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ORIGINAL PAPER

CONTENT OF POTASSIUM, CALCIUM, MAGNESIUM, PHOSPHORUS AND SODIUM IN MEADOW SWARD IRRIGATED WITH WASTEWATER*

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Abstract

The aim of this study was to determine the content of potassium (K), calcium (Ca), magnesium (Mg), phosphorus (P) and sodium (Na), and the K:(Ca+Mg) and Ca:P ratios in meadow sward irrigated with potato starch and brewery wastewater. The experiment was conducted in the center for wastewater treatment and use in Mątwica-Kupiski (668 ha), which has been equipped with facilities for flood irrigation with wastewater since 1965. Meadow sward was irrigated with wastewater in autumn and after the first harvest, at an annual rate of 200-300 mm. On average, wastewater contained (mg dm^{-3}): N – 144, P – 38, K – 314, Ca – 77, Mg – 47, Na – 76. In 1998, 2003, 2008, 2013 and 2018, before the first harvest, samples of meadow herbage were collected for chemical analyses from characteristic phytocenoses of different floristic types: DcCpPp – *Deschampsia caespitosa* + *Cardamine pratensis* + *Poa pratensis*, PhaRr – *Phalaris arundinacea* + *Ranunculus repens*, ApAre – *Alopecurus pratensis* + *Arrhenatherum elatius*, ApPp – *Alopecurus pratensis* + *Poa pratensis*, Ap – *Alopecurus pratensis*, ApPha – *Alopecurus pratensis* + *Phalaris arundinacea*, ApAr – *Alopecurus pratensis* + *Agropyron repens*, PpArDg – *Poa pratensis* + *Agropyron* repens + Dactylis *glomerata*. The DcCpPp community developed in the control treatment without irrigation. Meadow sward irrigated with wastewater was characterized by high abundance of P and Ca, excessively high K content, and Na and Mg deficiency. The Ca:P ratio was desirable, whereas the K:(Ca+Mg) ratio exceeded the recommended upper limit for high-quality fodder. In general, the analyzed floristic types of grassland communities did not differ significantly in their chemical composition; only the PhaRr community was characterized by the lowest K content, the highest Mg concentration and the significantly lowest K:(Ca+Mg) ratio. The average content of the analyzed elements in meadow herbage was as follows: K – from 17.4 (DcCpPp) to 39.2 g kg^{-1} (ApPha), Ca – from 3.2 (ApAr) to 6.7 g kg^{-1} (DcCpPp), Mg – from 1.2 (ApAr) to 2.6 g kg^{-1} (DcCpPp), Na – from 0.6 (ApAr and PpArDg) to 1.3 g kg^{-1} (DcCpPp), and P – from 2.2 (PhaRr) to 3.6 g kg^{-1} (ApAr). The K:(Ca+Mg) ratio ranged from 0.8 (DcCpPp) to 3.9 (ApAr), and the Ca:P ratio varied from 1.0 (ApAr) to 2.9 (PhaRr).

Keywords: meadow, potato starch and brewery wastewater, potassium, calcium, magnesium, phosphorus, sodium, K:(Ca+Mg), Ca:P.

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INTRODUCTION

Demand for freshwater is increasing, which requires rational management and reuse of wastewater (Hamilton et al. 2007). Food and agricultural wastewater contains many valuable minerals, and therefore it can be used as fertilizer and soil amendment. Good examples are effluents from the potato starch (Wang et.al. 2007, Singh, Swami 2014) and brewing (Nyilimbabazi et al. 2011, Senthilraja et al. 2013) industries. Wastewater can be used for agricultural purposes particularly in grasslands. If the productivity of such grasslands decreases, they can be used for bioenergy production (Lorenc-Plucińska et al. 2017). Meadow sward is composed of numerous plant species with different nutrient accumulation capacity (Kienzle et al. 2008, Acar et al. 2009, Pirhofer-Walzl et al. 2011, Yoshihara et al. 2013, Lüscher et al. 2014), therefore the chemical composition of green forage has to be monitored. The concentrations and mutual proportions of minerals in feed are key factors in animal nutrition (Zhao, Müller 2015). Particular attention should be paid to the K:(Ca+Mg) ratio, which may become imbalanced in response to Mg deficiency and K excess, and the Ca:P ratio (Cherney et al. 2002, Aydin, Uzun 2008, Gao et al. 2016, Hejcman et al. 2016). The objective of this study was to determine the content of K, Ca, Mg, P and Na, and the K:(Ca+Mg) and Ca:P ratios in meadow sward irrigated with potato starch and brewery wastewater.

