Original Research

Modeling Impact of Climate Change and Management Practices on Greenhouse Gas Emissions from Arable Soils

Alina Syp*, Antoni Faber, Jerzy Kozyra, Robert Borek, Rafał Pudełko, Magdalena Borzęcka-Walker, Zuzanna Jarosz

Department of Agrometeorology and Applied Informatics, Institute of Soil Science and Plant Cultivation, State Research Institute, Czartoryskich 8, 24-100 Puławy, Poland

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Abstract

Greenhouse gas emissions (GHG) were simulated from commonly used crop rotations in eastern Poland for conventional and conservation tillage systems. We used denitrification-decomposition (DNDC) model baseline climate conditions and two future climate scenarios (2030 and 2050). Analyzed cropping systems included corn, rapeseed, and spring and winter wheat. It has been shown that an increase of temperature and decrease of precipitation can reduce net global warming potential (GWP) by 2% in the 2030 climate scenario and by 5% in the 2050 scenario in conventional tillage with reference to the baseline scenario. In the case of conservation tillage, a reduction of GWP by 5% and by 10% was estimated. The use of conservation tillage results decrease the GWP by 17-19% in the baseline scenario, in the 2030 scenario by 16-18%, and in the 2050 scenario by 15-17%. It also has been shown that change in climate conditions has declined biomass production of winter wheat and corn, which may suggest that a larger area would be needed for these crops to maintain production at the same level.

Keywords: greenhouse gas emission, DNDC, nitrous oxide, carbon sequestration, tillage

Introduction

Agricultural lands occupy about 40-50% of the Earth's land surface. Because of their dimension and intensity, agricultural practices emit a large amount of greenhouse gases into the atmosphere, which presently accounts for about 60% of nitrous oxide (N_2O) and about 50% of methane (CH_4) [1]. There is limited information available regarding the effects of tillage practices on greenhouse gas (GHG) emissions in Poland. Assessment of the total GHG budget of tillage agricultural systems should take into account emissions of carbon dioxide (CO_2), N_2O, and CH_4. Emissions of CO_2 can be greater from tillage soils due to growth of microbial mineralization of plant residues. N_2O is formed by the microbial transformation of nitrogen in soils and manures, and the emission is often enhanced in areas where available nitrogen (N) exceeds plant requirements, especially under wet conditions [2]. According to FAO [3], agricultural N_2O emissions are projected to rise by 35-60% up to 2030 due to increased nitrogen fertilizer use and increased animal manure production. CH_4 is emitted under oxygen-deprived conditions, especially when soil water content is high.

*e-mail: asyp@iung.pulawy.pl

In many regions of the world, there is a growing concern about soil productivity and influence of the management practices on the environment [4]. Examples of such practices are two tillage systems: conventional and conservation. Conventional tillage is defined as the mechanical manipulation (ploughing, disking, and hoeing) of the topsoil, which leaves no more than 15% of the ground cover with crop residues. Such tillage tends to disrupt the soil structure, accelerating the decomposition of soil organic matter and making the bared topsoil vulnerable to erosion by rain and wind [5]. The alternative for conventional tillage is conservation tillage. The European Conservation Agriculture Federation (ECAF) defines conservation tillage as soil management practices that minimize the disruption of the soil's structure, composition, and natural biodiversity, thereby also minimizing erosion and degradation, and water contamination [6]. There has been a rising interest recently in the impact of conservation tillage practices on carbon sequestration. According to Holland [7], agriculture can act both as a sink and a source of CO_2 emissions and the use of conservation practices by agriculture could decrease this emission. Coverage of the soil surface with straw and cover crops increases biomass productivity and turns the soil into a tremendous carbon sink. Reducing the intensity of soil cultivation lowers energy consumption and the emission of carbon dioxide, while carbon sequestration is raised through the increase of soil organic matter (SOM) [7]. On the basis of long-term experiments, West and Post concluded that conversion of conventional tillage to no-till sequesters an average of 0.57 ± 0.14 t $C \cdot ha^{-1} \cdot yr^{-1}$ [8].

Long-term field experiments are the most reliable source information about GHG emissions from different agricultural systems. However, they are difficult to manage and limited by time and costs [9]. Simulation models provide an alternative method of assessment of agricultural practices effects [10]. Many models have been developed to describe the responses of crop growth, soil water dynamics, and soil biogeochemistry such as Roth C [11] for organic carbon turnover, CENTURY [12] or DNDC [13, 14] for carbon and nitrogen cycles. The review of models simulating N_2O emissions from agricultural lands has been made recently by Chen et al. [15].

Methods

The general approach of this study is to estimate the impact of climate change on GHG emissions under different management practices using the DNDC (denitrification-decomposition) biogeochemistry simulation model. Comparison of DNDC model outputs for baseline climate (1971-2000) and future climate scenarios for 2030 and 2050 provides insight into how gas emissions (N_2O, CH_4, and CO_2) may change under global warming and in different crop management practices. All emissions output data were estimated by averaging simulations for the 100-year stochastic climate series following changes in agricultural management, which is described below in detail. In the study, future N_2O, CH_4, and CO_2 fluxes were estimated from commonly used crop rotation in eastern Poland under conventional (mouldboard plowing) and conservation tillage (chisel plowing). In this paper, "tillage" is used for conventional tillage, and "reduced tillage" for conservation tillage.

