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Effects of the interaction between slurry, soil conditioners, and mineral NPK fertilizers on selected nutritional parameters of *Festulolium braunii* (K. Richt.) A. Camus

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Abstract. The research was aimed at assessing the biomass yield of *Festulolium braunii* and its content of raw protein and crude ash after application of slurry, both on its own and together with soil conditioners (UGmax and Humus Active), and mineral fertilizers. The studies were conducted on the basis of a two-year field experiment. The interaction between slurry and soil conditioners and between slurry and mineral fertilizers was studied on the Sulino variety of *Festulolium braunii*, a hybrid between *Lolium multiflorum* and *Festuca pratensis*.
Compared with plants treated with liquid manure on its own, slurry applied with soil conditioners and mineral fertilizer did not significantly increase the biomass yield of the grass. However, there was higher protein content in *Festulolium braunii*, even if statistically insignificant, as a response to slurry supplemented with mineral fertilizer than in plants treated with slurry only. Various forms of treatment did not differentiate crude ash content in plant dry matter in a statistically significant way.

Key words: forage grass, fertilization, nutritional value.

INTRODUCTION

Festulolium braunii (K. Richt.) A. Camus is a hybrid between *Lolium multiflorum* and *Festuca pratensis*. According to Borowiecki (2002a, 2002b), it produces higher yields of better nutritional value than meadow fescue. For this reason the grass is grown in arable fields to produce forage, but it is also used to overseed permanent grassland (Wolski et al., 2006). This species has high yield potential and provides good quality forage. In his research Sosnowski (2012) found that it produced a high yield of both fresh and dry matter (11–15 t ha^{-1} DM) with a favourable chemical composition, especially regarding protein content.

An organic fertilizer commonly applied to grassland, slurry is a very valuable source of organic matter and plant nutrients. According to Mazur & Mokra (2009), cow manure contains more dry matter and nutrients than pig manure. As reported by Christensen (2009), its available nitrogen accounts for 70% of its total nitrogen. According to Oenema et al. (2008), slurry nitrogen losses resulting from its release into the atmosphere range from 10% to over 30%. Grzebisz et al. (2007) recorded a reduction in nitrogen losses when aqueous chalk solution was added to slurry. Similarly, Kall et al. (2016) proved that the fertilizer value of liquid manure was largely dependent on application technology.

In the present research, an attempt was made to use biological soil amendments together with slurry in order to reduce its nitrogen losses and thus to increase nitrogen use efficiency. Moreover, slurry was supplemented with soil conditioners in order to study how it would affect the amount of biomass and the content of protein and ash in plants. The experiment was also to assess whether the addition of biological amendments to liquid manure could reduce the use of complementary mineral fertilizers.

The purpose of the studies was to assess the biomass yield of *Festulolium braunii* and the content of total protein and crude ash as an effect of slurry applied on its own but also together with soil conditioners (UGmax and Humus Active) and NPK mineral fertilisers.

MATERIAL AND METHODS

The studies were conducted on the basis of a two-year (2016–2017) field experiment established at the experimental facility of the University of Natural Sciences and Humanities in Siedlce (52°10′N, 22°17′E) in three replications, random layouts, and on plots of 4.5 m^2 (1.5×3.0 m). The main experimental factor tested in the research was slurry used on its own and supplemented with NPK mineral fertilizers and soil conditioners with the commercial names of UGmax and Humus Active. The experiment consisted of the following research units: (1) control (no treatment); (2) slurry; (3) slurry + UGmax; (4) slurry + Humus Active; (5) slurry + NPK.

The interaction between slurry and soil conditioners or mineral fertilizers was tested on forage grass of the *Festulolium braunii* species, the Sulino variety, sown in autumn 2015 at the sowing standard rate of 25 kg ha^{-1}. Liquid manure used in the experiment had been produced by dairy cows. Each year it was used at a total dose of 30 m^3 ha^{-1} divided into three parts applied before each growth cycle. The slurry had dry matter concentration of 10%, a narrow ratio of C:N (8:1), and the concentration of selected macronutrients as follows (g kg^{-1} DM): N-33, P_2O_5-16, K_2O-16, MgO-10, and Ca-21.

