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Effect of Guano Fertilisation on Yield and Some Quality Traits of Perennial Ryegrass Biomass

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ABSTRACT

Due to the lack of conclusive articles on the effect of guano, which is classified as a natural fertiliser, an experiment was conducted to evaluate its effect on the yield and quality of perennial ryegrass of the *Rela* variety. The guano used in the experiment contained significant concentrations in g·kg^{-1} DM of nitrogen (23.1), phosphorus (9.52) and magnesium (2.90). The concentration of heavy metals did not exceed the applicable standards in organic fertilisers. The total content of N and P in guano was higher relative to K, and Mg and Ca were similar. The concentration of N and Mg in guano is comparable to the content of these elements in poultry manure. The guano reaction was slightly acidic (5.86). The fertiliser value of guano was assessed in a vegetation-weed two-factor experiment. The test scheme included control, guano and guano with ammonium nitrate applied at three doses. The dry biomass yield of perennial ryegrass from individual cuts varied considerably. The objects with applied guano and guano with ammonium nitrate increased the average yield of perennial ryegrass from cut 1 by 102.9% compared to the control object. Applied guano fertilisation significantly increased the sum of perennial ryegrass yield from three cuts. As a result of the applied fertilisation, there was an increase in N, P and Ca content in perennial ryegrass, while K and Mg content increased to a negligible extent and thus contributed to optimal ionic ratios of Ca:P and K:(Ca+Mg). In contrast, the ionic ratio K:Mg deviated significantly from the optimal values for plants. The application of guano and guano with ammonium nitrate influenced the positive correlation between N and Ca content and the obtained yield of perennial ryegrass.

Keywords: guano, lolium perenne, yield, contenet macroelement, ionic ratios, correlation.

INTRODUCTION

Due to the increasingly poor state of the environment within the European Union, as well as the increase in negative climate change, the European Commission has published the European Green Deal [European Commission 2019]. An essential policy of the Green Deal concerning agriculture is the protection of biodiversity and ecosystems [European Commission 2020]. The planned measures are intended to reduce the negative impact of agriculture on the environment. Therefore, the application of mineral fertilisers and plant protection products should be kept to a minimum, which translates into a reduction in the introduction of nutrients leaching into waterways and reduces the degree of acidification of soils [Wiśniewski and Marka – Bielska 2022]. The use of mineral fertilisers in excessive doses can cause soil contamination. They are also carriers of heavy metals [Thomas et al. 2012; Qaswar et al. 2020]. The progressive development of agriculture in the modern world is linked to the introduction of new fertilisers. Nowadays, microbial fertiliser products play a significant role [Journal of Laws 2022.2364. The consequence of this is a constant search for new opportunities and products. In Poland, there has been a decrease in the production of natural fertilisers, the range of mineral fertilisers has changed, and their prices have risen considerably; the area under cereals and industrial crops has increased, leading to a negative balance of organic matter and nutrients in soils. As a result of this situation, natural and mineral fertiliser application rates per unit area have been reduced. It can lead to a reduction in soil fertility and fertility [Możdzer and Styrczula 2019]. Therefore, the search for new, cheap and environmentally safe sources of organic matter and plant nutrients has begun. Guano has found a unique role in organic farming. A composition of calcium and magnesium phosphate characterises it. It is the excrement of bats and several species of birds (cormorant, pelican, goosander). Bats are the second most abundant order of mammals. Research work has shown that bat guano can be a source of fungi due to the fact that they very readily inhabit attics of buildings, attics of houses, cellars and caves [Konieczna et al. 2007]. Poland is home to 21 species of bats representing two families: the vespertilionids and the horseshoe bats [Węgiel 2006]. All bats inhabiting Poland are insectivorous and live in human habitats [Smerczak et al. 2006]. Guano, the so-called gold of agriculture in the 19th century, has become a precious raw material. Since guano began to be used as a fertiliser, its positive effects on agricultural products have been recognised. It is a good fertiliser containing organic matter and significant amounts of the primary macronutrients nitrogen 8–11, phosphorus 7–15%, potassium 2–4% and calcium 10–13%. In comparison, chicken manure contains 2–4%, pigeon manure 1.5–5% and quail manure 4–4.8% nitrogen, which improves soil properties. The chemical composition of guano depends on its origin. Applying it to barren soil stimulates the development of beneficial micro-organisms in the soil. The use of the yield-forming value of guano in agriculture is critical from an environmental point of view. In Poland, excrements from livestock farming are referred to as natural fertilisers. Among these, excrement from cattle, pigs and poultry in the form of manure and slurry is the most important. The amount of these fertilisers in Poland has been declining steadily over recent years. It is the result of a long-term reduction in the animal population. It has, therefore, become a legitimate and vital issue to look for other sources of organic matter that could make a significant contribution to increasing the fertility, and thus productivity, of soils [Kuś et al. 2008; Możdżer and Jałoszyński 2019; Patorczyk-Pytlik and Gediga 2009; Wysokiński and Kalembasa 2011]. The health risks posed by mineral fertilisers have been popularised by organic farming, but bat guano is still not well enough known among the farming community, as there is no conclusive work on its effect on plant growth.