MATERIAL AND METHODS

The experiment was conducted in the center for wastewater treatment and use in Mątwica-Kupiski (668 ha), which has been equipped with facilities for flood irrigation with wastewater since 1965. Meadow sward was irrigated with wastewater in autumn and after the first harvest, at an annual rate of 200-300 mm. On average, wastewater contained (mg dm^{-3}): N – 141, P – 37, K – 315, Ca – 78, Mg – 45, Na – 72. In 1998, 2003, 2008, 2013 and 2018, before the first harvest, samples of meadow herbage were collected for chemical analyses from characteristic phytocenoses of different floristic types. The floristic classification based on the percentage of dominant species (above 20% share of the sward) revealed 8 grassland communities (Table 1). The DcCpPp community, which developed in the control treatment without irrigation, was characterized by the lowest percentage of valuable grass species and the highest percentage of herbs and weeds. In treatments irrigated with wastewater, ApAre and ApPp communities had the most desirable species composition. The Ca, K and Na content of plants was determined by flame photometry, P content was estimated by the colorimetric method with vanadium and molybdenum, and Mg content was determined by atomic

Table 1

Floristic types of grassland communities in Mątwica-Kupiski

Floristic type	Dominant species	Average content in dry matter (g kg^{-1})		
		valuable grass	low-value grass	herbs and weeds
DcCpPp	*Deschampsia caespitosa, Cardamine pratensis, Poa pratensis*	230	261	459
PhaRr	*Phalaris arundinacea, Ranunculus repens*	628	118	234
ApAre	*Alopecurus pratensis, Arrhenatherum elatius*	719	135	124
ApPp	*Alopecurus pratensis, Poa pratensis*	707	99	176
Ap	*Alopecurus pratensis*	616	143	218
ApPha	*Alopecurus pratensis, Phalaris arundinacea*	648	166	171
ApAr	*Alopecurus pratensis, Agropyron repens*	500	288	208
PpArDg	*Poa pratensis, Agropyron repens Dactylis glomerata*	345	301	336

absorption spectrometry (AAS). The nutrient content of meadow herbage was expressed on a dry mater basis. Statistical analyses of the results were performed using Statistica 13.3 software.

RESULTS AND DISCUSSION

Depending on the floristic type of grassland community, the average K content of meadow herbage ranged from 17.4 (DcCpPp) to 39.2 g kg^{-1} (ApPha), and it was lowest in the control treatment (without irrigation). In treatments irrigated with wastewater, the K content was similar to that in the control treatment only in the PhaRr community. The remaining treatments were characterized by significantly higher K content (Figure 1).

The high K content in meadow herbage resulted from K supply with wastewater and excessive K uptake by grasses (Acar et al. 2009, Kumar, Soni 2014). According to Wilkinson and Mayland (1997), a K concentration exceeding 30 g kg^{-1} poses a threat to animal health. It should be noted that potato processing wastewater has high K content (Hung et al. 2004, Wang et. al. 2007). Potassium deficiency in soil, related to the absence of fertilization, which was observed in this study in the control treatment without irrigation, contributed to the development of a community of low-quality grasses dominated by *Festuca rubra* and *Anthoxanthum odoratum*. In this community, the K content was half that noted in the meadow sward irrigated with wastewater. Acar et al. (2009), who investigated various grass species, demonstrated that *Festuca rubra* was characterized by the lowest K content.

