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The Effects of Various Organic Materials on *Dactylis glomerata* Yield and Content of Selected Macroelements

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ABSTRACT

The aim of the experiment was to assess the effects of various organic materials on *Dactylis glomerata* yield, on the content of selected macroelements (K, Ca and Mg) and on K:Ca, K:Mg and K:(Ca + Mg) ratios. As a valuable forage plant, *Dactylis glomerata* (cocksfoot grass) is a common grass in Poland both in grassland and in arable fields. Its rapid spring growth and its resistance to drought, low temperatures, but also to frequent mowing and pests, makes it a common species in meadows, pastures and grassland, both permanent and alternating. In order to achieve the research goal, a three-year pot experiment was established in a greenhouse. The experiment was conducted in a completely random design, in four replications. In the autumn before the experiment, soil was mixed with organic materials (chicken manure, mushroom substrate and rye straw) and put into pots. To selected units, an additional amount of mineral N was applied in the first year and NPK fertilizers in consecutive years. Mineral fertilizers were applied at the beginning of the growing period. Compared to control, the application of mineral and organic fertilizers resulted in a significant increase in *Dactylis glomerata* yield. The highest biomass yield (average over the growing periods) was recorded on the unit treated with manure, straw and mineral fertilizers (27.64 g·pot^{-1}) and on the one with mushroom substrate applied together with rye straw and mineral fertilizers (26.47 g·pot^{-1}). The K:(Ca+Mg) ratio in the forage was normal and averaged 0.933, but mineral fertilizers, compared to other treatments, narrowed it.

Keywords: *Dactylis glomerata, y*ield, organic materials, K, Ca, Mg.

INTRODUCTION

One of the effective ways to improve the fertility of soils, especially of light soils, is the use of various waste substances like straw, spent mushroom substrate or chicken manure. Safe management of waste intended for natural purposes, including agriculture, can result in measurable economic effects, at the same time preventing environmental pollution (Malinowska, 2016a, 2016b). Because of the low quality of Polish soils, and thus their poor resistance to various chemical pressures, efforts are being taken to improve their properties through the use of various waste substances, which is a highly rational procedure (Kalembasa and Wysokiński, 2004). Due to a decrease in the content of organic matter in intensively farmed soil, it is necessary to periodically introduce organic substances in various forms. Humus is a derivative of decomposed matter of plant and animal origin, and its content can be increased by applying organic fertilizers to soil. It promotes the formation of soil crumbly structure, positively affecting soil physical, biological and chemical properties. Organic fertilizers in turn promote humus formation and provide nutrients to plants. For example, in the first year after the application of mushroom substrate, crops can use 20–25% of its N, 100% of P and 90% of K.

Mushroom substrate is prepared with straw and chicken manure (sometimes with an addition of urea, coconut fibre, sphagnum peat moss and soy protein), with fen peat and dolomite in the casing layer (Kalembasa and Majchrowska-Safaryan, 2009). Spent mushroom substrate is a very valuable organic material (Niżewski et al., 2006; Jasińska et al., 2022), usually containing 32% of dry matter, 65% of which is organic matter. In contrast to cattle or chicken manure, or to other organic fertilizers, it is free from pathogens and weeds because it has been thermally disinfected. It is recommended for use on agricultural, vegetable and fruit crops (Rozporz. Min. Środow. 2015).

In the literature, there is little data on the agricultural use of chicken manure or poultry-slaughter waste and on their impact on soil properties. Chicken manure is widely available and cheap, and its agricultural value is additionally supported by its significant content of nutrients (López-Masquera et al., 2008; Dikinya and Mufwanzala, 2010). Based on previous research, it was assumed that it would have a positive effect on soil fertility and plant yield.

Due to a declining number of livestock population, which contributes to the reduction of manure and slurry, the main organic fertilizers (Wiater, 2000), other sources of organic matter are searched for (Salomez et al., 2009). The surface area of permanent grasslands in Poland has markedly decreased during the last decade (Gabryszuk et al., 2021). The results of the present experiment were expected to deepen and broaden knowledge on the agricultural use of organic materials that would contribute to increasing soil fertility and thus its productivity.

The aim of the studies was to assess the effects of various organic materials on *Dactylis glomerata* yield and content of selected macroelements.