Taking into account the data cited above, a study was undertaken to determine the effect of guano without and with mineral ammonium nitrate (34% N) fertilisation on yield, total N, P, K, Ca and Mg content, ionic and weight ratios and the correlation between yield and macronutrient content in perennial ryegrass of the *Rela* variety.

MATERIAL AND METHODS

The pot experiment was conducted at the vegetation hall of West Pomeranian University of Technology in Szczecin (53°26′50″N 14°31′45″E). In terms of agricultural suitability, the soil used for the experiment was classified as a good rye complex, bonitation class IV^{b}, with a slight acid reaction. The granulometric composition of silty and loamy sand characterised it. It is classified as light soil. The total content of macronutrients in the soil was in g·kg^{-1} DM for N – 0.81; P – 0.95; K – 2.81; Mg – 0.92; Ca – 1.95 and C$_{org.}$ – 8.83. The ratio of C$_{org}$ to N was 10.9. According to the guidelines of the Chemical and Agricultural Station, the abundance of plant-available forms of phosphorus was low (94.2 mg·kg^{-1} DM soil), potassium was medium (147.6 mg·kg^{-1} DM soil) and magnesium was very low (29.4 mg·kg^{-1} DM soil). The total content of N and P in guano was higher relative to K, and Mg and Ca were similar. The concentration of N and Mg in guano is comparable to the content of these elements in poultry manure. P, on the other hand, was similar to that in the used mushroom substrates 8–10 g·kg^{-1}DM [Wiśniewska-Kadżaja 2013]. The reaction of the guano was slightly acidic 5.86 (Table 1). The contents of th e heavy metals Cd, Cu, Ni and Zn were slightly higher, and Cr and Pb were lower in relation to the reported contents in poultry manure (Table 2).

The test scheme included control, guano and guano with ammonium nitrate applied at three rates. The fertiliser value of guano was assessed in a two-factor pot experiment. The first factor was the fertilisation of guano without and with ammonium nitrate (34% N). The second factor was increasing doses of guano. The test plant was perennial ryegrass of the *Rela* variety. The experiment was set up in a split-block design in four replications. The guano dose rate was determined by its nitrogen content. It was assumed that with

Table 1. Some chemical properties of guano

N	C	P	K	Mg	Ca	S	pH
$g \cdot kg^{-1}DM$							
23.1	410	9.52	2.94	2.90	2.84	0.30	5.86
Comparative values with poultry manure [Baran et al. 2011]							
21.0	256	3.70	6.10	3.10	6.0	1.0	5.5–7.5

Table 2. Total content of heavy metals in guano

Cd	Cr	Cu	Ni	Pb	Zn
$mg \cdot kg^{-1}DM$					
1.32	4.60	58.2	4.25	6.03	285
Comparative values with poultry manure [Baran et al. 2011]					
0.55	120	18.3	3.90	7.15	243