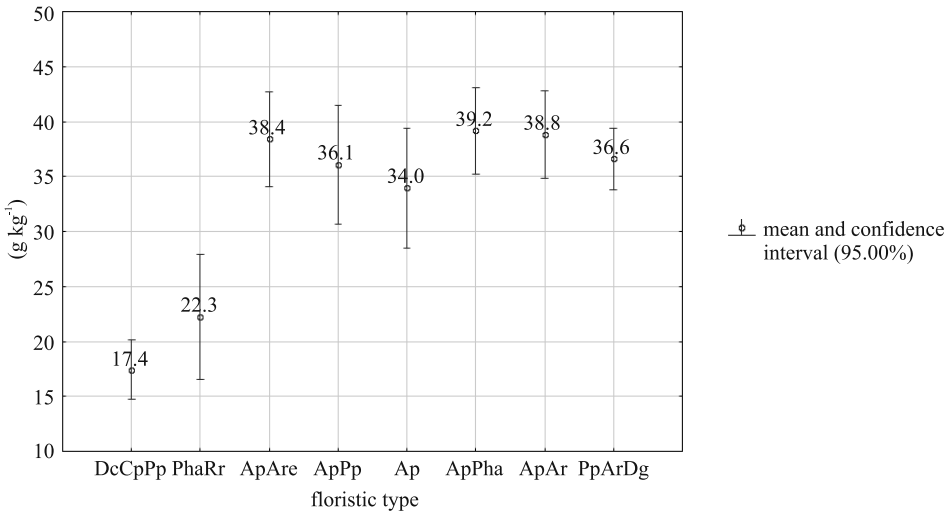

Fig. 1. Potassium (K) content in meadow herbage depending on the floristic type of grassland community

Significant differences were also found in the Ca content of meadow herbage (Figure 2). The highest average Ca content (6.7 g kg^{-1}) was noted in the DcCpPp community (a treatment without irrigation). In general, meadow vegetation irrigated with wastewater accumulated lower amounts of Ca, and a significant difference was observed between the PhaRr and PpArDg communities. The calcium content exceeded the value of 4 g kg^{-1} given by WILKINSON and MAYLAND (1997), which indicates that the fodder made from the analyzed grasses contained adequate amounts of Ca to meet

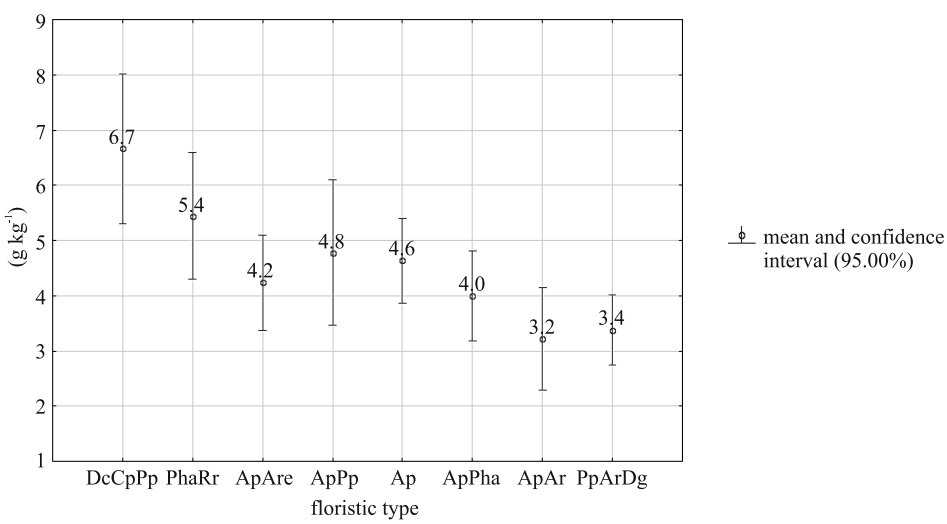

Fig. 2. Calcium (Ca) content in meadow herbage depending on the floristic type of grassland community

