Yield and Selected Physiological Parameters of Maize, Sorghum, and Triticale Depending on Fertilization System

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Effects of fertilization with digestate from agricultural biogas plant and its influence on growth and selected physiological parameters of maize, triticale, and sorghum plants cultivated for biogas production were studied in this work. The digestate was used as an organic fertilizer, being a substitute or supplement to mineral fertilization. The fertilization with the digestate had a positive effect on the fresh matter yield (FMY) of sorghum (85.4 Mg ha^{-1}), the dry matter content (DM) of maize (41.9%) and sorghum (23.6%), as well as on the dry matter yield (DMY) of triticale (12.2 Mg ha^{-1}) and sorghum (19.8 Mg ha^{-1}). Among the studied species, the maize fertilized with digestate (variants N2 and N3) showed better growth responses compared to the maize that was fertilized with mineral fertilizers (plant nutrition status - SPAD of 54.8). No significant influence of fertilization variant was observed on the photosynthetic active radiation (PAR) and the leaf area index (LAI) of the tested plant species. The digestate proved to be a good fertilizer, supporting high yields without adverse effects on the physiological parameters of the plants.

Keywords: Digestate; SPAD; PAR; LAI; Yield; Triticale; Maize; Sorghum; Energy crops

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INTRODUCTION

Based on the available literature, the yield of plants is correlated with the soil fertility status and mineral and organic fertilization programs (Serri *et al.* 2021). The use of mineral and organic fertilizers has varying levels of effectiveness on plant yield. Adamus *et al.* (1989) demonstrated that manure fertilization causes the smallest changes in the soil pH and physicochemical properties, and its beneficial role in this respect is also visible in combined organic-mineral fertilization. Moreover, it has been shown that the long-term use of mineral fertilization alone limits the yield increase and causes the soil fertility to decrease in comparison with other fertilization systems. Digestate (also called digestion pulp) is produced by the anaerobic processing of various organic substrates. While this process produces gaseous fuel, it is biodegradable and can be used as an organic fertilizer (Kalina *et al.* 2003; Teliga *et al.* 2011; Czekała *et al.* 2012). The organic fractions of the digestate can contribute to the transformation of organic matter in the soil, and it can help reduce soil acidification (Kalina *et al.* 2003; Teliga *et al.* 2011; Makádi *et al.* 2012; Möller and Müller 2012; Bachmann *et al.* 2016; Czekała 2019; Peng and Pivato 2019; Slepetiene *et al.* 2020). Many authors have shown that digestate contains valuable nutrients and organic matter, so it can be used as a fertilizer that contributes to improving the physical and chemical properties of the soil and the crop quality and yield (Gellings and Parmenter 2004; Garg *et al.* 2005; Węglarzy and Stekla 2009; Möller and Müller 2012; Gulyás *et al.* 2016; Ronewicz *et al.* 2016; Koszel *et al.* 2017; Risberg *et al.* 2017; Peng and Pivato 2019; Robles-Aguliar *et al.* 2019).

Möller and Müller (2012) showed that the use of the digestate compared to untreated manure contributed to an increase in the nitrogen availability and yield. In a study by Domínguez (2012), the effect of mineral fertilization and digestate was compared with an unfertilized control. Sorghum bicolor and winter wheat were cultivated in Germany. The application of slurry and digestate had less effect on the plant height (5%), the leaf area index (LAI) (15%), and the dry matter yield (DMY) (20%), compared to mineral nitrogen fertilizer. At the same time, in the cultivation of sorghum, fertilization with liquid and dehydrated digestate did not have a significant effect on the plant height and the LAI, compared to slurry.

Important physiological parameters for the assessment of fertilization efficiency are the plant nutrition status (SPAD), and the intensity of photosynthetic active radiation (PAR). The SPAD is an indicator of chlorophyll content and nitrogen nutrient status of plants (Monostori *et al.* 2016; Fiorentini *et al.* 2019).