One 4-year crop rotation has included corn, rapeseed, and spring and winter wheat, where emissions were estimated per hectare for each crop. GHG emissions were expressed in kilograms of carbon dioxide equivalents (kg CO_2 eq. ha^{-1}) using the assumed global warming potential (GWP) for CO_2, CH_4, and N_2O of 1, 23, and 298 over a 100-year time horizon [16]. According to our knowledge, this is the first study in Poland that has estimated the effects of future climate changes and management practices on GHG emissions from arable soils.

DNDC Model

The DNDC model has been developed since 1992, when it was applied to simulate N_2O emissions from cropped soils in the USA [13]. Since its initial development, other researchers have modified the model to adapt it to different production systems. The DNDC model has been widely used for regional modeling studies, i.e. in Europe [13, 14, 17, 18], the USA [9, 19], Canada [20-22], China [23, 24], and India [25]. DNDC consists of six sub-models for simulating soil climate, plant growth, decomposition, nitrification, denitrification, and fermentation. To simulate trace gas emissions for a specific site, DNDC requires a number of input parameters including daily meteorological data (max. and min. temperatures, precipitation), soil properties (SOC content, clay content, pH, and bulk density), and farming management measurements (tillage, mineral fertilization, manure, and crop rotation). However, the model does not take into account fuel use. DNDC model calibration was carried out comparing the measured and modeled yield values on the basis of real data from Grabów Experimental Station. The relative root mean squared error (RRMSE) with the respect to biomass yield was 15%. DNDC (version 9.2) was used with calibrations developed in DNDC-Europe (http://afoludata.jrc.ec.europa.eu/index.php/models/files/5).

Study Region Characteristics

The domain of interest is Grabów Experimental Station (51º21'N, 21º40'E and 167 m above sea level). The station conditions are assumed to be representative for eastern Poland. The soil type in Grabów was loamy sand. Input soil parameters for DNDC were assumed as follows: bulk density – 1.5 $g \cdot cm^{-3}$, soil pH – 7, clay fraction – 0.09, and initial value of SOC (soil organic carbon) was 0.01 kg $C \cdot kg^{-1}$ of soil. Crop rotation in the studies was representative for the region.

The climate model simulations for the baseline period (1971-2000) and for the future climate (2030 and 2050) were prepared as part of activity COST 734 Action: Impacts of Climate Change and Variability on European

Table 1. Crop rotations and quantity of fertilizer applied.

Crop type:	Corn	Spring wheat	Rapeseed	Winter wheat
Manure amended (kg C/ha/yr)	0	0	2000	0
Fertilizer N (kg N/ha/yr)	120	120	180	140
Manure N (kg N/ha/yr)	0	0	40	0
Planting	1.05	1.04	15.08	15.09
Harvesting	20.10	3.08	20.07	3.08

Table 2. Monthly mean climate statistics for baseline climate (1971-2000) and deviation from baseline for 2030 and 2050 climate (future-baseline).

Month	1971-2000		2030		2050	
	Baseline climate		Deviation from baseline		Deviation from baseline	
	T_{mean} (ºC)	Precipitation (mm)	T_{mean} (ΔºC)	Precipitation (% change)	T_{mean} (ΔºC)	Precipitation (% change)
1	-2.9	30.4	1.6	5.	2.8	4.7
2	-1.0	26.2	1.2	7.3	2.1	5.7
3	3.1	35	0.9	6.0	1.6	4.9
4	8.0	40.3	0.6	12.9	1.2	10.8
5	13.4	63.8	0.5	3.6	0.9	2.6
6	16.3	82.4	0.7	-0.7	1.3	-0.2
7	18.0	82.5	0.8	-6.1	1.5	-4.6
8	17.7	72.4	1.0	-10.9	1.8	-9.0
9	13.3	70.8	0.9	-8.6	1.7	-6.8
10	8.6	50	1.2	-0.8	2.1	-0.8
11	2.6	41	0.9	-4.1	1.6	-3.1
12	-0.5	36.9	1.3	6.0	2.4	4.3
Annual mean	8.1	631.6*	1.0	-1.0	1.7	-0.4

*Annual total

Agriculture – CLIVAGRI, particularly as a special activity of WG4 Risk Assessment and Foreseen Impacts on Agriculture (www.cost734.eu). The data from Grabów Weather Station (1971-2000) were used to train the stochastic weather generator M&rfi [26], to calculate 100-year stochastic weather series of daily sum of global radiation, maximum and minimum temperatures, sum of precipitation, daily mean air humidity, and wind speed. The data were assumed for a baseline climate scenario called C2000 [26-28]. The weather generator parameters for the future climate (2030 – scenario C2030 and 2050 – scenario C2050) were modified according to the ECHAM5/MPI-OM GCM, with the SRES-A2 emissions scenario for the IPPC Fourth Assessment Report [1]. More details on the SRES (Special Report on Emissions Scenarios) may be found in Nakićenović et al. [29], and additional details (including model validation) concerning the construction of the GDM-based climate scenarios for the climate change studies can be found in Dubrovský et al. [28].