dose I, guano contributed 0.24; with dose II, 0.48; and with dose III, 0.72 g N per pot, which corresponded to 80, 160 and 240 kg $N \cdot ha^{-1}$ (assuming that the mass of 20 cm of mineral soil layer from 1 ha weighs 3000 Mg). Guano was introduced into the pots filled with 9 kg of soil each and mixed to a depth of 15 cm. Ammonium nitrate was introduced into some of the pots. The application rate was 34 kg $N \cdot ha^{-1}$ or 100 kg ammonium nitrate (corresponding to 0.10 g N per pot). After the fertiliser application, the soil was remixed. Two grams of perennial ryegrass seed was sown into each experimental site. The controls were the objects without fertilisation. During the experiment, three cuts of perennial ryegrass biomass were made on the dates 05.06, 06.07, and 06.08.2021. After harvesting perennial ryegrass from each cut, the yield was determined. After drying, average object samples were prepared and ground in a laboratory mill. The averaged test plant biomass samples were subjected to chemical analyses in duplicate. In order to avoid lengthy descriptions of the fertiliser objects, the abbreviations used in this paper are guano – G and guano with ammonium nitrate – G+SA.

Analytical methods

Total nitrogen content in permanent ryegrass biomass was determined using the Kjeldahl method on the apparatus Büchi Distillation Unit B – 324 (Büchi Labortechnik AG, Szwajcaria), phosphorus by colorimetric method according to Barton on a spectrophotometer PerkinElmer Lambda EZ 150, of potassium, magnesium and calcium by atomic absorption spectrometry on a PerkinElmer AAS 300 spectrometer. The stock solution was obtained after wet mineralization of the plant material in a mixture of HNO_3 and $HClO_4$ acids in the ratio 3:1 according to PN-ISO 11466.

Statistical and calculation methods

Statistical elaboration of the study results was performed by two-factor analysis of variance in a randomised block design. To determine the significance of differences, half-confidence intervals were applied using the Tukey test for a level of $p = 0.05$, using the FR-ANALWAR program according to Rudnicki 4.3II. The mass ratios for Ca:Mg and Ca:P and the equivalent ratios for K:Ca, K:(Ca+Mg), K:Mg and N:P in the test plant were calculated on the basis of its determined N, P, K, Ca and Mg content.

The analysis of linear correlation *r* Pearson's between the yield of perennial ryegrass biomass and the content of macronutrients was performed using the Statistica 13.3 program. The significance of the correlation coefficient was tested using the *T-Student* significance test. The regression equation is given in the graphs.

RESEARCH RESULTS AND DISCUSSION

The yield of perennial ryegrass

The dry biomass yield of perennial ryegrass from individual cuts varied considerably. The average yield of grass dry biomass as a result of the applied fertilisation from cut I was 24.5%, from cut II – 33.2%, and from cut III – 42.4% of the total yield from the three cuts (Table 3). Successively increasing doses of guano and guano with ammonium nitrate caused a much more significant variation in the yield of perennial ryegrass from cut II than from cut I. The difference in yield between doses I and II was 33.6%, while between doses II and III, it was 28.7%.

The factors analysed in the experiment significantly differentiated the dry biomass yield of perennial ryegrass from all cuts and the total yield from three cuts. The average perennial ryegrass yield from three cuts on the individual fertiliser sites ranged from 7.39 to 14.3 g DM per pot. The lowest yields were obtained on the control. As a result of the application of increasing doses of G and G+SA, perennial ryegrass yields, depending on the cut, increased on average from 3.70 to 18.8 g DM per pot (Table 3). The average dry matter yield of perennial ryegrass per cut 3 from the G-fertilised objects was more than 3-fold higher and that of the G+SA-fertilised objects 4-fold higher than that of the control. The yield-forming effect of organic fertilisation on the crop is confirmed by the studies conducted by Bowszys et al. 2006; Stępń et al. 2006. These results indicate a high fertilising value of fertilisers containing organic matter depending on the applied dose. Similar relationships for perennial ryegrass were obtained by Kalembasa et al. 2014. The yield of perennial ryegrass obtained under fertilisation with increasing doses of G and G+SA was significantly higher compared to that of the control (Table 3, Fig. 1). Applied G alone also significantly increased perennial ryegrass yield. After the application of the third dose of G and G+SA, the most significant positive effect was found in that the yield of perennial ryegrass increased by 73.7% compared to the first dose applied. Objects with G and G+SA increased the average perennial ryegrass yield from cut 1 by 102.9% compared to the control. The applied fertilisation significantly increased the sum of perennial ryegrass yield from three cuts.