Based on the literature review, a hypothesis was formulated that the digestate obtained as a result of the biogas production process can be effectively used as an organic fertilizer, being a substitute or supplement to mineral fertilization.

EXPERIMENTAL

The field experiment was conducted between 2016 and 2018 at the Kepa Experimental Station of the Institute of Soil Science and Plant Cultivation - State Research Institute in Osiny, near Pulawy, Lublin Province, Poland (N:51°28´21,34", E:22°3´7,65"). The experiment was established on lessive soil, made of light clay sand. The area of a single experimental plot was 225 m^2, and the entire experimental area was 0.81 ha.

Table 1. Soil Properties

Soil Properties	Mean	Analyzing Methods
pH in KCl	5.3	PN ISO 103090 (1997)
P_2O_5 (mg/100g)	21.1	PN-R-04023 (1996)
K_2O (mg/100g)	15.2	PN-R-04022 (1996)/Az1 (2002)
MgO (mg/100g)	7.2	PN-R-04020 (1994)/Az1 (2004)
C Organic (mg/100g)	0.6	PB 21.1 – ed. I-10.05.2013

In a three-year field experiment, three species and varieties for biogas production were grown simultaneously in the rotation: triticale (var. Dublet C1 in 2016 and var. Maestro in 2017 to 2018), maize (var. Respect), and sorghum (var. Sucrosorgo 506). The experiment was established on the field after potatoes were gown without fertilization. Before the experiment was established, soil samples were taken from the arable layer (0 to 30 cm), in which the content of selected nutrients, the organic carbon level, and the pH were determined. The soil properties are given in Table 1. The pH was measured potentiometrically in a 1:2.5 (m V^{-1}) soil suspension in 1 mol L^{-1} KCl solution (PN-ISO10390 1997). The content of available phosphorus and potassium in mineral soils was measured by the Egner-Riehm method according to standards PN-R-04023 (1996) and PN-

R-04022 (1996), respectively. The magnesium content was determined by the Schachtschabel method according to PN-R-04020 (1994).

To increase the pH value (5.5) before sowing the tested plants, 3 Mg ha^{-1} of dolomite ($CaCO_3$ and $MgCO_3$) was applied. The first factor of the experiment was the species of the cultivated plant and the second was nitrogen fertilization variant: N1 - pre-sowing and topdressing with mineral fertilizers, N2 - pre-sowing fertilization with digestate from agricultural biogas plant, topdressing with mineral fertilizers, and N3 - pre-sowing and topdressing with digestate. Regarding the topdressing time, the triticale was done in three stem elongation staging, while the maize and sorghum in four booting staging, according to the BBCH-scale. Nitrogen fertilization was applied in the dose provided by pre-sowing (50 kg N ha^{-1} for triticale, 70 kg N ha^{-1} for maize and sorghum) and by top-dressing (70 kg N ha^{-1} for triticale, 90 kg N ha^{-1} for maize and sorghum). The basis for the annual determination of the dose of the digestate was its nitrogen content. The triticale biomass was harvested in the milk-wax phase, the maize in the late wax to full grain ripeness, while the sorghum was harvested after the first frosts. The fresh matter yield (FMY) was determined by taking four samples from 1 m^2 areas for each plot. Then dry matter content (DM) and the dry matter yield (DMY) were determined. For this purpose, the samples of the plant material were weighed and then dried for 7 d in a chamber dryer at 60 °C and weighed again. Every year, during the vegetation period (April to October), the SPAD, PAR, and LAI values were measured at two-week intervals.