Table 1 lists the quantity and type of fertilizer applied for each crop in each scenario. All the input parameters were constant in alternative scenarios (C2030 and C2050). The DNDC model was run for each scenario to simulate an annual flux of N_2O, CH_4, and CO_2 for the tested site.

Results and Discussion

Climate Change Projections

According to the generated data, the baseline mean annual air temperature (1971-2000) was 8.1ºC (C2000, Table 2). Under climate scenario C2030, average annual temperature increased by 1ºC, while under 2050 climate scenario C2050 by 1.7ºC. Temperature increases were observed during all months, with highest increases in January (1.6ºC for 2030, 2.8ºC for 2050) and lowest increases in May (0.5ºC for 2030, 0.9ºC for 2050) (Table 2).

Table 3. Estimated average annual N_2O, CH_4, and CO_2 emissions (or uptake) for 4-year complete crop rotation cycles for different climate scenarios and management practices.

	N_2O-N (kg N ha^{-1})*		CH_4-C (kg C ha^{-1})*		CO_2-C (kg C ha^{-1})*	
Scenario	Tillage	Reduced tillage	Tillage	Reduced tillage	Tillage	Reduced tillage
C2000	3.18±2.3a	2.80±1.9a	-0.73±0.05e	-0.81±0.07c	-140±2264a	-278±1923a
C2030	3.00±2.2a	2.65±1.9a	-0.78±0.05 d	-0.87±0.07b	-120±2386a	-255±2041a
C2050	2.86±2.1a	2.48±1.7a	-0.82±0.05c	-0.92±0.07a	-110±2488a	-244±2143a

*Within each column crop, scenario and management practices followed by the same letter are not significantly different at P<0.05 (Tukey HSD test).

The baseline mean yearly precipitation in Grabów according to generated data was 631 mm (C2000). The mean yearly precipitation for the future climate was simulated to decrease only 1.0% in scenario C2030 and about 1.2% in scenario C2050. It is very important for crop productivity in Poland using climate scenarios to predict an increase of precipitation sum in winter season (from December to May) and a decrease in growing season months (from June to November). The highest increase of precipitation sum was predicted in April (12.9% for C2030, 10.8% for C2050), and the highest decrease in August (-10.9% for C2030, -9.0% for C2050).

N_2O Emissions

Average cumulative annual soil N_2O emissions, estimated for a 4-years crop rotation cycle using the DNDC model were different for each climate scenario and tillage system. In the tillage system, in the C2030 scenario with an increase of temperature by 1ºC and a decrease of precipitation by 1%, N_2O emissions decreased by 6% compared with C2000. A further increase of temperature and decrease of precipitation in the C2050 scenario results in the reduction of N_2O emissions by 10% with relation to C2000 (Table 3). Under reduced tillage these differences were 6 and 11%, respectively, for C2030 and C2050 scenarios. However, there were no significant differences between scenarios (P≤0; α=0.05).

The impact of cultivation system on N_2O emissions was based on the changes from tillage (TL) to reduced tillage (RTL) in each scenario (Fig. 1a, b, c). Regression equations for N_2O emissions for C2000 (1), C2030(2), and C2050 (3) are:

1. $N_2O_{(RTL)} = 0.79 N_2O_{(TL)} + 138.71$ $R^2 = 0.90$
2. $N_2O_{(RTL)} = 0.82 N_2O_{(TL)} + 96.87$ $R^2 = 0.91$
3. $N_2O_{(RTL)} = 0.80 N_2O_{(TL)} + 88.97$ $R^2 = 0.92$

...where $N_2O_{(RTL)}$ and $N_2O_{(TL)}$ are N_2O emissions in kilograms of CO_2 equivalents per hectare under reduced tillage and tillage, respectively. The high values of R-squared statistics indicated a strong relationship between both tillage systems. In all climate scenarios there were statistically significant relationships between reduced tillage and tillage systems (P≤0.00; α=0.05). Standard error for each scenario was 0.02. The use of reduced tillage has decreased N_2O emissions by 19-23% in C2000, 16-20% in C2030, and 18-22% in C050. Jacinthe and Dick [33] and Kessavalou et al. [34] reported similar results in their studies. According to Grant et al. [12] the change of tillage system from conventional to no-till resulted in 17% fewer emissions of N_2O in Canada. The lower emissions of N_2O were the effect of slightly decreased microbiological activity. The difference comes from the fact that tillage disturbs structure, increases aeration, and releases more substrates for decomposition [12]. Two-factor Anova showed that crop type had a statistically significant effect on N_2O emissions in both management practices (P≤0.0;