According to the Institute of Soil Science and Plant Cultivation in Puławy, Poland, the soil conditioners used in the experiment improve soil properties. Their composition is presented in Table 1.

Table 1. Composition of soil conditioners

Soil conditioner	Macronutrients (g kg^{-1})						Micronutrients (mg kg^{-1})				Microorganism and others
	N	P	K	Ca	Mg	Na	Mn	Fe	Zn	Cu	
UGmax	1.2	0.2	2.9	-	0.1	0.2	0.3	-	-	-	Lactic acid bacteria, photosynthetic bacteria, Azotobacter, Pseudomonas, yeast, actinomycetes
Humus Active	0.2	1.3	4.6	3.0	0.5	-	15	500	3	1	Permanent active humus with beneficial microorganisms

Soil conditioners were applied each year in the spring at doses recommended by the manufacturer: UGmax at 0.6 L ha^{-1} and Humus Active at 50 L ha^{-1}. Mineral nitrogen-phosphorus-potassium fertilizers (NPK) were used as follows: N – 100 kg ha^{-1}, P (P_2O_5) – 80 kg ha^{-1}, and K (K_2O) – 120 kg ha^{-1}. Mineral nitrogen was in the form of ammonium nitrate (NH_4NO_3), phosphorus was used as granular triple superphosphate ($Ca(H_2PO_4)_2$), and potassium as potassium chloride (KCl). Phosphorus was applied once a year in the spring whereas nitrogen and potassium doses were divided into three equal parts: the first before the start of vegetation. the second and third before the second and third grass growth cycle.

The experiment was set up on the soil with granulometric composition of loamy sand, the order of anthropogenic soils, the type of culture earth soils, and the subtype of hortisole (Polish Soil Classification, 2011). According to chemical analysis of the soil, carbon concentration in organic compounds (C_{org}) was 14.50 g kg^{-1} DM, with total nitrogen of 1.36 g kg^{-1} DM. The ratio of C:N was 10.6 : 1, and the pH value was 6.7. The concentration of absorbable forms of phosphorus (170 mg kg^{-1} DM) and magnesium (84 mg kg^{-1} DM) was high, with moderate concentration of potassium (114 mg kg^{-1} DM).

Hydrothermal conditions were determined on the basis of meteorological data from the Hydrological and Meteorological Station in Siedlce. In order to measure temporal variability of weather conditions and their effects on plant growth and development Sielianinov's hydrothermal coefficient (Table 2) was determined (Bac et al., 1993). It was calculated using the monthly sum of atmospheric precipitation (P) and the monthly sum of average daily air temperatures (Σt), applying the formula: $K = P/0.1\ \Sigma t$ (Skowera & Puła, 2004).

Table 2. The value of Sielianinov's hydrothermal coefficient (K) in the growing seasons

Year	Month						
	April	May	June	July	August	September	October
2015	1.36 (o)	1.87 (mw)	1.64 (mw)	0.59 (sd)	1.92 (mw)	0.64 (sd)	0.12 (ed)
2016	1.22 (md)	2.63 (sw)	0.87 (d)	1.08 (md)	0.18 (ed)	1.46 (o)	1.94 (mw)
2017	2.88 (sw)	1.15 (md)	1.08 (md)	0.45 (sd)	0.96 (d)	1.92 (mw)	1.90 (mw)

$K \leq 0.4$ extremely dry (ed); $0.4 \leq K \leq 0.7$ severely dry (sd); $0.7 \leq K \leq 1.0$ dry (d); $1.0 \leq K \leq 1.3$ moderately dry (md); $1.3 \leq K \leq 1.6$ optimal (o); $1.6 \leq K \leq 2.0$ moderately wet (mw); $2.0 \leq K \leq 2.5$ wet (w); $2.5 \leq K \leq 3.0$ severely wet (sw); $K > 3.0$ extremely wet (ew).

