papers: Management, Economic Engineering in Agriculture & Rural Development, 20(3): 479-488.

Popescu A., 2020b. Sorghum production in Romania in the period 2010-2019 - Trends and determinant factors. Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, 20(3): 455-465.

Różewicz M., 2019. Triticale grain production in Poland and its feed value and use in poultry nutrition. Wiadomości Zootechniczne, 4(57): 121-132. (in Polish + summary in English)

Różewicz M., 2020. Potential of sorghum cultivation in Poland and fodder value and the possibility of using its grain in poultry nutrition. Wiadomości Zootechniczne. 1(58): 39-48. (in Polish + summary in English)

Romana K.K., Chander G., Deshpande S., Gupta R., 2018. Genomic-assisted enhancement in stress tolerance for productivity improvement in sorghum. Biotechnologies of Crop Improvement, Volume 3: Genomic Approaches, pp. 265-288, https://doi.org/10.1007/978-3-319-94746-4_12.

Sarshad A., Talei D., Torabi M., Rafiei F., Nejatkhah P., 2021. Morphological and biochemical responses of Sorghum bicolor (L.) Moench under drought stress. SN Applied Sciences, 3: 1-12, doi: https://doi.org/10.1007/s42452-020-03977-4.

Sobolewska M., Bury M., 2020. Sorghum flour - its property and composition. Przegląd Zbożowo-Młynarski, 64(6): 18-19. (in Polish + summary in English)

Sobolewska M., Jaroszewska A., Bury M., 2018. Influence of nitrogen fertilization on amylographic properties of sorghum flour. Przegląd Zbożowo-Młynarski, 62(6): 32-33. (in Polish + summary in English)

Soleymani A., Shahrajabian M.H., Naranjani L., 2011. The effect of plant density and nitrogen fertilization on yield, yield components and grain protein of grain sorghum. Journal of Food, Agriculture and Environment, 9(3): 244-246.

Sowiński J., Szydełko-Rabska E., 2013. Possibilities of cultivation of grain sorghum, cultivar 251 in conditions of Lower Silesia - preliminary results. Fragmenta Agronomica, 30(4): 138-146. (in Polish + summary in English)

Stachowiak B., Nowak J., Szambelan K., Bajon A., 2023. Sorghum - agricultural and industrial potential. Zagadnienia Doradztwa Rolniczego, 110(4), 49-61. (in Polish + summary in English)

Szumiło G., Rachoń L., 2014. Influence of sowing date and row spacing on the yield of sorghum [Sorghum bicolor (L.) Moench] cultivated for grain. Annales Universitatis Mariae Curie-Skłodowska. Sectio E, Agricultura, 69(4): 1-9. (in Polish + summary in English)

Yang G.D., Hu Z.Y., Zhou Y.F., Hao Z.Y., Li J.H., Wang Q., Meng X.X., Huang R.D., 2021. Effects of nitrogen application strategy and planting density optimization on sorghum yield and quality. Agronomy Journal, 113(2): 1803-1815, https://doi.org/10.1002/agj2.20629.

Wolska A., 2021. More and more sorghum is grown in the EU. Through climate change. https://www.euractiv.pl/section/rolnictwowpr/news/unia-europejska-sorgo-afrykazmiany-klimatyczne-ekologia-ziemia/ (accessed 21 July 2023). (in Polish)

Zand N., Shakiba M.R., Vahed M.M., Nasab A.D.M., 2014. Response of sorghum to nitrogen fertilizer at different plant densities. International Journal of Farming and Allied Sciences, 3(1): 71-74.

Author	ORCID
Marcin Różewicz	0000-0002-3281-5533

received – 1 September 2023
revised – 10 November 2023
accepted – 12 december 2023

Author declares no conflict of interest.