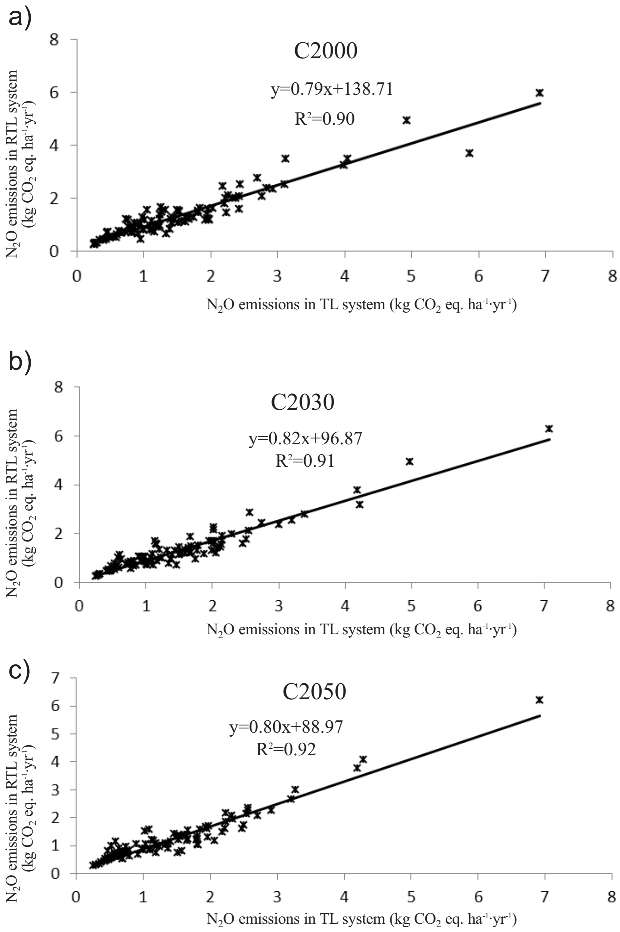

Fig. 1. Comparison of N_2O emissions between tillage and reduced tillage in scenarios: C2000 (a), C2030 (b), and C2050 (c). Abbreviations: TL – tillage system; RTL – reduced tillage system.

Table 4. Estimated average annual N_2O, CH_4, and CO_2 emissions in 4-year cropping systems for different climate scenarios and management practices.

Crop	Scenario	N_2O-N (kg N ha^{-1})*		CH_4-C (kg C ha^{-1})*		CO_2-C (kg C ha^{-1})*	
		Tillage	Reduced tillage	Tillage	Reduced tillage	Tillage	Reduced tillage
Corn	C2000	5.48±2.5a	4.51±2.4a	-0.73±0.04e	-0.81±0.06cd	933±937abc	286±956c
	C2030	5.39±2.5a	4.48±2.5a	-0.78±0.04 d	-0.87±0.06b	1,321±921ab	673±941bc
	C2050	5.2±2.4a	4.28±2.3a	-0.83±0.04 bc	-0.93±0.06 a	1,551±949a	905±961abc
Rapeseed	C2000	20.89±20.2abc	32.86±18.9c	-0.73±0.04e	-0.82±0.07cd	-2,447±713abc	-2,022±804a
	C2030	16.78±20.2ab	30.56±17.6bc	-0.78±0.04d	-0.88±0.06b	-2,781±703bc	-2,440±837ab
	C2050	14.48±20.4a	29.86±17.3abc	-0.82±0.04c	-0.93±0.06a	-3,054±689c	-2,704±827bc
Spring wheat	C2000	3.16±0.9bc	2.51±1.0ab	-0.71±0.05c	-0.8±0.07b	2,824±795a	2,704±827a
	C2030	3.16±0.7bc	2.44±0.8a	-0.76±0.05bc	-0.86±0.07a	2,786±8425a	2,349±866a
	C2050	3.2±0.7c	2.39±0.7a	-0.81±0.05b	-0.91±0.08a	2,783±847a	2,363±860a
Winter wheat	C2000	1.59±1.29a	1.63±1.35a	-0.73±0.05e	-0.82±0.07cd	-1,868±328b	-1,725±314ab
	C2030	1.35±0.81a	1.41±0.82a	-0.78±0.05d	-0.87±0.07b	-1,807±344b	-1,642±307ab
	C2050	1.20±0.46a	1.24±0.39a	-0.83±0.05 bc	-0.93±0.07a	-1,721±324ab	-1,541±285a

*Within each column, crop, scenario, and management practices followed by the same letter are not significantly different at $P<0.05$ (Tukey HSD test).

α=0.05), while average emission rates of climate scenarios were not significantly different from each other ($P\leq0.367$ and $P\leq0.331$; α=0.05, respectively for tillage and reduced tillage).