In the first year (2016) the optimum thermal and humidity conditions were only in September, with severely wet May, while June, July, and August, the most important months for plant growth and development, were dry, moderately dry, and extremely dry. In the second year of the experiment the period from May to August ranged from moderately dry to severely dry, and the optimum conditions were not recorded during any month of the growing season.

During the two-year experiment in each growing season three harvests of grass were collected. Immediately after each harvest fresh matter was weighed, and a sample of 0.5 kg was collected to determine the yield of dry matter and to perform chemical analyses. The yield of dry matter was determined by the drying method. Total protein and crude ash content was measured by the near-infrared spectroscopy method (NIRS), using the NIRFlex N-500 with the ready-to-use INGOT calibration for dry forage. The latter method is described in detail in the Polish standard of PN-EN ISO 12099:2010 and in the literature (Burns et al., 2010; Reddersen et al., 2012).

Analysis of variance for a three-factor experiment was used to process the results statistically. The statistical program of Statistica 6.0-2001 was used to evaluate forage parameters. The significance of differences was verified by Tukey's test at the level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The yield of *Festulolium braunii* dry matter (Table 3) significantly varied depending on the treatment and the harvest. In the first and second years of the experiment the greatest amount of biomass was on plots treated with slurry and from those where liquid manure was applied together with NPK, with the yield of 14.40 and 14.00 Mg ha^{-1}, respectively. In the second year the equally high level of the yield (14.00 Mg ha^{-1}) was recorded on plots where the Humus Active soil conditioner was applied together with slurry.

Table 3. Dry matter yield of *Festulolium braunii* (Mg ha^{-1} DM)

Growing season (B)	Harvest (C)	Treatment (A)					Means
		*O	S	S+UGmax	S+HA	S+NPK	
2016	I	3.40	5.10	5.30	5.50	5.60	4.98 (0.81)
	II	3.50	4.00	3.90	4.60	4.70	4.14 (0.45)
	III	3.30	4.30	3.80	4.10	4.10	3.92 (0.35)
	Total	10.20	13.90	13.00	14.20	14.40	13.00
2017	I	3.20	5.30	5.50	5.20	5.70	4.98 (0.91)
	II	2.70	3.80	4.10	4.50	4.30	3.88 (0.64)
	III	2.80	4.40	3.80	4.30	4.00	3.86 (0.57)
	Total	8.70	13.50	13.40	14.00	14.00	12.72
Means across growing seasons		9.45 ***(0.75)	13.70 (0.20)	13.20 (0.20)	14.10 (0.10)	14.20 (0.20)	12,9 (0.16)

$HSD_{0.05}$ for: A = 0.57; B = **NS; C = 0.37; A/B = 0.42; B/A = 0.28; A/C = 0.52; C/A = 0.43; B/C = NS; C/B = NS

*O – control object (without fertilization); S – slurry; S +UGmax – slurry + UGmax soil conditioner; S + HA – slurry + Humus Active soil conditioner; S + NPK – slurry + mineral NPK fertilizers. **NS – not significant; ***(…) – standard deviation.

The lowest yield was on the control plot, with 10.20 Mg ha^{-1} in the first year and 8.70 Mg ha^{-1} in the second. Compared with plants treated with slurry on its own, the addition of soil conditioners or mineral fertilizer did not significantly increase plant biomass. In both years of research, compared with plants treated with slurry on its own, there was a decrease in the total amount of biomass on plots with liquid manure applied together with the UGmax soil conditioner. As an average of all treatments, the highest yield of grass in both years was in the first harvest (the same amount of 4.98 Mg ha^{-1} in both years), with the smallest in the third one (3.92 and 3.86 Mg ha^{-1}).

As an average for both growing seasons, *Festulolium braunii* (Fig. 1) produced a significantly higher yield on plots where plants were treated with slurry together with mineral fertilizers and on those with slurry supplemented with Humus Active than on plots treated with slurry on its own.

