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Quantification and comparison of ecosystem services of grasslands versus another fodder crop (maize) based on mineral nitrogen content in the 60–90 cm soil layer

Kwantyfikacja usług ekosystemowych użytków zielonych na tle innych upraw paszowych (kukurydzy) w oparciu o zawartość azotu mineralnego w warstwie gleby 60–90 cm

Summary. grasslands provide many ecosystem services. Apart from being a source of fodder for animals, grasslands regulate water and soil quality by reducing nitrogen emissions to the environment. The aim of the study was to determine the biophysical and monetary value of ecosystem services of grassland based on the "mineral nitrogen content in the soil layer 60–90 cm" indicator depending on the method of use and the type of soil, against the cultivation of maize for green fodder. The study area encompassed three provinces, different in terms of soil use, livestock population and intensity of grassland use. The investigation indicated that the value of ecosystem services provided by grasslands varied spatially and depended on the type of use and type of soil. In mineral soils, the lowest levels of this index were recorded from sites used for pasturing, while the highest levels were found under maize crops. In organic soils (without maize crops), the smallest losses of N_{min} were observed in meadows while the highest losses were in pastures. N_{min} losses in organic soils were higher than in mineral soils. The losses observed were highest in Opolskie Province, followed by Podlaskie Province, with the lowest losses in Lubelskie Province.

Key words: ecosystem services, grasslands, maize crops, mineral nitrogen losses

INTRODUCTION

Grasslands provide many ecosystem services. They represent a considerable (20%) portion of agricultural land in Poland [Statistics Poland 2020] and Europe [Kronenberg 2016]. They perform several important functions ranging from production, and protection to landscape and cultural functions which are often under appreciated by the general public [Ruskule et al. 2015] The main benefits of grassland ecosystems include the provision of fodder for both farm livestock and wild animals. These services, however, largely depend on the supply of other – supporting, regulatory or maintenance – services, with the removal or accumulation of nitrogen in the soil is being quite significant [Kronenberg 2016]. The migration of nitrogen in the soil profile can be inhibited by plants, including fodder plants. These plants remain in the fields in different seasons (maize, grasslands) while in grasslands, vegetation cover stays all year round and can minimize the leaching of nitrogen to groundwater. Grasslands constitute a perfect geochemical barrier to the flow of n and p and prevent eutrophication of surface waters [Burzyńska and Wesołowski 2015]. Meadow vegetation can also absorb considerable amounts of nutrients, e.g. nitrates, which significantly affects their levels in the environment. Pollution by nitrogen compounds necessitate the implementation of many costly pro-environmental measures (e.g. The nitrate directive, Helsinki convention). Thus the possibility of using fodder plants to reduce nitrogen emissions to the environment is of great practical (environmental, production and economic) significance [Watros et al. 2018a] to ensure the provision of ecosystem services [Vooren et al. 2018]. Knowledge of various biochemical processes in grassland ecosystems (ecosystem services in the regulating category) and the economic valuation of these services can enhance protection and better management of these resources [Villoslada et al. 2018]. Identification, assessment and valuation of ecosystem services of grasslands has been poorly studied in Poland, with few studies occurring throughout Europe [Hönigová et al. 2018].

The aim of the study was to determine the biophysical and monetary value of ecosystem services of grassland based on the "mineral nitrogen content in the soil layer 60–90 cm" indicator depending on the method of use and the type of soil, against the cultivation of maize for green fodder (other fodder plant).

The research hypothesis is that the volume ($kg \cdot ha^{-1}$) and value ($PLN \cdot ha^{-1}$) of grassland ecosystem services is higher than for maize cultivation and varies depending on the use, soil type and location. H_0 = the value of grassland and maize cultivation ecosystem services does not differ. The study area encompassed three provinces, different in terms of soil use, livestock population and intensity of grassland utilization [Jankowska-Huflejt et al. 2019].

MATERIALS AND METHODS

Location and scope of study

Empirical data from the national chemical and agricultural station in Warsaw were used in the study. Data were collected between 2011–2014 from farm holdings in the Provinces of Lubelskie, Podlaskie and Opolskie. Data from 1648 measurement points

were analysed, including 792 from Podlaskie Province where the proportion of grassland ecosystems is 32% of arable land, 556 measurement points in Lubelskie Province, where grasslands account for about 16% of arable land, and 300 points in Opolskie Province, 10% of grasslands [Jankowska-Huflejt et al. 2019].

In the grassland area, 1128 points were selected where the same type of use was conducted (cutting, pasturing, cutting and grazing, short-term grassland – on arable land): 916 of the selected points were located in mineral soils while 212 points were in organic soils (fig. 1). For comparison purposes, analysis was also carried out for maize crops (520 points) on mineral soils only (maize is not grown on organic soils). If maize was cultivated in subsequent years, the mean value from the relevant years was assessed.