Generally, the highest N_2O N-emission rates were found in the tillage system for all crops except for rapeseed (Table 4). The highest yearly N_2O emission rates were predicted for baseline scenarios C2000. The emission under rapeseed for tillage was 20.89 N_2O-N kg·ha^{-1}·yr^{-1}, whereas for reduced tillage it was 32.86 N_2O-N kg·ha^{-1}·yr^{-1} (Table 4). Respectively, in scenario C2030, the emissions were estimated at 16.78 and 30.56 N_2O-N kg·ha^{-1}·yr^{-1}. In scenario C2050, the N_2O fluxes were 14.48 and 29.86 N kg·ha^{-1}·yr^{-1}, but the differences between emissions were not statistically significant. The estimated values of N_2O fluxes in all scenarios for corn, and spring and winter wheat were much lower than for rapeseed. The lowest average values of N_2O emissions were estimated for winter wheat in scenario C2050 as 1.2 and 1.24 N kg·ha^{-1}·yr^{-1}, for tillage and reduced tillage, respectively (Table 4). They were nearly 50% lower than the values for spring wheat. According to Flessa et al. [30], annual emission rates from arable soils can be in the range from 0.1 up to 150 kg N·ha^{-1}·yr^{-1}, but generally they are lower than 5 kg N·ha^{-1}·yr^{-1}. Grant et al. [12] estimated average N_2O emissions in Canada at 1.49 kg N·ha^{-1}·yr^{-1}. Freibauer and Kaltschmitt [31] found that the emissions from European cropland soils are generally below 3 kg N·ha^{-1}·yr^{-1}. Bouwman et al. [32] reported that emissions of N_2O from fertilized soils typically lie in the range of 1-3 kg N·ha^{-1}·yr^{-1}. The estimated N_2O fluxes in our study were in these ranges (Tables 3, 4), except for emissions under corn

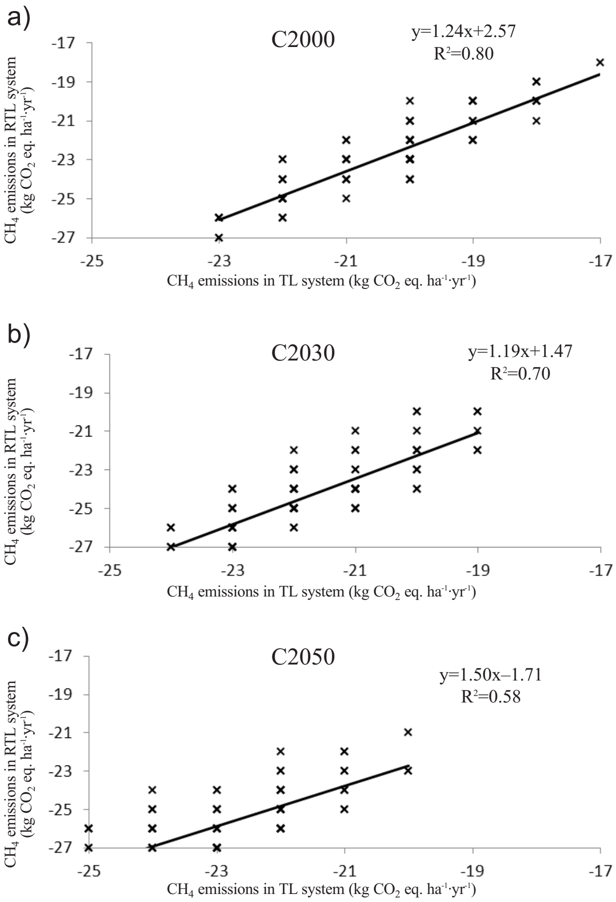

Fig. 2. Comparison of CH_4 emissions between tillage and reduced tillage in scenarios C2000 (a), C2030(b), and C2050 (c). Abbreviations: TL – tillage system; RTL – reduced tillage system.

and rapeseed (Table 4). As for climate changes, the increase of temperature and decrease of precipitation had an impact on N_2O emissions.

CH_4 Emissions

Net methane uptake was in all scenarios under tillage and reduced tillage. Absorption of methane was about 10% higher in reduced tillage compared with tillage. A combination of the rise of temperature and decline of precipitation resulted in the increase of uptake of methane under all scenarios (Table 4). The differences between scenarios were statistically significant. The higher CH_4 uptake rates under reduced tillage are comparable with Venterea et al. studies [35]. According to Ball et al. [36], this effect has been attributed to a more stable porous soil structure under reduced tillage that simplify CH_4 diffusion into oxidizing zones, and to negative effects of tillage on methanotrophic activity [34, 37]. The impact of a cultivation system on CH_4 emissions was analyzed on the basis of the regression between results from tillage and reduced tillage in every scenario (Fig. 2 a, b, c).

In all climate scenarios, there were statistically significant relationships between emissions in tillage and reduced tillage system ($P \leq 0.00$; $\alpha = 0.05$). Standard errors for scenarios were as follows: C2000 – 0.06; C2030 – 0.08, and C2050 – 0.09. The use of reduced tillage has increased on CH_4 uptake by 70-80% in C2000, 74-90% in C2030, and 85-100% in C050.

CO_2 Emissions

The DNDC model simulates carbon fluxes occurring at the interface between the atmosphere and ecosystem. In the studied complete 4-year crop rotation, assumed climate changes in future scenarios has led to lower C accumulation rates. For conventional tillage under the C2000, C2030, and C2050 scenarios, the soil accumulates 140, 120, and 110 CO_2-C $ha^{-1} \cdot yr^{-1}$, respectively, whereas under reduced tillage the numbers are 278, 255, and 244 CO_2-C $ha^{-1} \cdot yr^{-1}$ (Table 3). There were no statistical differences between scenarios and cultivation systems. The results from this study indicate that under conservation systems C sequestration were about 100% higher than under conventional tillage.