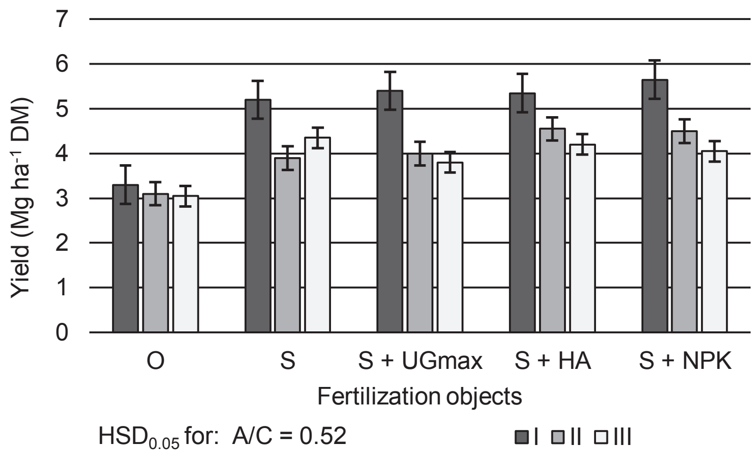

Figure 1. The effect of treatment on average yields of *Festulolium braunii* (Mg ha^{-1} DM) across harvests.

*O – control object (without fertilization); S – slurry; S +UGmax – slurry + UGmax soil conditioner; S + HA – slurry + Humus Active soil conditioner; S + NPK – slurry + mineral NPK fertilizers; I – standard deviation.

Festulolium braunii is a grass species that can be used on temporary grassland only for a few years. This is also confirmed by the studies of Borowiecki (2002a, 2002b) and Staniak (2005, 2010). According to their reports the level of *Festulolium braunii* yields ranges from 11 to 15 Mg ha^{-1}. This grass belongs to the species strongly reacting to nitrogen fertilizer. In the research conducted by Adamovies et. al. (2019) nitrogen fertilizer increased the amount of biomass even by 80% compared to control. Additionally, Obraztsov et al. (2018) recorded a significant effect of nitrogen fertilizer on the seed yield of this grass.

In the present experiment the best results with the increased *Festulolium braunii* annual yield of 14.20 Mg ha^{-1} (an average from all harvests) were recorded on plots where slurry was supplemented with mineral fertilizer. According to Olszewska (2008) crop yields are the basic criterion for assessing the effectiveness of fertilizer treatments. A yield increase as a response to natural fertilizer treatment in the cultivation of grasses was also confirmed by Barszczewski et al. (2011). Additionally, many other authors (Sosnowski & Jankowski, 2010) observed that the yield of the first harvest was the highest. In the present experiment the highest yield of grass dry matter, as an average response to the treatments, was also in the first harvest (4.98 Mg ha^{-1}).

In addition to fertilizer treatments, meteorological conditions, in particular the average air temperature and the volume of atmospheric precipitation, also affected forage grass yields. With regard to the level of yields (on average 13.04 in the first and 12.72 Mg ha^{-1} DM in the second year), it turned out that *Festulolium braunii*, with a low sensitivity to water shortages, was resistant to very adverse weather conditions prevailing in both years of research.

The ineffectiveness of the interaction between slurry and soil conditioners undoubtedly resulted from adverse meteorological conditions. In the first year (2016) the optimum thermal and humidity conditions were only in September, with severely wet May, while June, July and August, the most significant months for the growth and development of plants, were dry, moderately dry, and extremely dry. In the second year of the experiment (2017), the period from May to August ranged from dry to very dry, and the optimum conditions were not recorded during any month of the growing season.

Total protein content in plant dry matter (Table 4) was significantly differentiated by the treatments; there were also differences across harvests and growing seasons.

