Bulletin of Geography. Physical Geography Series, No. 13 (2017): 39–49
http://dx.doi.org/10.1515/bgeo-2017-0012

ISSN 2080-7686

The use of agricultural soils as a source of nitrous oxide emission in selected communes of Poland

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Abstract. Nitrous oxide (N_2O) is one of the main greenhouse gases, with a nearly 300 times greater potential to produce a greenhouse effect than carbon dioxide (CO_2). Almost 80% of the annual emissions of this gas in Poland come from agriculture, and its main source is the use of agricultural soils. The study attempted to estimate the N_2O emission from agricultural soils and to indicate its share in the total greenhouse gas emissions in 48 Polish communes. For this purpose, a simplified solution has been proposed which can be successfully applied by local government areas in order to assess nitrous oxide emissions, as well as to monitor the impact of actions undertaken to limit them. The estimated emission was compared with the results of the baseline greenhouse gas inventory prepared for the needs of the low-carbon economy plans adopted by the studied self-governments. This allowed us to determine the share of N_2O emissions from agricultural soils in the total greenhouse gas emissions of the studied communes. The annual N_2O emissions from agricultural soils in the studied communes range from 1.21 Mg N_2O-N to 93.28 Mg N_2O-N, and the cultivation of organic soils is its main source. The use of mineral and natural fertilisers, as well as indirect emissions from nitrogen leaching into groundwater and surface waters, are also significant. The results confirm the need to include greenhouse gas emissions from the use of agricultural soils and other agricultural sources in low-carbon economy plans.

Key words:
nitrous oxide,
greenhouse gases,
emission,
agricultural soils,
communes,
Poland

Introduction

Nitrous oxide (N_2O) is a greenhouse gas with a nearly 300 times greater potential to produce a greenhouse effect than carbon dioxide (CO_2) and a very long duration of persistence in the atmosphere, estimated to be over 100 years (Turbiak et al. 2011; IPCC 2013; Prather et al. 2015). According to the National Centre for Emissions Management (KOBiZE 2016), in 2014, N_2O emissions in Poland were estimated at 66,300 Mg (5.2% of total greenhouse gas emissions), 78.9% of which came from agriculture. Agricultural soils are mainly responsible for the share of N_2O emissions from this sector being so significant; they account for about 68% of the N_2O emissions. Nitrous oxide is produced in the soil mainly as a result of nitrification and denitrification processes, as well as the process of nitrogen binding by bacteria. Many factors influence the quantity of the emission of N_2O from soils, e.g. climate, texture, temperature and soil moisture, secondary binding of nitrogen oxides in the soil, land use and cultivation, the type and amount of fertiliser doses, and biomass burning on the ground (Mercik et al. 1995; Bremner 1997; Khalil et al. 2004; Sapek 2008; Leppelt et al. 2014; Żyłowski 2016).

Agricultural N_2O emissions are currently being measured in two ways: direct emission measurement from a given source, and emission modeling from various sources on a global or regional scale (Sapek 2008; Nyćkowiak et al. 2012; Jarosz et al. 2013; Kolasa-Więcek 2013). There are no reports showing research findings on N_2O emissions from agriculture at local levels. This is despite the fact that, although they play a significant role in total greenhouse gas emissions, rural areas and associated agricultural activity ought to play vital roles in shaping low carbon economies. A properly carried out inventory of greenhouse gas emissions, including agricultural emissions, should be the reference point for the adopted development directions and planned mitigation measures at the local government level.

Evaluating the possibilities of reducing N_2O emissions from cultivated soils in Poland, Sosulski et al. (2017) further stress the difficulty of such a task due to the poor documentation of N_2O emissions in Polish literature and to the estimation of the gas based purely on foreign research results and mathematical models that do not correspond to national conditions. Nyćkowiak (2014) and Syp and Faber (2016) both point to problems with the correct estimation of simulated N_2O emissions from soils in Poland and the distinct differences that arise in its estimation depending on the methodology used. The calculators of greenhouse gas emission from agriculture so far developed are far too complex and often require data which is quite difficult to obtain at the local government level (Wu 2011; Colomb et al. 2012; Tuomisto et al. 2014).

Bearing in mind the above factors, as well as the results of previous authors' research (Wiśniewski and Kistowski 2016, 2017; Wiśniewski 2017) which focus almost exclusively on CO_2 emissions prepared for local low carbon economy plans and which do not take into account other gases and bypass agriculture in the inventory of emissions, the aim of this study was to estimate N_2O emissions from agricultural soils and to indicate their contribution to overall greenhouse gas emissions in selected communes in Poland.

