# CONCENTRATIONS OF K, Mg AND Na AND THEIR IONIC RELATIONS IN *DACTYLIS GLOMERATA* L. BIOMASS GROWN IN SOIL WITH MUSHROOM SUBSTRATE AND MINERAL FERTILISERS

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(Received 7th Dec 2016; accepted 7th Mar 2017)

**Abstract.** The aim of the research was to determine potassium, magnesium and sodium concentration but also the weight ratio of those macro elements in the biomass of *Dactylis glomerata* L. grown in a three-year experiment. The experiment was carried out on loamy sand soil fertilized with fermented cow manure and mushroom growing substrate, the latter on its own and with mineral fertilisers applied additionally. The concentrations of those macro elements in the biomass of *Dactylis glomerata* showed considerable differences, depending on what fertilisers were used and from which year and cut the samples were taken. On average the concentration of potassium, magnesium and sodium in the biomass of *Dactylis glomerata* increased considerably if mushroom substrate and mineral fertilisers were applied. The experiment found that potassium and magnesium concentration in the grass was much higher than optimal concentration, while sodium concentration was too low.
**Keywords:** *organic waste, fertilization, biomass of grass, chemical composition*

## Introduction

In Poland tillage reduces the amount of organic matter in most types of soil used for farming (Gonet, 2007). That is why such soil should be enriched with organic fertilizers and with those kinds of organic waste which are allowed to be used in agriculture. One kind of organic waste, whose amount is growing in particular in mid-eastern Poland, is mushroom substrate, left after harvesting mushrooms (Kalembasa and Majchrowska-Safaryan, 2009a, 2009b, 2006). According to Regulation of the Minister of the Environment of 27 September 2001 mushroom substrate, classified as ‘other waste not mentioned here’, is part of a group of waste produced. in agriculture, horticulture, hydroponic cultivation, fishery, forestry, hunting and in food processing (Regulation of the Minister of the Environment of 27 September, 2001).

To utilize mushroom substrate in agriculture its properties and chemical composition must be determined. With its nutrients easily available to plants the use of this waste in farming seems to be most appropriate as long as mushroom substrate meets the standards of environmental protection.

Chemical composition of mushroom substrate depends on production technology and the yield of mushrooms. Earlier research done by Kalembasa and Wiśniewska (2001) found that chemical composition of mushroom substrate varied considerably. According to their study potassium concentration was highly unstable, which is probably caused by the fact that this element does not occur as part of any stable organic compounds and because of that it can be easily leached from mushroom substrate during watering.


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1503_12691278

Kalembasa and Majchrowska-Safaryan (2009a; 2009b) argue that the concentration of assimilable phosphorus and calcium is the most unstable while the concentration of organic matter and the pH value are the least unstable. Other publications (Uzun, 2004; Jordan et al., 2008; Maszkiewicz, 2010; Wiśniewska-Kadżajan, 2012, 2013) on the chemical composition of mushroom substrate confirm variability of its chemical composition and its chemical imbalance. Many studies have shown that composting spent mushroom substrate with other organic materials maybe a viable alternative means to reduce the environmental problems (Paredes et al., 2016; Gonzales-Marcos et al., 2014; Zhou et al., 2014; Lou et al., 2016)

The aim of the research was to determine the concentration of potassium, magnesium and sodium and the ratio of the weight of those macro elements in the biomass of *Dactylis glomerata* grown in soil fertilized with mushroom substrate and supplemented with nitrogen and potassium fertilizers.

## Materials and methods

To do the research a three-year (2012-2014) field experiment was set up (with plots of an area of $3m^2$) at the Experimental Station of Siedlce University of Natural Sciences and Humanities (*Figure 1*). The experiment was located in the Masovian Province which is located in central-eastern part of Poland.


***Figure 1.*** *Place of research [http://google.pl/maps/place/Siedlce in own modification]*

The research was replicated three times in a randomized design. The experiment was carried out on soil with the granulometric structure of loamy sand, belonging to the order of anthrosol soils, the group of cultural anthropogenic soils of hortic type (Marcinek, and Komisarek, 2011). The pH value of the soil in 0.01 M $CaCl_2$ was 6.8, carbon concentration in organic form was 13.45 g $kg^{-1}$ of soil, total nitrogen was 1.32 g $kg^{-1}$, while C:N ratio was 10.2. The concentration of assimilable phosphorus was very high (P - 170 mg $kg^{-1}$ of soil), potassium concentration was average (K – 114.0 mg $kg^{-1}$ of soil), while assimilable magnesium concentration was high (Mg – 84.0 mg $kg^{-1}$ of soil).


