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ORIGINAL PAPER

THE EFFECT OF LONG-TERM WASTEWATER IRRIGATION ON THE BOTANICAL COMPOSITION OF MEADOW SWARD, YIELD AND NUTRITIONAL VALUE OF HAY*

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Abstract

The aim of this study was to determine the effect of 20-year-long irrigation of permanent grasslands with potato starch and brewery wastewater on the botanical composition of sward, yield and nutritional value of hay. 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. Potato starch and brewery effluents were mixed in a storage reservoir at a ratio of 1:0.4. Meadow sward was irrigated with wastewater in autumn and after the first harvest, at an annual dose of 200 – 300 mm. On average, wastewater contained (mg dm^{-3}): N – 223, P – 48, K – 285, Ca – 80, Mg – 46, Na – 68. Before the first harvest in 1998, 2003, 2008, 2013 and 2018, the floristic composition of meadow sward was determined on an 11-degree scale by the Klapp method. Yield was determined in trial plots. Based on the percentage of dominant species (above 20% share of the sward), several floristic types of grassland communities were identified. Herbage samples were collected for detailed botanical and chemical analyses according to the floristic composition of the identified grassland communities. Chemical analyses of plant material were performed by standard methods. Long-term irrigation of meadow sward with wastewater contributed to the development of agronomically important plant communities, except for the *Agropyron repens* community in the western part of the research site. The yield of grassland irrigated with wastewater, regardless of a floristic type, was 2- to 3-fold higher than the yield of non-irrigated grassland. Hay harvested in wastewater-irrigated meadows met the crude fiber, ash and fat requirements of animals. The total protein content of hay remained within the recommended limits for high-quality fodder, except for the *Alopecurus pratensis* + *Agropyron repens* community.

Keywords: meadow irrigation with wastewater, plant communities, nutritional value of hay.

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INTRODUCTION

The use of industrial wastewater from the agri-food sector for irrigating grasslands is the most common and natural method of their biological treatment in the soil environment (Kutera, Czyżyk 1992, Talik, Pławiński 1995, Arienzo et al. 2009, Hamilton et al. 2011, Aryal, Reinhold 2015, Buelow et al. 2015). The group of food and agricultural waste includes wastewater from the potato processing industry (Charmley et al. 2006, Wang at al. 2007, Li at al. 2010, Singh, Swami 2014) and brewery wastewater (Senthilrajd et al. 2013). Grassland plant species with well-developed root systems accumulate organic matter and mineral nutrients in the turf layer, which affect the species composition of sward, sward density, yield and nutritional value of hay (Kutera, Czyżyk 1992, Grabowski et al. 2008, Yong 2017).

The succession of plant communities irrigated with wastewater for prolonged periods of time is difficult to predict due to considerable changes such as simplification of the floristic composition of sward, tuft loosening, decreased productivity and reduced fodder value (Mikhailova et al. 2000, Baryła 2005, Grabowski et al. 2008, Bosak et al. 2016).

The aim of this study was to determine the effect of 20-year-long irrigation of permanent grasslands with potato starch and brewery wastewater on the botanical composition of sward, yield and nutritional value of hay.

MATERIALS AND METHODS

The experiment was conducted in the center for wastewater treatment and use in Mątwica-Kupiski (668 ha) near Łomża, which has been equipped with facilities for flood irrigation with wastewater since 1965. Potato starch and brewery effluents were mixed in a storage reservoir at a ratio of 1:0.4. Meadow sward was irrigated with wastewater in autumn and after the first harvest, at an annual dose of 600 mm at the beginning of the experiment, and 200 - 300 mm since 1992.