MATERIALS AND METHODS

In order to accomplish the research goal, a three-year pot experiment was established in a greenhouse complex of the University of Natural Sciences and Humanities in Siedlce, Poland. The plant used in the experiment was *Dactylis glomerata* cult. Berta, sown with a seeding rate of 1 g pot^{-1}. Before sowing the plant, each pot was filled with 10 kg of soil taken from the humus layer. It was light soil with pH 0.01M $CaCl_2$ of 6.60 and with a granulometric composition of loamy sand (PN-ISO 10390:1997). The content of total P and K was determined by inductively coupled plasma atomic emission spectroscopy (*ICP-AES*), and total N by the Kjeldahl method (Kalembasa et al., 1989). The total content of selected chemical elements was as follows (g. kg^{-1} of soil): C_{org} 30.5; N 1.40; total P 1.20; total K 0.736. Determined by the Egner-Riehm method, the content of available forms was as follows: P 1009 mg. P_2O_5 kg^{-1}, K 128.4 mg. K_2O kg^{-1} and Mg 70.2 mg Mg. kg^{-1} of soil.

Mineral fertilizers were applied at the beginning of the growing period: N in the form of ammonium nitrate, P as triple superphosphate and K as potassium salt. In the spring of the second and third years, N, P and K fertilizers were added to

Table 1. Pot experiment scheme

Symbols used to mark treatment variants	1st year	2nd year	3d year
a	control	control	control
b	NPK 3 g N. 2.4 g P. 3.6 g K · pot^{-1}	NPK 3 g N; 2.4 g P; 3.6 g K· pot^{-1}	NPK 3 g N; 2.4 g P; 3.6 g· K pot^{-1}
c	manure	-	-
d	manure + 1.5 g N · pot^{-1}	1.5 g N; 1.2 g P; 1.8g K · pot^{-1}	1.5 g N; 1.2 g P; 1.8 g K · pot^{-1}
e	manure + straw	-	-
f	manure + straw + 1.5 g N · pot^{-1}	1.5 g N; 1.2 g P; 1.8g K · pot^{-1}	1.5 g N; 1.2 g P; 1.8 g K · pot^{-1}
g	mushroom substrate	-	-
h	mushroom substrate + 1.5 g N · pot^{-1}	1.5 g N; 1.2 g P; 1.8 g K · pot^{-1}	1.5 g N; 1.2 g P; 1.8g K · pot^{-1}
i	mushroom substrate + straw	-	-
j	mushroom substrate + straw + 1.5 g N · pot^{-1}	1.5 g N ; 1.2 g P; 1.8 g K · pot^{-1}	1.5 g N; 1.2 g P; 1.8 g K · pot^{-1}

selected experimental units in the amounts of 1.5, 1,2; 1.8 g·pot^{-1}, respectively. In the spring of the first year, mineral N in the amount of 1.5 g was added to selected experimental variants (Table 1).

Organic fertilizers were applied in the autumn before the experiment. Fresh organic materials (not composted), with their doses determined on the basis of N amounts, i.e. 3 g N·pot^{-1}, were mixed with soil in pots. Organic fertilizers contained the following amounts of N (g·kg^{-1} DM): chicken manure 45.8; mushroom substrate 22.6; rye straw 6.20. The addition of rye straw in some experimental units accounted for 30% of total organic matter. Mushroom substrate came from a farm where white button mushrooms (*Agaricus bisporus*) had been cultivated for six weeks, while manure came from laying hens kept on bedding. The chemical composition of organic materials used in the experiment was determined by the ICP-AES method, after dry mineralization, with total N measured by the Kjeldahl method and C_{org} by the oxidation-titration method.

Four times a year, each time after about 30 days of growing, grass was harvested. Dry matter was determined by drying a sample at 105 °C until constant weight was obtained. Then plant material was sampled and the total content of K, Ca and Mg was determined by the ICP-AES method after dry mineralization in a muffle furnace at a temperature of 450 °C. Then 5 ml of diluted HCl (1:1) was added to the crucible and evaporated on a sand bath to decompose carbonates and separate silica. Next 10 ml of 10% HCl was added, and the solution was transferred quantitatively to a 100 ml volumetric flask. The quantitative ratios between the selected elements, i.e. K:Ca, K:Mg and K:(Ca+Mg), were calculated.

