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Potentials to mitigate greenhouse gas emissions from Swiss agriculture

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ABSTRACT

There is an urgent need to identify and evaluate management practices for their biophysical potential to maintain productivity under climate change while mitigating greenhouse gas (GHG) emissions from individual cropping systems under specific pedo-climatic conditions. Here, we examined, through DayCent modeling, the long-term impact of soil management practices and their interactions on soil GHG emissions and GHG intensity from Swiss cropping systems. Based on experimental data from four long-term experimental sites in Switzerland (Therwil, Frick, Changins, and Reckenholz), we robustly parameterized and evaluated the model for simulating crop productivity, soil C dynamics and soil N_2O emissions across a range of management practices and pedo-climatic conditions. Net soil GHG emissions (NSGHGE) were derived from changes in soil C, N_2O emissions and CH_4 oxidation. Soils under conventional management acted as a net source of soil GHG emissions (1361–1792 kg CO_2eq ha^{-1} yr^{-1}) and NSGHGE were dominated by N_2O (50–63%). Reduced tillage and no-tillage reduced long-term NSGHGE by up to 31 and 58%, respectively. Organic farming, represented by organic fertilization, reduced NSGHGE by up to 31% compared to systems based solely on mineral fertilization. Replacement of slurries with a composted FYM led to an additional reduction in NSGHGE by 46%, although our approach considered only soil GHG emissions and thus did not take into account GHG emissions from the composting process. Cover cropping did not significantly influence NSGHGE, however vetch tended to reduce NSGHGE (-19%). The highest mitigation potential was associated with organic farming plus reduced tillage management, it reduced long-term NSGHGE by up to 128%. Soil C sequestration accounted, on average, for 89% of GHG mitigation potentials, consequently N_2O dominated NSGHGE across all treatments and sites (60 − 80%). This indicates that these mitigation potentials are time limited and reversible, if the management is not maintained, in contrast to the reduction in N_2O emissions, which is considered permanent. Not all the management practices sustained crop yields. Nevertheless, composting of organic manures, reduced tillage and no-tillage effectively reduced NSGHGE and GHG intensity without a noticeable yield reduction. Our results suggest that implementation of the above soil management practices in Swiss cropping systems have a considerable potential for climate change mitigation, although time-limited.

1. Introduction

There is a global concern related to the increase in greenhouse gases (GHG) in the atmosphere, primarily CO_2, N_2O, and CH_4 and their impact on climate change. Intensification of agriculture due to technological advancement has doubled crop yields between 1970 and 2010, but also posed severe environmental problems (Pimentel et al., 1995; FAOSTAT, 2017). Cultivation of agricultural land has caused a historical loss of 50 Pg of soil organic carbon (SOC) (Houghton, 1999). Soil and manure management, enteric fermentation, biomass burning, and rice cultivation have become the largest anthropogenic source of N_2O and CH_4, although there are regional differences in importance of these

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emissions sources (Smith et al., 2014). In 2010, agriculture accounted for 5.0–5.8 Pg CO_2eq yr^{-1}, i.e., 10–12% of total global anthropogenic GHG emissions (Tubiello et al., 2013; FAOSTAT, 2017). Switzerland is small, but a large part of its area (1522.7 km^2) is used for agriculture. In 2015, agriculture accounted for 12.6% (6.07 Tg CO_2eq yr^{-1}) of total Swiss GHG emissions (FOEN, 2017). Soil management, which is the second largest source, induces N_2O emissions that account for 30.9% of Swiss agricultural GHG emissions (FOEN, 2017). Reduction of these emissions therefore constitutes an important part of agriculture's GHG mitigation potential concerning climate change as well as achieving Swiss GHG reduction targets aiming to limit global climate warming below 2 °C by 2100 in line with the RCP2.6 scenario (Kyoto Protocol, Lima 2014 and Paris 2015 agreements).

Research proposed a number of management options that can significantly contribute to reducing soil GHG emissions from cropping systems, such as more efficient use of fertilizers (Bouwman et al., 2002; Venterea et al., 2012), organic farming (Gattinger et al., 2012; Skinner et al., 2014), reduced tillage intensity or no-tillage (West and Marland, 2002; Six et al., 2004; van Kessel et al., 2013; Cooper et al., 2016), residue retention, cover cropping (Poeplau and Don, 2015; Kaye and Quemada, 2017), improved water and rice management. The biophysical mitigation potential of these practices need to be evaluated for individual cropping systems under specific pedo-climatic conditions, historical land use and management (Smith, 2012). Previous research on Swiss cropping systems has been designed to investigate the influence of a range of soil management practices on agronomic performance, SOC and soil fertility (Mäder et al., 2002; Fließbach et al., 2007; Berner et al., 2008; Krauss et al., 2010; Wittwer et al., 2017). Yet, relatively little is known about effects of these practices on soil GHG emissions. Identification and quantification of GHG mitigation potentials associated with soil managements is key to designing effective agricultural mitigation strategies. In addition to evaluation of mitigation options on an area basis, more attention has been recently paid to assessment of GHG intensity (GHGI) per agricultural product unit that indicates the GHG efficiency of production (Burney et al., 2010). This assessment has been allied to the concept of sustainable intensification (Godfray et al., 2010; Tilman et al., 2011; Smith, 2013) and promotes management practices that increase production without a commensurate increase in emissions (Smith et al., 2014).