Throughout the experiment, wastewater contained on average (mg dm^{-3}): N – 223, P – 48, K – 285, Ca – 80, Mg – 46, Na – 68. Supplementary mineral fertilization was not applied during irrigation. The floristic composition of grassland communities was determined before the first harvest in 1998, 2003, 2008, 2013 and 2018:

– Pha + Rr – *Phalaris arundinacea* L.+ *Ranunculus repens* L.;
– Ap + Are – *Alopecurus pratensis* L. + *Arrhenatherum elatius* L.;
– Ap – *Alopecurus pratensis* L.;
– Ap + Pha – *Alopecurus pratensis* L. + *Phalaris arundinacea* L.;
– Ap + Ar – *Alopecurus pratensis* L. + *Agropyron repens* L.;

– Pp + Ar + Dg – *Poa pratensis* L. + *Agropyron repens* L. + *Dactylis glomerata* L.

The Dc + Cp + Pp – *Deschampsia caespitosa* (L.) P.B. + *Cardamine pratensis* L. + *Poa pratensis* L. community developed in the control treatment without irrigation. The remaining communities developed in treatments irrigated with wastewater.

Herbage samples for detailed botanical and chemical analyses were collected from selected grassland communities based on their floristic composition. A fractional botanical analysis was performed to determine the percentage of agronomically important and unimportant grass species, legumes, herbs and weeds on a dry matter basis. The chemical analyses of plant material were conducted by standard methods: nitrogen – by the Kjeldahl method, crude fiber – by the method proposed by Henneberg and Stohmann, crude fat – by Soxhlet extraction, and crude ash – by incineration in a muffle furnace at a temp. of around 550°C. The nutrient content of meadow sward was expressed on a dry mater basis. Only mean values and ranges are presented. Statistical analyses were performed using Statistica 13 software.

RESULTS AND DISCUSSION

The botanical composition of meadow sward irrigated with wastewater was closely correlated with habitat conditions (soil type, fertility and moisture content) and human activity. After 20 years of irrigation, regardless of a soil type, valuable and agronomically important grass species predominated in meadow sward (344.8-719.4 g kg^{-1} DM), whereas grasses of low economic importance (118.2-301.4 g kg^{-1} DM), herbs and weeds (124.0-335.8 g kg^{-1} DM) were less common. Legumes were encountered only sporadically (4.0-23.0 g kg^{-1} DM) – Figures 1–4. However, only a few valuable grasses (*Alopecurus pratensis* L., *Phalaris arundinacea* L., *Arrhenatherum elatius* L., *Dactylis glomerata* L. and *Poa pratensis* L.) were dominant species, which suggests that meadows irrigated with wastewater could be sown with those species, as noted by Talik and Pławiński (1995), Baryła (2005) and Grabowski et al. (2008). In the control treatment (without irrigation), where the grassland community was dominated by *Deschampsia caespitosa* + *Cardamine pratensis* + *Poa pratensis*, the percentage share of agronomically important species was significantly lower than in the irrigated treatment, except for the *Poa pratensis* + *Agropyron repens* + *Dactylis glomerata* community. Significant differences were also found between the floristic types of grassland communities that developed in response to wastewater irrigation (Figures 1-4). The following communities were characterized by the most desirable floristic composition of sward: *Alopecurus pratensis* + *Arrhenatherum elatius* and *Alopecurus pratensis* + *Poa pratensis*, located on peat-muck soil in the southern part of the research site. The proportion