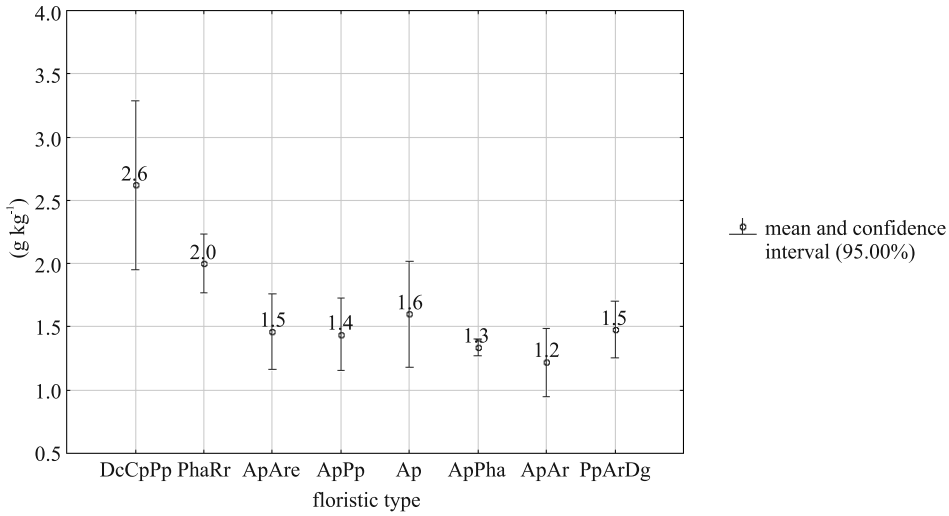

Fig. 3. Magnesium (Mg) content in meadow herbage depending on the floristic type of grassland community

the requirements of cattle. The Mg content of meadow herbage (Figure 3) followed a similar pattern to the Ca content, which ranged from 1.2 (ApAr) to 2.6 g kg^{-1} (DcCpPp). In 2 grassland communities (DcCpPp, PhaRr), an average Mg content reached the value of 2 g kg^{-1}, which is typical of high--quality feed for livestock (Grunes, Welch 1989).

The average P content (Figure 4) ranged from 2.2 (PhaRr) to 3.6 g kg^{-1} (ApAr), and no significant differences were found between treatments. The concentration of P in meadow herbage was sufficient to meet the P

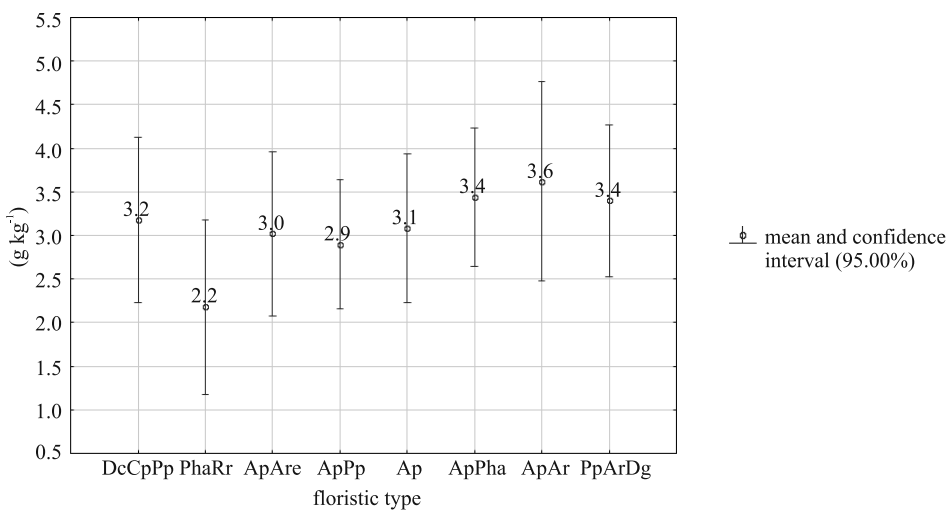

Fig. 4. Phosphorus (P) content in meadow herbage depending on the floristic type of grassland community

requirements of cattle (Márquez-Madrid et al. 2017). Pirhofer-Walzl et al. (2011) demonstrated that the P concentration in grassland herbage was determined by its species composition, and that forage herbs effectively increased the mineral content of feed. The concentration of P in plants is affected by a growth stage and the leaf:stem ratio; leaves are more abundant in P than stems, and the P content in feed decreases with plant aging (Marković et al. 2009).