The results were statistically processed. Differences between the means were assessed with analysis of variance for a two-factor experiment in a split-plot design. In the case of significance, the $LSD_{0.05}$ value was calculated according to Tukey's test. Then, on this basis, homogeneous groups were obtained. Statistica, version 13.1 StatSoft (2021) was used for calculations. Fertilizer treatments constituted factor A and harvest/years factor B.

The following mathematical models were used:

The effect of treatment across years:

$$y_{ijl} = m + a_i + g_j + e^1_{ij} + b_l + ab_{il} + e^2_{ijl} \quad (1)$$

where: m – overall population mean;
a_i – effect of years;
g_j – effect of replications;
e^1_{ij} – random error effect 1;
b_l+ – effect of treatment;
ab_{il}+ – effect of interaction between years and treatment;
e^2_{ijl} – random error effect 2.

The effect of treatment on harvest quality:

$$y_{ijl} = m + a_i + g_j + e^1_{ij} + b_l + ab_{il} + e^2_{ijl} \quad (2)$$

where: m – overall population mean;
a_i – effect of treatment;
g_j – effect of replications;
e^1_{ij} – random error effect 1;
b_l – effect of harvest;
ab_{il} – effect of interaction between harvests and treatment;
e^2_{ijl} – random error effect 2.

RESULTS

Organic materials used in the experiment varied in terms of their chemical composition and dry matter content (Table 2). The highest C_{org} content was in rye straw, followed by mushroom substrate, and the lowest in chicken manure. However, N content in manure was two times higher than in mushroom substrate and seven times higher than in rye straw. Besides, P, K and S content in manure was higher than in other organic materials. The amounts of other macronutrients (Ca, Mg and Na) were greater in spent mushroom substrate than in chicken manure or straw. The content of micronutrients and heavy metals in organic materials also varied. The highest amounts of Fe, Co, Pb, Cr, Cu, Zn and Ni were recorded in chicken manure, Mn, B and Mo in mushroom substrate, while Cd in rye straw.

According to statistical analysis, the dry-matter yield of *Dactylis glomerata* significantly varied across experimental factors (Table 3). Its highest values, as a three-year average, were recorded for plants on the unit with manure, rye straw and mineral fertilizers (27.64 g DM·pot^{-1}) and on the one with mushroom substrate, rye straw and mineral fertilizers (26.47 g DM·pot^{-1}). The addition of straw probably limited soil organic matter mineralization, resulting in more effective nutrient absorption and in the highest yield, twice as high as on the control unit where it was 12.04 g

DM·pot^{-1}. Across four harvests, the highest value was recorded in the first one, with 6.98 g DM· pot^{-1} as a three-year average, while the lowest in the fourth (4.24 g DM·pot^{-1}).

The dry matter yield of *Dactylis glomerata* (Figure 1) largely varied growing periods. In the second year, the biomass yield was lower than in the remaining years of vegetation. Compared to

Table 2. Chemical composition of chicken manure, spent mushroom substrate and rye straw

Component	Chicken manure	Mushroom substrate	Rye straw
Dry matter (%)	26.5	28.5	85.0
C:N	5.13	12.35	69.84
Content (g · kg^{-1} DM)			
C_{org}	235.0	279.0	433.0
N_{tot}	45.80	22.60	6.20
P	9.17	8.02	0.687
K	14.35	10.24	0.538
Ca	10.19	72.36	3.39
Mg	3.45	4.39	0.361
Na	2.31	15.69	0.691
S	1.53	1.08	0.249
Content (mg · kg^{-1} DM)			
Fe	3318.8	2069.5	114.4
Mn	306.9	352.0	57.04
B	8.20	11.20	1.25
Mo	0.840	1.22	0.118
Co	0.820	0.389	0.109
Pb	10.90	3.58	3.70
Cd	0.407	0.269	0.559
Cr	4.82	3.14	0.612
Cu	14.82	11.24	1.51
Zn	219.2	167.8	19.52
Ni	67.42	3.89	3.17

Table 3. *Dactylis glomerata* biomass yield (g DM·pot^{-1}) in consecutive harvests (average across years)