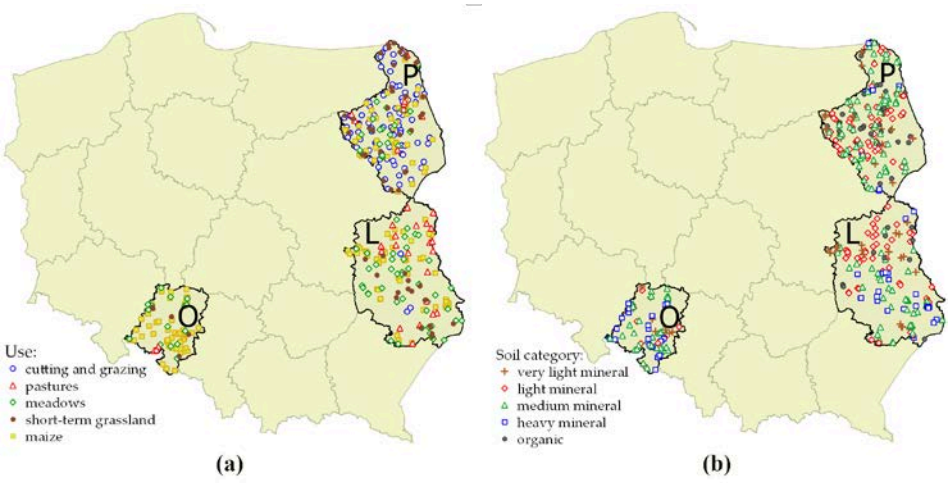

Fig. 1. The distribution of measurement points according to the type of use (a) and the type of soil (b) at the measurement points in the provinces under study (L – Lubelskie, P – Podlaskie, O – Opolskie)

The location of each measurement points was described with geographic coordinates, by means of a GPS locator, which enabled sampling on the same spot in the subsequent years of the study.

Nitrogen content

Mineral and organic soil samples obtained from fields, each covering up to 4 ha, were used to analyse N_{min} levels in the 60–90 cm soil layer. A composite sample (weighing about 100 g) consisted of 15–20 original samples obtained from an area of not more than 100 sq m. Soil samples were stored at –18°C. The samples, with a natural water content (after de-freezing), were subjected to extraction with a 1% potassium sulphate solution at a ratio of 1 : 10. In the extracts obtained, the nitrate and ammonium nitrogen levels were determined using the spectrophotometric method and a skalar san plus system automated analyser (PN-R-04028 1997). Dry matter content was also determined

in the samples. N_{min} levels, as a sum of nitrate and ammonium nitrogen, were expressed in $mg \cdot kg^{-1}$ of dry matter (samples), and then converted into N_{min} content in kg per hectare, using appropriate conversion rates specified for the particular agronomic categories of mineral soils. These conversion rates were not used for organic soil; hence, having the results of $N\text{-}NO_3$ and $N\text{-}NH_4$ level determination (in $mg \cdot kg^{-1}$ of dry matter), the N_{min} content in the assessed soil layers (in kg $N \cdot ha^{-1}$) was calculated as the sum of nitrate and ammonium nitrogen multiplied by the volumetric density of the soil (0.5) and conversion rate of 3 (corresponding to the 30 cm soil layer).

Biophysical and economic value of ecosystem service

The calculated N_{min} content in the soil layer 60–90 cm (average for the spring and autumn sampling dates) was assumed as the loss of nitrogen ($kg \cdot ha^{-1}$). It was therefore assumed that the lower the loss of n, the greater the value of the ecosystem service is. Its monetary value, expressed in the polish currency ($PLN \cdot ha^{-1}$) was calculated by multiplying N_{min} by the price of 1 kg of n in mineral fertilizers ($PLN \cdot kg^{-1}$), according to the current market prices [de Groot et al. 2002, Żylicz 2010, Wieliczko 2016]. It should be remembered, however, that the value of goods and services in different regions or provinces is influenced by free market mechanisms [Wieliczko 2016]. Therefore, local market prices of 1 kg of n in mineral fertilizer were used for each province, i.e. 4.0 ($PLN \cdot kg^{-1}$) in Lubelskie Province, 4.5 ($PLN \cdot kg^{-1}$) in Opolskie Province and 4.20 ($PLN \cdot kg^{-1}$) in Podlaskie Province (according to the mean price of the pure ingredient published by the appropriate CDR – Agricultural Advisory Centre, 2018 year).

Statistical analysis

Due to the highly asymmetrical distribution of the physicochemical properties under study, data were transformed using log10(x), where x stands for mineral nitrogen content or value of ecosystem services respectively. Differences among the groups should be seen as a comparison of orders of magnitude and not as actual measured values. The following factors were considered in the analyse: province (3 levels: identifying the provinces from which data originate: Lubelskie, Podlaskie and Opolskie), soils (3 levels: category of mineral soils: very light + light, medium + heavy, and organic soil), type of use (5 levels: meadows, pastures, cutting and grazing, short-term grassland, maize crops). To indicate significant differences among individual data subgroups, Tukey's honestly significant difference post-hoc test was used. A significance level = 0.05 was adopted. Dell Statistica ver.13.1 was used.

Spatial data referring to the potential of the ecosystem services of grasslands and maize crops in the provinces analysed were presented as maps using Arcmap v.10.6. Polygon layers defining state and province borders were obtained in ESRI shapefile format (vector files) from the national register of boundaries and areas of territorial division units, available on the website of the head office of geodesy and cartography (GUGiK). Based on the geographic location of measurement points, polygon objects defining provinces were assigned mean monetary values for each use type for the ecosystems under study. These values were shown on maps using a gradient scale.

RESULTS

Biophysical value of ecosystem service

When evaluating N_{min} content from the 60–90 cm layer of soil, it was observed that in very light and light mineral soils in Lubelskie Province, the highest N_{min} levels occurred in sites under short-term grassland, while the lowest levels were in pastures. However, the differences were not significant. Significant differences in N_{min} levels were found in medium and heavy mineral soils between sites under short-term grassland (the lowest levels) on the one hand and, on the other, sites used for cutting (meadows) and maize crops. The highest levels of this index were in the soil beneath these forms of use. N_{min} content in organic soils in this province was significantly higher in meadows than in pastures (tab. 1).