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1503_12691278

The organic fertilisers applied were fermented cow manure (used as standard) and mushroom substrate. The concentration of potassium, magnesium and sodium in both kinds of organic substance is presented in *Table 1*.

Compared to manure, mushroom substrate had a lower concentration of potassium (10.8 g $kg^{-1}$ DM) and magnesium (3.60 g $kg^{-1}$ DM), but higher concentration of sodium (1.90 g $kg^{-1}$ DM). The concentration of potassium in manure was 16.5 g $kg^{-1}$ DM, magnesium – 5.30 g $kg^{-1}$ DM and sodium – 1.10 g $kg^{-1}$ DM.

***Table 1.*** *Dry matter (%) and selected macro elements (g $kg^{-1}$ DM) concentration in organic materials used in the experiment*

| **Organic material** | **The content of macro elements (g · $kg^{-1}$ DM)** | | |
|---|---|---|---|
| | **K** | **Mg** | **Na** |
| **Farmyard manure** | 16.5 | 5.30 | 1.10 |
| **Mushroom substrate** | 10.8 | 3.60 | 1.90 |

Both mushroom substrate and manure were applied in one dose of 20 t $ha^{-1}$ in autumn before the grass was sown. Additionally every year the plots with mushroom substrate were fertilized with two different doses $N_1$ $K_1$ and $N_2K_2$.

The doses of nitrogen were as follows: $N_1$ – 60 and $N_2$ – 120 kg·$ha^{-1}$, in the form of $NH_4NO_3$, while potassium doses were $K_1$ – 80 and $K_2$ – 160 kg $ha^{-1}$, in the form of $K_2SO_4$. Because of the high content of assimilable phosphorus in the soil, this mineral fertiliser was not applied. Yearly doses of fertilisers were divided into three equal parts. The first part was applied in spring before the growing season, the others after the second and third cut. The field was divided into the following experimental plots:

1. a control plot, without fertilisers
2. a plot with fermented manure
3. a plot with mushroom substrate
4. a plot with mushroom substrate + $N_1K_1$
5. a plot with mushroom substrate + $N_2K_2$.

The grass *Dactylis glomerata* L. of the Amila variety was used in the experiment. During each growing season three cuts were harvested. Immediately after the harvest the biomass from each plot was weighed, with 0.5 kg samples taken to be analyzed.

Each year potassium, magnesium and sodium concentration in dry matter was measured after the samples had been air dried and mineralized in a muffle furnace at the temperature of 450°C. The ash was put in crucibles and the hydrochloric acid was added (HCl : $H_2O$ = 1:1) to dissolve carbonates and to separate silica. The chlorides formed this way were put into a 100-$cm^3$ flask, with silica removed by filtration. The AAS method with the *Varian Spectra AA-20* atomic absorption spectrophotometer, together with the Merck test kit, was used to measure the concentration of potassium, magnesium and sodium.

Metrological data from between 2012 and 2014 were provided by Hydrological and Meteorological Station in Siedlce.

Sielianinow's hydrothermal index K was used to determine temporal and spatial variation of meteorological elements and to assess their influence on the growth of plants. It was calculated (Bac et al., 1993) dividing the sum of monthly rainfall by one-


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DOI: http://dx.doi.org/10.15666/aeer/1503_12691278

tenth of the total average daily temperature of the month (*Table 2*). The calculated values of the hydrothermal index show that there were periods of drought and severe drought during summer months.

