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Short-term land-use change from grassland to cornfield increases soil organic carbon and reduces total soil respiration

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ABSTRACT

Land-use change between grasslands and croplands has a significant influence on soil organic carbon (SOC) and soil respiration (RS). However, the response of the different components of RS to land-use changes and variations in temperature and moisture regimes is poorly understood. This study investigated the responses of RS, heterotrophic respiration (RH) and root respiration (RR) to changes of soil temperature, moisture and nitrogen (N), and changes in SOC, accompanying with land-use changes for 11 years. The study was conducted in a > 30-year old permanent grassland (OG; 2005–2009), that was ploughed and converted to a cornfield (2010–2012) and then converted to a new grassland (NG; 2013–2015). Three treatments, chemical fertilizer and manure, chemical fertilizer only, and unfertilized control, were assessed. Fluxes of RS and RH were measured using the closed chamber method. SOC was monitored at 0–15 and 15–30 cm soil depth.

On average, RS decreased by 25–43% after conversion from OG to cornfield and then increased by 21–33% after the change from cornfield to NG. Contrary to RS, RH increased by more than 30% following land-use change from OG to cornfield and declined by at least 20% after converting cornfield to NG. The contribution of RH to RS was significantly higher in cornfield (60–100%) than in OG (38–60%) and NG (47–80%). The different trends of RS and RH following land-use change calls for a clear distinction of the CO_2 source when reporting its emissions from soil. The influence of soil temperature, moisture and N on RS and RH differed among the land-uses. The conversion of grassland to cornfield significantly increased SOC, especially in the manure-amended plot. This increase in SOC in the first 1–3 years of conversion indicates that conversion or ploughing of grassland is important to turn plant litter/applied manure into actual soil carbon. These results call for a rethink of the commonly held notion that conversion of grassland to cropland depletes SOC, as the conversion could be beneficial if done for shorter time periods.

1. Introduction

Increasing atmospheric greenhouse gas (GHG) concentrations is of major global concern due to their effect on global climate change (IPCC, 2014). Carbon dioxide (CO_2) is one of the major GHGs emitted from soils with a huge impact on the terrestrial carbon (C) cycle (Schlesinger and Andrews, 2000; Yan et al., 2010).

Total CO_2 emission from soil (soil respiration; RS) is composed of autotrophic root respiration (RR), from plant roots and associated rhizosphere organisms (Hanson et al., 2000), and heterotrophic respiration (RH), associated with microbial decomposition of organic matter (Balogh et al., 2016). Soil respiration represents one of the largest flows of C between the terrestrial ecosystem and the atmosphere (Luo et al., 2016; Schlesinger and Andrews, 2000). Changes in RS fluxes have large implications on soil C storage (Peng et al., 2009).

Soil organic C (SOC) storage is influenced by the balance between C input, from plant residues or animal manure, and C output through RS or C leaching. Changes in soil temperature, moisture, and nitrogen (N) content can lead to significant changes in RS and soil C (Song and Zhang, 2009; Suseela et al., 2012; Zhou et al., 2014). Soil respiration increases with increasing soil temperature (Chen and Tian, 2005; Peng et al., 2009; Song and Zhang, 2009), however, the magnitude of the influence of temperature on RS can differ across different biomes (Chen and Tian, 2005). Increasing soil temperatures might also stimulate RH and RR differently (Gaumont-Guay et al., 2008). Increasing soil N content and N fertilization has potential to increase the capacity of soils to sequester C (Lal, 2004; Schlesinger and Andrews, 2000). However, the reported effect of N fertilization on RS is contradictory among different studies with positive (Luo et al., 2016; Song and Zhang, 2009), negative (Bowden et al., 2004) or no effect (Brumme and Beese, 1992)

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Table 1
Rates of inorganic fertilizer N, manure N and manure C application from 2005 to 2015 in F and MF plots.

Plot†	Land-use	Year	Inorganic Fertilizer ($kg\ ha^{-1}$)			Manure ($Mg\ ha^{-1}$)	Manure ($kg\ ha^{-1}$)			Lime ($kg\ CaCO_3\ ha^{-1}$)
			N	P_2O_5	K_2O	C	N	P_2O_5	K_2O	
F	OG	2005	164	45	264.5	0	0	0	0	0
		2006	183	67.2	273.1	0	0	0	0	0
		2007	74	23.3	109.4	0	0	0	0	0
		2008	74	20.3	109.4	0	0	0	0	500
		2009	91.4	25.1	135.4	0	0	0	0	500
	Corn	2010	104	144	80.0	0	0	0	0	400
		2011	104	144	80.0	0	0	0	0	400
		2012	96.6	133.7	70.8	0	0	0	0	400
	NG	2013	40	100	60.0	0	0	0	0	300
		2014	150.2	107.9	212.2	0	0	0	0	300
		2015	103.8	40	141.3	0	0	0	0	300
MF	OG	2005	130	6.8	70.4	5.8	236	191.0	266.3	0
		2006	133	6.0	129.5	6.0	310	310.2	254.4	0
		2007	21	0	0	7.7	331	331.4	345.0	0
		2008	0	0	0	8.0	308	259.6	261.6	500
		2009	0	0	0	9.0	491	564.2	698.3	500
	Corn	2010	104	144.0	80.0	8.9	599	599.1	572.9	400
		2011	104	144.0	80.0	6.7	216	397.0	325.1	400
		2012	96.6	127.5	70.9	6.7	343	561.3	411.3	400
	NG	2013	40	100.0	60.0	7.3	448.4	715.1	579.9	300
		2014	47	46.9	50.0	0	0	0	0	300
		2015	56.9	22.2	68.8	6.8	165.4	208.5	143.7	300