The SPAD was measured using the SPAD 502 Plus chlorophyll meter (Konica Minolta, Tokyo, Japan). The SPAD was measured for each plot on the 30 youngest, fully developed leaves. The LAI is defined geometrically as the total vertical projection of a unilateral surface of functional tissue photosynthetically, per unit of substrate area above. The PAR and LAI parameters were tested directly in the canopy for each plot at three heights: 0, 30, and 100 cm by SunScan Canopy Analysis System (Potter *et al.* 1996). The measurement was performed in the morning, with a minimum solar radiation intensity of more than 500 µmol m^2/s. A beam fraction sensor (BFS) (Delta-T Devices, Cambridge, UK) was used to measure the total PAR in the direct radius. The sensor measured total and diffused PAR and the presence of sunlight using seven photodiodes. The PAR readings were expressed in units of quantum flux µmol/m^{2}s, while the LAI readings were expressed in m^2 m^{-2}. To eliminate factors that may have affected the PAR measurement, the results were presented as a percentage ratio of absorbed to incident photosynthetic radiation. The temperature and the precipitation were controlled during the period of the experiment to determine the effect of weather on the results. Based on weather conditions, a conversion was prepared according to the hydrothermal index of Sielaninov, which was calculated according to Eq. 1,

$$k = \frac{\mathrm{P}}{0.1 \cdot \sum t} \tag{1}$$

where k is the value of the Sielaninov hydrothermal index, P is the sum of the monthly precipitation (mm), and t is the sum of the average daily air temperatures for the month (°C).

The Sielaninov index provided the characteristics of the hydrothermal conditions from very dry (vd) $k \leq 0.7$; dry (d) $0.7 < k \leq 1.0$; fairly dry (fd) fd $1.0 < k \leq 1.3$; optimal (o) $1.3 < k \leq 1.6$; fairly wet (fw) $1.6 < k \leq 2.0$; wet (w); $2.0 < k \leq 2.5$; and very wet (vw) $k > 2.5$ (Table 4) (Skowera and Puła 2004).

The average value and standard deviation were determined for each of the tested variables. The Shapiro-Wilk test was used to assess normal distribution. The verification of the hypothesis assuming uniformity of variance was performed using Brown and Forsythe's test. To compare the magnitude of differences between the tested variants and species, analysis of variance (ANOVA) testing was performed. Tukey's post-hoc HSD test was used to determine the significance of differences between all the tested samples. All the statistical analyses were performed at the significance level $p < 0.05$, in Statistica 7 (StatSoft, Tulsa, OK, USA).

RESULTS AND DISCUSSION

Weather Condition

The most important influence on the growth and development of the examined plants was caused by the weather conditions in the period from April to September. The average air temperature in all the years of the study was higher than the average from the years 1955 to 2000. The highest air temperatures were recorded in the last year of the study (2018), especially in the months April to October. At the same time, it was a year of low precipitation. In contrast to 2018, the amount of precipitation in 2016 and 2017 was much higher than the average from the years 1955 to 2000.

On average, between 2016 and 2018, high precipitation values were recorded in the summer months (July to September). During this period, the precipitation values reached up to 55 mm of rainfall per day (Table 2).

Table 2. Monthly Average Air Temperatures (°C) and Precipitation Totals (mm) Between 2016 and 2018 Compared to the Multi-Year Averages from 1950 to 2000 for the Osiny Weather Station

Month	Average Air Temperature (°C)				Precipitation (mm)			
	2016	2017	2018	1950 to 2000	2016	2017	2018	1950 to 2000
Janury	-3.6	-4.7	0.4	-2.9	35	5	17	29
February	3.5	-0.8	-3.8	-2.0	71	51	17	28
March	4.0	5.9	0.1	1.9	51	34	31	28
April	9.2	7.5	13.6	8.1	43	72	30	42
May	14.7	13.8	17.1	13.8	43	68	59	55
June	19.1	18.1	18.8	17.1	29	34	38	71
July	19.4	18.6	20.6	18.6	80	120	123	78
August	18.3	19.7	20.8	17.8	105	108	28	67
September	15.6	14.0	15.7	13.3	17	110	48	53
October	7.4	9.5	10.3	8.4	127	95	41	39
November	2.9	4.5	3.7	3.1	47	54	9	39
Decemer	0.5	2.4	0.9	-0.9	80	21	61	39
Average	**9.2**	**9.0**	**9.9**	**8.0**	**-**	**-**	**-**	**-**
Total	**-**	**-**	**-**	**-**	**728**	**772**	**502**	**568**

The value of the hydrothermal index in the key period for triticale growth and development, (April to July) indicated that it was quite dry (1.15) in 2016, optimal (1.38) in 2017, and quite dry (1.11) in 2018. For the cultivation of sorghum and maize in 2016, the hydrothermal index indicated that it was dry (0.85) in 2017, quite moist (1.65), and quite dry (0.98) in 2018 (Table 3).