***Table 2.*** *Sielianinow's hydrothermal index (K) by months of growing seasons 2012 – 2014*

| **Month** | **Years** | | |
|---|---|---|---|
| | **2012** | **2013** | **2014** |
| IV | 1.12 | 1.60 | 1.53 |
| V | 1.22 | 2.20 | 2.29 |
| VI | 1.56 | 1.80 | 1.20 |
| VII | 0.69 | 1.50 | 0.16 |
| VIII | 0.94 | 0.25 | 1.95 |
| IX | 0.27 | 2.70 | 0.59 |
| X | 1.32 | 1.22 | 0.13 |

(K < 0.5 severe drought; 0.51 – 0.69 drought; 0.70 – 0.99 mild drought; K >1 no drought)

All of the data were statistically analyzed and differences between means were assessed using analysis of variance with the Statistica software, Version 10.0 StatSoft, applied. Tukey's test was used to determine $LSD_{0.05}$ for means that were significantly different (StatSoft, Inc. 2011).

## Results

There was a considerable variety in the concentration of potassium in the biomass of *Dactylis glomerata* (*Table 3*). This concentration was dependent on fertilisation, cut and the year of the experiment.

The highest concentration of potassium in the biomass of *Dactylis glomerata* in the first and third year of the experiment (42.53 and 40.53 g $kg^{-1}$ DM respectively) was observed on the plots where mushroom substrate was used and where the higher dose of fertilizers was applied ($N_2K_2$), while in the second year (41.20 g $kg^{-1}$) on the plot with the lower dose of fertilisers.

Magnesium concentration in the biomass of *Dactylis glomerata* (*Table 4*) showed considerable differences in relation to fertilization, cut and the year of the experiment. In the first and second years of the experiment, *Dactylis glomerata* from the plots with mushroom substrate and the higher dose of mineral fertilisers ($N_2K_2$) had the highest concentration of magnesium in the biomass: 4.62 and 4.94 g $kg^{-1}$, respectively, while in the third year (4.98 g $kg^{-1}$) in the grass from the plots with mushroom substrate and the lower dose of mineral fertilisers ($N_1K_1$). The lowest concentration of magnesium was in the first year of the experiment in the grass from the plot with manure (3.07 g $kg^{-1}$), in the second year in the grass from the plot with mushroom substrate (3.46 g $kg^{-1}$), while in the third year in the grass from the control plot (3.45 g $kg^{-1}$). The three-year average of magnesium concentration in the biomass of the grass tested on the plots with mushroom substrate only was lower (3.48 g $kg^{-1}$) than in the grass from the plot fertilized with manure, which was (4.00 g $kg^{-1}$).


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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***Table 3.*** *Potassium concentration in the biomass of Dactylis glomerata [g kg$^{-1}$ dm] in relation to fertilization, cut and year of research*

| Plots | Cut | Research year | | | Average |
|---|---|---|---|---|---|
| | | 2012 | 2013 | 2014 | |
| **Control plot** | I | 30.73 | 28.80 | 26.70 | 28.74 |
| | II | 29.90 | 31.71 | 23.00 | 28.20 |
| | III | 29.30 | 22.50 | 22.70 | 24.83 |
| **Manure** | I | 33.51 | 37.60 | 31.72 | 34.26 |
| | II | 33.90 | 27.80 | 29.80 | 30.50 |
| | III | 37.52 | 30.20 | 30.52 | 32.73 |
| **Mushroom substrate** | I | 32.10 | 37.30 | 32.70 | 34.03 |
| | II | 35.60 | 32.80 | 30.51 | 32.96 |
| | III | 33.90 | 29.60 | 30.10 | 31.20 |
| **Mushroom substrate +$N_1K_1$** | I | 40.23 | 42.30 | 41.81 | 41.43 |
| | II | 39.80 | 41.90 | 40.50 | 40.73 |
| | III | 35.60 | 39.40 | 37.21 | 37.4 |
| **Mushroom substrate +$N_2K_2$** | I | 43.50 | 42.90 | 42.70 | 43.03 |
| | II | 42.11 | 41.50 | 40.50 | 41.36 |
| | III | 42,02 | 38.50 | 38.40 | 39.63 |
| **Plot average** | | | | | |
| Control plot | | 29.96 | 27.66 | 24.13 | 27.25 |
| Manure | | 34.96 | 31.86 | 30.66 | 32.50 |
| Mushroom substrate | | 33.86 | 33.23 | 31.10 | 32.73 |
| Mushroom substrate+$N_1K_1$ | | 38.53 | 41.20 | 39.83 | 39.85 |
| Mushroom substrate+$N_2K_2$ | | 42.53 | 40.96 | 40.53 | 41.34 |
| **Average** | | 35.97 | 34.98 | 33.25 | 34.73 |

$LSD_{0,05}$ for:
A - fertilization A = 0.42 B = 0.27 C = 0.27
B - cut A/B = n.s. B/A = n.s. A/C = 0,73
C - years C/A = 0.61 B/C = n.s. C/B = n.s.