Table 1. Comparison of mean N_{min} content ($kg \cdot ha^{-1}$) in the 60–90 cm soil layer among 5 types of use (cutting and grazing, pastures, meadows, short-term grassland, maize crops) in different soil categories in three provinces as a proxy for ecosystem services

Soil category	Statistics	Type of use				
		cutting and grazing	pastures	meadows	short-term grassland	maize
Lubelskie Province						
Mineral, very light and light	N mean ±se	n.d.	44 ^{a}11.9 ±1.4	72 ^{a}13.3 ±3.2	40 ^{ab}23.9 ±5.7	100 ^{a}12.1 ±0.9
Mineral, medium and heavy	N mean ±se	24 ^{a}16.8 ±2.5^{xy}	32 ^{ab}6.2 ±2.7^{xy}	72 ^{b}22.2 ±2.7^{y}	48 ^{a}10.7 ±1.6^{x}	72 ^{a}22.0 ±3.0^{y}
Organic	N mean ±se	n.d.	20 ^{ab}22.3 ±5.0^{x}	32 ^{bc}32.6 ±6.0^{y}	n.d.	n.d.
Opolskie Province						
Mineral, very light and light	N mean ±se	n.d.	n.d.	24 ^{bc}27.2 ±2.8	20 ^{bc}19.6 ±0.8	44 ^{b}46.8 ±5.6
Mineral, medium And heavy	N mean ±se	n.d.	20 ^{ab}18.0 ±1.2	44 ^{cd}30.8 ±2.9	24 ^{d}48.0 ±9.1	124 ^{b}42.9 ±2.4
Podlaskie Province						
Mineral, very light and light	N mean ±se	136 ^{a}28.2 ±1.5	16 ^{bc}30.1 ±3.1	28 ^{bc}26.6 ±2.6	48 ^{bc}22.4 ±1.9	76 ^{b}33.1 ±2.0
Mineral, medium and heavy	N mean ±se	96 ^{a}28.5 ±1.5	20 ^{bc}30.0 ±1.8	24 ^{bc}4.1 ±2.1	84 ^{bc}22.7 ±1.4	104 ^{b}33.6 ±2.0
Organic	N mean ±se	108 ^{b}70.0 ±5.7	16 ^{d}96.5 ±10.0	36 ^{d}58.9 ±8.1	n.d.	n.d.

N – number of observations, se – standard error of the mean, ^{abcde} groups not having the same letter are significantly different within a single column (for use), ^{xy} groups not having the same letter are significantly different within a single row (for a specific province and soil category), lack of letter markings – no significant differences, significance level $\alpha = 0.05$, n.d. – no data available

In Opolskie Province, N_{min} content in light and very light mineral soils did not differ significantly among use types. Nonetheless, nitrogen content of these soils under maize crops was nearly twice as high as in land under short-term grasslands or meadows.

In medium and heavy soils, N_{min} levels in sites with short-term grassland and maize were similar, nearly 2–3 times as high as in pastures or meadows. However, due to the small size of the groups, despite clear differences of the mean values, the statistical test did not confirm their significance (e.g. in 8 measurements) (tab. 1).

In Podlaskie, N_{min} content on both soil types did not differ significantly by use type either. In mineral soils, the highest of N_{min} content in the 60–90 cm layer was found under maize crops, while in organic soils (where maize crops were not considered) – in soils under pastures.

Sites used for cutting and grazing had N_{min} content of mineral soils in Lubelskie was half that similar soils in Podlaskie. Significantly (the groups were small). Differences N_{min} content between mineral and organic soils (were the latter, N_{min} content is usually higher). In Podlaskie Province, N_{min} content in organic soils was 60% higher while in Lubelskie Province, it was 70% higher than in mineral soils.

In areas used for pasturing in Lubelskie Province, N_{min} levels in organic soils were significantly higher than those in mineral soils. The lowest levels occurred in very light and light mineral soil. N_{min} levels in areas used for pasturing in Opolskie Province (on medium and heavy mineral soils only) were similar to those in Lubelskie and those in mineral soils in Podlaskie. In Podlaskie Province, no significant differences in N_{min} content were found among the types of mineral soils, but the content in pastures on organic soils was significantly higher (nearly three times) than on mineral soils. Similar (significant) differences in N_{min} content in organic soils were found with Podlaskie: three times higher than Lubelskie.

In the case of meadows, the lowest values of this index (13.3 kg $N \cdot ha^{-1}$) found in very light and light mineral soils of Lubelskie Province, while the highest values (58.9 kg $N \cdot ha^{-1}$) were in organic soils of Podlaskie Province. Significant differences were observed among values obtained in Lubelskie Province, where values in very light and light mineral soils were nearly those in medium and heavy mineral soils and nearly three times low than those in organic soils. Within other provinces, no significant differences were observed for the values of this index in various kinds of soil. Significant differences of N_{min} content were found between very light and light soils (Lubelskie and Podlaskie : Lubelskie and Opolskie).

N_{min} content under short-term grassland, did not differ significantly in N_{min} content were found in various types of soil within the provinces under study. In medium and heavy mineral soils in Lubelskie Province, N_{min} content was significantly lower than in the other two provinces (N_{min} values). For all sites on very light and light soils, did not differ significantly among the provinces.