Analyzing the emissions under each crop, the highest CO_2 emission rates were under spring wheat and winter corn in both cultivation systems (Table 4). In baseline scenario C2000 under spring wheat there were emitted to the atmosphere 2,824 and 2,704 kg CO_2-C $ha^{-1} \cdot yr^{-1}$, respectively, for tillage and reduced tillage. With an increase of temperature and decrease of average rainfall sum, CO_2 emission rates under spring wheat rapeseed have decreased. There were not significant differences in simulated CO_2 fluxes between tillage and reduced tillage systems. Under corn in scenario C2030, an increase of temperature by 1ºC and decreased average precipitation by 1 mm caused an increase of emissions by 388 and 387 kg CO_2-C $ha^{-1} \cdot yr^{-1}$ for tillage and reduced tillage, respectively (Table 4). The more extreme climate scenario C2050 has deepened a further increase of emissions by 618 and 619 kg CO_2-C $ha^{-1} \cdot yr^{-1}$, for both tillage systems in comparison with baseline scenarios. It was found that rapeseed and winter wheat mitigate emissions through C sequestration. The estimated mean C sequestration rates were higher in conventional tillage than in conservation tillage systems. The C accumulation in scenario C2030 under winter wheat have declined by 61 CO_2-C $ha^{-1} \cdot yr^{-1}$ in tillage and by 83 kg CO_2-C $ha^{-1} \cdot yr^{-1}$ in reduced tillage. In scenario C2050 the C accumulation has declined by 147 and 184 kg CO_2-C $ha^{-1} \cdot yr^{-1}$ for tillage and reduced tillage, respectively. The difference was statistically significant. In contrast to winter wheat, the C accumulation under rapeseed has increased in conjunction with global warming impacts in respective scenarios: by 334-418 kg CO_2-C $ha^{-1} \cdot yr^{-1}$ in scenario C2030, and by 607-682 kg CO_2-C $ha^{-1} \cdot yr^{-1}$ in scenario C2050 (difference were statistically significant) (Table 4).

Using the same model DNDC, Li et al. [24] indicated that a change in tillage from conventional tillage to no-till, had an effect on accumulation of C-CO_2 in soil (231 kg C·$ha^{-1} \cdot yr^{-1}$ *vs.* -2,339 kg C·$ha^{-1} \cdot yr^{-1}$) due to an increase of straw and crop residue that elevated SOC accumulation rates. The C sequestration rates depend on crop rotation systems. The studies of West et al. [8] found that mean C sequestration rates for cropping systems were significantly greater than for continuous monocultures. Alvaro-Fuentes et al. [38] in long-term field experiments in Spain, in the continuous barley cropping system, has found that SOC sequestration rates were at 180 and 240 kg C·$ha^{-1} \cdot yr^{-1}$ under tillage and reduced tillage, respectively. On the basis of experimental data, van den Bygaart et al. [39] calculated an average rate of SOC for western Canada to be 320±150 kg C·$ha^{-1} \cdot yr^{-1}$, while the average rate of SOC in no-till experiments was only 50±160 kg C·$ha^{-1} \cdot yr^{-1}$. In the central USA, soil storage rates of 40±61 kg C·$ha^{-1} \cdot yr^{-1}$ were detected for reduced tillage [37].

In our research the annual changes in SOC rates were adopted as the net CO_2 emissions from soil to atmosphere. The influence of the tillage system on changes in C sequestration was analyzed on the basis of the changes from tillage to reduced tillage systems in every scenario (Fig. 3a, b, c). The high values of R-squared statistics indicated a strong relationship between both tillage systems. In all climate scenarios, there were statistically significant relationships between emissions in tillage and reduced tillage systems ($P \leq 0.00$; $\alpha = 0.05$). Standard errors for scenarios were: C2000 – 0.04, C2030, and C2050 – 0.01. The use of reduced tillage has increased C sequestration by 45-53% in C2000, 15-17% in C2030, and 14-16% in C2050.

Total Biomass of Crop

The highest total biomass was estimated for corn in tillage as well as in reduced tillage cultivation of 7,249 kg C·$ha^{-1} \cdot yr^{-1}$ (Table 5). In a baseline scenario crop biomass has decreased in the following order in both systems – corn, rapeseed, and spring and winter wheat, except for reduced

Table 5. Estimated average biomass crop in 4-year cropping systems for different climate and management practices.