Macronutrient content in plants

The content of N, P, K, Ca and Mg in perennial ryegrass was generally higher as a result of the application of the second or third dose of G and G+SA. Fertilisation with increasing doses of G significantly increased the content of N, P, K, Ca and Mg in perennial ryegrass compared to the control (Table 4, 5, 6). Similar results were obtained by Antonkiewicz et al. [2020], Kirchmann et al. [2017], Możdżer and Styrczula [2019]; Styrczula et al. [2013]. The magnesium content of the test plant was similar to all fertilisation objects

Table 3. Effect of guano fertilisation without and with ammonium nitrate on the yield of perennial ryegrass

Fertilization (F)	Dose (D)			
	I d	II d	III d	Mean
Crop 1				
G	13.5	15.3	15.7	14.8
G + SA	15.1	15.9	17.2	16.1
Mean	14.3	15.1	16.1	15.2
Control	4.90			
LSD $_{0.05}$ for: F – 0.122; D – 0.188; F x D – 0.212				
Crop 2				
G	4.96	9.20	17.2	10.5
G + SA	5.80	13.1	18.8	12.6
Mean	5.38	11.1	18.0	11.5
Control	1.75			
LSD $_{0.05}$ for: F – 0.127; D – 0.195; F x D – 0.220				
Crop 3				
G	3.70	4.83	5.10	4.53
G + SA	3.50	5.00	6.75	5.10
Mean	3.60	4.91	5.93	4.80
Control	1.90			
LSD $_{0.05}$ for: F – 0.059; D – 0.091; F x D – 0.102				

Note: G – guano, G+SA – guano with ammonium nitrate.

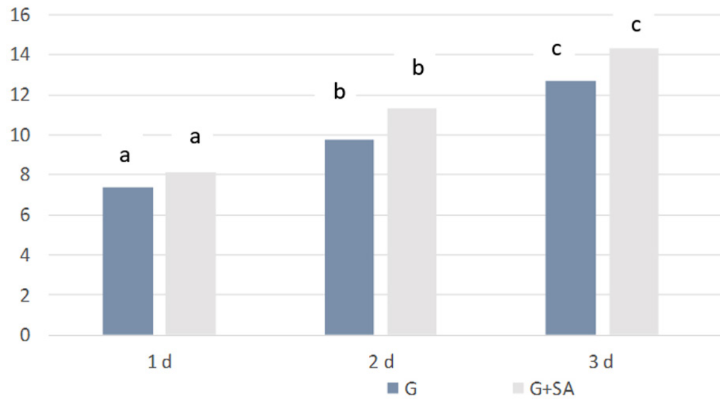

Fig. 1. Effect of G and G+SA fertilisation on perennial ryegrass yield (g DM per pot). Data points and represent the respective averages. Different letters indicate significant differences (*$p<0.05$*) between factors according to the Tukey test

Table 4. Effect of guano fertilisation without and with ammonium nitrate on total nitrogen and phosphorus content in perennial ryegrass. Data in g·kg^{-1} DM

Fertilization (F)	N				P			
	Dose (D)				Dose (D)			
	I d	II d	III d	Mean	I d	II d	III d	Mean
	Crop 1				Crop 1			
G	18.4	18.3	19.0	18.6	2.53	3.43	3.39	3.12
G + SA	18.6	18.5	19.3	18.8	2.62	3.45	3.41	3.16
Mean	18.5	18.4	19.1	18.7	2.58	3.44	3.40	3.14
Control	16.65				2.43			
Crop 2				Mean	Crop 2			Mean
G	18.0	17.8	18.4	18.1	2.71	3.51	3.46	3.23
G + SA	18.3	18.0	18.6	18.3	2.66	3.49	3.44	3.20
Mean	18.1	17.9	18.5	18.2	2.69	3.50	3.45	3.22
Control	17.0				2.41			
Crop 3				Mean	Crop 3			Mean
G	17.4	17.0	17.9	17.4	2.86	3.39	3.54	3.27
G + SA	17.7	17.1	18.2	17.7	2.70	3.52	3.48	3.24
Mean	17.5	17.0	18.0	17.5	2.78	3.46	3.51	3.25
Control	16.82				2.40			
$LS_{D\text{ for }0.0}5$	F – 0.128; D – 0.193; F x D – n.s.				F – n.s.; D – 0.079; F x D – n.s.			