The Na content of meadow herbage varied widely (Figure 5), therefore no significant differences were found between the analyzed types of meadow

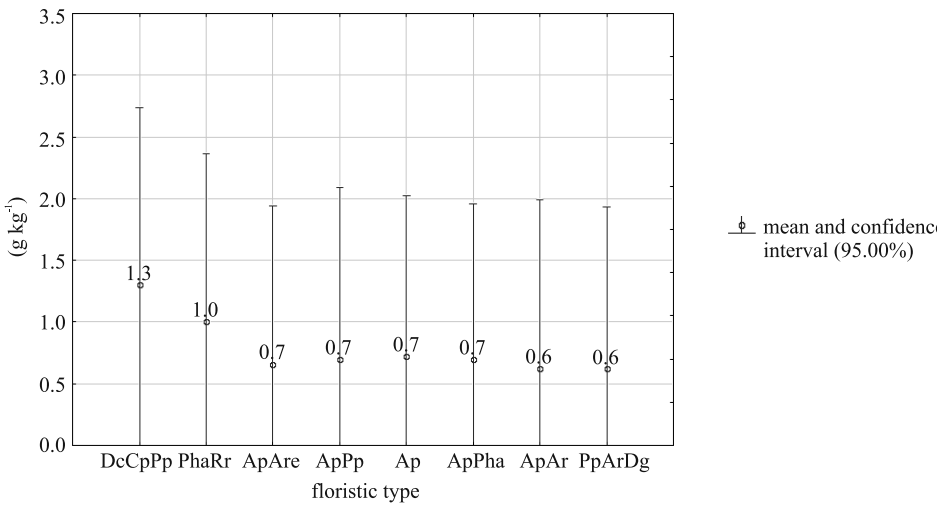

Fig. 5. Sodium (Na) content in meadow herbage depending on the floristic type of grassland community

communities. The average Na content ranged from 0.6 (PpArDg and ApAr) to 1.3 g kg^{-1} (DcCpPp), which indicates that cattle feed was deficient in this nutrient (Kuusela 2006). The concentration of Na in grassland herbage tended to decrease in response to wastewater application. According to McDonnell et al. (2018), an increase in the K content of plants is accompanied by a decrease in the concentrations of Na, Mg and Ca.

The K:(Ca+Mg) ratio in meadow herbage varied (Figure 6). Its lowest value (0.8) was noted in the DcCpPp community where wastewater irrigation was not applied. In grassland communities representing the remaining floristic types, irrigated with wastewater, the K:(Ca+Mg) ratio was significantly higher, ranging from 1.3 (PhaRr) to 3.9 (ApAr). In high-quality cattle feed, the K:(Ca+Mg) ratio should not exceed 2.2 (Acar et al. 2009, Gao et al. 2016). In the current study, meadow irrigation with wastewater contributed to exceeding the above threshold value, mostly due to the fact that wastewater supplied large amounts of K, thus leading to excessive K uptake by grasses (Kuusela 2006, Kumar, Soni 2014).