For maize crops, no significant differences were found among different types of soils within the provinces. On the other hand, N_{min} levels were only significantly lower in very light and light mineral soil in Lubelskie than in any soil type Podlaskie and Opolskie.

Economic value of ecosystem services

If higher N_{min} content in the 60–90 cm soil layer generates its higher losses (per value of nitrogen in mineral fertilizer), the greatest losses in Lubelskie Province (130.2 PLN·ha^{-1}) were recorded for grassland ecosystems with organic soils used for meadows. The smallest losses (42.7 PLN·ha^{-1}) were found in short-term grassland on medium and heavy mineral soil (tab. 2). In this province, nitrogen losses in very light

and light mineral soils did not differ significantly. A completely different trend was documented in heavier soils where short-term grassland generated lower losses (42.7 PLN·ha^{-1}), than in meadows (88.8 PLN·ha^{-1}) or maize (87.9 PLN·ha^{-1}). In organic soils, losses generated by grassland ecosystems used for cutting (meadows) were only slightly greater than in pastures (tab. 2).

Table 2. Comparison of mean value of ecosystem services among 5 types of use (cutting and grazing, pastures, meadows, short-term grassland, maize crops) in different soil types or categories in three provinces based on N_{min} content (PLN·ha^{-1}) in the 60–90 cm soil layer, shown as the loss of the nutrient in fertilizers

Soil category	Statistics	Type of use				
		cutting and grazing	pastures	meadows	short-term grassland	maize
Lubelskie Province						
Mineral, very light and light	N	n.d.	44	72	40	100
	mean ±se		^{a}47.5±5.5	^{a}53.1 ±12.9	^{ab}95.6 ±22.9	^{a}48.4 ±3.8
Mineral, medium and heavy	N	24	32	72	48	72
	mean ±se	^{a}67.0 ±9.8^{xy}	^{b}64.7 ±10.9^{xy}	^{b}88.8 ±10.7^{y}	^{a}42.7 ±6.4^{x}	^{a}87.9 ±12.2^{y}
Organic	N	n.d.	20	32	n.d.	n.d.
	mean ±se		^{cd}126.0 ±18.4	^{bc}130.2 ±24.2		
Opolskie Province						
Mineral, very light and light	N	n.d.	n.d.	24	20	44
	mean ±se			^{bc}122.6 ±12.6	^{bc}88.8 ±3.7	^{b}210.7 ±25.3
Mineral, medium and heavy	N	n.d.	20	44	24	124
	mean ±se		^{bc}80.8 ±5.3	^{bc}138.4 ±13.1	^{c}215.8 ±40.7	^{b}193.2 ±11.0
Podlaskie Province						
Mineral, very light and light	N	136	16	28	48	76
	mean ±se	^{b}118.3 ±6.2	^{cd}126.4 ±12.9	^{bc}111.9 ±11.1	^{bc}94.1 ±8.0	^{b}139.1 ±8.3
Mineral, medium and heavy	N	96	20	24	84	104
	mean ±se	^{b}119.6 ±6.3	^{cd}126.1 ±7.8	^{bc}101.4 ±8.7	^{bc}95.4 ±5.8	^{b}141.2 ±8.4
Organic	N	108	16	36	n.d.	n.d.
	mean ±se	^{c}293.9 ±23.9	^{e}405.3 ±42.2	^{d}247.3 ±34.1		

N – number of observations, se – standard error of the mean, ^{abcd} groups not having the same letter are significantly different within a single column (for use), ^{xy} groups not having the same letter are significantly different within a single row (for a specific province and soil category), lack of letter markings – no significant differences, significance level $\alpha = 0.05$, n.d. – no data available

In Opolskie Province, the highest levels (215.8 PLN·ha^{-1}) of N_{min} losses were recorded in sites under short-term grassland, in medium and heavy soils, while the lowest levels (80.8 PLN·ha^{-1}) – in the same types of soils used for pasturing. Although no significant difference was found in the statistical test, nitrogen losses amounting to 135.0 PLN·ha^{-1}, more than twice as high, were significant from a practical point of view. In this soil categories, nitrogen losses in sites with maize (193.2 PLN·ha^{-1}) were similar to those in short-term grasslands (215.8 PLN·ha^{-1}). Considerable nitrogen losses, from the practical perspective, were also recorded in very light and light soils. The losses found in sites with maize crops (210.7 PLN·ha^{-1}) were more than twice as high as in short-term grasslands (88.8 PLN·ha^{-1}) (tab. 2).

In Podlaskie Province, the greatest nitrogen losses were observed in organic soils in sites used for pasturing (405.3 PLN·ha^{-1}), while the lowest values – in sites under short-term grassland on very light and light soils (94.1 PLN·ha^{-1}). The difference between these values were as much as 311.2 PLN PLN·ha^{-1}. In very light and light soils, nitrogen losses in sites under alternating use as well as sites used for pasturing and cutting were similar. Greater (nearly 1.5 times) nitrogen losses were found in sites with maize crops (141.2 PLN·ha^{-1}) than in short-term grasslands (95.4 PLN·ha^{-1}). Similar relationships were also observed in heavier soils. In organic soils, the greatest nitrogen losses were observed in areas used for pasturing (405.3 PLN·ha^{-1}). Nitrogen losses per hectare were 1.6 times higher than those in sites used for cutting (meadows) and 1.3 times higher than those in sites under alternating use (cutting and grazing).