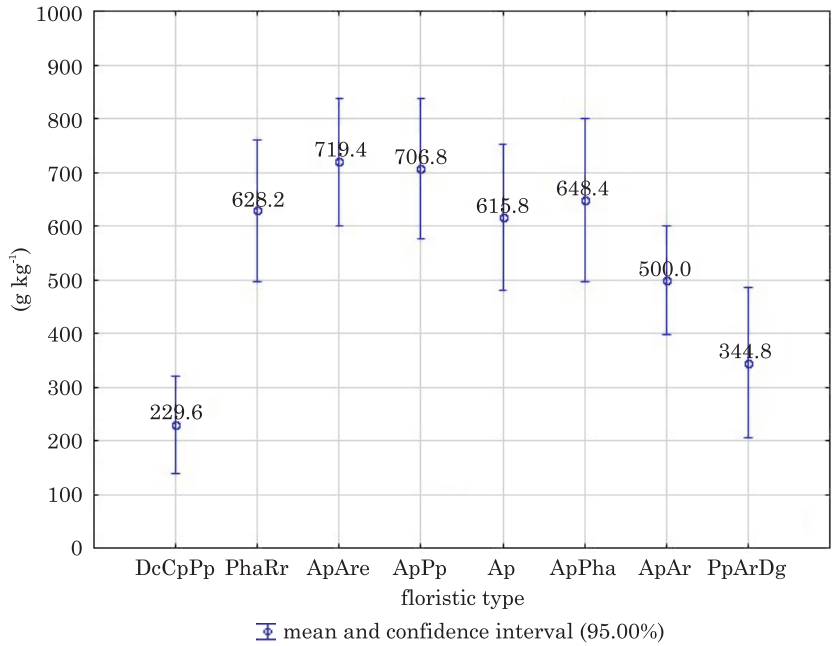

Fig. 1. Participation of valuable grasses in meadow sward

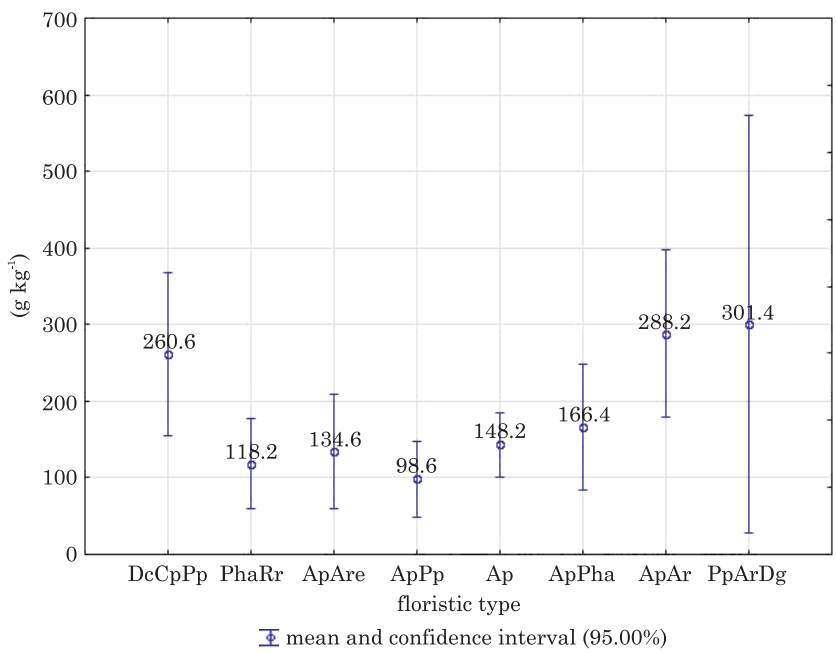

Fig. 2. Participation of low value grasses in meadow sward

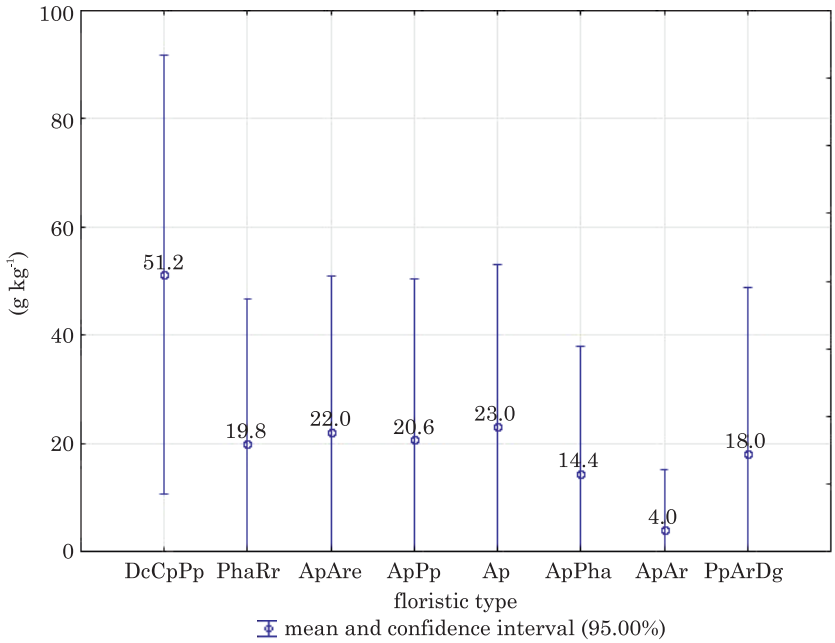

Fig. 3. Participation of legumes in meadow sward

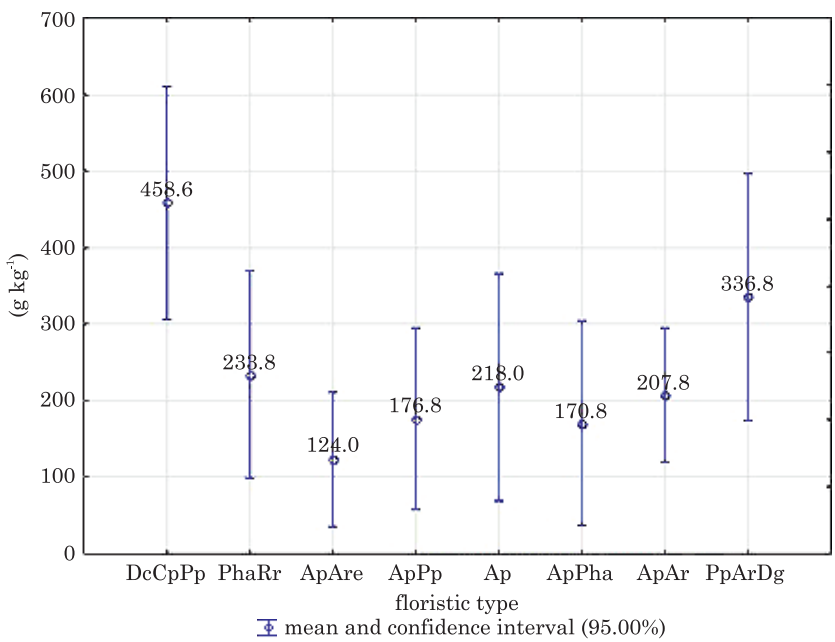

Fig. 4. Participation of herbs and weeds in meadow sward

of valuable grass species ranged from 706.8 to 719.4 g kg^{-1} DM on average, and it was significantly (more than 3- fold) higher than in the non-irrigated treatment (Figure 1).

According to Kryszak and Grynia (2001), communities of the *Alopecurus pratensis* type can be found under different habitat conditions, and their floristic composition changes depending on moisture levels. Kitczak et al. (2001) also demonstrated that *Alopecurus pratensis* is a persistent species that can withstand flooding. A study by Talik and Pławiński (1995) confirmed that *Alopecurus pratensis* is well suited to effluent irrigation. According to Trąba and Wyłupek (1993), foxtail grass (*Alopecurus*) communities are common in floodplain meadows, which contributes to the simplification of their floristic composition. In the present study, the percentage share of *Arrhenatherum elatius* in meadow sward decreased as a result of flood irrigation with wastewater. Czyż et al. (2001) found that *Arrhenatherum elatius* communities often occupy slopes of hills because the species is sensitive to irrigation and excess soil moisture, which is consistent with our findings.