Note: G – guano, G+SA – guano with ammonium nitrate.

of the experiment. However, significant differences were found in the effect of the 2nd and 3rd G and G+SA doses on the content of N, P, K and Ca in perennial ryegrass. The average content of N from three cuts in the test plant under the effect of increasing doses of G was at the level of 18.04 g·kg^{-1} DM and was lower in comparison with the applied G+SA (Table 4). Report that as a result of the application of natural fertilisers under the cultivation of perennial ryegrass, the average N content was 24.0 g·kg^{-1} DM [Kalembasa et al. 2007]. In their study, however, a lower by 32.1% N content in perennial ryegrass was recorded.

The highest increase in N content in perennial ryegrass of 7.65% was obtained under the influence of the applied second dose of G between the first and third cuts. A higher N concentration was obtained in the grass fertilised with G+SA. A lower N content characterised the third cut of grass compared to the two earlier harvests. The N content of the test plant from all cuts was decreased according to fertilisation. Kalembasa and

Table 5. Effect of guano fertilisation without and with ammonium nitrate on total potasium and calcium content in perennial ryegrass. Data in g·kg^{-1} DM

Fertilization (F)	K				Ca			
	Dose (D)				Dose (D)			
	I d	II d	III d	Mean	I d	II d	III d	Mean
	Crop 1				Crop 1			
G	8.74	8.79	8.82	8.79	3.25	3.30	3.45	3.34
G + SA	8.76	8.83	8.87	8.82	3.28	3.36	3.35	3.33
Mean	8.75	8.81	8.84	8.80	3.30	3.33	3.40	3.35
Control	8.66				3.19			
	Crop 2			Mean	Crop 2			Mean
G	8.76	8.82	8.84	8.80	3.36	3.40	3.51	3.43
G + SA	8.80	8.86	8.89	8.85	3.31	3.35	3.37	3.35
Mean	8.78	8.84	8.86	8.82	3.34	3.38	3.44	3.39
Control	8.68				3.24			
	Crop 3			Mean	Crop 3			Mean
G	8.81	8.85	8.86	8.84	3.46	3.55	3.62	3.55
G + SA	8.86	8.88	8.91	8.88	3.34	3.36	3.39	3.37
Mean	8.84	8.87	8.89	8.86	3.40	3.56	3.51	3.49
Control	8.64				3.21			
LSD for $_{0.05}$	F – n.s.; D – 0.025; F x D – n.s.				F – n.s.; D – 0.055; F x D – 0.063			

Note: G – guano, G+SA – guano with ammonium nitrate.

Wiśniewska [2007] obtained similar results in the first year of the test plant. On sites with applied G, the average P content in perennial ryegrass from individual cuts varied and ranged from 2.53 to 3.54 g·kg^{-1} DM. An increase in P content in grass was found as a result of applying higher doses of G from the second and third cuts by 33.6% and 35.4%, respectively, compared to the control (Table 4).

The highest increase of 13% in P content in grass biomass was obtained under the influence of the 1st G dose applied between the first and third cuts. In contrast, the P concentration was significantly lower on the G+SA fertilised object. Increasing doses of G+SA did not result in an increase in P content in the grass tested. The average P content in perennial ryegrass from three cuts at the 2nd and 3rd G and G+SA doses increased by 30.5% and 30.1%, respectively, compared to the first dose. Similar results were obtained by Wesołowski (2012), who reports that the average P content from three cuts in the grass as a result of manure application is 3.60 g·kg^{-1} DM, while in his research, it was 3.20 g·kg^{-1} DM. The average phosphorus content from three cuts of perennial ryegrass under the effect of increasing doses of G and G+SA was at a similar level. On objects with applied G, the average K content in perennial ryegrass from individual cuts varied and ranged from 8.74 to 8.91 g·kg^{-1} DM. On objects fertilised with G+SA, the K concentration was higher. Increasing doses of G+SA contributed to an increase in K content in the grasses tested. The highest K content was characterised by grass fertilised with the third dose of G+SA from the third cut, and on the other objects, it ranged from 8.74 to 8.91 g·kg^{-1} DM (Table 5). The average potassium content in perennial ryegrass from three cuts between the first and second doses of G and G+SA increased by 1.49% and 1.03%, respectively. The application of the third dose had no significant effect on the content of K. The average content of this nutrient in the test plant under the influence of increasing doses of G was at the level of 8.84 g·kg^{-1} DM and was lower in comparison with the object with the applied G+SA. The potassium content of the test plant is 41% lower than the reported optimum content for forage grasses. The results of Krzywy-Gawrońkiej and Gutowskiej [2007] show that organic fertilisation with composts influenced a higher content of this element in perennial ryegrass compared to the experimental results (23.2 g·kg^{-1}DM). Increasing doses of G contributed to a significant variation in P and K content in perennial ryegrass in individual cuts. The results

