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Impact of reduced tillage on CO_2 emission from soil under maize cultivation

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ABSTRACT

Carbon dioxide is an important greenhouse gas, which is released through human activities such as deforestation, burning fossil fuels, agriculture, and degradation of soil. The type of soil tillage systems has a very important impact on soil CO_2 emissions. Usually higher soil CO_2 emission have been observed under conventional tillage compared to reduced tillage. Maize is one of the main cereals grown around the world that reacts positively on conservation tillage. We hypothesized that reduced tillage with sub-soil fertilizer application could increase maize yield and reduce carbon emissions compared to conventional plowing. Therefore we studied CO_2 emissions from soil under a conventional and innovative, environmentally safe, low-cost maize production system dedicated both to reduce time and resources and to manage the field sustainably with a lower CO_2 footprint. We observed that the magnitude of grain yield depended on soil and climate conditions but not on the cultivation system. The CO_2 emission level depended on the year of the study and the soil tillage method and was subject to considerable changes during the growing season. The use of reduced soil tillage significantly limited emissions of the analyzed gas into the atmosphere. Depending on the year of the study, CO_2 emissions in the reduced tillage system were 7 to 35% lower than those in the conventional system. The extent of the reduction in CO_2 emissions achieved under reduced tillage is very large relative to conventional tillage, which is probably due to the relatively low organic matter content of the both investigated soils in the conventional tillage. We could show that on sandy soils with a low organic matter content reduction in tillage is a factor significantly diminishing CO_2 emissions.

1. Introduction

Carbon dioxide and nitrous oxide are basic greenhouse gases (Krištof et al., 2014). In 2015, a total of 10.7 billion tonnes of CO_2 were produced. In global CO_2 emissions, China's share is around 30%, the USA's 14%, and the European Union's 10% (Olivier et al., 2016). In the EU, greenhouse gas emissions from agriculture decreased from 617 million tonnes of CO_2 equivalent in 1990 to 469 million tonnes of CO_2 equivalent in 2012, which is a reduction of about 23%. However, the share of agriculture in total greenhouse gas emissions during that period decreased only slightly, from 11% in 1990 to 10% in 2012 (Olivier et al., 2016). In greenhouse gas emissions from agriculture, the largest share is ascribed to the emissions from arable soils (5.27%), followed by animal intestinal fermentation (3.21%) and emissions associated with the utilization of livestock excreta (1.58%) (EAT, 2015; Philippe and Nicks, 2014). Because the reduction in total CO_2 emissions in agriculture is small, methods of reducing them are constantly being sought (Muñoz et al., 2010). A reduction in 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 such as energy crops, (iii) improved crop- and grassland management which offers the possibility to sequester significant amounts of carbon in the soil, (iv) afforestation of agricultural land (Frank et al., 2017). Agronomic factors influencing CO_2 emission into the atmosphere include the method of soil cultivation, introduction of organic matter, and mineral fertilization (Krištof et al., 2014; Lu et al., 2015). Transformations of carbon compounds are directly related to the microbial activity of the soil. Different types of soil cultivation are a fundamental treatment modifying this activity, and at the same time greenhouse gas emissions. Increasingly, there appear methods of reduced tillage in agriculture, which, on the one hand, improve soil structure and lower soil temperature, thereby limiting greenhouse gas emissions. Tillage has a very important impact on soil CO_2 emissions. Conventional tillage may result in a loss of about 50% of organic carbon content due to the stimulation of the organic matter oxidation and mineralization processes. Many authors have determined higher soil

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CO_2 emissions under conventional tillage compared to no-tillage, an increase in soil organic carbon content and lower soil CO_2 emissions on no-tilled soils compared to conventionally tilled soils. Reduced tillage limits the diffusion and amount of air-filled pores in the soil, by which soil CO_2 emissions are very low or non-existent (Hu et al., 2015; Ussiri and Lal, 2009).

Conservation tillage is increasingly used in crop production due to its environmental and economic advantages over traditional moldboard plowing systems. However, zero tillage does not always produce equivalent crop yields especially in climates with sub-optimal soil temperatures, cold springs, and poorly drained soils (Salem et al., 2015; Hu et al., 2015; Yadav et al., 2016).

We tested the hypothesis that reduced tillage with sub-soil fertilizer application could increase maize yield and reduce carbon emissions compared to a conventional mouldboard plowing system. Therefore, the objectives of this study were: (i) to compare the effects of conventional and reduced tillage on maize yield, and (ii) to determine soil CO_2 emission during the maize growing season as affected by tillage practices.