Quantitative and qualitative differences in the botanical composition of sward were noted in the following grassland communities: *Phalaris arundinacea* + *Ranunculus repens* on peat-muck soil in the southern part of the research site, and *Alopecurus pratensis* and *Alopecurus pratensis* + *Phalaris arundinacea* on mineral-muck soil in the central part of the research site. The proportions of agronomically important grass species were comparable (615.8-646.4 g kg^{-1} DM on average) and significantly (2.7-2.8-fold) higher than in the non-irrigated treatment (Figure 1). Czyż et al. (2001) also found that *Phalaris arundinacea* communities on mineral-muck soils were characterized by poor floristic composition. A positive development observed in our study was an increase in the percentage share of low-growing grasses (*Poa pratensis* L. and *Festuca rubra* L.), and the presence of legumes (*Trifolium pratense* L., *Trifolium repens* L., *Lotus corniculatus* L. and *Medicago lupulina* L.) in sward. Grassland communities of the following types: *Alopecurus pratensis* + *Agropyron repens* and *Poa pratensis* + *Agropyron repens* + *Dactylis glomerata,* occupying muck soils in the western part of the research site, were characterized by the most simplified and impoverished floristic composition (Figure 1). The above communities were dominated by grasses of low economic value as well as herbs and weeds unsuitable for fodder (Figures 2, 4). The proportion of low-quality grasses, except for the *Poa pratensis* + *Agropyron repens* + *Dactylis glomerata* community, was significantly (2.1- fold) higher than in the non-irrigated treatment (Figure 1).

According to Talik and Pławiński (1995), grassland irrigation with high doses of wastewater accelerates sward degradation since grasses sensitive to excess soil moisture are gradually replaced with nitrogen-loving species that are resistant to seasonal flooding. Kotlarz et al. (2010) demonstrated

that any transformations in the habitat and land use usually lead to the loss of floristic diversity in grassland communities.

The *Deschampsia caespitosa* + *Cardamine pratensis* + *Poa pratensis* community developed in the control non-irrigated treatment. The community was dominated by low-quality grasses (260 g kg^{-1} DM), herbs and weeds (458.6 g kg^{-1} DM) – Figures 1-4.

Flood irrigation with wastewater, regardless of a soil type, had a significant effect on the productivity of plant communities, except for the *Poa pratensis* + *Agropyron repens* + *Dactylis glomerata* community. Irrespective of the floristic type of meadow sward, average dry matter yields ranged from 7.7 to 11.5 t ha^{-1} DM and significantly (2- to 3-fold) exceeded dry matter yields in the non-irrigated treatment (Figure 5). Kutera and Czyżyk (1992)

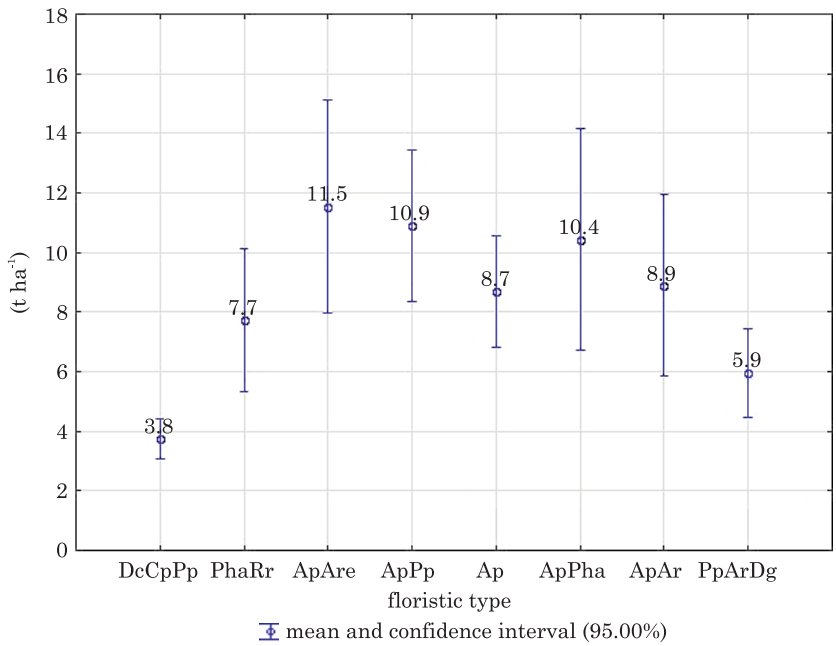

Fig. 5. Yield of dry matter (t ha^{-1})

noted a steady increase in hay yields in response to wastewater irrigation at an annual dose of 100-800 mm. However, the highest hay yield, more than 200% higher than in the non-irrigated treatment, was achieved at an irrigation dose of 200-400 mm.