Material and methods

N_2O emissions calculations from agricultural soils were performed for 48 selected rural, urban–rural and urban communes representing all voivodships in Poland. These communes occupy a total area of 6,200 km^2 (nearly 2% of the country's area) and are inhabited by 1,149,000 people (3% of the population). Owing to the aim of the study it was assumed that, regardless of commune type, the share of agricultural land in the area should not be less than 25%. In total, agricultural land in the selected communes occupies 57.3% of the area (Fig. 1). The selected communes have a huge differentiation of soil parent materials and main soil types. According to the WRB classification system (IUSS Working Group WRB 2015) the soil cover of most of the studied communes is dominated by Luvisols and Podzols. The other important soil units are the Cambisols, Brunic Arenosols and Fluvisols. Additionally, the Phaeozems and Chernozems occur locally, covering small areas (e.g. in the Regimin, Przeworsk and Żary communes). Leptosols, Calcaric Cambisols and Calcisols are very rare (e.g. in the Morawica, Skoczów, Żarów and Nowy Targ communes). Among the organic soils, the Murshic Histosols and Fibric/Hemic/Sapric Histosols prevail. Typological differentiation of soils also contributes to differences in nitrogen content. Fotyma et al. (2004) indicate that the average content of mineral nitrogen (Nmin) in Polish soils is 76–90 kg N/ha in the spring and 83–97 kg N/ha in the autumn, and average content of nitrate nitrogen (N-NO_3) is, 50–60 kg N/ha in the spring and 60–70 kg/ha in the autumn.

In order to calculate the N_2O emissions, a simplified methodology was applied. This was implemented earlier during the Pilot program of the low carbon development of Starogard County, in the Pomeranian Voivodeship, implemented in 2014–2015 within the framework of the project "The Good Climate for Counties" by the Institute for Sustainable Development and the Association of Polish Counties and Community Energy Plus in cooperation with the society, authorities and institutions of Starogard County (Instytut na rzecz Ekorozwoju 2015a). The Pilot program of the low carbon development of Starogard County is the first such doc-

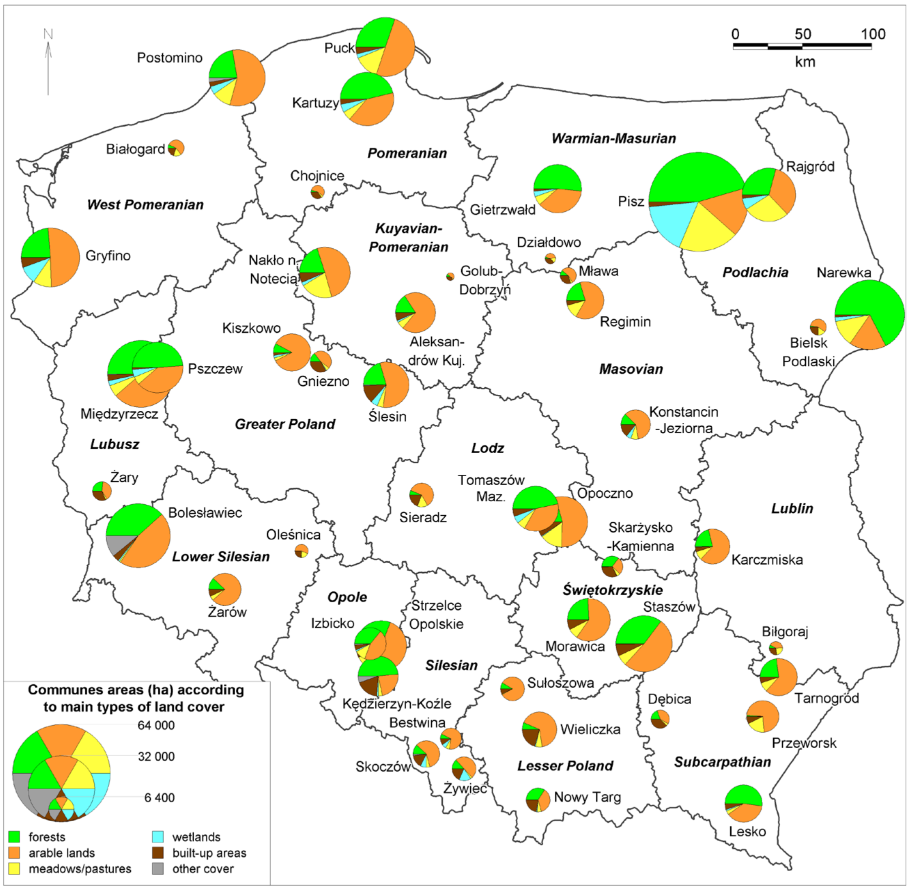

Fig. 1. The area and structure of land use of communes selected for analysis (based on Corine Land Cover 2012)

