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Soil N_2O emissions under conventional and reduced tillage methods and maize cultivation

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ABSTRACT

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The study concerned the determination of nitrous oxide (N_2O) emissions under conventional and reduced tillage conditions. In the reduced cultivation, a soil cultivating seed drill was used for simultaneous sowing of seeds and subsurface application of fertilizer. The emission levels of the gas tested were dependent on the year of the study and the method of soil tillage, and were subject to considerable changes during the growing season. The use of reduced soil tillage significantly limited emissions of the analysed gas into the atmosphere. Depending on the year of the study, N_2O emission in the reduced tillage system was from 15% to 40% lower than in the conventional system. Low levels of easily mineralized components in soil could have been the cause of the reduction in N_2O emissions to the atmosphere.

Keywords: greenhouse gas; global warming; *Zea mays*; conventional tillage

The emission of nitrogen (N) to the atmosphere as nitrous oxide (N_2O) has received recent attention due to its role as a powerful greenhouse gas (GHG) with a global warming potential (GWP) 298 times greater than the carbon dioxide (www.epa.gov).

The total N_2O emission in Poland in 2016 amounted to 66.26 thousand tonnes, of which agriculture's share is estimated at 79%. In agriculture, the highest share (86%) in N_2O emissions is that of the emissions from arable soils. A study by Syp et al. (2016) showed that N_2O emissions from cultivated soils in Poland varied within the range of 1.99–3.78 kg N_2O ha/year. A reduction in these greenhouse gas emissions from agriculture can be achieved by: (i) large-scale implementation of precision farming; (ii) growing crops with a high carbon sequestration potential; (iii) organic fertilization; (iv) growing energy crops; (v) organic farming; (vi) afforestation of agricultural land (Sosulski et al. 2017). The agronomic factors influencing N_2O emission into the atmosphere include the method of soil cultivation, introduction of organic matter, and mineral fertilization (Ball et al. 2014, Martins et al. 2015, Pimentel et al. 2015).

Transformations of carbon and nitrogen compounds are directly related to the microbial activity of the soil. Different types of soil cultivation are a fundamental treatment modifying this activity, which

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Table 1. Properties of the soils in field experiments

Field	Location	Soil type	pH	P	K	Mg	C_{org}	N_{tot}	C:N
				(mg/kg)			(g/kg)		
Żelazna	51°87'N, 20°13'W	Luvisol (loamy sand)	6.30	69.50	82.80	96.23	5.40	0.52	10.40
Baborówko	52°58'N, 16°63'W	Cambisol (sandy loam)	5.80	76.08	65.57	33.17	5.85	0.53	11.00
Grabów	51°34'N, 21°67'W	Luvisol (sandy loam)	5.15	74.77	60.59	22.16	6.98	0.65	10.72
Czesławice	51°30'N, 22°25'W	Haplic Luvisol (silt loam)	6.49	163.21	142.31	106.71	18.82	1.69	11.13

modifies, at the same time, greenhouse gas emissions. Moreover, the methods of reduced tillage appear in agriculture, which, on the one hand, improve soil structure and lower its temperature, thereby limiting greenhouse gas emissions. On the other hand, they increase soil moisture and improve the soaking up of water, which creates anaerobic conditions and is particularly conducive to N_2O emissions (van Kessel et al. 2013, Akbolat et al. 2016).

The aim of the study was to assess the effect of reduced soil tillage on the amounts of N_2O emissions under maize cultivation.

MATERIAL AND METHODS

The study on N_2O emissions from the soil was conducted in 2014–2015. It was conducted under the conditions of field experiments located at four experimental stations in Żelazna, Baborówko, Grabów and Czesławice (Table 1, Figure 1).

The plant cultivated in the experiments was maize grown for grain. Two maize cultivation systems were used: (T) conventional (plough) tillage, and (W) reduced (ploughless) tillage (Table 2).