Treatment variants (A)	Grass yield in each harvest (B)				Total
	I	II	III	IV	
a	3.74	3.35	2.90	2.05	12.04e
b	7.53	5.15	4.39	3.28	20.35c
c	5.37	4.96	3.26	3.30	16.89d
d	6.50	5.91	4.58	4.51	21.50c
e	6.34	4.68	4.01	4.00	19.03c
f	10.36	7.05	5.63	4.60	27.64a
g	6.81	7.37	5.63	5.49	25.30ab
h	7.29	6.00	4.95	5.82	24.06b
i	7.30	5.38	4.31	4.13	21.12c
j	8.52	6.63	6.09	5.23	26.47ab
Mean	6.98A	5.65B	4.58BC	4.24C	21.45
Means marked with the same small letter (a, b ,c, d, e) do not differ significantly at $p \leq 0.05$, means marked with the same capital letters (A, B, C) do not differ significantly at $p \leq 0.05$					

Note: a – control, b – NPK, c – chicken manure, d – manure + mineral fertilizers, e – manure + straw, f – manure + straw + mineral fertilizers, g – mushroom substrate, h – mushroom substrate + mineral fertilizers, i – mushroom substrate + straw, j – mushroom substrate +straw + mineral fertilizers.

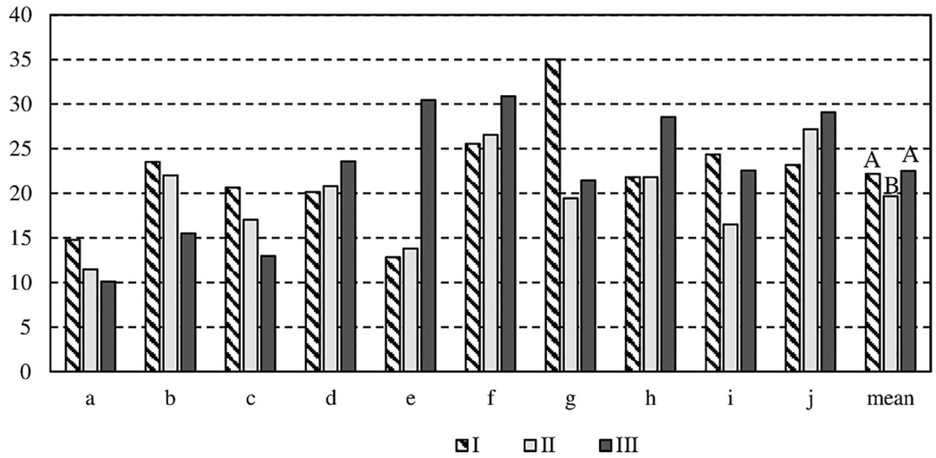

Figure 1. *Dactylis glomerate* dry matter yield (g·pot^{-1} DM) in consecutive years (total of four harvests), a – control, b – NPK, c – chicken manure, d – manure + mineral fertilizers, e – manure + straw, f – manure + straw + mineral fertilizers, g – mushroom substrate, h – mushroom substrate + mineral fertilizers, i – mushroom substrate + straw, j – mushroom substrate +straw + mineral fertilizers

the second and third ones, in the first year higher biomass yield was recorded on control (a), on the unit with mineral fertilizers (b), on the one with chicken manure (c), on the one with mushroom substrate (g) and on the one with mushroom substrate applied together with rye straw (i). No such increase was found on other treatment variants.

In the third year of the experiment on the variant with chicken manure applied together with straw (e), the yield of *Dactylis glomerata* was twice as high as in the first. Also in the third year, a significantly higher biomass yield was obtained than in previous years on the variant where chicken manure was used with straw and mineral fertilizers (f), on the one with mushroom substrate and mineral fertilizers (h) and on the one with mushroom substrate applied with straw and mineral fertilizers (j). In total, in the third year the yield was significantly higher than in previous years.