***Table 4.*** *The concentration of magnesium in the biomass of Dactylis glomerata [g kg$^{-1}$ DM] in relation to fertilization, cut and year of research*

| Plots | Cut | Research year | | | Average |
|---|---|---|---|---|---|
| | | 2012 | 2013 | 2014 | |
| **Control plot** | I | 4.12 | 3.97 | 3.87 | 3.98 |
| | II | 4.25 | 3.58 | 3.54 | 3.79 |
| | III | 3.21 | 3.14 | 2.96 | 3.10 |
| **Manure** | I | 3.31 | 4.78 | 4.82 | 4.30 |
| | II | 3.05 | 4.64 | 4.26 | 3.98 |
| | III | 2.85 | 4.21 | 4.10 | 3.72 |
| **Mushroom substrate** | I | 4.13 | 3.87 | 3.87 | 3.95 |
| | II | 3.56 | 3.58 | 3.64 | 3.59 |
| | III | 2.82 | 2.89 | 2.97 | 2.89 |
| **Mushroom substrate +$N_1K_1$** | I | 4.75 | 5.41 | 5.47 | 5.21 |
| | II | 4.69 | 4.65 | 5.23 | 4.85 |
| | III | 3.75 | 4.10 | 4.25 | 4.03 |
| **Mushroom substrate +$N_2K_2$** | I | 4.92 | 5.78 | 5.68 | 5.46 |
| | II | 4.45 | 4.34 | 4.64 | 4.47 |
| | III | 4.50 | 4.70 | 4.29 | 4.49 |


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DOI: http://dx.doi.org/10.15666/aeer/1503_12691278

| Plot average | | | | |
|---|---|---|---|---|
| Control plot | 3.86 | 3.56 | 3.45 | 3.62 |
| Manure | 3.07 | 4.54 | 4.39 | 4.00 |
| Mushroom substrate | 3.50 | 3.46 | 3.49 | 3.48 |
| Mushroom substrate +$N_1K_1$ | 4.39 | 4.72 | 4.98 | 4.70 |
| Mushroom substrate +$N_2K_2$ | 4.62 | 4.94 | 4.87 | 4.81 |
| **Average** | 3.89 | 4.24 | 4.23 | 4.12 |

$LSD_{0.05}$ for:
A - fertilization A = 1.16 B = 0.46 C = 0.76
B - cut A/B = n.s. B/A = n.s. A/C = n.s.
C - years C/A = n.s. B/C = n.s. C/B = n.s.

Sodium concentration in the biomass of *Dactylis glomerata* (*Table 5*) showed considerable differences dependent on fertilization, cut and the year of the experiment. The highest concentration of sodium in the biomass of *Dactylis glomerata* was noted in the first year of the experiment (1.49 g $kg^{-1}$) on the plots where mushroom substrate was applied together with the higher dose of mineral fertilizers ($N_2K_2$). In the second and third year of the experiment the highest concentration (1.29 and 1.21 g $kg^{-1}$, respectively) was in the grass with mushroom substrate and the lower dose of mineral fertilizers ($N_1K_1$).

***Table 5.*** *The concentration of sodium in the biomass of Dactylis glomerata [g $kg^{-1}$ DM] related to fertilization, cut and year of research*