In the year preceding the establishment of the field experiments, liming was applied on the entire surface at a dose of 1.43 t Ca/ha (as $CaCO_3$, $MgCO_3$ 60% CaO) and potassium fertilization at a dose of 265.0 kg K/ha (high-grade potassium salt KCl 48% K). The maize plants were fertilized with nitrogen at 120 kg N/ha and phosphorus at 26 kg P/ha. In the conventional plough tillage system, nitrogen was used in the form of urea ($CO(NH_2)_2$ 44% N), and phosphorus in the form of superphosphate ($Ca(H_2PO_4)_2$ 17% P). In the ploughless system, fertilization with nitrogen and phosphorus was applied below the soil surface in the form of granular fertilizer UreaPhoS(Micro) produced at the New Chemical Syntheses Institute in Puławy (INS), with the following chemical composition in g/kg: N – 200, P – 43.6, S – 70, Cu – 1.5, Zn – 3, B – 0.6. The fertilizer was applied by means of a soil cultivating seed drill that enabled simultaneous sowing of seeds and subsurface application of the fertilizer. Large fertilizer granules (10 mm) were placed 25 cm deep, corn was sown at 5 cm depth and small fertilizer granules (4 mm) were put 10 cm into the ground (Talarczyk et al. 2016).

Measurements of N_2O emissions from the soil were made using a portable FTIR spectrometer model Alpha (Bruker, Ettlingen, Germany) with an enclosed measuring compartment and a 10 min exposure time. The measurements were made each year on three test dates: (1) mid-June, stage BBCH 18–19 (8–9 leaves); (2) first 10 days of July, stage BBCH 51 (panicle emergence) and (3) last 10 days of August, stage BBCH 73–75 (milk grain maturity).

The results were statistically analysed with ANOVA using the Statistica PL software (Tulsa, USA).

Table 2. Description of the cultivation systems

Treatment	Autumn	Spring
Conventional (plough) tillage	skimming (field after maize); P and K fertilization; ploughing (25 cm)	harrowing (dragging on compact soil); N fertilization pre-sowing dose; pre-sowing soil treatment; sowing (seeding depth 5 cm, row spacing 75 cm, number of plants per hectare 80 000; N top-dressing
Reduced (ploughless) tillage		simultaneous sowing of maize seeds and fertilizer application (seeding depth 5 cm, row spacing 75 cm, number of plants per hectare 80 000)

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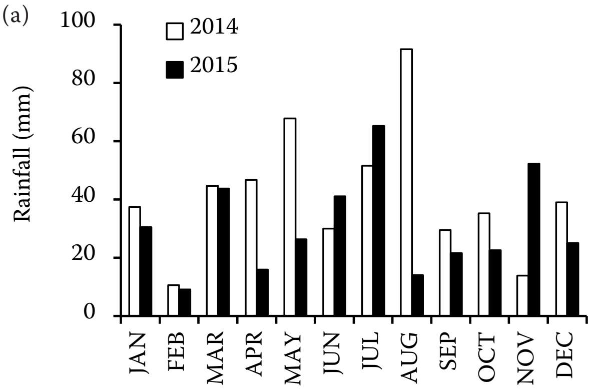
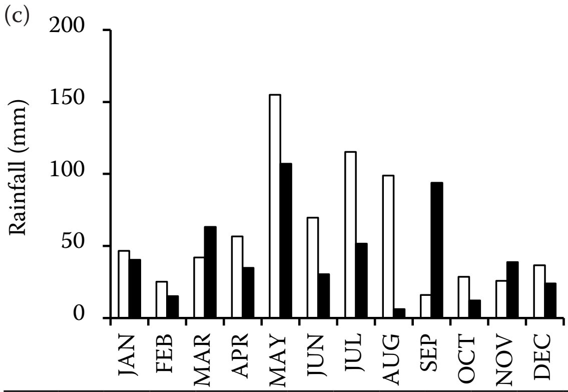
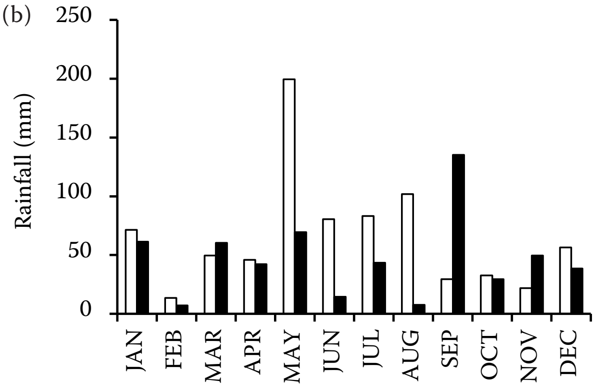