Table 4. Protein concentration in *Festulolium braunii* dry matter (g kg^{-1} DM)

Growing season (B)	Harvest (C)	Treatment (A)					Means
		*O	S	S+UGmax	S+HA	S+NPK	
2016	I	128.9	153.4	155.1	154.7	165.9	151.6 (13.6)
	II	113.8	149.4	146.2	157.3	158.3	145.0 (18.2)
	III	120.5	145.6	138.7	140.2	154.2	139.8 (12.4)
	Means	121.1	149.5	146.7	150.7	159.5	145.6
2017	I	128.9	165.2	155.6	159.5	170.1	155.9 (16.0)
	II	129.7	164.8	142.0	168.0	165.4	154.0 (17.1)
	III	124.2	159.3	157.0	152.9	156.3	149.9 (14.6)
	Means	127.6	163.1	151.5	160.1	163.9	153.3
Means across growing seasons		124.4	156.3	149.1	155.5	161.7	149.3
		***(6.26)	(8,14)	(7.83)	(9,13)	(6.30)	(6.00)

$HSD_{0.05}$ for: A = 9.09; B = 5.96; C = 4.02; A/B = **NS; B/A = NS; A/C = NS; C/A = NS; B/C = NS; C/B = NS

*O – control object (without fertilization); S – slurry; S + UGmax – slurry + UGmax soil conditioner; S + HA – slurry + Humus Active soil conditioner; S + NPK – slurry + mineral NPK fertilizers. **NS – not significant; ***(…) – standard deviation.

The largest protein concentration, average for all harvests, was noted in plants treated with slurry supplemented with mineral NPK, with 159.5 g kg^{-1} DM in the first year and 163.9 g kg^{-1} DM in the second. The smallest average protein concentration in *Festulolium braunii* was recorded on control plots: 121.1 g kg^{-1} in the first year and 127.6 g kg^{-1} in the second year of the experiment. Combined application of slurry and soil conditioners did not have a favourable effect compared with plants treated with slurry applied on its own. Mean protein content across growing seasons and treatments decreased with consecutive harvests (Fig. 2), and it was the largest in the first one and the smallest in the third.

A very important parameter determining the nutritional value of forage grasses is total protein content. According to Grygierzec (2012) the minimum concentration of this nutrient in forage should range from 150 to 170 g kg^{-1} DM. This amount of protein is necessary for the proper functioning of the digestive tract of dairy cows. According to Jankowska-Huflejt et al. (2011) protein content of grasses is a species trait. *Festulolium braunii* contains approximately 130 g kg^{-1} DM, which is less than in some other grasses. Many authors (Kotlarz et al., 2010; Szkutnik et al., 2012) indicate that plant protein content increases as nitrogen doses increase. In the present experiment it was found that the largest protein content in *Festulolium braunii* biomass was obtained with slurry supplied with NPK, but this was not significantly greater than in plants treated with slurry applied on its own. Moreover, the addition of soil conditioners to slurry did not significantly increase the yield of the grass. This is confirmed by the study of Ciepiela (2004), Jankowska et al. (2008), and Szkutnik et al. (2012), who point out that the content of total protein is not always increased proportionally to the nitrogen applied. Ciepiela (2004) claims that this phenomenon may be due to the dilution of the content of this ingredient in a higher amount of biomass. In the present experiment slurry supplemented with soil conditioners did not increase protein content in plants, which might have been caused by nitrogen uptake from slurry as a result of the bacteria activity in the conditioners.

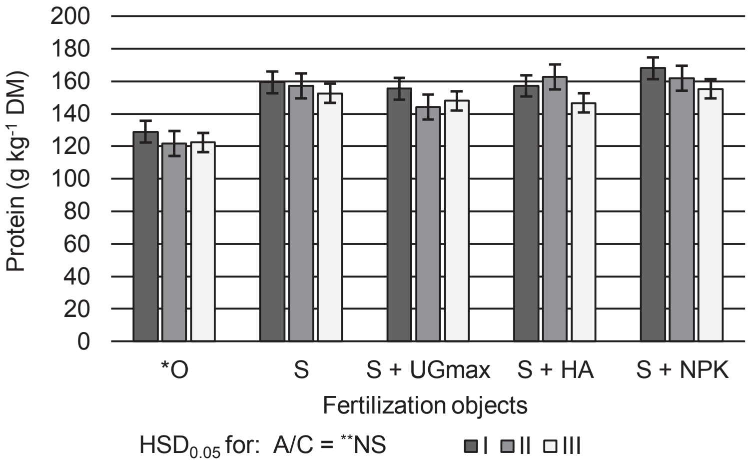

Figure 2. The effect of treatment on total protein concentration in *Festulolium braunii* (g kg^{-1} DM) across harvests.