ument devoted to the low carbon economy, which was drawn up on county scale in Poland and developed with the co-author of this paper. Agriculture and rural areas are two of its main areas of activity and are a significant development axis (Instytut na rzecz Ekorozwoju 2015b; Wiśniewski 2015). The proposed solution is in line with the methodology and standard indicators of the Intergovernmental Panel on Climate Change (IPCC 2000, 2006), and, in order to obtain more accurate emissions data, takes into account elements of national methodology and emission factors developed by the National Centre for Emission Management for the purposes of preparing annual inventory reports.

In order to estimate N_2O emissions resulting from the use of soils in the studied communes, the following factors were taken into account:

- the mass of nitrogen in the used mineral fertilisers minus the amount emitted in the form of ammonia and nitrogen oxides NO_x,
- the mass of nitrogen in the used natural fertilisers, adjusted by ammonia and nitrogen oxides NO_x emissions, excluding the amount of nitrogen in faeces excreted by animals on pasture,
- the mass of nitrogen introduced into the soil as a result of biological binding by Fabaceae plants (legumes),
- the mass of nitrogen introduced into soils with post-harvest plant residues,
- emissions from organic soils,
- emissions from the excrement of animals left on the pasture,
- indirect emission from the deposition of atmospheric nitrogen,
- indirect emission from the leaching of nitrogen from the ground.

Data on the annual usage of mineral fertilisers, livestock and organic soil necessary for estimation were obtained from the Local Data Bank of the Central Statistical Office (LDB CSO). The annual harvest of main crops (wheat, rye, barley, oats, triticale, cereal, potato, sugar beet, rapeseed, maize and legumes) was determined using data regarding the area planted in individual communes and the average yield of these plants in the voivodship, based on the National Agricultural Census 2010. In order to estimate the level of emissions related to the use of soil, the indicators recommended by the IPCC (IPCC 2000, 2006) and the National Centre for Emissions Management (KOBiZE 2014) were additionally used.

In order to estimate the emissions related to the use of mineral fertilisers, the default nitrous oxide emission factor was used at the level of 0.0125 kg N_2O-N/kg N (IPCC 2000). This indicator was also used to estimate the mass of nitrogen entering the soil as a result of biological binding by Fabaceae plants, and plant residues. The mass of nitrogen was derived from the use of mineral fertilisers adjusted by the amount emitted in the form of ammonia and NOx nitrogen oxides according to the formula (1):

$$F_{SN} = N_{FERT} \times (1 - Frac_{GASF}) \qquad (1)$$

where: F_{SN} – mass of mineral fertilisers applied to soil adjusted by NH_3 and NO_x emission [kg N/year]; N_{FERT} – use of mineral fertilisers [kg/year]; $Frac_{GASF}$ – indicator that measures the nitrogen content in mineral fertilisers emitted as NH_3 and NO_x, which is 0.1 kg NH_3-N+NO_x-N/kg of the applied fertilisers.

In the case of emissions associated with the use of natural fertilisers, the nitrogen mass adjusted by emission of ammonia and nitrogen oxides NO_x, excluding the amount of nitrogen contained in the faeces excreted by animals in the pasture, according to the formula (2):

$$F_{AM} = \Sigma_T (N_{(T)} \times Nex_{(T)}) \times (1 - Frac_{GASM}) \times (1 - Frac_{GRAZ}) \qquad (2)$$

where: F_{AM} – mass of nitrogen contained in organic fertilisers adjusted by NH_3 and NO_x emissions [kg N/year]; Nex – default indicators of nitrogen content in livestock excreta (Table 1); $\Sigma_T(N_{(T)} x Nex_{(T)})$ – total amount of nitrogen contained in organic fertilisers produced within a year [kg N/year]; $Frac_{GASM}$ – indicator that measures the nitrogen content in faeces in the form of NH_3 and NO_x, which is 0.2 kg NH_{3-}N+NO_{x-}N/kg of nitrogen excreted by animals; $Frac_{GRAZ}$ – indicator that measures the nitrogen content in faeces left by grazing animals on soils, amounting to 0.07 kg N_2O-N/year.