Total K content of *Dactylis glomerata* varied significantly across experimental factors and ranged from 13.00 to 39.28 g·kg^{-1} DM (Table 4). Its average amount across years of research and treatment combinations was 26.04 g·kg^{-1} DM. In the first harvest of *Dactylis glomerata* K content (average across years of research) was the highest (32.04 g·kg^{-1} DM). In subsequent harvests it decreased and was 28.80 g·kg^{-1} DM in the second, 23.65 g·kg^{-1} DM in the third and 19.65 g·kg^{-1} DM in the fourth. Across treatment combinations, the highest K accumulation was in response to mineral fertilizers (33.93 g·kg^{-1} DM) and to chicken manure with the addition of rye straw and mineral fertilizers (30.70 g·kg^{-1} DM). On control, K content was almost two times lower and averaged 16.60 g·kg^{-1} DM.

The content of K varied throughout the experiment (Figure 2). In the first and second year

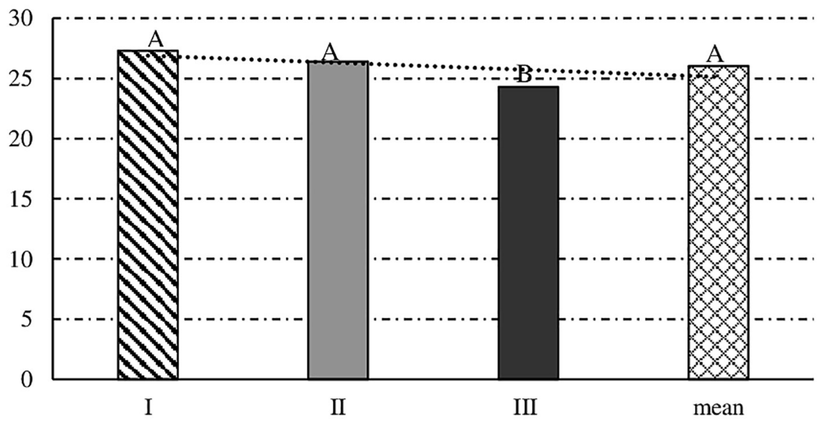

Figure 2. K content of *Dactylis glomerata* biomass (g·kg^{-1} DM) in consecutive years (average across harvests)

Table 4. Total K content of *Dactylis glomerata* biomass (g·kg^{-1} DM) in consecutive harvests (average across years)

Treatment variants (A)	Average K content of each harvest (B)				Mean
	I	II	III	IV	
a	21.03	18.24	14.12	13.00	16.60e
b	38.23	34.23	35.12	28.14	33.93a
c	28.36	25.14	20.12	14.78	22.10d
d	35.41	31.12	28.46	20.47	28.87bc
e	32.01	29.45	27.41	26.14	28.75bc
f	39.28	37.12	25.17	21.23	30.70b
g	29.45	27.45	20.11	14.18	22.80d
h	32.41	30.12	26.12	24.33	28.25c
i	28.12	25.66	18.45	14.12	21.59d
j	36.12	29.45	21.39	20.14	26.78c
mean	32.04A	28.80B	23.65C	19.65D	26.04
Means marked with the same small letter (a, b ,c, d, e) do not differ significantly at p≤ 0.05, means marked with the same capital letters (A, B, C) do not differ significantly at p≤ 0.05					

Note: a – control, b – NPK, c – chicken manure, d – manure + mineral fertilizers, e – manure + straw, f – manure + straw + mineral fertilizers, g – mushroom substrate, h – mushroom substrate + mineral fertilizers, i – mushroom substrate + straw, j – mushroom substrate +straw + mineral fertilizers.

of the study, the content of K was similar, and the lowest in the 3rd year of the study.

The average Ca content was 19.86 g·kg^{-1} DM and, like in the case of K, it decreased with consecutive harvests (Table 5); in the first harvest of *Dactylis glomerata* an average of 24.19 g·kg^{-1} DM was recorded, 21.27 in the second, 18.34 in the third and 15.62 g Ca·kg^{-1} DM in the fourth. The highest content of Ca was found on the unit treated with mineral fertilizers (26.32 g·kg^{-1} DM), followed by the one with manure, straw and mineral fertilizers (25.72 g·kg^{-1} DM) and by the one with manure with the addition of mineral fertilizers (25.00 g·kg^{-1} DM). On the remaining variants, Ca content was significantly lower; on control it was more than two times lower. The average Ca content varied throughout the experiment. In the first year, Ca content in plants was much higher than in the other years of research (Fig. 3).