In the present study, the *Alopecurus pratensis* + *Arrhenatherum elatius* community was characterized by the highest productivity (11.5 t ha^{-1} DM). Similar dry matter yields were harvested in grasslands representing the following floristic types: *Alopecurus pratensis* + *Poa pratensis* and *Alopecurus pratensis* + *Phalaris arundinacea* (10.4-10.9 t ha^{-1} DM on average). In the remaining communities, except for the *Poa pratensis* + *Agropyron repens* +

Dactylis glomerata one, dry matter yields were also significantly higher than in the non-irrigated treatment (Figure 5).

The results of studies conducted Baryła (2005), Grabowski et al. 2008 show that in wastewater-irrigated meadows, plants effectively use nutrients, which has important economic (yield increase) and environmental implications. In the current study, nutrient concentrations in meadow sward irrigated with wastewater were similar across the analyzed types of grassland communities (Figures 6-9). The total protein content of biomass

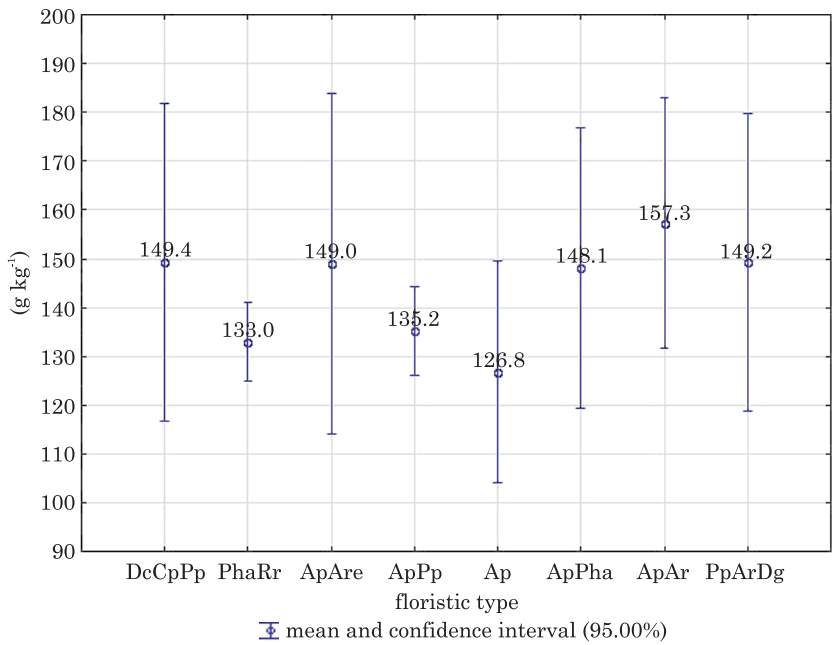

Fig. 6. Mean content of total protein in meadow sward

(126.8-157.3 g kg^{-1} DM) varied depending on the floristic composition of sward, plant growth stage, natural soil trophism and, above all, nitrogen supply with wastewater (Kutera, Czyżyk 1992, Talik, Pławiński 1995, Grabowski, Bieniek 2004). Total protein concentration in meadow sward (Figure 6) remained within the recommended limits for high-quality fodder (150-170 g kg^{-1} DM), except for the following communities: *Phalaris arundinacea* + *Ranunculus repens, Alopecurus pratensis* + *Poa pratensis* and *Alopecurus pratensis*. No significant differences in the crude fiber content of grass (261.2-275.6 g kg^{-1} DM) were found between the analyzed plant communities, particularly in the irrigated treatment (Figure 7). Crude fiber content is affected by harvest date, the botanical composition of sward, plant growth stage and habitat conditions. According to Nazaruk et al. (2009), Kotlarz et al. (2010) and Grygierzec (2012), delayed harvest, in particular of first-cut herbage, contributes to an increase in the crude fiber content of fodder, and