*O – control object (without fertilization); S – slurry; S + UGmax – slurry + UGmax soil conditioner; S + HA – slurry + Humus Active soil conditioner; S + NPK – slurry + mineral NPK fertilizers. **NS – not significant; I – standard deviation.

Average protein content across years and treatments decreased in subsequent harvests. In the first one it was the largest and in the third the smallest. The impact of the harvest on total protein content in the dry matter of grass is confirmed by Tonn et al. (2013).

Another parameter used to assess plant nutritional value is crude ash content. This content in the dry mass of *Festulolium braunii* (Table 5) did not vary significantly as a response to different forms of treatment.

In the first year the largest amount of ash (112.6 g kg^{-1}) was in plants treated with slurry supplemented with the Humus Active soil conditioner. In the second year the highest average concentration of ash was recorded on plots where slurry was applied on its own (121.1 g kg^{-1}). In the first year the smallest crude ash concentration was noted in plants treated with slurry supplemented with the UGmax soil conditioner (106.6 g kg^{-1}), and in the second on the control plot (97.4 g kg^{-1}). There were also differences between the harvests. In the first year the greatest ash concentration was recorded in the biomass of the third harvest (114.1 g kg^{-1}) and in the second year in the first harvest (111.8 g kg^{-1}).

The lowest concentration was in the first harvest of the first year (105.4 g kg^{-1}) and in the second and third ones in the second year (108.4 g kg^{-1}).

Table 5. Crude ash concentration in *Festulolium braunii* dry matter (g kg^{-1} DM)

Growing season (B)	Harvest (C)	Treatment (A)					Means
		*O	S	S+UGmax	S+HA	S+NPK	
2016	I	104.3	103.5	103.6	111.2	104.3	105.4 (3.27)
	II	115.3	113.8	103.4	110.3	102.8	109.1 (5.79)
	III	109.2	110.6	112.8	116.2	121.6	114.1 (4.96)
	Means	109.6	109.3	106.6	112.6	109.6	109.5
2017	I	92.8	131.4	123.4	118.9	126.9	118.7 (15.7)
	II	99.8	123.6	102.9	102.8	112.8	108.4 (9.82)
	III	99.7	108.4	97.9	115.6	120.6	108.4 (9.83)
	Means	97.4	121.1	108.1	112.4	120.1	111.8
Means across growing seasons		103.5 ***(7.94)	115.2 (10.4)	107.4 (9.23)	112.5 (5.74)	114.9 (9.84)	110.7 (4.79)

$HSD_{0.05}$ for: A = **NS; B = NS; C = NS; A/B = 15.9; B/A 10.8; A/C = NS; C/A =NS; B/C = 8.27; C/B = 10.2

*O – control object (without fertilization); S – slurry; S + UGmax – slurry + UGmax soil conditioner; S + HA – slurry + Humus Active soil conditioner; S + NPK – slurry + mineral NPK fertilizers. **NS – not significant; ***(…) – standard deviation.

Overall, crude ash content across growing seasons (Fig. 3) was the smallest on the control plot and the largest in plants treated with slurry only.