Net potential of soil management practices to contribute to GHG mitigation depends on the direction and magnitude of changes in SOC, N_2O and CH_4 emissions associated with their implementation compared to conventional practices. Direction and magnitude of soil GHG emissions and thus mitigation potentials might change over time in response to the management and climate change (Smith, 2012). Long-term field experiments (LTE) suggest that rates of SOC change in response to soil management are the greatest in the first 10 years and then attenuate when reaching a new steady-state (Johnston et al., 2009; Gattinger et al., 2012). Six et al. (2004) and van Kessel et al. (2013) found a noticeable time dependency in no-tillage and reduced tillage effects on N_2O emissions. Nevertheless, there is a lack of long-term observations. Most GHG studies are based on a sampling period over one to two growing seasons that does not even cover the entire crop rotation length. Soil management and crop interaction effects on soil GHG emissions can be complex and cannot be entirely identified in a short-term. This is most pronounced in complex cropping systems, like those in organic farming leading to a pronounced temporal decoupling of N input und corresponding N_2O emissions (Skinner et al., 2014). Therefore, there is an urgent need for long-term monitoring of management-specific GHG emissions over entire crop rotations preferably across a wide range of pedo-climatic conditions to elucidate long-term N and C dynamics in response to changes in management. However, the spatial and temporal resolution and the extent of GHG measurements are generally limited by cost and time constraints.

Alternatively, ecosystem process-based models that are capable of capturing complex long-term dynamics in soil-crop-atmosphere systems, when correctly integrated with empirical data, provide effective and robust tools to bridge data gaps, to understand and quantify soil GHG emissions responses to changes in soil management. Furthermore, these models can be used to identify and evaluate long-term effects and strengths of selected GHG mitigation options and thus support climate change strategies. DayCent (Del Grosso et al., 2001; Campbell and Paustrian, 2015) is a dominant coupled soil-plant dynamic model that has been widely used to simulate long-term ecosystem responses to changes in soil management and climate in the US (Parton and Rasmussen, 1994; Del Grosso et al., 2008b; De Gryze et al., 2011; Lee et al., 2015). However, its application to European cropping systems has been limited (e.g., Foereid et al. (2012), Alvaro-Fuentes et al. (2017)). Hence, if DayCent is to be reliably used to address agriculture GHG mitigation under Swiss conditions, it requires robust parameterization for common Swiss crops and management practices, and evaluation across a range of management practices and pedo-climatic conditions. Accordingly, this study was designed with the following objectives: i) to parameterize DayCent for common crops and management practices using long-term empirical data collected under various pedo-climatic conditions in Switzerland; ii) to evaluate the model's ability to simulate long-term crop productivity, SOC dynamics and soil N_2O emissions in diverse Swiss cropping systems; and iii) to examine the long-term impact of management practices and their interactions on soil GHG emissions and GHGI at each experimental site.

2. Materials and methods

2.1. LTE descriptions

The empirical data was derived from four Swiss LTEs located in Changins (P29C LTE), Therwil (DOK LTE), Reckenholz (FAST LTE) and Frick (Frick LTE, Table 1). These LTEs have evaluated effects of various farming systems and soil management practices (Table 2).

DOK LTE compares farming systems differing with respect to fertilization and plant protection management: a) biodynamic (D2) and organic (O2) systems fertilized with farmyard manure (FYM) and slurry

Table 1
Soil and climate characteristics of Swiss long-term field experimental (LTE) sites.

LTE	Location	Coordinates	Soil type	Sand (%)	Clay (%)	Soil bulk density (g cm^{-3})	Soil C (%)	Soil pH	Mean annual temperature (°C)	Mean annual precipitation (mm)
P29C	Changins (Clay)	46°24′N, 06°14′E	Calcaric Cambisol	16	46	1.17	2.92	6.2	10.2	999
	(Loam)			30	26	1.44	1.34	6.8		
DOK	Therwil near Basel	47°30′N, 7°33′E	Haplic Luvisol	12	16	1.22	1.66	6.3	9.5	791
FAST	Reckenholz near Zurich	47°26′N, 8°31′E	Calcareous Cambisol	43	23	1.48	1.44	7.3	9.4	1054
Frick	Frick	47°30′N, 8°01′E	Stagnic Eutric Cambisol	22	45	1.58	2.20	7.1	8.9	1000