The annual amount of nitrogen bound by legumes cultivated in the studied communes was estimated according to the formula (3), while the mass of nitrogen introduced into soils with post-harvest plant residues was estimated according to the formula (4).

$$F_{BN} = Crop_{BF} \times (1 + Res / Crop) \times Frac_{DM} \times Frac_{NCR} \qquad (3)$$

where: F_{BN} – mass of nitrogen bound by legumes [kg/year]; $Crop_{BF}$ – annual harvest of legumes [kg]; $Res/Crop$ – the ratio of non-agricultural to agricultural harvest (Table 2); $Frac_{DM}$ – share of dry mass in the aboveground biomass (Table 2); $Frac_{NCR}$ – nitrogen content in legume biomass (Table 2).

$$F_{CR} = Crop_{Y} \times Frac_{DM} \times Res / Crop \times Frac_{NCR} \times (1 - Frac_{BURN} - Frac_{R}) \qquad (4)$$

where: F_{CR} – mass of nitrogen in plant residues left in soil [kg]; $Crop_Y$ – annual relevant harvest [kg]; $Frac_{DM}$ – share of dry mass in the aboveground biomass (Table 2); $Res/Crop$ – the ratio of non-agricultural to agricultural harvest (Table 2); $Frac_{NCR}$ – nitrogen content in legume biomass (Table 2); $Frac_{BURN}$ – the share of burned biomass, which amounts to 0.03 kg N/kg of leftover nitrogen; $Frac_R$ – the share of biomass of the crop removed from the field, which amounts to 0.44 kg N/kg of nitrogen left.

Table 1. Indicators used to estimate N_2O emissions associated with the use of natural fertilisers and N_2O emissions from animal excreta left over on pasture and grooming areas

Animals	Indicators of nitrogen content in livestock excreta	Share of livestock keeping systems		
	(kg/animal/year)	(%)		
		non-bedding	bedding	pasture
Dairy cows	70.0	10.5	79.2	10.3
Other cattle	50.0	5.1	82.9	12.0
Sheep	16.0	-	80.0	20.0
Goats	25.0	-	78.0	22.0
Horses	25.0	-	78.0	22.0
Swine	20.0	24.3	75.7	-
Poultry	0.6	11.0	89.0	-

Source: Instytut na rzecz Ekorozwoju 2015a

Table 2. Coefficients used for estimation of the mass of nitrogen bound by legumes and mass of nitrogen introduced into soils with post-harvest plant residues

Crop	Ratio of non-agricultural to agricultural harvest	Share of dry mass in aboveground biomass	Nitrogen content in biomass
Wheat	0.85	0.85	0.0068
Rye	1.40	0.86	0.0053
Barley	0.80	0.86	0.0069
Oats	1.10	0.86	0.0075
Triticale	1.10	0.86	0.0063
Cereal	0.90	0.86	0.0071
Potato	0.10	0.25	0.0203
Rapeseed	1.20	0.87	0.0068
Maize	1.30	0.52	0.0094
Legumes	0.90	0.86	0.0180

Source: Instytut na rzecz Ekorozwoju 2015a

Direct emissions from organic soils were estimated based on their surface area and a default emission coefficient for the cold climate, which amounts to 8 kg N_2O-N/year (IPCC 2000). The amount of emissions from animal excreta left over on pasture and grooming areas was estimated, however, taking into account the share of particular livestock husbandry systems in Poland as well as the default indicators of nitrogen content in livestock manure (Table 1), using the formula (5):

$$N_2O - N_{GR} = Nex_{GR} \times EF_{GR} \qquad (5)$$

where:

$N_2O\text{-}N_{GR}$ – emission of nitrous oxide from livestock excreta left over in pasture and grooming areas [kg N_2O-N]; Nex_{GR} – mass of nitrogen left by animals on pastures [kg]; EF_{GR} – nitrous oxide emission factor for grazing animals, which amounts to 0.02 kg N_2O-N/kg N.