The content of Mg in the forage was slightly different from that of K and Ca (Table 6). On average, its greatest amounts were noted in *Dactylis glomerata* treated with mushroom substrate applied with straw and mineral fertilizers (4.45 g·kg^{-1} DM). The use of substrate with mineral fertilizers without the addition of straw resulted in lower Mg content (3.84 g·kg^{-1} DM). On the other hand, the use of mushroom substrate on its own also resulted in lower Mg content than on other treatment variants, except for control.

As in the case of Ca, across years of research higher content of Mg in plants was recorded in the first year than in the second or third (Fig. 4).

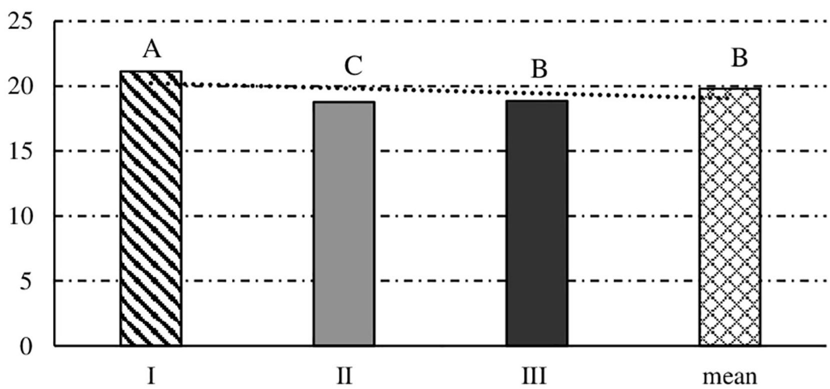

Figure 3. Ca content of *Dactylis glomerate* biomass (g·kg^{-1} DM) in consecutive years (average across harvests)

Table 5. Total Ca content of *Dactylis glomerata* biomass (g·kg^{-1} DM) in consecutive harvests (average across years)

Fertilization variants (A)	Average Ca content of each harvest (B)				Mean
	I	II	III	IV	
a	10.23	8.46	10.23	7.12	9.01e
b	30.12	29.12	25.69	20.36	26.32a
c	26.12	22.34	20.14	17.48	21.52b
d	31.41	25.69	22.34	20.56	25.00a
e	22.36	20.34	17.45	17.02	19.29c
f	29.41	28.55	24.49	20.41	25.72a
g	18.46	17.25	15.22	13.20	16.03d
h	28.14	24.80	20.47	18.12	22.88b
i	19.46	15.69	13.25	10.37	14.69d
j	26.23	20.45	14.15	11.58	18.10c
mean	24.19A	21.27B	18.34C	15.62D	19.86
Means marked with the same small letter (a, b, c, d, e) do not differ significantly at p≤ 0.05, means marked with the same capital letters (A, B, C) do not differ significantly at p≤ 0.05					

Note: a – control, b – NPK, c – chicken manure, d – manure + mineral fertilizers, e – manure + straw, f – manure + straw + mineral fertilizers, g – mushroom substrate, h – mushroom substrate + mineral fertilizers, i – mushroom substrate + straw, j – mushroom substrate + straw + mineral fertilizers.

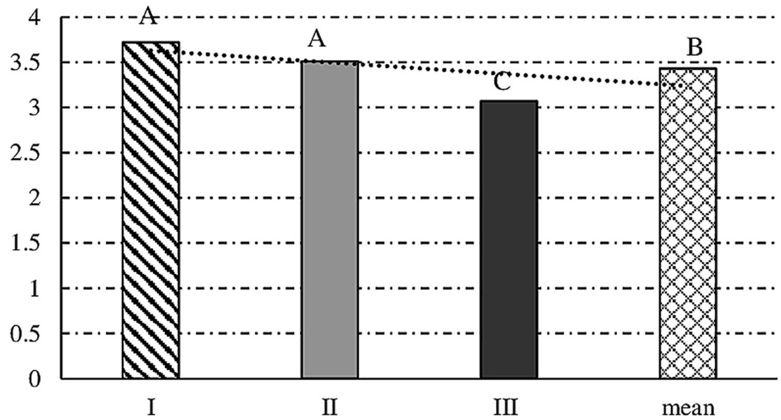

Figure 4. Mg content of *Dactylis glomerate* biomass (g·kg^{-1} DM) in consecutive years (average across harvests)