Table 3. Sielaninov Hydrothermal Index

Month	2016	2017	2018
April	1.56 (o)	1.26 (fd)	0.73 (s)
May	0.94 (d)	1.57 (o)	1.11 (fd)
June	0.50 (fd)	0.62 (vd)	0.68 (vd)
July	1.33 (o)	2.07 (w)	1.91 (fw)
August	1.84 (fw)	1.77 (fw)	0.43 (vd)
September	0.37 (vd)	2.62 (vw)	1.02 (fd)
Average *k* Value for April to July	1.15 (fd)	1.38 (o)	1.11 (fd)
Average *k* Value for June to September	0.85 (d)	1.65 (fw)	0.98 (d)

Yields

The highest (78.4 Mg ha^{-1}) and lowest (26.0 Mg ha^{-1}) FMY values, regardless of the fertilization and the year of the experiment, were recorded for sorghum and triticale, respectively (Table 4). For the sorghum, the FMY varied significantly between variants, from 69.3 Mg ha^{-1} where only mineral fertilization was applied (N1), to 85.4 Mg ha^{-1}, where only the digestate was applied (N3). The lowest DM, regardless of the fertilization, was found in the sorghum biomass (21.1%). Significantly higher values of this parameter were recorded for maize and triticale biomass (42.7 and 44.1%, respectively). The lowest DM was observed in the cultivation of sorghum in variant N1 (22.1%), while the highest was observed in the cultivation of maize, also in variant N1 (45.1%). Moreover, the DM in sorghum biomass in variant N1 was significantly lower than in the N2 and it was comparable to the N3 variant where only digestate was applied. In the case of the maize, the DM significantly decreased in fertilization with the use of digestate (N2 and N3). In the triticale cultivation, the DM did not differ significantly between the applied variants of fertilization.

The species that were studied had significantly different DMY values (Table 4). Regardless of the fertilization, the lowest average DMY from the three years of the study was obtained for triticale (11.3 Mg ha^{-1}). In the fertilization variants, N1 and N2, the highest DMY was obtained for the maize and in the variant N3 for sorghum. The applied variants of fertilization had no significant effect on the DMY of the maize. The triticale DMY significantly differed between the fertilization variants N1 and N3, while for sorghum it was significantly lower for the fertilization variant N1 as compared to variants using digestate (N2 and N3).

In comparison with the results obtained in this study, Oleszek and Matyka (2018) obtained lower DM values of triticale (18.8%) and maize (33.5%), while determining a similar DM value of sorghum (19.2%). Similarly, in the studies of Księżak *et al.* (2012), the DM of maize was also lower (average 42.7%) than the DM that was obtained in this research, ranging from 31.1% to 37.4%. On the other hand, the DM of sorghum was in the range 19.0% to 29.6%, which was similar to the value obtained in this experiment (23.1%).