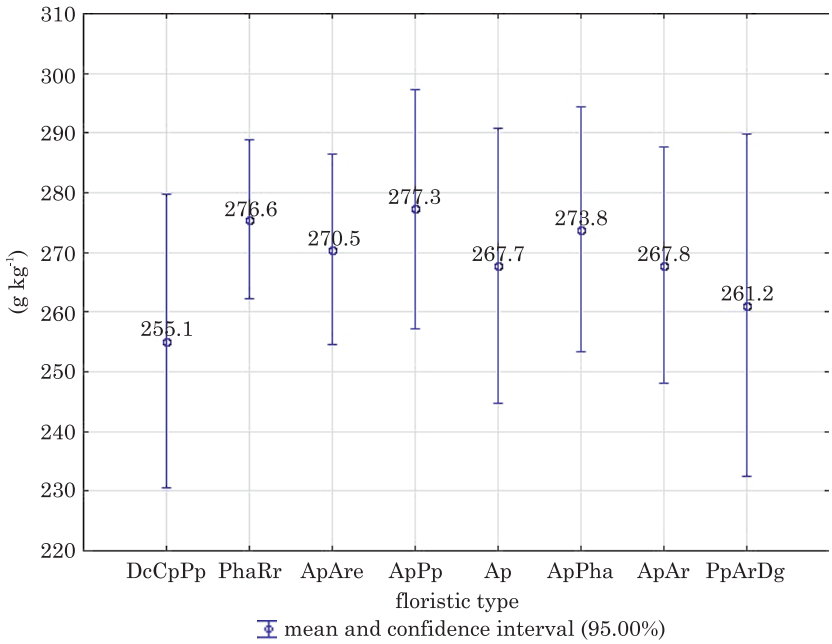

Fig. 7. Mean content of crude fiber in meadow sward

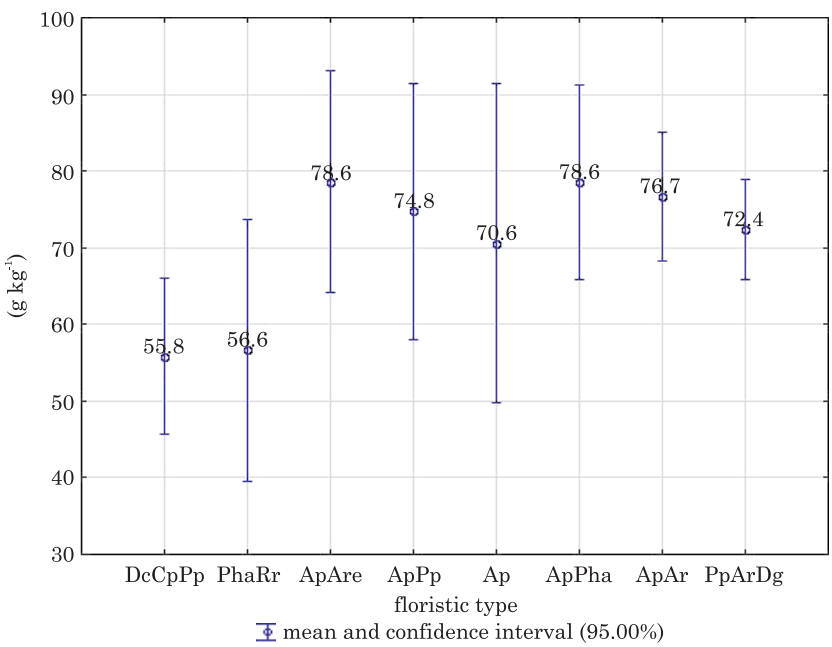

Fig. 8. Mean content of crude ash in meadow sward

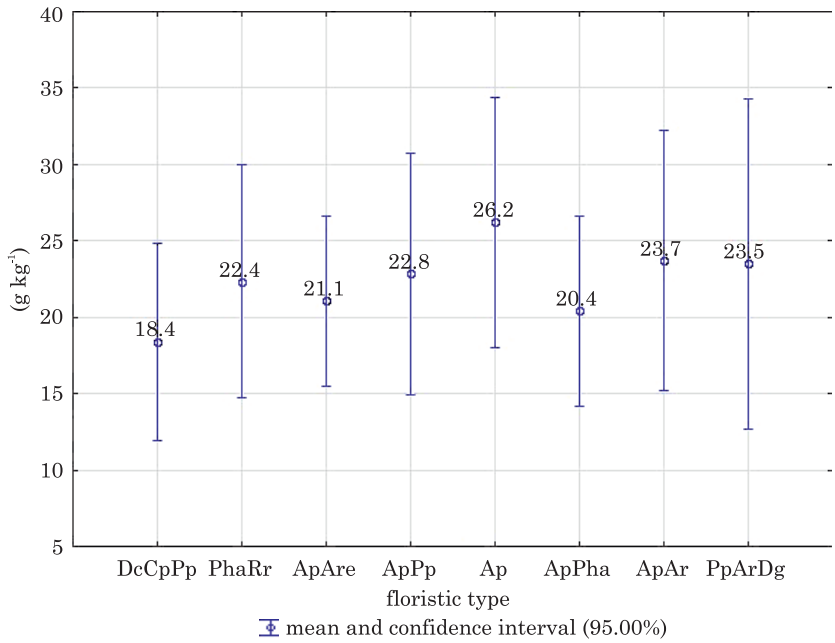

Fig. 9. Mean content of crude fat in meadow sward

a decrease in protein content, digestibility and nutritional value. Wastewater-irrigated sward had the highest crude ash content (56.6-78.6 g kg^{-1} DM) (Figure 8). Significant differences in crude ash content were observed only between the following communities: *Alopecurus pratensis* + *Phalaris arundinacea, Alopecurus pratensis* + *Agropyron repens* and *Poa pratensis* + *Agropyron repens* + *Dactylis glomerata* versus the *Deschampsia caespitosa* + *Cardamine pratensis* + *Poa pratensis* community where irrigation was not applied. Plant communities irrigated with wastewater usually accumulate more crude ash (Talik, Pławiński 1995, Bosak et al. 2016, Hejcman et al. 2016). During the study, the average crude fat content of meadow sward was relatively stable (20.4-26.2 g kg^{-1} DM) and somewhat higher in the irrigated treatment (Figure 9). Nazaruk et al. (2009) reported that the crude fat content of hay depended on plant development stage at harvest.

CONCLUSIONS

1. Twenty years of irrigation of a permanent meadow through a flood system with starch and brewery sewage favourably affected the botanical composition of sward by increasing the share of valuable pasture grasses, yielding and the value of obtained hay.

2. The following grassland communities were characterized by the most desirable floristic composition: *Alopecurus pratensis* + *Arrhenatherum elatius* and *Alopecurus pratensis* + *Poa pratensis*. The following communities were characterized by a stable percentage share of plant species: *Phalaris arundinacea* + *Ranunculus repens, Alopecurus pratensis* and *Alopecurus pratensis* + *Phalaris arundinacea*. The following communities were characterized by simplified and impoverished floristic composition: *Alopecurus pratensis* + *Agropyron repens* and *Poa pratensis* + *Agropyron repens* + *Dactylis glomerata*.

3. The yield of grassland irrigated with wastewater, regardless of floristic type, was 2- to 3-fold higher than the yield of non-irrigated grassland.

4. Hay harvested in wastewater-irrigated meadows met the crude fiber, ash and fat requirements of animals. The total protein content of hay remained within the recommended limits for high-quality fodder, except for *Palaris arundinacea* + *Ranunculus repens, Alopecurus pratensis* + *Poa pratensis* and *Alopecurus pratensis* communities.

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