Table 6. Effect of guano fertilisation without and with ammonium nitrate on total magnesium content in perennial ryegrass. Data in g·kg^{-1} DM

Fertilization (F)	Mg			
	Dose (D)			
	I d	II d	III d	Mean
	Crop 1			
G	1.59	1.58	1.56	1.58
G + SA	1.57	1.55	1.53	1.55
mean	1.58	1.57	1.56	1.54
Control	1.51			
Crop 2				Mean
G	1.71	1.66	1.67	1.68
G + SA	1.63	1.61	1.59	1.61
mean	1.67	1.64	1.63	1.65
Control	1.50			
Crop 3				Mean
G	1.80	1.75	1.71	1.76
G + SA	1.75	1.71	1.68	1.72
mean	1.78	1.73	1.70	1.74
Control	1.53			
LSD for $_{0.05}$	F – n.s.; D – 0.022; F x D – n.s.			

Note: G – guano, G+SA - guano with ammonium nitrate.

indicated that there was an increase in calcium content in perennial ryegrass as a result of the application of higher G rates (Table 5). A similar relationship was obtained by Antonkiewicz et al. [2020], Krzywy-Gawrońska and Gutowska [2007]. Calcium concentration was higher on G-fertilised sites. Increasing doses of G+SA contributed to an increase in calcium content in the grasses studied. The average calcium content of perennial ryegrass from three cuts between the 1st and 3rd G dose increased by 5.1%. The application of the third dose had a significant effect on the calcium content. The average calcium content of the test plant under the effect of increasing G and G+SA doses was at a similar level.

The applied fertilisation had no significant effect on the increase of magnesium in the test plant (Table 6). The average magnesium content of perennial ryegrass from the three cuts was highest as a result of the first dose of G and G+SA applied (1.70 i 1.65 g kg^{-1} DM). The introduced second and third doses contributed to a decrease in the magnesium content of the test plant. The content of N, P, Ca and Mg in perennial ryegrass was within the optimal values reported for forage grasses. Fertilisation with G and G+SA had no significant effect on the content of P, K, Ca and Mg in the test plant. Nevertheless, it improved the quality of perennial ryegrass in terms of chemical composition.

Interactions between yield and N, P, K and Ca content

Correlation analysis between macronutrient content in perennial ryegrass and yield showed correlations within N and Ca (Table 7, Fig. 2). A positive correlation was found between nitrogen and calcium content and yield in perennial ryegrass. The coefficient of determination for nitrogen and calcium determined that their content depended from 16% to 19% on yield, respectively, and 84% and 81% on other factors. The highest correlation was found between nitrogen content and biomass yield in perennial ryegrass.

Table 7. Correlation coefficient (r) and coefficient of determination (r^2) between N, P, K and Ca content and biomass yield of perennial ryegrass

Element	Correlation coefficient (*r*)	Determination coefficient (*r*^{2})
N	0.385	0.156
P	0.299	0.042
K	0.207	0.061
Ca	0.136	0.185