Table 4. FMY, DM, and DMY Values of the Tested Plants

Property	Plant	Fertilization Variant			
		N1	N2	N3	Mean
FMY ($Mg\ ha^{-1}$)	Triticale	24.4^{aA*}	26.0^{aA}	27.6^{aA}	26.0^{A}
	Maize	46.8^{aB}	50.3^{aB}	47.3^{aB}	48.1^{B}
	Sorghum	69.3^{aC}	80.3^{bC}	85.4^{bC}	78.4^{C}
	Mean	46.9^{a}	52.2^{a}	53.5^{a}	
DM (%)	Triticale	43.9^{aA}	44.0^{aA}	44.5^{aA}	44.1^{A}
	Maize	45.1^{aA}	41.9^{bA}	41.0^{aB}	42.7^{A}
	Sorghum	22.1^{aB}	23.6^{bB}	23.5^{abC}	23.1^{B}
	Mean	37.0^{a}	36.5^{a}	36.4^{a}	
DMY ($Mg\ ha^{-1}$)	Triticale	10.6^{aA}	11.3^{abA}	12.2^{bA}	11.3^{A}
	Maize	20.3^{aB}	20.8^{aB}	19.3^{aB}	20.2^{B}
	Sorghum	15.1^{aC}	18.5^{bB}	19.8^{bB}	17.8^{C}
	Mean	15.3^{a}	16.9^{a}	17.1^{a}	

N1- only mineral fertilization, N2- mineral fertilization pre-sowing, and digestate topdressing, N3- only digestate fertilization *The averages marked with the same capital letter do not differ significantly in Tukey's test for $p < 0.05$ between plants and the averages marked with the same lowercase letter do not differ significantly between tested variants.

The FMY and DMY levels of the studied plants was comparable with the data presented by other authors. González-García *et al.* (2013) found the FMY of triticale to be 37 Mg ha^{-1}. Oleszek and Matyka (2018) found that the FMY of triticale varied, depending on the nitrogen dose, from 37 to 47 Mg ha^{-1}, which was higher than the values that were obtained in this study (24 to 28 Mg ha^{-1}). Bauböck *et al.* (2014) reported that the DMY of triticale ranged from 12 to 16 Mg ha^{-1}, which was comparable to the yield obtained in the field experiment (11 to 12 Mg ha^{-1}). In a study conducted in southern Spain (Sanz *et al.* 2011), the DMY of triticale harvested at the stage of milky maturity was 3 to 8 Mg ha^{-1}, depending on the variety and location, which was much lower than the values obtained in this experiment. These discrepancies may result from different weather conditions as well as other varieties included in the study.

According to the Central Statistical Office of Poland, in 2018, the average DMY of maize for green fodder was 42.6 Mg ha^{-1}, which was similar to the value that was obtained in this research (Central Statistical Office of Poland 2019). Szlachta and Tupiecka (2013) obtained a DMY value of 41.5 Mg ha^{-1}. A similar FMY value (54 Mg ha^{-1}) was obtained by Gorzelany *et al.* (2011) and Kacprzak *et al.* (2012). According to Bauböck *et al.* (2014), the DMY of maize in Germany was 12 to 19 Mg s.m. ha^{-1}, depending on soil quality. These values were lower than the average value that was obtained in this study (20 Mg ha^{-1}).

Matyka and Madej (2015), studying the economic efficiency of sorghum for biogas, obtained an average FMY of 93 Mg ha^{-1} (ranging from 58 to 145 Mg ha^{-1}), which was higher than the value that was obtained in this study, while Kacprzak *et al.* (2012) obtained a lower FMY for sorghum (58 Mg ha^{-1}) compared to the results of this study. Sowiński *et al.* (2016) found that the FMY of sorghum Sucrosorgo 304 fertilized with mineral nitrogen was 50 Mg ha^{-1}, while the DMY was 11.9 Mg ha^{-1}. These values were lower than those obtained in this study.

Physiological Parameters of the Plants

Achieving a high yield of good quality is conditioned by an optimal supply of macro and microelements to the crop. However, nitrogen, which is a building element, is of primary importance in plant nutrition, mainly due to its role in plant metabolism as well as its losses by several phenomena (Aghaye Noroozlo *et al.* 2019). The deficiency of nitrogen generally a decrease in crop yield (Stanisławska-Glubiak and Korzeniowska 2007). The optimal supply of nitrogen to plants contributes to maximizing yields while rationalizing production costs. Excess nitrogen results in its leaching, but also in the emission of greenhouse gases, such as nitrous oxide and ammonia (Rashid *et al.* 2004; Blecharczyk *et al.* 2009; Souri and Neumann 2018). The state of plant nutrition with nitrogen can be assessed by means of a SPAD test, which is an indicator of chlorophyll content in the leaves (Monostori *et al.* 2016; Fiorentini *et al.* 2019).