When analysing nitrogen losses within a particular use type, it no statistically significant differences were found in sites used for cutting and grazing on mineral soils. Nonetheless, nitrogen losses in medium and heavy soils in Lubelskie Province were nearly half the losses in both categories of mineral soils in Podlaskie Province. In cutting and grazing sites on mineral soils, significantly lower (4.3–2.4 times) nitrogen losses compares with sites on organic soils in Podlaskie Province.

In sites used for pasturing, no significant differences were found in the volume of losses between among the different soil types within the provinces under study, with the exception of Podlaskie where pasturing had significantly greater N_{min} losses in organic soils than in mineral soils. Significant differences were also recorded in sites located on very light and light mineral soils in Lubelskie and in mineral and organic soils in Podlaskie.

Where grassland communities were used as meadows, the smallest losses of N_{min} were found in very light and light mineral soils in Lubelskie (53.1 PLN·ha^{-1}). These losses were significantly lower (1.6–4.6 times) than losses found in the other soil types in each province under study. Among the sites assessed, the highest losses (247.3 PLN·ha^{-1}) were recorded in organic soils in Podlaskie Province, followed by medium and heavy mineral soils in Opolskie Province (138.4 PLN·ha^{-1}). However, the losses differed significantly only in very light and light soils as well as medium and heavy soils in Lubelskie Province.

In sites under short-term grassland (on mineral soils only), no significant differences in N_{min} loss were found in various types of soil within each province. The smallest losses were found in medium and heavy mineral soils in Lubelskie Province. These losses were significantly lower than the losses in this type of soil in the other two provinces and then in light and very light soils in Podlaskie Province.

Also in the case of maize crops, no significant differences in N_{min} losses were found between different categories of soils within each province. However N_{min} levels were significantly lower in very light and light mineral soils in Lubelskie Province (48.4 PLN·ha^{-1}) than any of the soil types from Podlaskie (139.1 PLN·ha^{-1}) or Opolskie (210.7 PLN·ha^{-1}). Such a significant difference was not found in a similar case between Podlaskie Province and Opolskie Province. The biggest losses were generated by maize crops on very light and light mineral soils in Opolskie Province (210.7 PLN·ha^{-1}) compared to the losses that were recorded for all other objects.

When analysing the monetary value of the ecosystem services based on the index of N_{min} level in the 60–90 cm soil layer in the particular provinces, regardless of the type and category of soil and type of use, it was found that this value was the highest in Opolskie Province (value 177.45 PLN·ha^{-1}) than in Podlaskie Province (value 152.71 PLN·ha^{-1}) with Lubelskie Province (67.55 PLN·ha^{-1}) (fig. 2).