| **Plots** | **Cut** | **Research year** | | | **Average** |
|---|---|---|---|---|---|
| | | **2012** | **2013** | **2014** | |
| **Control plot** | I | 1.12 | 0.98 | 0.87 | 0.99 |
| | II | 0.94 | 0.85 | 0.76 | 0.85 |
| | III | 0.93 | 0.75 | 0.75 | 0.81 |
| **Manure** | I | 0.90 | 1.00 | 0.99 | 0.96 |
| | II | 0.86 | 0.96 | 0.92 | 0.91 |
| | III | 0.85 | 0.87 | 0.78 | 0.83 |
| **Mushroom substrate** | I | 1.51 | 1.88 | 1.12 | 1.50 |
| | II | 1.46 | 1.76 | 1.01 | 1.41 |
| | III | 1.25 | 1.08 | 0.99 | 1.11 |
| **Mushroom substrate +$N_1K_1$** | I | 1.52 | 1.41 | 1.30 | 1.41 |
| | II | 1.20 | 1.36 | 1.24 | 1.27 |
| | III | 1.34 | 1.12 | 1.08 | 1.18 |
| **Mushroom substrate +$N_2K_2$** | I | 1.54 | 1.14 | 1.25 | 1.31 |
| | II | 1.48 | 1.01 | 1.10 | 1.19 |
| | III | 1.46 | 0.99 | 0.94 | 1.13 |
| **Plot average** | | | | | |
| Control plot | | 0.99 | 0.86 | 0.79 | 0.88 |
| Manure | | 0.87 | 0.94 | 0.89 | 0.90 |
| Mushroom substrate | | 1.41 | 1.57 | 1.04 | 1.34 |
| Mushroom substrate +$N_1K_1$ | | 1.35 | 1.29 | 1.21 | 1.28 |
| Mushroom substrate +$N_2K_2$ | | 1.49 | 1.05 | 1.09 | 1.21 |
| **Average** | | 1.22 | 1.14 | 1.01 | 1.12 |

$LSD_{0.05}$ for:
A - fertilization A = 0.15 B = 0.09 C = 0.09
B - cut A/B = n.s. B/A = n.s. A/C = 0,26
C - years C/A = 0.22 B/C = n.s. C/B = n.s.


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The three-year average of sodium concentration in the biomass of the grass tested on plots with mushroom substrate only was higher (1.34 g $kg^{-1}$) than in the plot fertilized with manure (0.90 g $kg^{-1}$).

The ratio of macroelements in *Dactylis glomerata* grown on the plots with mushroom substrate and on plots with mushroom substrate with mineral fertilizers was much lower than optimal (*Table 6*). The average ratio of K : Na in the grass from all plots ranged from 1.48 in the grass from the plot where mushroom substrate was used only to 1.29 in the grass where both mushroom substrate and the higher dose of mineral fertilisers were applied ($N_2K_2$).

***Table 6.*** *Ions ratio of the macro elements tested in the biomass of Dactylis glomerata related to fertilization, cut and year of research*

| **Plots** | **Cut** | **Research year** | | | **Average** |
|---|---|---|---|---|---|
| | | **2012** | **2013** | **2014** | |
| **K : Na (plot average)** | | | | | |
| Plot | | 1.13 | 1.36 | 1.69 | 1.39 |
| Manure | | 1.01 | 1.38 | 1.92 | 1.44 |
| Mushroom substrate | | 0.92 | 1.66 | 1.86 | 1.48 |
| Mushroom substrate +$N_1K_1$ | | 0.98 | 1.65 | 1.77 | 1.47 |
| Mushroom substrate +$N_2K_2$ | | 1.03 | 1.30 | 1.55 | 1.29 |
| **Average** | | 1.01 | 1.47 | 1.76 | 1.41 |
| **K : (Ca + Mg) (Plot average)** | | | | | |
| Control plot | | 1.13 | 1.36 | 1.69 | 1.39 |
| Manure | | 1.01 | 1.38 | 1.92 | 1.44 |
| Mushroom substrate | | 0.92 | 1.66 | 1.86 | 1.48 |
| Mushroom substrate +$N_1K_1$ | | 0.98 | 1.65 | 1.77 | 1.47 |
| Mushroom substrate +$N_2K_2$ | | 1.03 | 1.30 | 1.55 | 1.29 |
| **Average** | | 1.01 | 1.47 | 1.76 | 1.41 |

## Discussion

The potassium content obtained from eksperiment are confirmed by similar pot experiments on the effect of mushroom substrate on the growth of Italian ryegrass (Kalembasa and Wiśniewska, 2004, 2006, 2008a, 2008b). According to Jankowska-Huflejt and Wróbel (2006, 2008) as well as Jankowska-Huflejt et al. (2006) such research on mineral substances concentration in grass is very important in breeding of ruminants because pasture grass is often the only feed for them. Jankowska-Huflejt (2009) cited by Fabijańska (1997), shortage of mineral nutrients, including potassium, in feed has a harmful effect on the growth of the young and production of mature animals, in particular on cows producing large amounts of milk. When too much potassium fertiliser is applied, plants absorb too much of this element and the absorption of other nutrients like calcium, magnesium and sodium is inhibited, which causes cation imbalance in plant and animal cells.