The studied species differed significantly in the value of the SPAD parameter (Fig. 1). The highest and lowest SPAD values were observed for maize and triticale, respectively. There was no effect of the fertilization variant on the SPAD of triticale and sorghum. On the other hand, in the case of maize, better plant nutrition was demonstrated in the fertilization variants N2 and N3.

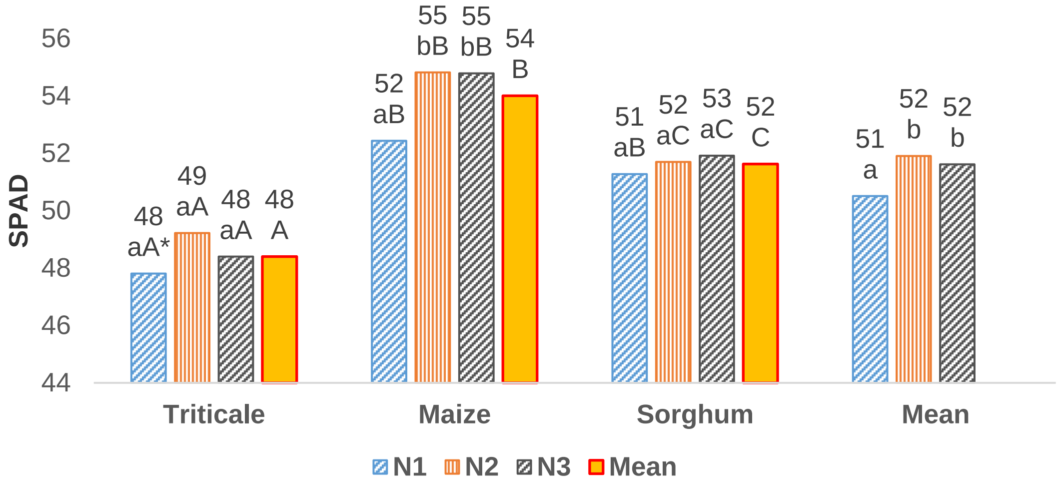

Fig. 1. The values of the SPAD test for the tested plants depending on the fertilization variant. *The means marked with the same capital letter do not differ significantly in Tukey's test for $p < 0.05$ between plants and the means marked with lowercase letter did not differ significantly between the tested variants.

When comparing mineral and organic fertilization (including the use of digestate), Kvasoviene-Petraityte *et al.* (2019) found no significant differences in the chlorophyll content in winter wheat leaves. The SPAD values for triticale in this research ranged from 42.5 to 57.3, which were similar to those obtained by other authors (Giunta *et al.* 2002; Janusauskaite *et al.* 2017; Kizilgeçi 2019). In a pot experiment with silica sand, Robles-Aguliar *et al.* (2019) compared the effect of fertilization with digestate and mineral fertilizers on the SPAD values of maize. It was found that the SPAD values increased significantly in pots where they applied digestate. In the clay soil, Robles-Aguliar *et al.* (2019) observed a significant decrease in the SPAD values in plants fertilized with digestate (17.0) compared to plants fertilized with mineral fertilizers (26.8). Rashid *et al.* (2004) found that, depending on the nitrogen dose (50 to 200 kg/ha), the SPAD values for maize ranged from 20 to 40. Pepó and Vári (2016) reported higher SPAD values (57.0 to 61.0) than those observed in this study. The SPAD values for sorghum from this study ranged between 20.2 and 55.0. Similar values were observed in other studies (Yamamoto *et al.* 2002; Uchino *et al.* 2013a,b).

On average, during the three-year study period, the analyzed species differed significantly in the amount of PAR absorbed by the plant canopy (Table 5).