2. Materials and methods

2.1. Site, treatments, and experimental design

The study on CO_2 emission from the soil was conducted in 2014–2015. It was conducted under the conditions of field experiments located at two experimental stations in Żelazna (belonging to Warsaw University of Life Sciences) and Czesławice (belonging to University of Life Sciences in Lublin) (Table 1). The two places were selected for this study because they significantly differ in soil properties. Weather conditions in the vegetation period (May-September) in 2014 were similar in both locations. The sum of precipitation in that period was 494 mm in Czesławice and 349 mm in Żelazna, and the average temperature was the same – 16.7° C. In 2015 (vegetation period) the sum of precipitation in Czesławice was 270 mm and in Żelazna 167 mm. Very low precipitation occurred in June (14.6 mm) and August (7.6 mm) in Czesławice. The lowest precipitation in Żelazna was found to occur in August (18.1 mm) and in September (29.3 mm). Czesławice was characterized by the highest precipitation in September (135.1 mm) (Fig. 1).

In the year 2012, preceding the establishment of the field experiments lime was applied on the entire experimental area of 2 ha at a dose of 1.43 t Ca ha^{-1} (as $CaCO_3$, $MgCO_3$ 60% CaO) and potassium fertilization at a dose of 265.0 kg K ha^{-1} (high-grade potassium salt KCl 48% K). In 2013 the crop cultivated in the experimental fields was maize, cultivar Magello, grown for grain. In the years 2014 and 2015 two maize cultivation systems were applied: conventional (plow) tillage, and reduced (plowless) tillage (Fig. 2). In both cultivation systems seeding depth was 5 cm, row spacing 75 cm, number of plants per hectare 80 000. In both years corn was planted during the last week of April.

The maize was fertilized with nitrogen at 120 kg N ha^{-1} and phosphorus at 26 kg P ha^{-1}. In the conventional 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 reduced tillage system granular nitrogen and phosphorus fertilizer was applied below the soil surface in the form of UreaPhoS(Micro) produced at the New Chemical Syntheses Institute in Puławy (INS), with the following chemical composition in g kg^{-1}: N – 200, P – 43.6, S – 70, Cu – 1.5, Zn – 3, B – 0.6. A dose of 600 kg ha^{-1} of UreaPhoS (Micro) was applied, which corresponds to 120 kg N ha^{-1} and 26 kg P ha^{-1}. The Industrial Institute of Agricultural Engineering in Poznań has designed and built a research model of a machine for strip tillage, fertilization and corn sowing (Strip-Till). The fertilizer was applied by means of a soil cultivating seed drill (Strip-Till) 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 a depth of 5 cm and small fertilizer granules (4 mm) were put 10 cm into the ground (Talarczyk et al., 2016).

2.2. Data collection

2.2.1. Determination of soil properties

In the year 2012 preceding the establishment of the field experiments main physical and chemical properties of the soil were determined. Granulometric composition was analyzed by sieving and sedimentation method (ISO 11277: 2009). Core samples of 100 cm^3 volume were taken at a depth from 0 to 5 cm with a steel core sampler for dry bulk density (ISO 11272: 2017) and water holding capacity (ISO 11465: 1993).

Soil samples for the basic chemical and physical soil analyses were taken with a steel soil probe from the depth of 0–20 cm according to ISO 10381-1:2002. Soil samples were air dried and sieved to < 2 mm. Soil samples were characterized for: pH – by potentiometric method after extraction with 1 mol dm^{-3} KCl (ISO 10390:2005), total organic carbon after dry combustion (ISO, 10694:1995), total nitrogen by modified Kjeldahl method (ISO 11261: 1995), available P and K by Egner-Riehm (DL) method (PN-R-04023:1996; PN-R-04022:1996), and available Mg by the Schachtschabel method (PN-R-04020:1994)

2.2.2. Determination of plant dry mass

Plants were harvested at the growth stages of 8–9 leaves, panicle emergence, and milk grain maturity in 2014 and 2015. Nine plants were harvested from the middle rows of each plot. From this sample, biomass was measured by drying the plants at 80 °C to constant weight.

2.2.3. Determination of CO_2 emission

Measurements of CO_2 emission 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. Measurement of CO_2 emissions from the soil was preceded by 10 min ventilation of the measuring chamber (ø = 29.5 cm, h = 20 cm) by atmospheric air, placing the chamber at a height of 1 m above the

Table 1
Properties of the soils in field experiments in 0–20 cm soil layer.

Field	Soil	Soil texture			WHC[a]	BD[b]	pH	P	K	Mg	Corg	Nt	C:N
					(%)	(g cm^{-3})			(mg kg^{-1})		(g kg^{-1})		
Żelazna 51°52′N 20°6′E	Luvisoil	Loamy sand			20.29	1.57	6.30	69.50	82.80	96.23	5.40	0.52	10.40
		Sand (%) 87	Silt (%) 6	Clay (%) 7									
Czesławice 51°17′N 22°12′E	Haplic Luvisol	Silt loam			32.17	1.49	6.49	163.21	142.31	106.71	18.82	1.69	11.13
		Sand (%) 15	Silt (%) 74	Clay (%) 11									

[a] Water holding capacity (WHC) in 0–5 cm soil layer.
[b] Bulk density (BD) in 0–5 cm soil layer.