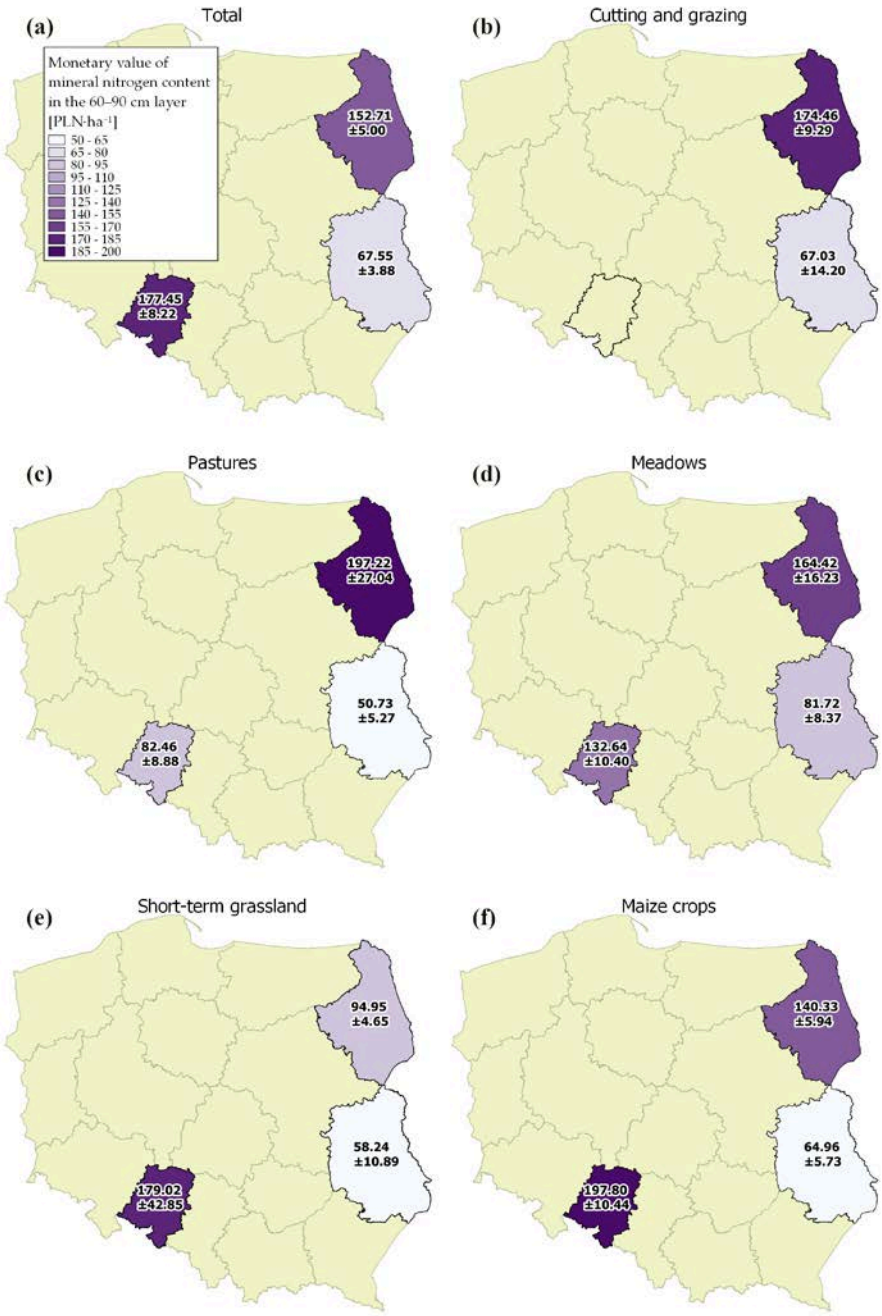

Fig. 2. The potential of grassland ecosystems to provide regulating and supporting services total (a), cutting and grazing (b), pastures (c), meadows (d), short term grassland (e) based on the index of N_{min} content in the 60–90 cm soil layer versus maize crops (f) in the provinces under study, calculated as the loss of fertilizer ingredient (PLN·ha^{-1}) (mean ±standard error)

Taking into account the mean value of N_{min} for all measurement points in sites used for cutting and grazing, the highest values were found in Podlaskie Province (174.46 PLN·ha^{-1}), while in Lubelskie Province they were many times lower (67.03 PLN·ha^{-1}). In Opolskie Province, this type of use of grassland ecosystems was not analysed. The largest losses of N_{min} were also found in Podlaskie Province – in sites used for pasturing and as meadows. The lowest values in these sites were recorded from Lubelskie Province (50.73 and 81.72 PLN·ha^{-1}, respectively). When analysing the assessed index for arable land, i.e. Land under short-term grassland and for maize crops, the highest (potential) N_{min} losses were found in Opolskie Province and the smallest losses were recorded in Lubelskie Province.

Table 3. The means biophysical (kg N·ha^{-1}) and monetary (PLN·ha^{-1}) values of the ecosystem service of grassland communities and maize crops (per one hectare of a given crop) in the provinces under study, based on the index of N_{min} content in the 60–90 cm soil layer

Lubelskie Province		Opolskie Province		Podlaskie Province		Total means	
Type of use							
grasslands	maize crops	grasslands	maize crops	grasslands	maize crops	grasslands	maize crops
Biophysical value (kg·ha^{-1})							
^{a}17.1 ±1.2	^{a}16.2 ±1.4	^{b}29.6 ±2.1	^{c}44.0 ±2.3	^{b}37.9 ±1.5	^{bc}33.4 ±1.4	^{x}28.9 ±0.98	^{y}31.20 ±1.13
Monetary value (PLN·ha^{-1})							
^{a}67.3 ±4.9	^{a}65.0 ±5.7	^{b}133.2 ±9.6	^{c}197.8 ±10.4	^{b}159.1 ±6.2	^{b}140.33 ±5.9	^{x}125.2 ±4.1	^{y}134.0 ±5.0

^{abcd} homogeneous groups of means in a row, according to province and form of use (if statistically significant differences at the level $\alpha = 0.05$ were found), ^{xy} homogeneous groups of means in a row, regardless of province, for general means (if statistically significant differences at the level $\alpha = 0.05$ were found)

Comparative analyses for voivodships were performed taking into account the average transformed (logarithmic) values, without division into soil types and methods of use. The mean total (of 3 provinces) biophysical values of the index (N_{min} in the 60–90 cm layer, treated as a loss) were significantly higher in the soils under maize crops (31.20 kg·ha^{-1}) than under grassland ecosystems (28.9 kg·ha^{-1}), and they were the highest values for maize crops (44.0 kg·ha^{-1}) in Opolskie Province (tab. 3). The findings for the monetary value of this service are similar. The mean total value of losses from one hectare of grassland communities is PLN 122.2. In comparison, the losses generated by maize crops were estimated at PLN 134.0. The differences were confirmed statistically.

DISCUSSION

The concept of valuating ecosystem services provides a new perspective on the links among economy, society and the environment, and indicate that environmental protection has a strong economic justification [Costanza et al. 2014]. At present, the public does not always notice this correlation because ecosystem services have not been fully or universally estimated yet and, consequently, the valuation results are not always accepted and taken into account. In addition, variability people use most ecosystem services

without being aware of this, which is an additional obstacle in assessing their value [Pascual et al. 2010]. The concept of environment valuation is a difficult subject to study not only for social reasons but also from the ethical perspective. The question of whether the value of the environment can be estimated at all [Kronenberg 2016]. Some are opposed to placing a monetary value on something that they regard as priceless. The fact that most benefits related to ecosystem services are of non-monetary or even non-economic character also raises a question about how realistically their value can be reflected in the results of economic studies. In this context, a non-monetary valuation seems much less controversial, but also less convincing [Norgaard 2013]. Despite these reservations, literature offers examples of monetary valuation used in the process of making various decisions [Becla 2013, Kallis 2013, Kronenberg 2016, Rūsiņa 2017].

This study sought to evaluate ecosystem services provided by grassland communities versus maize crops used as fodder for ruminants. It is because grassland ecosystems have a considerable share in the land use structure and perform a number of functions [Grzegorczyk 2016]. Such studies are lacking in Poland [Goliński and Foltynowicz 2018], with only a few European studies concerned with identifying, assessing and valuing grassland ecosystem services [Zisenis et al. 2011].