Table 5. PAR (%) Absorbed by the Tested Plants Depending on the Fertilization Variant

Specification	Variant			Mean
	N1	N2	N3	
Level 0 cm**				
Triticale	$33.46 \pm 9.44^{aA*}$	30.86 ± 11.02^{aA}	39.83 ± 11.80^{aA}	34.72 ± 11.16^{A}
Maize	23.90 ± 11.43^{aB}	21.76 ± 11.76^{aAB}	24.08 ± 10.80^{aB}	23.25 ± 11.06^{B}
Sorghum	14.91 ± 5.07^{aC}	15.72 ± 7.70^{aC}	19.28 ± 9.34^{aB}	16.63 ± 7.61^{C}
Mean	24.09 ± 11.67^{a}	22.78 ± 11.84^{a}	27.73 ± 13.68^{a}	
Level 30 cm				
Triticale	54.00 ± 12.83^{aA}	49.01 ± 15.22^{aA}	41.84 ± 13.83^{aA}	48.28 ± 14.50^{A}
Maize	25.74 ± 10.40^{aB}	26.21 ± 9.45^{aB}	26.81 ± 8.32^{aB}	26.26 ± 9.17^{B}
Sorghum	17.42 ± 6.41^{aC}	17.63 ± 6.42^{aC}	21.58 ± 7.62^{aB}	18.88 ± 6.92^{C}
Mean	32.39 ± 32.40^{a}	30.95 ± 17.15^{a}	30.08 ± 13.27^{a}	
Level 100 cm				
Triticale	75.81 ± 12.65^{aA}	76.03 ± 13.81^{aA}	71.69 ± 10.28^{aA}	74.51 ± 12.14^{A}
Maize	35.73 ± 12.85^{aB}	32.73 ± 6.69^{aB}	36.32 ± 6.95^{aB}	34.93 ± 9.15^{B}
Sorghum	29.58 ± 9.44^{a}	27.70 ± 6.75^{aB}	31.06 ± 10.12^{aB}	29.45 ± 8.74^{B}
Mean	47.04 ± 47.04^{a}	45.49 ± 23.93^{a}	46.36 ± 20.38^{a}	

* The means marked with the same capital letter do not differ significantly in Tukey's test for $p < 0.05$ between plants and the means marked with lowercase letter did not differ significantly between the tested fertilization variants.
*measurement height in the field.

The lowest PAR values were recorded for sorghum and the highest for triticale. Regardless of the species, no effect of the fertilization variant on the value of the PAR absorbed by the plant canopy was found. Lower PAR values were noted in the canopy of plants characterized by higher LAI values. On average, during the three-year period of the study, the amount of absorbed PAR ranged from 14.9% (in the canopy of sorghum, in N1, at the level of 0 cm, with an LAI value of 4.50) to 76.03% (in the canopy of triticale, in N2, at the level of 100 cm, with an LAI value of 0.50).

Both the amount of light absorbed and reflected from the canopy depends on several factors, such as the age of plants, their health, the density and structure of the canopy, the nutritional status of the plants, and their water supply (Farré and Faci 2006; Pecio *et al.* 2009). Kulig *et al.* (2007) found that the amount of PAR absorbed by the field of faba bean was variable over the years. In the first year of measurements, the PAR values ranged from 70.0% to 85.4%, while in the second year it ranged from 81.8% to 90.7%. These values also differed from one another depending on the variety and the density of the plants. Farré and Faci (2006) found that the amount of PAR absorbed depended on the phase of plant development. The PAR values of this study ranged from 20% to 90% for maize and 15% to 95% for sorghum.

The studied species differed significantly in the LAI values (Table 6). The smallest LAI value was recorded in triticale (N1) at the level of 100 cm (0.45), and the largest LAI value was recorded in sorghum (N2) at the level of 0 cm (4.95). Regardless of the species no influence of the fertilization variant on the LAI value was found. Within the individual species, the LAI value did not differ significantly depending on the fertilization variant. The only exception was a measurement made at 100 cm for maize, for which a significantly higher LAI value was found in the case of fertilization with mineral fertilizers and digestate (N2).