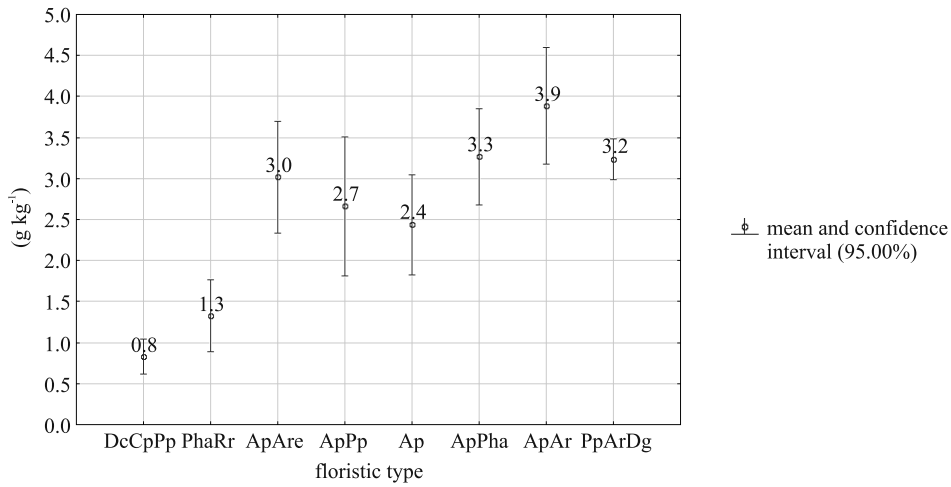

Fig. 6. The K:(Ca+Mg) ratio in meadow herbage depending on the floristic type of grassland community

The Ca:P ratio (Figure 7) ranged from 1.0 (ApAr) to 2.9 (PhaRr), and no significant differences were observed between treatments. In meadow sward irrigated with wastewater, the average Ca:P ratio did not exceed 2, except in the PhaRr community.

Calcium and P play a very important role in the growth, development and bodily functions of animals. Both macroelements should be analyzed together because the content of P and Ca in animal diets should be balanced to ensure their proper utilization (Albu et al. 2012). The optimal Ca:P ratio is 2. Higher values of the Ca:P ratio can lead to disorders and disrupt

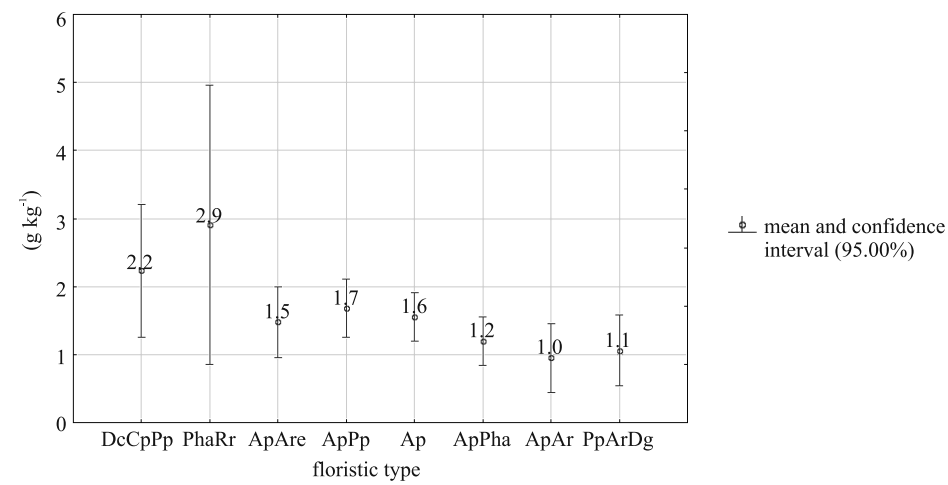

Fig. 7. The Ca:P ratio in meadow herbage depending on the floristic type of grassland community

homeostasis (Ayan et al. 2010, Kumar, Soni 2014). Even when the Ca:P ratio is "ideal", i.e. in the range of 1.1 to 2.1, Ca and P requirements should be formulated independently to prevent an excess supply of one of the elements (Kuusela 2006).

CONCLUSIONS

1. Meadow sward irrigated with wastewater was characterized by a high abundance of P and Ca, excessively high K content, and Na and Mg deficiency. The Ca:P ratio was desirable, whereas the K:(Ca+Mg) ratio exceeded the recommended upper limit for high-quality fodder.

2. The analyzed floristic types of grassland communities did not differ significantly in their chemical composition; only the PhaRr community was characterized by the lowest K content, the highest Mg concentration and the significantly lowest K:(Ca+Mg) ratio.

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