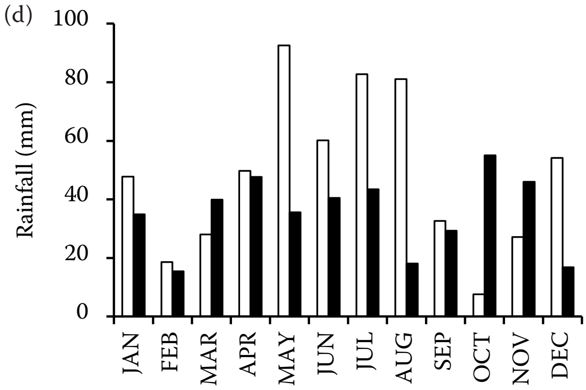
	Temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	–1.2	3.7	7.0	11.2	14.2	17.4	23.0	18.6	15.8	11.2	5.8	2.0
2015	1.8	1.2	5.1	8.5	12.8	15.7	19.2	22.5	14.5	7.6	6.1	5.5



	Temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	–3.2	1.1	5.9	9.7	13.7	16.4	20.8	18.9	14.1	9.0	4.1	–0.2
2015	0.6	0.3	4.6	8.7	12.8	17.0	21.9	24.4	15.1	6.1	4.8	3.3



	Temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	–2.6	1.4	6.3	9.9	13.5	15.2	20.4	17.9	14.4	9.8	4.7	0.5
2015	1.0	0.5	5.0	8.1	12.7	16.9	19.7	22.1	15.0	6.8	5.0	3.9



	Temperature (°C)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	–1.6	1.7	6.4	10.3	14.1	16.4	20.9	17.9	14.4	9.2	5.1	0.6
2015	1.5	0.8	4.6	8.2	13.1	17.0	19.7	21.5	14.6	6.6	5.2	4.7

Figure 1. Weather data in the experimental field: (a) – Żelazna; (b) – Baborówko; (c) – Grabów and (d) – Czesławice

RESULTS

Plant yields varied widely from 2.90 to 14.1 t/ha (Table 3). In 2014, a significantly higher crop yield was achieved compared to the year 2015. It was found that the cultivation system did not significantly affect the yield of maize.

Depending on the year and location of the experiment, N_2O emissions from the soil ranged from 8.30 to 14.36 μg N-N_2O m^2/h. In the conventional system of maize cultivation and fertilization, the highest average N_2O emission from the soil was observed in Grabów, significantly lower in Czesławice, Żelazna and Baborówko (Table 4).

Table 3. Grain yield of maize (t/ha)

Cultivation and fertilization	Żelazna		Baborówko		Grabów		Czesławice	
	2014	2015	2014	2015	2014	2015	2014	2015
Conventional (plough) tillage	11.45	2.90	8.55	6.69	8.62	4.98	15.6	13.6
Reduced (ploughless) tillage	11.94	2.97	8.41	6.61	8.23	4.61	17.3	14.1
$LSD_{0.05}$ for cultivation	ns	ns	ns	ns	ns	ns	ns	ns
Year	1.12		0.73		0.81		1.22	