Table 6. LAI (m^2 m^{-2}) for the Tested Plants Depending on the Fertilization Variant

Specification	Variant			Mean
	N1	N2	N3	
Level 0 cm**				
Triticale	1.83 ± 0.48^{aA*}	2.27 ± 0.67^{aA}	1.82 ± 0.69^{aA}	1.98 ± 0.64^{A}
Maize	2.91± 0.77^{aB}	3.24 ± 2.63^{aB}	3.04± 0.77^{aB}	3.07 ± 0.78^{B}
Sorghum	4.50 ± 0.92^{aC}	4.95 ± 0.85^{aC}	4.40 ± 0.88^{aC}	4.62 ± 0.90^{C}
Mean	3.08 ± 1.33^{a}	3.50 ± 1.35^{a}	3.09 ± 1.34^{a}	
Level 30 cm				
Triticale	1.02 ± 0.56^{aA}	1.31 ± 0.72^{aA}	1.45 ± 0.65^{aA}	1.26 ± 0.65^{A}
Maize	2.63 ± 0.75^{aB}	2.79 ± 0.60^{aB}	2.72 ± 0.76^{aB}	2.71 ± 0.68^{B}
Sorghum	4.11 ± 1.05^{aC}	4.48 ± 0.67^{aC}	4.08 ± 1.06^{aC}	4.22 ± 0.93^{C}
Mean	3.59 ± 1.50^{a}	2.86 ± 1.46^{a}	2.75 ± 1.36^{a}	
Level 100 cm				
Triticale	0.45 ± 0.36^{aA}	0.50 ± 0.39^{aA}	0.56 ± 0.32^{aA}	0.50 ± 0.35^{A}
Maize	2.04 ± 0.55^{aB}	2.48 ± 0.29^{bB}	2.18 ± 0.42^{aB}	2.23 ± 0.46^{B}
Sorghum	3.47 ± 1.03^{aC}	3.66 ± 062^{aC}	3.67 ± 0.90^{aC}	3.60 ± 0.84^{C}
Mean	1.98 ± 1.43^{a}	2.21 ± 1.39^{a}	2.14 ± 1.41^{a}	

* The means marked with the same capital letter in did not differ significantly in Tukey's test for $p < 0.05$ between plants and the means marked with lowercase letter did not differ significantly between the tested variants.
*measurement height in the field.

Jaśkiewicz (2007) observed that the LAI index for triticale was 3.61 and it was conditioned by the level of NPK fertilization and plant density. In the study by Biskupski *et al.* (2014), the average value of the LAI parameter from the three years of the study for maize was 2.34. In the experiment conducted in lysimeters, the LAI index was dependent on the drought stress, and it ranged from 1.91 to 2.7 for maize, and between 1.47 and 1.91 for sorghum for plants with optimal degrees of soil moisture (Tolk *et al.* 1997). Pepó and Vári (2016) found that the LAI value in maize (2.3 to 4.2) depended on the year of the study and changes in soil moisture. Maddonni and Otegui (1996) found that the LAI value (3.65 to 5.03) depended on the sowing date.

CONCLUSIONS

1. This study found that the digestate from an agricultural biogas plant can be used as a substitute for mineral nitrogen fertilizer without a negative impact on plants yields and their nutrition.
2. Fertilization with the digestate had a positive effect on the dry matter (DM) content of maize and sorghum biomass, as well as on the dry matter yield (DMY) of triticale and the FMY and DMY of sorghum.

3. Regarding the plant nutrient status (SPAD) values, maize fertilized with digestate (variants N2 and N3) was better nourished compared to that fertilized with only mineral fertilizer (N1).
4. No significant differences were observed between the fertilization variants in terms of the photosynthetic active radiation (PAR) and the leaf area index (LAI) for all the tested plant species.
5. The results showed that digestate from agricultural biogas plant is an effective fertilizer, imparting high yields without negative effects on the physiological parameters of plants.

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