Table 6. Total Mg content of *Dactylis glomerata* biomass (g·kg^{-1}DM) in consecutive harvests (average across years)

Treatment variants (A)	Average Mg content of each harvest (B)				Mean
	I	II	III	IV	
a	2.19	2.09	1.58	1.42	1.82e
b	4.30	3.89	2.99	2.55	3.43bcd
c	3.51	3.01	3.20	3.02	3.19cd
d	4.62	4.25	3.89	3.43	4.05ab
e	3.89	3.85	2.33	2.30	3.09cd
f	5.01	4.44	4.02	3.88	4.34a
g	3.21	2.89	2.55	2.31	2.74d
h	4.56	4.03	3.78	2.98	3.84abc
i	3.89	3.56	3.14	3.01	3.40bcd
j	5.13	4.55	4.03	4.10	4.45a
Mean	4.03A	3.66AB	3.15B	2.90B	3.43
Means marked with the same small letter (a, b ,c, d, e) do not differ significantly at p≤ 0.05, means marked with the same capital letters (A, B, C) do not differ significantly at p≤ 0.05					

Note: a – control, b – NPK, c – chicken manure, d – manure + mineral fertilizers, e – manure + straw, f–manure + straw + mineral fertilizers, g – mushroom substrate, h – mushroom substrate + mineral fertilizers, i – mushroom substrate + straw, j – mushroom substrate + straw + mineral fertilizers.

Table 7. Quantitative K:Ca, K:Mg and K:(Ca+Mg) ratios in *Dactylis glomerata* (average across cuts and years)

Treatment variants	K:Ca	K:Mg	K:(Ca+Mg)
a	0.529	0.118	0.647
b	0.769	0.162	0.819
c	0.950	0.232	1.18
d	0.846	0.226	1.07
e	0.654	0.173	0.827
f	0.818	0.228	1.05
g	0.684	0.194	0.878
h	0.790	0.219	1.01
i	0.665	0.254	0.918
j	0.660	0.267	0.927
Mean	0.736	0.207	0.933

Note: a – control, b – NPK, c – chicken manure, d – manure + mineral fertilizers, e – manure + straw, f – manure + straw + mineral fertilizers, g – mushroom substrate, h – mushroom substrate + mineral fertilizers, i – mushroom substrate + straw, j – mushroom substrate + straw + mineral fertilizers.

The nutritional value of forage is determined by its chemical composition, but also by ratios between chemical elements. The results of the present research (Table 7) indicated that the widest K:Ca and K:(Ca+Mg) quantitative ratios of 0.950 and 1.18, respectively, were recorded in the forage treated with manure on its own. The ratio of K:Mg was the widest for grass treated with mushroom substrate with the addition of straw and mineral fertilizers (0.267). The narrowest quantitative ratios were in control plants. The average value of *Dactylis glomerata* ratios across treatment combinations and years of research was 0.736 for K:Ca, 0.207 for K:Mg, and 0.933 for K:(Ca+Mg).

Differences between the effects of organic materials applied on their own and together with mineral fertilizers on quantitative ratios in the vast majority were small. Mineral fertilizers narrowed the quantitative ratios of K:Mg and K:(Ca+Mg) compared to other treatment variants.

DISCUSSION

The yield-increasing effect of organic materials has been confirmed by the research of many authors (Harlt et al., 2003; Petersen et al., 2003). Adequate doses of organic fertilizers positively affect crop yields and their quality on the one hand, and, on the other, they reduce pressure on the environment (Łabętowicz et al., 2019). Natural use of waste is also important from an economic point of view, being an element of circular economy (Bolan et al., 2014; Malinowska 2016c). The amount of nutrients that should be applied to soil together with organic materials varies, depending on the latter's chemical composition (Kalembasa et al., 2014). To introduce sustainable fertilizer treatment, chemical composition of organic fertilizers and organic materials is indispensable. However, chemical composition of manure or slurry is largely determined by the way animals are fed. On some farms, the diet of animals may contain significant amounts of concentrated feed rich in N (protein) and P, and their content in manure increases. Numerous studies (Geisert et al., 2005; Kebreab et al., 2010; Latshaw and Zhao, 2011) have proven that there is a close quantitative relationship between the intake of these components by animals in feed and their removal in dung and urine.