The indirect emission from the deposition of atmospheric nitrogen was estimated according to the formula (6), while the formula (7) was used to estimate indirect emissions from nitrogen leaching.

$$N_2O_{(G)} - N = \{(N_{FERT} \times Frac_{GASF}) + [\sum_T (N_{(T)} \times Nex_{(T)})] \times Frac_{GASM}\} \times EF_{AD} \qquad (6)$$

where: $N_2O_{(G)}$ – emission of nitrous oxide as a result of deposition of nitrogen compounds from the atmosphere into the soil [kg N_2O-N]; N_{FERT} – annual consumption of mineral fertilisers in the commune converted into pure nitrogen [kg]; $Frac_{GASF}$ – indicator which measures nitrogen content in mineral fertilisers, released as NH_3 and NO_x, which amounts to 0.1 kg NH_3-N+NO_x-N/kg of applied fertilisers; Nex – default indicators of nitrogen content in faeces of farm animals (Table 1); $\Sigma_T(N_{(T)}xNex_{(T)})$ – total mass of nitrogen excreted in animal faeces [kg]; $Frac_{GASM}$ – indicator of nitrogen content in excreta released as NH_3 and NO_x, which amounts to 0.2 kg NH_3-N+NO_x-N/kg of nitrogen excreted by animals; EF_{AD} – default emission indicator of nitrogen compounds deposited from the atmosphere, which amounts to 0.01 kg N_2O-N/kg NH_4-N and NO_x-N.

$$N_2O_{(L)} - N = [N_{FERT} + \sum_T (N_{(T)} \times Nex_{(T)})] \times Frac_{LEACH} \times EF_{LR} \qquad (7)$$

where: $N_2O_{(L)}\text{-}N$ – emission of nitrous oxide due to leaching of nitrogen compounds from soil to water [kg N_2O-N]; N_{FERT} – annual consumption of mineral fertilisers in the commune converted into pure nitrogen [kg]; N_{ex} – default indicators of nitrogen content in faeces of farm animals (Table 1); $\Sigma_T(N_{(T)}xNex_{(T)})$ – total mass of excreted nitrogen in animal faeces [kg]; $Frac_{LEACH}$ – the share of nitrogen leached as NH_3 and NO_x, which amounts to 0.3 kg N/kg of nitrogen in applied mineral fertilisers; EF_{LR} – default emission indicator for nitrous oxide from nitrogen leaching from the soil, which amounts to 0.025 kg N_2O-N/kg of leached nitrogen.

Estimated N_2O emissions from agricultural soils were subjected to statistical and comparative analysis. In order to calculate the Pearson correlation coefficients, the relationship between the emissions amount of nitrous oxide and the variables such as of consumption mineral fertiliser, livestock population, crop yields, and organic soil surface were assessed. The calculated N_2O emissions were also compared with the results of a baseline greenhouse gas inventories prepared for the needs of the low-carbon economy plans adopted by the studied self-governments, thereby allowing us to determine the share of N_2O emissions from the use of agricultural soils in total greenhouse gas emissions within the surveyed communes. In order to avoid double counting, the results of the baseline inventories were reduced by the amount of emissions from agricultural sources. However, this was only applied to two communes (Kiszkowo and Oleśnica), because this sector has yet to be taken into account in the basic inventories of other communes. In order to standardise the results and carry out comparative analyses, the emissions from agricultural soils as well as for the greenhouse gas inventory for individual communes were expressed in carbon dioxide equivalent (CO_2eq), assuming global warming potential (GWP) as defined in the IPCC Fifth Assessment Report on climate change (IPCC 2013).

Results and discussion

The performed calculations show that the annual N_2O emissions from agricultural soils in the studied communes range from 1.21 Mg N_2O-N (321.94 Mg CO_2eq) in the municipality of Żary to 93.28 Mg N2O-N (24,719.47 Mg CO_2eq) in the urban–rural commune of Pisz, with an average value of 22.83 Mg N_2O-N (6,049.95 Mg CO_2eq) and a standard deviation of 20.81 Mg N_2O-N (5,514.65 Mg CO_2eq). Among the studied communes, the highest average annual emission of nitrous oxide from agricultural soils is typical for urban–rural communes, and amounts to 35.06 Mg N_2O-N (9,290.9 Mg CO_2eq), which is 43% higher than the average emission in rural communes and almost four times higher than for municipalities (Table 3).