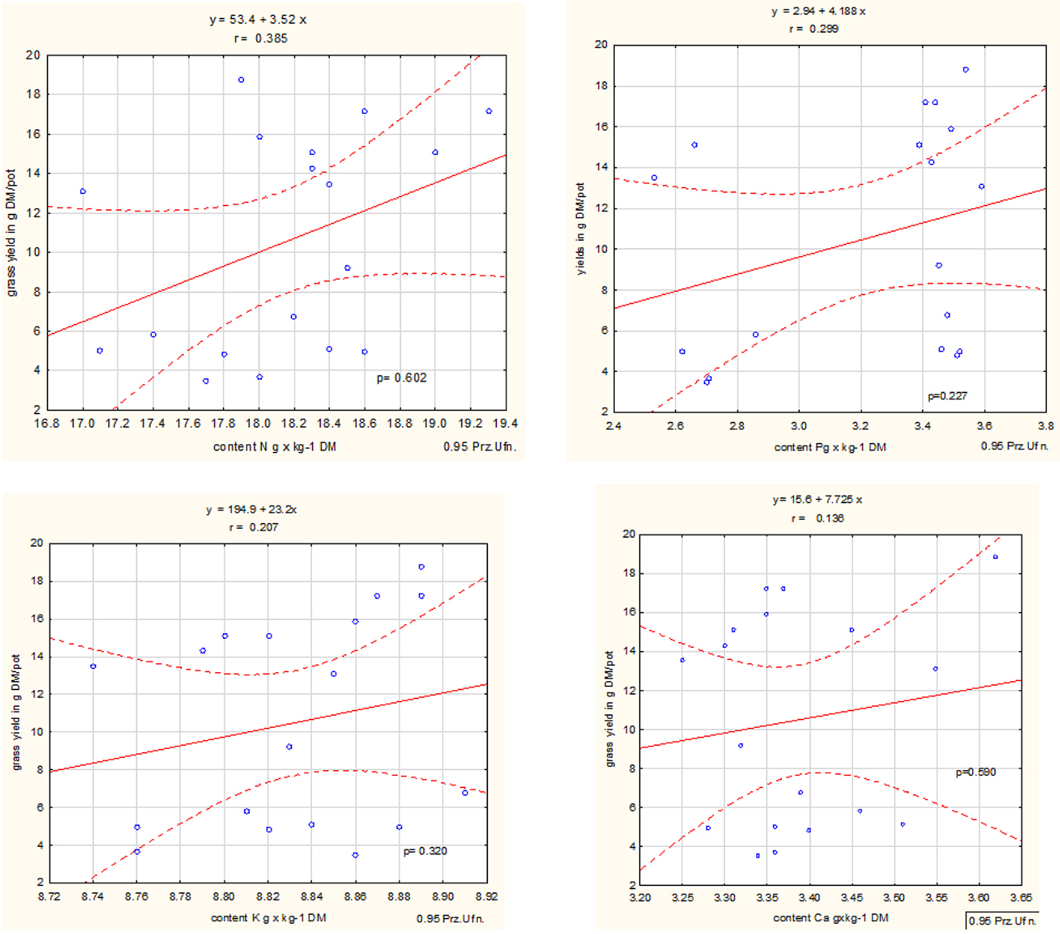

Fig. 2. Relationships between the biomass yield of perennial ryegrass and the content of macronutrient

Ion and weight ratios

When assessing the suitability of feed for livestock, it is not only the macronutrient concentration that is important but also the optimal ionic relationships [Szpunar-Krok et al. 2009; Klikocka et al. 2018]. The metabolism of calcium and phosphorus in animals is linked to each other, and in turn, magnesium is linked to the functions of calcium and phosphorus [Kumara and Soni 2014]. The chemical composition of perennial ryegrass was assessed on the basis of forage nutritive value criteria, where the recommended optimum ratios are given in Tables 8, 9 and 10. In the experiment, the broadest and optimum Ca:P ratio was obtained under the application of the first dose of G and G+SA. The second and third dose applications of fertilisers resulted in a narrower

Table 8. Effect of guano fertilisation without and with ammonium nitrate on Ca:P and N:P ionic ratios in perennial ryegrass

Fertilization (F)	Ca:P				N:P			
	Dose (D)				Dose (D)			
	I	II	III	Mean	I	II	III	Mean
G	1.92	1.53	1.60	1.68	14.7	11.4	11.8	12.7
G + SA	1.93	1.49	1.51	1.64	15.3	11.5	12.0	12.9
Control	1.80				14.1			
LSD for $_{0.05}$ F – 0.034.; D – 0.053; F x D – n.s.					LSD for $_{0.05}$ F – 0.195; D – 0.303; FxD – 0.338			
Optimal values 1.8:2.1					No optimal value has been indicated			

Note: G – guano, G+SA – guano with ammonium nitrate.