The assessment of ecosystem services in this study was carried out in two dimensions: biophysical and economic. The biophysical focused on one possible index of ecosystem services, specifically N_{min} content in the 60–90 cm layer of soil. It is treated as a potential loss because N_{min} leached beyond the main rhizosphere of meadow plants (0–25 cm) is not used by these plants and can change chemical and physicochemical properties of soil or pollute water [Watros et al. 2018b, 2019a].

As demonstrated in this study, biophysical values of ecosystem services measured based on N_{min} content in the 60–90 cm layer differed depending on use and soil types. Values of the index (treated as a loss) were higher in soils under maize crops than in grassland soils (increase about 9%). This relationship was confirmed by Watros et al. [2019a] who found that the content of this component in the 60–90 cm soil layer under grasslands was nearly twice as low as content under maize crops. This study shows that, in mineral soils, the lowest values of this ecosystem services indicator (N_{min}) were observed on pasture and mowing – pasture land, and the highest for maize crops. Other uses, i.e. Meadows and even short-term grassland, also generated smaller losses than maize crops. Therefore, it can be suggested that grasslands reduced infiltration of nitrogen into the soil. Thus, grasslands are better in protecting groundwater against contamination with nitrogen [Pawluczuk and Szymczuk 2008, Burzyńska 2014, Watros et al. 2019b]. It has been confirmed that N_{min} content at the depth of 60–90 cm in the soil is positively and significantly correlated the concentration of nitrates in water [Arregui and Quemada 2006]. This makes it possible to use a simple model of correlation of N_{min} content in the 60–90 cm layer with their levels in a saturated solution of aquifer soil, by means of appropriate conversion indices [Fotyma et al. 2010]. Previous studies by other authors also confirm that, among various agricultural cultures, grassland communities are the most suited to serve as a biological filter even though it is not a well appreciated ecosystem service in these prato-ecosystems. Ryszkowski et al. [2003] prove in their studies that meadows used as a protection belt, 8–10 m wide, removed 64–97% of nitrates (90% on average) from the water filtering through their root systems. Even in periods of low biological activity during the spring thaw, the amounts

of nitrates in water from drainage ditches adjoining arable fields was larger (13 mg·dm^{-3}) than in the water from ditches separated from the fields by a meadow or woodlot (5 mg·dm^{-3}) [Ryszkowski et al. 2003].

The present study found that N_{min} levels in mineral soils were lower than in organic soils. Similar correlations were also found by other authors [Pietrzak et al. 2006, Sapek and Sapek 2007, Watros et al. 2019a]. In their opinion, the lower content of this component in the 60–90 cm layer mineral soils can result from their poorer mineralization in comparison with organic soils. Poorer processes of mineralization in mineral soils are associated with lower levels of organic carbon, which seems to be confirmed by studies by Tian et al. [2017] as well.

Investigations conducted on organic soils (without maize crops) demonstrated that among all the assessed use types of grassland communities, the smallest losses of N_{min} occurred in meadows, followed by areas used for cutting and grazing, while the highest losses were in areas used as pastures. Pawluczuk and Szymczyk [2008] also found that N_{min} levels in peat-muck soils under extensively used meadows were lower than in peat-muck soils under pastures. However, they also found higher nitrate levels in groundwater under meadows than under pastures, which was caused by the greater phytosorption of nitrogen by pasture plants and lower groundwater level in pasture. These factors have an adverse influence on the migration of nitrate nitrogen deeper into the soil profile. Also in studies conducted by Watros et al. [2018b] on organic soils, the lowest levels of N_{min} in the non-root layer of soil were found in sites used for cutting, while the biggest losses were observed in conditions of alternating use for cutting and grazing. The present study found that biophysical values and corresponding monetary values of meadows and pastures on organic soils in Lubelskie Province were similar.

As demonstrated in this study, values of grassland ecosystem services, measured based on N_{min} content in the 60–90 cm layer, also varied spatially among the individual provinces characterized by varying intensity of agricultural production. The biggest losses were recorded in Opolskie Province where maize crops characteristic of intensive agriculture were predominant, and livestock density per 100 ha of arable land was the lowest [Bojarczuk et al. 2015]. Smaller losses were found in Podlaskie Province where very intensive livestock production primarily based on cattle is conducted, and the smallest losses occurred in Lubelskie Province where the livestock population is at a medium level. The obtained results seem to confirm studies by Watros et al. [2018a] who demonstrated the highest levels of N_{min} in the 60–90 cm layer with the livestock density of not more than 0.75 lsu (livestock units), and the lowest levels in farms with the livestock density ranging between 0.75 and 1.5 lsu of biophysical values of ecosystem services based on the N_{min} content index in the 60–90 cm soil layer were used to calculate the economic value of the service provided by one hectare of grassland in comparison with (one hectare) maize crops. The mean total value of losses from one hectare of maize crops was significantly higher than the value estimated for grasslands (PLN 134.0 and PLN 125.2, respectively). Assuming that the lower the N_{min} loss, the greater the potential of a given crop to provide ecosystem services, the advantage of grassland over maize, another fodder crop, was demonstrated with respect to regulatory and maintenance services [Ingraham and Foster 2008]. A reduction of nitrogen emissions is a considerable benefit (ecosystem service) for the society and the environment [Kronenberg 2016].