Nearly 50% of the total N_2O emission associated with the use of agricultural soils in the studied communes comes from the cultivation of organic soils. In municipalities, this share is particularly high, at 73%, while in urban–rural communes it is 51.5%, and 39% in rural communes (Fig. 2). These results confirm the assumptions of Turbiak et al. (2011), who indicate that among soil types, the organic soils may be one of the main sources of nitrous oxide emissions. They emphasise that following the use of organic soils for agricultural purposes, which entails the lowering of groundwater levels, there is an intensive organic matter mineralisation in these soils. According to Okruszko and Piaścik (1990), in the climatic conditions of Poland, about 10 Mg/ha of organic matter is subjected to annual mineralisation, which results in the release of up to 400 kg/ha of mineral nitrogen into the environment.

Moreover, the use of fertilisers – both mineral (14.5% of total emissions for agricultural soils in the studied communes) and natural (10.8%) – is an important source of direct nitrous oxide emissions from agricultural soils. In rural communes, this share is the highest and reaches 18.1% for mineral fertilisers and 12.8% for organic ones. In urban–rural communes it amounts to 13.6% and 10.8%, respectively, compared to 8.2% and 5.3% of total N_2O emissions from agricultural soils in municipalities. However, minimal importance in direct N_2O emissions is attributed to nitrogen fertilisation with crop residues (1.7% of total emissions in the studied communes), and to excretion of animal faeces left on pastures and grazing areas (1.2%).

Nitrogen leaching into groundwater and surface waters is the main source of indirect N_2O emissions associated with the use of agricultural soils in the studied communes. Its share in total N_2O emissions from agricultural soils ranges from 9.7% in the studied municipalities to 22.4% in rural communes. The deposition of nitrogen released into the air from the fields in the form of nitrogen oxide (NO_x) and ammonia (NH_3), after the application of natural and inorganic fertilisers, is significantly less important in indirect N_2O emissions. It corresponds to 4.4% of total N_2O emissions from agricultural soils in rural communes, 3.5% in urban–rural communes, and 1.9% in municipalities.

Statistical analysis indicates high and very high correlations of N_2O emission from agricultural soils to mineral fertiliser consumption, cattle population and organic soil surface (Table 4). The Pearson linear correlation coefficients obtained between these variables are similar to those derived by modelling nitrous oxide emissions from agricultural sources using linear regression, as carried out by Kolasa-Więcek (2013). There are, however, differences in the strength of correlation relationships, depending on the type of communes. In the case of the studied rural communes, a very high relationship was observed between the amount of N_2O emissions from agricultural soils and the consumption of mineral fertilisers. In urban–rural communes, there was a very high positive correlation with N_2O emissions for such variables as the area of organic soils and cattle population. In municipalities, however, there is almost a full correlation between the amount of nitrous oxide emissions and the area of organic soils and the size of legume crops.

A compilation of the results of the authors' calculations with the results of the baseline inventory of greenhouse gas emissions presented in the low-carbon economy plans adopted by the studied communes has made it possible to determine the approximate share of N_2O emissions from the use of agricultural soils in total greenhouse gas emissions (without other agricultural sources). The average in all the studied communes is 4.6%, ranging from 0.1% in the municipality of Żary to 57.2% in the urban–rural commune of Rajgród (Fig. 3). Taking into account the type of communes, the largest share of N_2O emissions in total greenhouse gas emissions (with an average of 12%) is typical for rural communes. In the Kiszkowo commune it is

Table 3. Statistical analyses of N_2O emissions from agricultural soils according to type of commune

Type of commune	Minimum	Maximum	Average	Standard deviation
	(Mg N_2O-N)			
Rural communes	6.20	55.96	24.59	12.13
Urban-rural communes	3.13	93.28	35.06	23.79
Municipalities	1.21	69.84	8.86	16.52
All communes	1.21	93.28	22.83	20.81

Table 4. Pearson's correlation coefficient between selected variables and N_2O emissions from agricultural soils in the studied communes

Variable	Correlation coefficient			
	Rural communes	Urban–rural communes	Municipalities	All communes
Use of mineral fertilisers	**0.802**	0.395	0.471	**0.604**
Cattle population	**0.703**	**0.861**	0.228	**0.797**
Sheep population	0.073	0.229	0.127	0.211
Goat population	-0.049	-0.291	0.010	0.061
Horse population	-0.021	0.268	0.136	**0.372**
Swine population	**0.678**	0.289	-0.026	**0.458**
Poultry population	0.114	0.112	0.013	0.224
Harvest of legumes	-0.247	-0.260	**0.970**	0.061
Wheat harvest	**0.565**	-0.095	0.408	0.284
Rye harvest	**0.610**	0.307	0.055	**0.433**
Barley harvest	**0.741**	0.036	0.150	**0.360**
Oats harvest	**0.545**	0.146	0.356	**0.397**
Triticale harvest	**0.758**	0.465	0.077	**0.560**
Harvest of mixed cereals	**0.535**	0.460	**0.660**	**0.573**
Potato harvest	0.266	-0.055	0.021	0.226
Rape harvest	**0.674**	0.046	0.356	**0.334**
Maize harvest	0.024	0.152	0.180	0.254
Area of organic soils	**0.674**	**0.903**	**0.995**	**0.882**