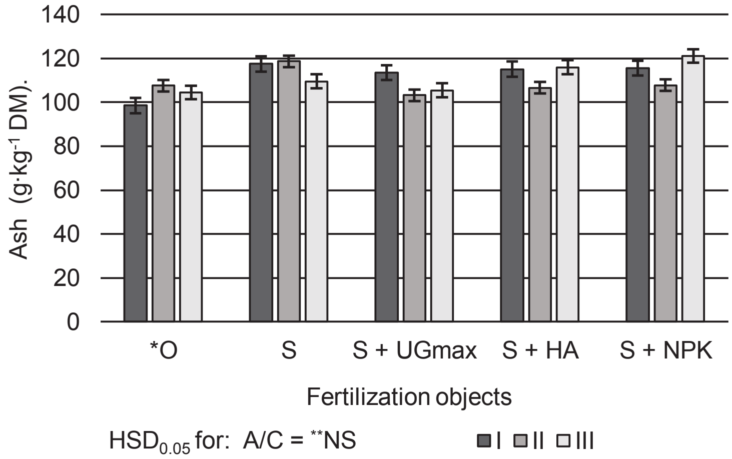

Figure 3. The effect of treatment on crude ash concentration in *Festulolium braunii* (g kg^{-1} DM) across harvests.

*O – control object (without fertilization); S – slurry; S +UGmax – slurry + UGmax soil conditioner; S + HA – slurry + Humus Active soil conditioner; S + NPK – slurry + mineral NPK fertilizers. **NS – not significant; I – standard deviation.

Another ingredient in the assessment of grass nutritional value is crude ash. Its adequate quantity in feed is necessary for the normal growth and development of animal organisms. According to Nazaruk et al. (2009) when crude ash concentration is too high, above 150 g kg^{-1} DM, it may mean that plant material is contaminated with soil. The results of the present experiment indicate that crude ash content of *Festulolium braunii* (the average of the treatments) was 109.5 g kg^{-1} in the first year and 111.8 g kg^{-1} in the second and did not exceed the above limit, which shows the purity of the material analysed.

In the present experiment the analysis of the content of this parameter did not demonstrate significant interaction between slurry and soil conditioners and slurry and mineral fertilizer, compared to the effect of slurry applied on its own or to control plots. This could be due to the fairly high content of absorbable forms of minerals in the soil.

Fairly high content of assimilable forms of P, K, and Mg in the soil might account for a lack of effect of fertilizers on the content of raw ash in the biomass. In addition, the content of these macronutrients constituted a significant share in raw ash. Contrary to that, Jankowska-Huflejt & Wróbel (2010), Barszczewski et al. (2010) as well as Wróbel et al. (2013) recorded an increase in raw ash content of meadow grass as a result of natural fertilizer application. Sosnowski (2012) found that crude ash concentration of *Festulolium braunii* was 109.6 g kg^{-1} DM, and the use of the UGmax soil conditioner did not affect this value significantly. However, mineral fertilizer significantly increased the content of this ingredient (up to 120.8 g kg^{-1} DM). In the present experiment *Festulolium braunii* crude ash content increased in successive harvests of the first year, just like in the studies carried out by Barszczewski et al. (2010). In the second year of this research there was a reverse trend.

CONCLUSIONS

1. The dry mass yield of *Festulolium braunii* was significantly dependent on the treatment applied and on the harvest. Compared with plants treated with slurry only, its addition to soil conditioners or to mineral fertilizer did not significantly increase the biomass of the grass.
2. Total protein content in grass dry matter was significantly differentiated by the treatments applied, the years of research, and the harvest. Compared to the effect of slurry applied on its own, its interaction with soil conditioners contributed to a reduction in protein content in the biomass. Compared to plots where slurry was applied on its own, a non-statistically significant increase in protein content was recorded in plants treated with liquid manure supplemented with NPK.
3. Crude ash content in the dry matter of *Festulolium braunii* showed a significant variation depending on the treatment. The lack of a clear trend was probably due to the relatively high concentration of absorbable forms of basic minerals in the soil.
4. Compared to plants treated with slurry on its own, the combined use of biological soil conditioners and slurry did not result in an expected increase in the yield of *Festulolium braunii* or in its protein content. At the same time, it was found that the use of slurry with biological soil conditioners did not increase the yield and protein content more than combine application of slurry with NPK mineral fertilizers.

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