Crop biomass*(kg C $ha^{-1}·yr^{-1}$)			
Crop	Scenario	Tillage	Reduced tillage
Corn	C2000	7,249±988a	7,249±988a
	C2030	7,049±960a	7,049±960a
	C2050	6,925±921a	6,925±921a
Rapeseed	C2000	6,125±710ab	5,929±649a
	C2030	6,407±667ab	6,137±593ab
	C2050	6,583±633b	6,247±549ab
Spring wheat	C2000	5,000±749bcd	4,378±551a
	C2030	5,151±747cd	4,542±563ab
	C2050	5,278±740d	4,678±571abc
Winter wheat	C2000	4,686±709a	4,541±681a
	C2030	4,564±744a	4,375±660a
	C2050	4,383±699a	4,161±604a

*Within each column crop, scenario, and management practices followed by the same letter are not significantly different at P<0,05 (Tukey HSD test).

tillage where winter wheat biomass was larger than spring wheat. With an increase of temperature and decrease of precipitation, biomass has decreased in both systems of cultivation, except rapeseed and spring wheat. The increase of crop biomass in the tillage system in scenario C2030 in comparison with baseline scenario C2000 was 282 kg C·$ha^{-1}·yr^{-1}$ for rapeseed and 151 kg C·$ha^{-1}·yr^{-1}$ for spring wheat (Table 5). The differences between scenario C2050 and C2000 were higher by 458 and 278 kg C·$ha^{-1}·yr^{-1}$ for rapeseed and spring wheat, respectively. In the reduced tillage system the increase of crop biomass was lower for rapeseed, but slightly higher for spring wheat. Winter wheat biomass has decreased by 122 and 166 kg C·$ha^{-1}·yr^{-1}$ in scenario C2030 and by 303 and 380 kg C·$ha^{-1}·yr^{-1}$ in scenario C2050, in tillage and reduced tillage respectively. In all scenarios total biomass was higher in tillage than in the reduced tillage system. Predicted climate change resulted in the decline of total crop biomass of winter wheat and corn. This means that the larger area would be needed for winter wheat and corn to maintain production at the same level.

Net Global Warming Potential

Our simulations suggest that a rise of temperature by 1ºC and decline of precipitation by 1 mm could lower GHG emissions by 2 and 3% in tillage and reduced tillage systems, respectively (at assumption of avoiding natural carbon displacement). A further increase of temperature by 0.7ºC and a decrease of precipitation by 0.4 mm can reduce emissions by 5 and 10% respectively with reference to the baseline scenario (Table 6).

Table 6. Estimated net global warming potential (GWP) for a 4-year complete crop rotation cycle for different climate scenarios and management practices.

GWP (kg CO_2 eq. $ha^{-1}·yr^{-1}$)		
Scenario	Tillage	Reduced tillage
C2000	954±8,758	265±7,315
C2030	936±9,282	273±7,806
C2050	909±9,698	237±8,187

Influence of tillage system on GWP was analyzed on the basis of the regression between results from the tillage to reduced tillage systems in each scenario (Fig. 4a, b, c). The high values of R-squared statistics indicated a strong relationship between both tillage systems. In all climate scenarios there were statistically significant relationships between emissions in tillage and reduced tillage systems (P≤0.00; α=0.05). Standard error for each scenario was 0.01. The use of reduced tillage has decreased GWP by 17-19% in C2000, 16-18% in C2030, and 15-17% in C2050.

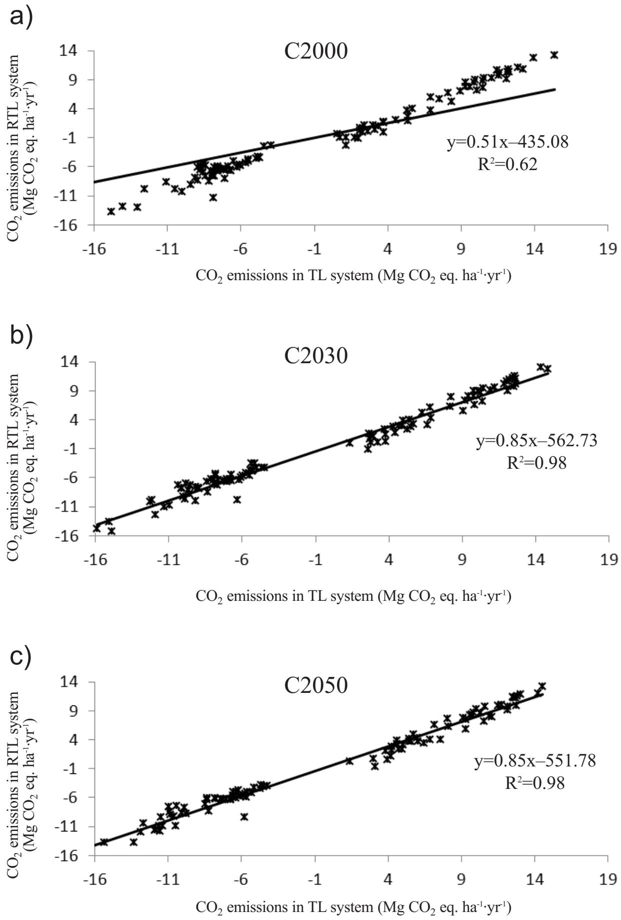

Fig. 3. Comparison of CO_2 emissions between tillage and reduced tillage in scenarios C2000 (a), C2030 (b), and C2050 (c). Abbreviations: TL – tillage system, RTL – reduced tillage system.