Explanations: significance level p = 0.05; bold – statistically significant correlations

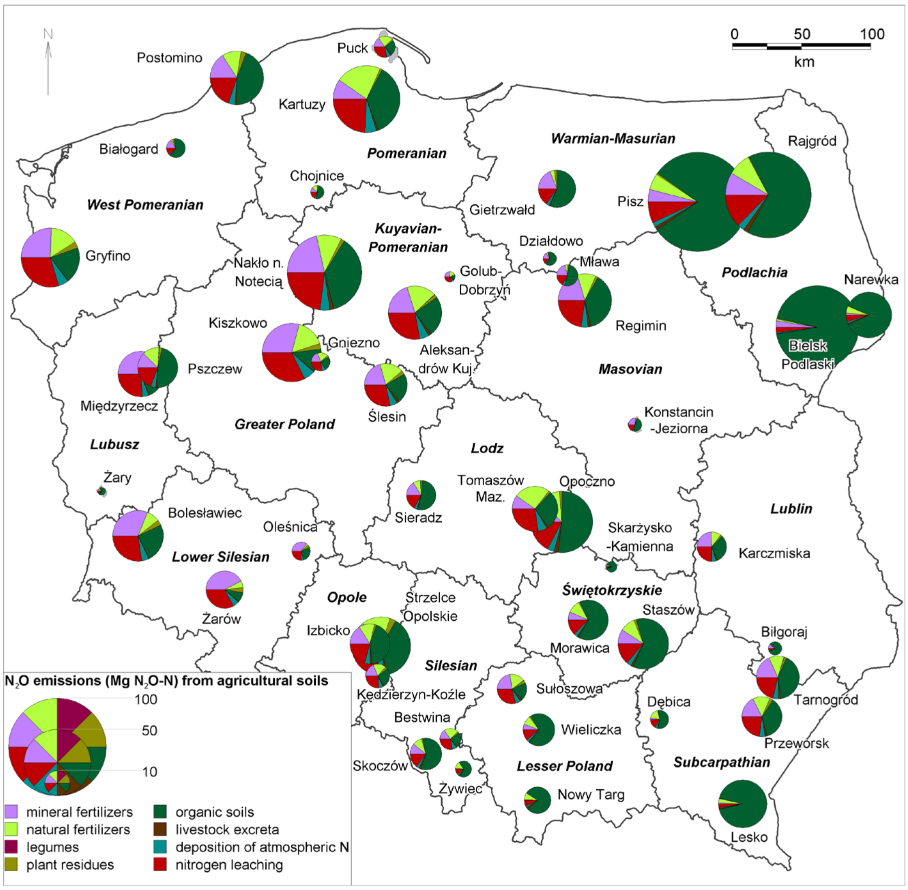

Fig. 2. Size and structure of N_2O emissions from agricultural soils in the studied communes