† *Note*: The unfertilized control plot (CT) did not receive inorganic fertilizer or manure, but received the same amount of lime as the two plots in the above table for each year. † OG is old grassland, corn is cornfield and NG is new grassland.

of N fertilization on RS. These contradictions could be due to the different responses of RS components (RH and RR) to N fertilization (Yan et al., 2010) or could be due to different responses by different land-uses (Zhou et al., 2014). Equally, the effect of soil moisture on RS could be influenced by the different responses of RH and RR (Balogh et al., 2016; Yan et al., 2010). More research is clearly needed to improve our understanding of how RS and its components will respond to a changing climate and N fertilization regimes.

Land-use change between grassland and cropland often results in large changes in soil C, available N and several other soil properties. Grasslands usually accumulate large amounts of litter and soil organic matter (SOM) that leads to high SOC and organic N (Ryals et al., 2014). Converting grassland to cropland will convert the accumulated SOM into available C and N during mineralization (Necpálová et al., 2013), which in turn will increase microbial activity and have significant effect on RS (Smith et al., 2008). Croplands that undergo annual tillage, such as ploughing, usually tend to have lower SOM content but could have higher decomposition rates. Tillage activities often lead to disruption of soil structure, increased surface area of the contact between SOM and soil microbes, physical release of SOM previously trapped/bound, break down of plant residue and increased aeration which provides aerobic conditions that enhance SOM decomposition and soil microbial activity (Govaerts et al., 2007; Kravchenko et al., 2011; Ussiri and Lal, 2009). These changes can have large implications on RS and C storage in soils. Converting cropland to perennial crops like grassland has been reported to mitigate CO_2 emissions and to increase sequestration of C in the soil (Guo and Gifford, 2002). However, how much C can be sequestered and how much time from the conversion of cropland to grassland would be required to achieve significant reductions in CO_2 emissions is still uncertain. Moreover, the effects of land-use change between grassland and cropland can be further complicated by differences in fertilization management among land uses. To fully understand the direction of these changes, long-term studies that monitor changes in the same soil after land-use change between grassland and croplands are needed.

In this study, we present results from a field study that monitored CO_2 and soil C continuously for 11 years in a managed grassland that was converted to cornfield and then reverted back to grassland. We discuss the influence of temperature, soil moisture and N fertilization on RS, RH, and RR and evaluate the effect of land use change on SOC and C budget dynamics.

2. Materials and methods

2.1. Site description

The study site is located at the Shizunai livestock farm of Hokkaido University in Southern Hokkaido, Japan (42°26′N, 142°29′E). The site has a humid continental climate characterized by very cold winters and relatively warm summers with mean annual temperature and precipitation of 8.1 °C and 1252 mm, respectively. The soil is a Mollic Andosol (IUSS Working Group WRB, 2006) and the main properties of the topsoil (0–15 cm) are: pH (H_2O) 5.1; total C 3.8%; total N 0.33%; bulk density 0.81 g m^{-3}; sand 72.7%; silt 23.7%; clay 3.6%.

2.2. Experimental design

The land-use was an old permanent grassland (> 30 years old; OG) from 2005 to 2009, cornfield from 2010 to 2012, and new grassland (NG) from 2013 to 2015. Herbicide was applied in September 2009 to kill the grass and the dead grass was incorporated into the soil by ploughing. Date of conversion from OG to cornfield was regarded as the day of herbicide application on 1st October 2009, while the date of converting cornfield to NG was 17th October 2012, the day of manure application for next growing season. The dominant grass species were reed canary grass (*Phalaris arundinacea* L.) and meadow foxtail (*Alopecurus pra- tensis* L.) in OG, and timothy grass (*Phleum pretense* L.) in NG.

Changes in RS and RH were monitored in three treatments; chemical fertilizer plus composted manure (MF), chemical fertilizer only (F) and unfertilized control (CT). All treatments were replicated 4 times in a complete randomized design. The rates of fertilizer and manure application are shown in Table 1. Details and dates of field management