Falkowski et al. (2000) say that potassium concentration in meadow and pasture grass should range from 17.00 to 20.00 g K $kg^{-1}$ DM. According to Jankowska-Huflejt et al. (2009) satisfactory concentration of potassium in hay should be 16.6 g $kg^{-1}$ DM.


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DOI: http://dx.doi.org/10.15666/aeer/1503_12691278

However, Wasilewski (1997) is of an opinion that potassium concentration in grass from grasslands should be 25.0 g $kg^{-1}$ DM at the most.

According to the findings of the experiment it should be said that the average potassium concentration in *Dactylis glomerata* was very high. This high concentration of potassium in the grass was probably because of the mineral fertilisers applied. A noticeable increase of potassium concentration in the grass tested was observed on the plots with nitrogen and potassium mineral fertilisers, with both $N_1K_1$ and $N_2K_2$ doses. Compared to potassium concentration in the grass from the plot where only mushroom substrate was applied, nitrogen and potassium fertilization caused a potassium concentration increase of about 20%.

Magnesium concentration was significantly higher in the grass from plots fertilised with mushroom substrate together with mineral nitrogen and potassium. It might have been caused by a pH rise after the use of the substrate. The findings of magnesium concentration in the grass tested were similar to those published by Kalembasa and Wiśniewska (2004, 2006, 2008b), who carried out an experiment using mushroom substrate to grow Italian ryegrass.

According to Falkowski et al. (2000) satisfactory magnesium concentration in fodder from meadows, pastures and hay ranges between 2.0 g $kg^{-1}$ and 2.7 g $kg^{-1}$ DM. However, Wasilewski (1997) says that magnesium concentration in pasture grass from 2.0 to 3.0 g $kg^{-1}$ DM is optimal. Comparing data on magnesium concentration in different feed given in the above publications and the concentration of magnesium in *Dactylis glomerata* presented here, it could be said that the latter concentration was above optimum.

In research by Falkowski et al. (2000), to meet requirements of ruminants sodium concentration in fodder should range from 1.5 to 2.5 g $kg^{-1}$. In every year of the experiment in the grass from all plots there was a deficiency of this macro element.

Correlation between potassium and sodium is negative, i.e. a higher concentration of potassium causes a lower concentration of sodium and that is why the weight ratio (K : Na) between those ions is important and should be 5 : 1 (Falkowski et al. 2000)**.** According to Jankowska-Huflejt et al. (2009) the satisfactory concentration of Na in feed from meadows and pastures is 1.0 g kg DM in hay and 1.5 g kg DM in grass.

Jankowska-Huflejt et al. (2009) cited by Wasilewski (1997) gives that the optimal K: (Ca +Mg) weight ratio in pasture grass should range between 1.9 and 2.2. On average in grass from all plots the ratio K: (Ca +Mg) was lower and ranged from 1.29 in the grass from the plot with mushroom substrate and the higher dose of mineral fertilisers ($N_2K_2$) to 1.48 in the grass grown on mushroom substrate only. Feeding animals with grass in which the ratio differs from the optimal can cause metabolism disruption, which can lead to health problems and a medical condition, like tetany.

## Conclusions

Potassium magnesium and sodium concentration in the biomass of *Dactylis glomerata* showed considerable differences, dependent on fertilisation, cut and the year of the experiment.

Each year the highest concentration of potassium and magnesium in the biomass of *Dactylis glomerata* was on the plots with mushroom substrate together with the higher dose of mineral fertilisers ($N_2K_2$). The highest concentration of sodium was in the grass grown in the soil with mushroom substrate and the lower dose of mineral fertilisers ($N_1K_1$).


http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1503_12691278

According to the findings, potassium and magnesium concentration in the biomass of *Dactylis glomerata* was significantly higher than that considered to be optimal, while there was a deficiency of sodium. This means that the weight ratio of those macro elements was not suitable.

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