Table 9. Effect of guano fertilisation without and with ammonium nitrate on K:Mg and K:Ca ionic ratios in perennial ryegrass

Fertilization (F)	K:Mg				K:Ca			
	Dose (D)				Dose (D)			
	I	II	III	Mean	I	II	III	Mean
G	1.58	1.63	1.66	1.62	1.94	1.82	1.78	1.85
G + SA	1.64	1.68	1.71	1.69	1.98	1.90	1.76	1.88
Control	3.50				1.72			
LSD for $_{0.05}$	F – 0.020; D – 0.030; F x D – n.s.				LSD for $_{0.05}$ F – n.s.; D – 0.027; F x D – 0.030			
Optimal values 6:1					Optimal values 2:1			

Note: G – guano, G+SA – guano with ammonium nitrate

Table 10. Effect of guano fertilisation without and with ammonium nitrate on K:(Ca+Mg) and Ca:Mg ionic ratios in perennial ryegrass

Fertilization (F)	K:(Ca+Mg)				Ca:Mg			
	Dose (D)				Dose (D)			
	I	II	III	Mean	I	II	III	Mean
G	1.68	1.75	1.70	1.71	1.18	1.23	1.29	1.23
G + SA	1.73	1.80	1.74	1.76	1.20	1.24	1.26	1.23
Control	1.43				1.21			
LSD for $_{0.05}$ F – n.s.; D – 0.042; F x D – n.s.					LSD for $_{0.05}$ F – n.s.; D – n.s; F x D – n.s.			
optimal values 1.6–2.2:1					optimal values 3:1			

Note: G – guano, G+SA – guano with ammonium nitrate.

Ca:P ratio in the test plant. The narrowest Ca:P ratio was obtained as a result of the application of the second dose of G and G+SA. The values were less than optimal and ranged between 1.49 and 1.60. Both too narrow and too wide Ca:P ratios when feeding animals with Ca:P ratio feeds for a long time can contribute to health disorders. It has been found that feeding animals with a Ca:P ratio above 5 can lead to milk fever [Başbağ et al. 2018; Özyazıcı and Açıkbaş 2020].

The lowest K:(Ca+Mg) ratio was obtained from the application of the 1st G dose and the highest from the applied 2nd G+SA dose (Table 10). The applied fertilisation contributed to the optimum K:(Ca+Mg) ratio on all fertilisation sites in perennial ryegrass except the control. Similar test results as a result of the application of organic mixtures were obtained by Antonkiewicz et al. [2018]. Feeding animals with too low K:(Ca+Mg) ratios, as well as ratios that are too wide, contributes to hypomagnesia. In the study conducted, the K:Mg and Ca:Mg ratios were narrow compared to the optimal value. The K:Ca ion ratio was slightly below the optimum value as a result of the 1-dose application of G and G+SA and extended to 3.50 on the control object (1.94,1.98). The Ca:P and K:(Ca+Mg) ratios were within the optimum range.

Applied G alone did not result in optimal macronutrient ratios in perennial ryegrass in most cases. Therefore, supplementary mineral fertilisation should be applied to optimise the chemical composition of perennial ryegrass produced for forage. Tables 8, 9 and 10 show the optimal values C:P, N:P, K:Mg, K:Ca, K:(Ca+Mg), Ca:Mg according to Maćkowiak et al. [2011] and Klikocka et al. [2018].

CONCLUSIONS

More significant yield-forming effects of perennial ryegrass were obtained on G+SA-applied sites compared to the control. Applied G and G+SA increased N, P and Ca content in perennial ryegrass, while K and Mg content increased slightly. The average N and P content of perennial ryegrass under increasing G doses was slightly lower compared to G+SA-applied sites, with K almost the same and Ca and Mg higher.

The study showed that the applied G and G+SA fertilisation contributed to optimal Ca:P and K:(Ca+Mg) ion ratios, while Ca:Mg were narrowed down from the optimal value. The values of the K:Mg ionic ratios in perennial ryegrass under the influence of applied fertilisation deviated significantly from the optimal values for the plants. The applied fertilisation influenced the positive correlation between N and Ca content and yield in perennial ryegrass, and the highest correlation was found between N content and biomass yield in perennial ryegrass. In view of the small number of experiments confirming the unequivocal effect of guano on crop quality, further research would be appropriate.

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