LSD – least significant difference

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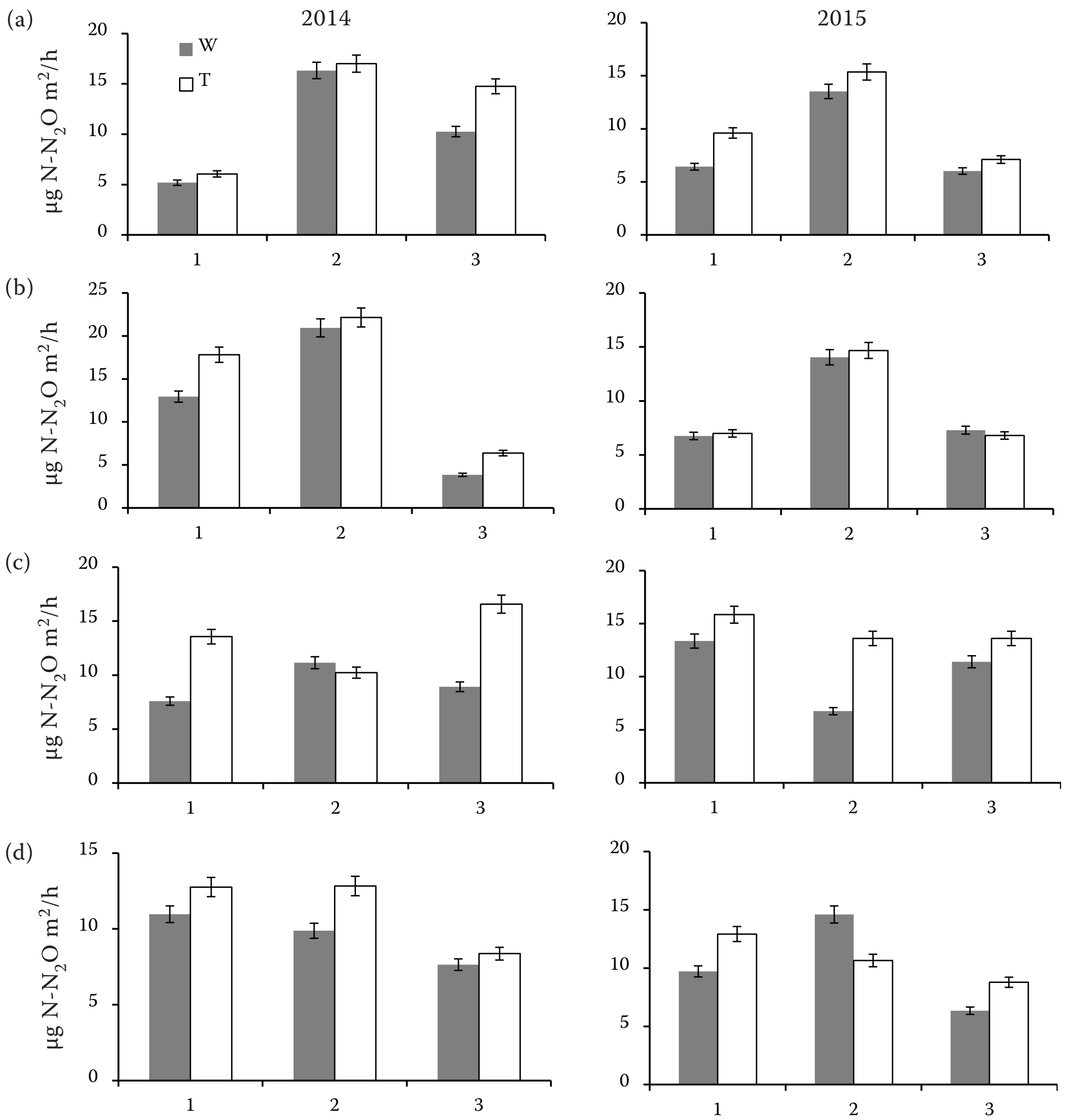

Figure 2. N_2O emission from soil depending on the tillage method and test date in (a) Żelazna; (b) Baborówko; (c) Grabów, and (d) Czesławice. 1, 2, 3 – test date; T – conventional (plough) tillage; W – reduced (ploughless) tillage

In all the experiments, in the conventional cultivation and fertilization system, N_2O emissions from the soil were higher on average about 17% in 2014 and 22% in 2015 than in the ploughless cultivation system with subsurface application of fertilizers.

Regardless of the year and localization of the experiments, the higher N_2O emission from the

Table 4. Effect of ploughless and conventional tillage on N_2O emission from soil (μg N-N_2O m^2/h)

Cultivation and fertilization		Żelazna	Baborówko	Grabów	Czesławice	Average
2014	conventional (plough) tillage	10.69^b	11.13^b	14.36^b	12.06^b	12.06^b
	reduced (ploughless) tillage	8.66^a	9.26^a	8.30^a	10.54^a	9.19^a
2015	conventional (plough) tillage	10.43^b	9.48^a	12.51^b	10.78^b	10.80^b
	reduced (ploughless) tillage	9.18^a	9.60^a	7.50^a	9.22^a	8.87^a

[a,b]the same letters indicate homogenous groups

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soil was observed in conventional tillage compared to reduced tillage (Table 4). In 2014, in the ploughless system with subsurface application of fertilizers, the N-N_2O emission from the soil in Czesławice was slightly higher than in Żelazna and Baborówko, while the lowest amounts of N_2O were emitted from the soil in Grabów. In conventional tillage the highest emission N-N_2O was observed in Grabów and the lowest in Żelazna. In 2015, in the ploughless system with subsurface application of fertilizers, the lowest N-N_2O emission from the soil was observed in Grabów. At the same time, this place was characterized by the highest emission of N-N_2O in conventional cultivation.