The content of N, P and K in chicken manure determined in the present experiment was confirmed by Pietrzak and Fila (2016) and Dróżdż et al. (2020) even though in the case of Ca, Dróżdż et al. (2020) recorded much higher content. The mushroom substrate used in the experiment was characterized by a notable content of dry matter (30%) and macroelements. Similar values have been reported by many other authors (Guo and Chorover, 2004; Becher, 2013; Majchrowska-Safaryan and Tkaczuk, 2016). According to many studies, the addition of mushroom substrate to soil increases plant yield and improves soil physicochemical properties (Wiśniewska-Kadżajan, 2014; Wiśniewska-Kadżajan and Malinowska 2022).

The average K content of *Dactylis glomerata* was 26.04 $g \cdot kg^{-1}$ DM, Mg 19.86 $g \cdot kg^{-1}$ DM and Ca 3.43 $g \cdot kg^{-1}$ DM. Similar content of these macroelements in Italian ryegrass treated with compost from organic waste was reported by Malinowska (2016c). Similar K levels were found also in some cereal plants such as meadow and red fescue (14.5 ± 2.0 and 14.4 ± 1.9 $g \cdot kg^{-1}$ DM) as well as smooth brome (14.3 ± 1.7 $g \cdot kg^{-1}$ DM) (Juknevičius and Sabienė, 2007). However, the nutritional value of forage plants is determined not only by the content of macro and microelements, but also by their ratios (Kalembasa et al., 2014; Sosnowski and Król, 2018). In the case of macronutrients, it is very difficult to ensure favourable quantitative ratios of chemical elements or their groups in plant material. In *Dactylis glomerata*, the ratio of monovalent to divalent elements was calculated because they are very important for maintaining proper animal health. According to Czuba and Mazur (1988), the average value of the K:(Ca + Mg) ratio in forage should range from 1.6 to 2.2. A higher value indicates too little Mg and Ca in plants. In *Dactylis glomerata*, the ratio averaged 0.933, which, according to Gaweł (2009), is normal. According to the same author, for roughage the optimal ratio should be in the range of 0.66–0.98. Sosnowski and Król (2018) recorded a lower value of the K:(Ca + Mg) ratio in the dry matter of hybrid alfalfa (0.75) and meadow clover (0.79). Subsequent studies by this author indicate a similar value of K:(Ca+Mg) in *Lolium multiflorum* under the influence of Tytanit application (Sosnowski et al., 2023). The content of macro- and microelements and the ratios between chemical elements are also affected by the frequency of mowing, and by how long the grassland has been used (Gaweł, 2009).

CONCLUSIONS

The content of macro- and microelements and heavy metals in organic materials varied. It was the highest in rye straw and the lowest in chicken manure. However, chicken manure had higher content of N, P, K and S, as well as Fe, Co, Pb, Cr, Cu, Zn and Ni than other organic materials.

The highest yield of *Dactylis glomerata* (average across consecutive years) was recorded on the variant with manure, straw and mineral fertilizers (27.64 $g \cdot pot^{-1}$) and on the one with mushroom substrate, straw and mineral fertilizers (26.47 $g \cdot pot^{-1}$). The yield on those variants was more than twice as high as on control.

With consecutive harvests of *Dactylis glomerata*, a significant decrease in the content of K, Ca and Mg (average across years of research) was noted. The greatest accumulation of K and Ca was in response to NPK mineral fertilizers, while the highest Mg amounts were on the unit with mushroom substrate, straw and mineral fertilizers.

Compared to other treatments, mineral fertilizers narrowed the quantitative ratio of K:Mg and K:(Ca+Mg) in the grass. The average K:(Ca+Mg) ratio of 0.933 was typical for *Dactylis glomerata*.

Compared to the effects of mineral fertilizers used on their own, the combination of mineral and organic fertilizers applied to *Dactylis glomerata* resulted in higher yield of better quality, with obvious economic and environmental benefits.

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