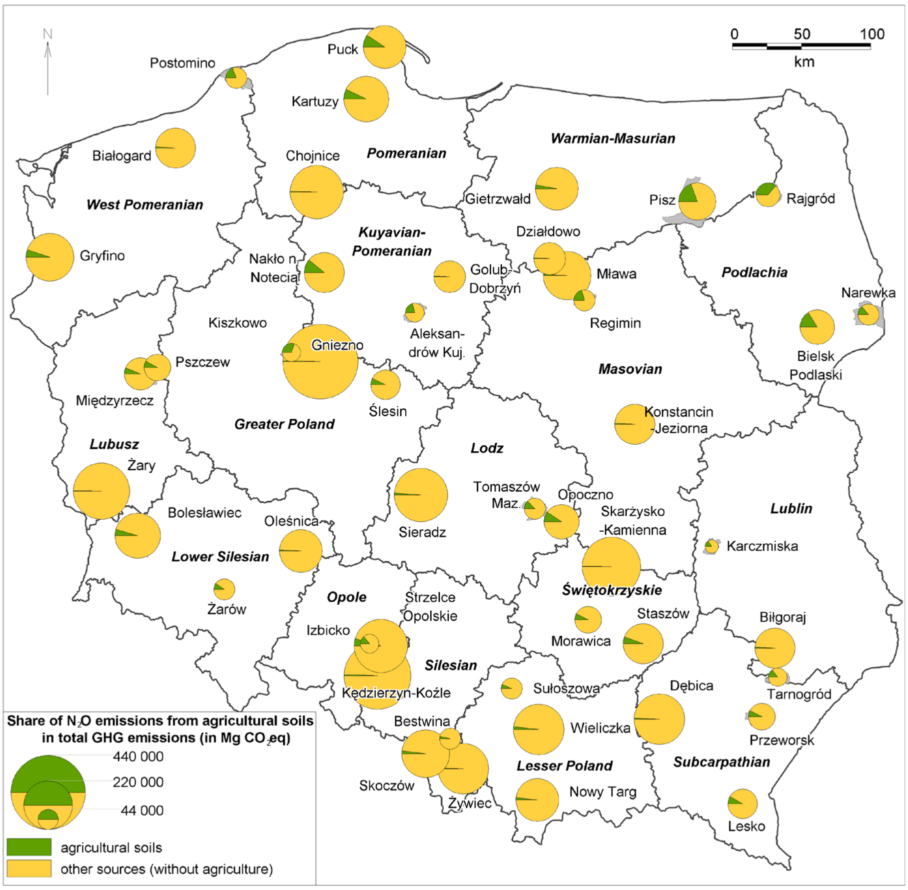

Fig. 3. Share of N_2O emissions from agricultural soils in total greenhouse gas emissions (excluding other agricultural sources) in the studied communes

43%, and in the communes of Aleksandrów Kujawski, Regimin and Postomino it is over 20%. Only in two rural communes (Bestwina and Gietrzwałd) is this share lower than the average for all the studied communes, amounting to 3.4% and 2.8%, respectively. The average share of N_2O emissions from agricultural soils in total greenhouse gas emissions in urban–rural communes is slightly lower, and reaches 7.6%. Apart from the above-mentioned commune of Rajgród, it amounts to 24.3% in the Pisz commune and in four units of similar type (Żarów, Nakło nad Notecią, Tarnogród and Opoczno) it exceeds 10%. Municipalities, generally speaking, have a small share of N_2O emissions from agricultural soils in the overall emissions (on average 1.1%). However, in Bielsk Podlaski it amounts to 19.2% (mainly due to the significant share of organic soils), but in 13 out of 16 studied cities it does not exceed 1%.

Conclusions

1. The annual N_2O emissions from agricultural soils in the studied communes range from 1.21 Mg N_2O-N (321.94 Mg CO_2eq) to 93.28 Mg N_2O-N (24,719.47 Mg CO2eq), with an average value of 22.83 Mg N_2O-N (6,049.95 Mg CO_2eq) and a standard deviation of 20.81 Mg N_2O-N (5,514.65 Mg CO_2eq).

2. Almost 50% of the total N_2O emissions from agricultural soils in the studied communes come from organic soil cultivation, which confirms that this is the main source of direct nitrous oxide emissions associated with the agricultural use of soil. The use of mineral fertilisers (14.5% of emissions) and natural fertilisers (10.8%) is also significant. The leaching of nitrogen into groundwater and surface water (18.4%) is the main source of indirect emissions associated with the agricultural use of soils.

3. The results of statistical analysis indicate, among other things, high and very high correlations between the amount of N_2O emissions from agricultural soils and the use of mineral fertilisers, cattle population and surface of organic soils. The strength of correlation relationships varies, depending on the type of commune.

4. The estimated share of N_2O emissions in total greenhouse gas emissions (excluding other agricultural sources) in the studied communes ranges, based on the authors' own calculations, from 0.1% to 57.2%, and by 4.6% on average.

5. The results confirm the need to include greenhouse gas emissions from agricultural soils and other agricultural sources in low-carbon economy plans. Without doing that, it is not possible to properly plan actions designed to reduce these emissions or their negative effects on the atmosphere, climate and other ecosystem components. This need is particularly true for rural and urban–rural communes, but it even requires greater consideration in municipalities, where the share of agricultural land is significant.

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Received 30 September 2017
Accepted 30 October 2017