In 2014, regardless of the method of soil cultivation and plant fertilization, more N_2O was emitted from the soil in Żelazna, Baborówko and Czesławice on the second test date than on the other dates (Figure 2). In Grabów, in the conventional cultivation and fertilization system, N_2O-N emission from the soil was the lowest in the second test dates. In the ploughless system with subsurface application of fertilizers, the emission of this gas on the second test date was higher than on the first and third test date. In 2015, in Żelazna and Baborówko, an increase in N_2O emission from the soil was observed between the first and the second test date, and a decrease on the third test date. In Czesławice, the emissions on the first and second test date were at a similar level and decreased on the third test date. In Grabów, however, the N_2O emission from the soil in the field under conventional cultivation and fertilization was the lowest on the second test date. On the same date, the observed N_2O emission from the soil under reduced tillage was the highest.

In our researches N_2O emission was not dependent on crop yield but on cultivation system and meteorological conditions. The higher emission of this gas was observed in 2014, which was characterized by a greater amount of precipitation in the vegetation period compared to 2015.

DISCUSSION

Depending on the year and location of the study, the N_2O emission from the soils in the experiments ranged from 8.30 to 14.36 μg N-N_2O m^2/h. The measured N_2O emission was lower in the reduced tillage system with subsurface fertilizer application than in the conventional one (Table 4). Many authors concluded that deep placement of N fertilizer could be an effective means to reduce N_2O emissions in no tillage systems (van Kessel et al. 2012, Linquist et al. 2012, Millar et al. 2014). Experiments were conducted on light soils (except Czesławice), which, despite compaction, retain a considerable volume of large air-filled pores, and most of all are characterized by low ability to soak up and retain water. Therefore, in dry years, higher N_2O emissions are not associated with soil compaction (Sosulski et al. 2014, 2015). In addition, a significant factor limiting the emission of this gas from the soil could have been amounts of simple organic compounds released during the mineralization of organic matter insufficient for the denitrification process.

In field experiments with surface application of organic matter, Smith et al. (2012) obtained N_2O emissions at a level of 26.4 μg N-N_2O m^2/h. By introducing organic matter below the surface, they found a significant increase in N_2O emissions, reaching up to 237.7 μg N-N_2O m^2/h. Bayer et al. (2015) did not observe the effect of soil tillage on the changes in the amount of N_2O emission to the atmosphere. They only found an increase in N_2O emission when crop residues were introduced into the soil. Similarly, in this study, in all the experiments with the conventional system of soil tillage and maize fertilization in which crop residues were mixed with the soil, N_2O emissions were higher (by about 23% in 2014 and 22% in 2015, on average) than in the reduced (ploughless) tillage system with subsurface application of fertilizers (Table 4).

As has been shown in many studies, the increase in N_2O emission over time is usually caused by increasing soil compaction in the reduced tillage system and, as a result, the promotion of denitrification (Bayer et al. 2015). However, some authors recorded higher N_2O emissions under reduced tillage compared to the conventional plough tillage (Mangalassery et al. 2014). Van Kessel et al. (2013) showed that on clay soils, after changing over from conventional to reduced tillage, N_2O emissions increased significantly in the initial period of up to 10 years. After 10 years of reduced tillage, they observed a significant decrease in the emissions compared to plough cultivation. They explained these changes by accumulation of organic matter, which, by improving soil texture, limits the intensity of denitrification.

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Dos Santos et al. (2016) indicate that, apart from the amount of organic matter, the increase in N_2O emission is also correlated with the increase in soil moisture. Immediately after rain, the pores in the soil become filled with water, which creates anaerobic conditions in the soil and contributes to an increase in N_2O emissions. In our research, N-N_2O emission was higher in 2014, which was characterized by higher precipitation (Table 4, Figure 1). Also, Snowdon et al. (2013) showed that the increase in N_2O emission was observed after atmospheric precipitation. At the same time, they pointed out that the increase in N_2O emission at the beginning of the growing season is caused by the application of nitrogen fertilizers.

Our research indicates that independently on soil texture and organic matter content reduction in tillage is a main factor significantly limiting N_2O emission.

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