The modeled results suggest that reduced tillage has a positive impact on the mitigation of global warming. Similarly, working with DNDC, Li et al. [24] reported that mitigation of GWP in reduced tillage was at the average level of 91 kg CO_2 eq. $ha^{-1}\cdot yr^{-1}$ in comparison with the negative value of 1,183 kg CO_2 eq. $ha^{-1}\cdot yr^{-1}$ in tillage. According to Grant et al. [12], in Canada the average combined net GHG reduction when changing the tillage to no-till was estimated at 610 kg CO_2 eq. $ha^{-1}\cdot yr^{-1}$.

The net GWP per unit of biomass was different depending on the type of crop. The highest values of GWP were estimated for spring wheat in all scenarios in both systems. GWP for rapeseed and winter wheat was negative (Table 7).

Table 7. Estimated averaged net global warming potential (GWP) per unit biomass for 4 crops for different climate and management practices.

GWP/Crop biomass (kg CO_2 eq $ha^{-1}\cdot yr^{-1}$)			
Crop	Scenario	Tillage	Reduced tillage
Corn	C2000	0.88±0.54bca	0.48±0.54a
	C2030	1.09±0.54cd	0.69±0.54ab
	C2050	1.22±0.54d	0.81±0.53bc
Rapeseed	C2000	-1.27±0.49ab	-1.06±0.56b
	C2030	-1.45±0.44ab	-1.28±0.56ab
	C2050	-1.59±0.44a	-1.46±0.58ab
Spring wheat	C2000	2.41±0.71a	2.25±0.74a
	C2030	2.31±0.73a	2.16±0.75a
	C2050	2.25±0.68a	2.09±0.69a
Winter wheat	C2000	-1.29±0.17a	-1.20±0.19a
	C2030	-1.30±0.14a	-1.21±0.15a
	C2050	-1.30±0.12a	-1.21±0.12a

*Within each column crop, scenario, and management practices followed by the same letter are not significantly different at $P<0.05$ (Tukey HSD test).

Conclusions

1. Emissions of N_2O, CH_4, and CO_2 were affected by all assumed climate scenarios and management tillage practices.
2. The use of reduced tillage has decreased N_2O emissions by 19-23% in the C2000 scenario, 16-20% in the C2030 scenario, and 18-22% in the C2050 scenario. Increase of temperature and decrease of precipitation has reduced N_2O emissions in both conventional and conservative systems by 6% (C2030 scenario) and by 12% (C2050 scenario).
3. The highest carbon accumulation rates were found in conservation tillage. The differences were 45-53% in C2000 scenario, 15-17% in C2030, and 14-16% in C2050 compared to tillage system.
4. Reduced tillage has decreased GWP by 17-19% in C2000, 16-18% in C2030, and 15-17% in C2050 in comparison with tillage.
5. Reduced tillage has a negative effect on corn and winter wheat biomass. Therefore, in the future more land area could be required for crops to maintain production at the same level.

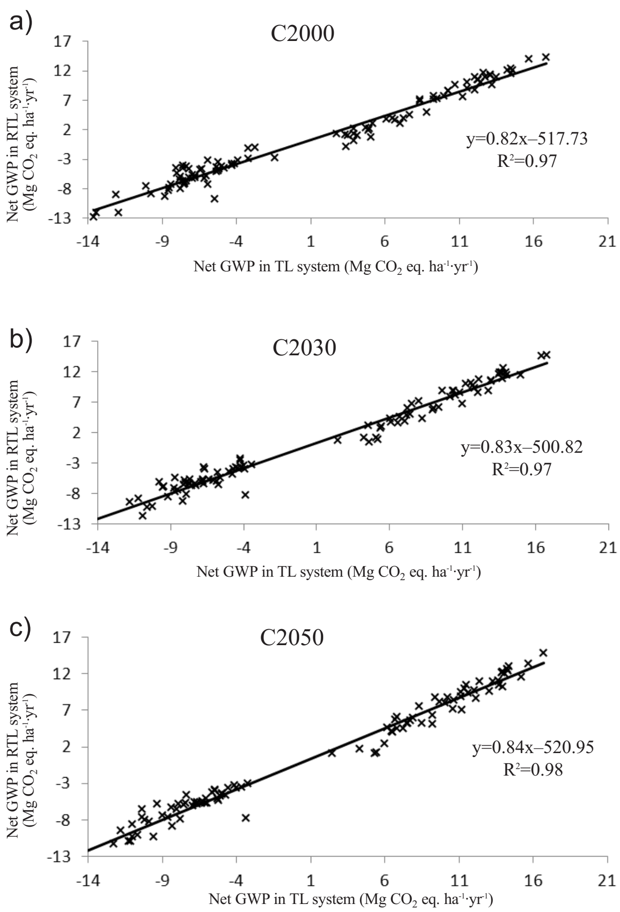

Fig. 4. Comparison of GWP between tillage and reduced tillage in scenarios: C2000 (a), C2030 (b), and C2050 (c). Abbreviations: TL – tillage system; RTL – reduced tillage system.

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