Economic valuations of these services including grassland ecosystems, have been conducted by other researchers. At the same time, it is worth stressing the difficulty of comparing valuations of specific services as well as comprehensive valuations due to the diversity of methods and different scopes of research [de Groot et al. 2002]. The available literature showed no scientific reports using N_{min} content in the 60–90 cm soil layer as an index of ecosystem services provided by grasslands. Studies of other authors, as in this paper, use the current market prices of the researched resource (e.g. N) or values based on the costs of its replacement to estimate the value of grassland ecosystem services [de Groot et al. 2002, Wieliczko 2016]. Unfortunately, the cited studies do not refer to nitrogen loss, but the value of services was most frequently expressed as the cost of purifying water or soil from bio-elements, including nitrogen. Furthermore, since the data pertain to various years, such comparisons have the character of an estimate. Nonetheless, it is evident that the problem of grassland ecosystem services is discussed more and more often. An attempt at an economic valuation of these services can serve as a bridge between production and environmental function of grasslands. It can also enhance maintenance and management of grasslands and, consequently, to benefits stemming from the natural environment [Vooren et al. 2018, Villoslada et al. 2018].

An estimation of grassland ecosystem services based on the value of water purification, habitat maintenance and erosion control was carried out by Ingraham and Foster [2008]. The estimated value of these services (according to prices from 2008, converted using the national bank of Poland currency exchange rate in the year the study was published) was PLN 152 $ha^{-1} \cdot year^{-1}$.

In a study by de Groot et al. [2002], the obtained monetary values of ecosystem services from permanent grasslands with regard to mediation of waste ranged from PLN 32 to 871 $ha^{-1} \cdot year^{-1}$ (according to 2007 estimates). Hönigová et al. [2018] estimated the value of ecosystem services of grassland communities with respect to the mediation of waste in the soil at PLN $232.12 \cdot ha^{-1}$ (according to 2012 estimates). In Poland an attempt was also made to estimate the value of ecosystem services on 962 ha of grassland. The valuation for the entire area was PLN 16.9 million per year, i.e. PLN 18,250 per hectare. The value of services related to the prevention of the chemical contamination of groundwater was PLN $791 \cdot ha^{-1}$ [Goliński and Foltynowicz 2018]. The a estimated values presented above prove that monetary valuation of grassland ecosystem services is possible and, despite being somewhat imperfect, it can justify the preservation and rational use of grassland potential in a more convincing way than biophysical values alone, thus influencing decisions made by people responsible for managing these resources [de Groot et al. 2002, Zisenis et al. 2011]. Rational use of environmental resources during a global climate catastrophe means, among others, taking often difficult decisions about the manner and directions of spatial management. Without a proper, research-based evaluation of the value of the natural environment, it is impossible to discuss about rationality of actions, both from economic and political point of view [La Notte et al. 2017]. The biophysical and monetary value of grassland ecosystem services estimated during the study shows the volume of potential losses in the ecosystem as a result of changes in the use of the lands for other purposes. The ecosystem services "N_{min} content in the soil layer 60–90 cm" indicator used in the study can be used in estimating environmental impact assessments, in particular as a source of input data in cost-benefit analyses in the planned changes in the forms of spatial development. In the future use of other indicators of grassland ecosystem services is planned for this purpose.

CONCLUSIONS

The studies support the hypotheses, that in terms of the volume and value of ecosystem services, grassland exceeds maize – another forage crop. The value of these services vary depending on location, type of use and soil type and category. In mineral soils, the highest potential to provide ecosystem services in the regulatory and maintenance group (N_{min} content) was shown by pastures followed by (in the order of decreasing potential) grasslands used for cutting and pasturing, meadows, short-term grasslands and maize crops. In organic soils (without maize crops), the highest potential was demonstrated by meadows and the lowest potential – by pastures. A higher potential of ecosystem services occurred in mineral soils than in organic soils under grasslands. The highest values of ecosystem services were found in Lubelskie Province where the intensity of farming is the lowest among the provinces under study.

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Streszczenie. Celem badań była ocena usług ekosystemowych użytków zielonych w oparciu o zawartość azotu mineralnego w warstwie gleby 60–90 cm oraz rozpoznanie zależności ich wielkości biofizycznej oraz wartości monetarnej od sposobu użytkowania oraz rodzaju gleby na tle uprawy kukurydzy. Obszar badań stanowiły trzy województwa, zróżnicowane pod względem użytkowania gleb, pogłowia bydła i intensywności gospodarowania na użytkach zielonych. Wyliczoną zawartość N_{min} w warstwie gleby 60–90 cm przyjęto jako stratę tego składnika, zakładając, że im jest ona mniejsza, tym większa jest usługa ekosystemowa. Badania wykazały, że wielkość usług ekosystemowych użytków zielonych jest zróżnicowana w zależności od sposobu użytkowania i rodzaju gleby oraz przestrzennie. Na glebach mineralnych najwyższą wartość usług ekosystemowych wykazywały pastwiska, natomiast najniższą uprawy kukurydzy. Na glebach organicznych (bez uprawy kukurydzy) najmniejsze straty azotu mineralnego uzyskano na obiektach łąkowych, największe zaś na pastwiskowych. Większe straty N_{min} notowano na glebach organicznych niż mineralnych. Stwierdzone straty były największe w województwie opolskim, następnie w województwie podlaskim, a najmniejsze w województwie lubelskim.

Słowa kluczowe: usługi ekosystemowe, użytki zielone, uprawy kukurydzy, straty azotu mineralnego

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