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The carbon balance of temperate grasslands part II: The impact of pasture renewal via direct drilling

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ABSTRACT

Pasture renewal (or pasture renovation) is a common management practice in grass-based production systems aimed at restoring pasture production and forage quality. It is important to understand the impact of pasture renewal on soil organic carbon stocks.

Here we report the CO_2 and C balance of three blocks of an intensively managed temperate grassland in New Zealand. Two blocks underwent pasture renewal using the spray and direct drill approach (no ploughing), while the third block served as an undisturbed Control. Net ecosystem production (NEP) was measured using eddy covariance, and additional in- and outputs of C (e.g. C in pasture removed by grazers and returned in dung) either measured or estimated.

NEPs of the renewed blocks were between 149 and 212 $g\,C\,m^{-2}\,y^{-1}$ lower than the NEP of the Control block during the year of pasture renewal. While CO_2 sink strength was obviously diminished as a result of pasture renewal, neither renewed block was a source for CO_2, presumably due the relatively warm climate which enabled year-round growing conditions.

Despite the non-negative NEPs during the year of pasture renewal, both renewed sites were found to lose soil C as indicated by the negative net ecosystem carbon balances (NECBs). NECBs of the renewed blocks were −156 and −222 $g\,C\,m^{-2}\,y^{-1}$, compared to a near-neutral NECB of the Control block.

Comparison of the findings from the current study on pasture renewal without ploughing to those from an earlier study on pasture renewal including ploughing led to the following conclusions: i) our data did not suggest lower rates of respiratory CO_2 losses when spray-and-direct-drill approach was used instead of ploughing; ii) as both the direct CO_2 losses due to microbial degradation and the decrease in CO_2 uptake through photosynthesis contribute to the total impact of pasture renewal on NEP, the duration of fallow period was found to be important in determining the short-term CO_2 losses due to pasture renewal, with shorter fallow period leading to lower net CO_2 losses; iii) addition of C in the form of manure, effluent, or extra supplemental feed for cattle may help to reduce the negative impact of pasture renewal on soil C loss at the renewed site.

1. Introduction

Globally, soils are the largest terrestrial pool of carbon (C) (Jobbagy and Jackson, 2000; Janzen, 2004). Human-induced land use change related to conversion of natural to managed ecosystems has led to a drastic reduction in the global soil C pool, with agricultural soils on average having lost around 60% of their original soil organic C pool (Lal, 2003). Mechanisms like cultivation and other disturbances are thought to be responsible for soil C losses of between 40 and 90 Pg globally in the last 150 years (Smith, 2008).

Reduction of the size of the C pool can significantly contribute to the rise in atmospheric CO_2 concentration (Follett, 2001; Smith, 2008; Chen et al., 2015) and the resulting, potentially damaging, effects of climate change. In addition, carbon loss from soils is of concern because it can lead to a decline in soil health and productivity (Sparling et al., 2006; Johnston et al., 2009; Milne et al., 2015).

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In particular, soils used for cropping have lost large amounts of soil organic carbon (SOC) as a result of reduced C inputs from plant material (much of which is harvested), increased erosion, and enhanced soil organic matter decomposition due to disturbance by tillage as a result of the destruction of soil aggregates, increased aeration, increased soil temperatures and shifts toward more bacterial-dominated communities (Six et al., 2004; Grandy and Robertson, 2006; Quincke et al., 2007; Carolan and Fornara, 2016). A range of potential land management options have been proposed to increase C sequestration in soil as a way of drawing down atmospheric CO_2 and thus mitigating greenhouse gas emissions (Follett, 2001; Ogle et al., 2005; Smith et al., 2008; Lal et al., 2011). Among the proposed practices are reduced tillage (seed bed preparation before sowing without using a mouldboard plough) or no-tillage farming (when only a narrow slot is opened for sowing seeds so that mechanical disturbance is minimal) (Smith et al., 1998). Adoption of these management practices is expected to increase C sink strength of arable lands until a new steady state has been reached, estimated to be between 20 and 100 years (Smith et al., 1998; Follett, 2001).

In temperate regions, soil C stocks under well managed permanent pasture are relatively high compared to those of cropland soils (Conant et al., 2001; Tate et al., 2005; Johnston et al., 2009) as a result of greater C inputs, lower soil temperatures, infrequent cultivation and year-round plant cover (Guo and Gifford, 2002; Smith, 2005). Because grassland soils have such large C stocks, and considering that it is easier and faster to lose C than to gain it (Johnston et al., 2009), efforts to protect and maintain levels of soil C and thus avoid losses are of high priority (Powlson, 2011; Smith, 2014).

Pasture renewal (PR; also referred to as reseeding, pasture restoration or pasture renovation) is a common practice in intensively managed permanent pastures to maintain or increase pasture production and farm profitability (Stevens et al., 2007; Velthof et al., 2010). PR may include spraying the old pasture sward with a general herbicide once or twice, thereby killing the existing sward and weeds to control competition of new seedlings with established pasture (Thom et al., 2011). Traditionally, PR also includes cultivation of the soil, for example by ploughing, before seeds of the new sward are sown (e.g. Velthof et al., 2010; Carolan and Fornara, 2016). Alternatively, if the renewal is pasture-to-pasture (without a crop rotation in between) and cultivation has not taken place, seeds can be directly drilled into the soil (Thom et al., 2011; Beare et al., 2012), which can be described as 'direct drilling', 'no-tillage' or 'direct seeding' (Baker and Saxton, 2007).

Little is known globally about the impact of pasture renewal on C dynamics, either with or without cultivation. Only a few studies have examined the impact of infrequent tillage (or 'rotational zero tillage') on SOC stocks (Conant et al., 2007; Govaerts et al., 2009; Carolan and Fornara, 2016). In a modelling study, Conant et al. (2007) showed that even occasional (infrequent) tillage could lead to substantial losses of soil carbon.

Measuring C loss due to pasture renewal is challenging. A limited set of chamber studies focussed on CO_2 losses due to pasture renewal, including cultivation, report contradictory results: some find larger CO_2 losses (respiration) as a result of pasture renewal compared to uncultivated controls (Eriksen and Jensen, 2001; Grandy and Robertson, 2006; Rutledge et al., 2014), while others report lower CO_2 losses (Yamulki and Jarvis, 2002; MacDonald et al., 2010; Willems et al., 2011). While chambers are usually utilised to measure only one component of the CO_2 exchange (i.e. respiration), the use of eddy covariance allows determination of the full CO_2 balance (including photosynthesis), including after seedlings have emerged, and a more complete picture of the impact of PR on the CO_2 balance can be obtained. Recently, several studies have monitored CO_2 exchange over intensively managed temperate pastures undergoing pasture renewal using the eddy covariance technique, and they generally found lower CO_2-sink strength during years of pasture renewal compared to years without pasture renewal (Ammann et al., 2013; Hirata et al., 2013; Merbold et al., 2014; Rutledge et al., 2014).

In New Zealand, pastoral agriculture is the dominant land use, with approximately 45% of the land used for grazing (Statistics New Zealand, 2012b). The annual rate of pasture renewal on intensively managed dairy farms has been estimated between 6% and 8% of the farmed area (Pasture Renewal Charitable Trust, 2013; Kerr et al., 2015) and this rate has been increasing over the last few decades (Beare et al., 2012). While pasture renewal traditionally involved cultivation, the spray and direct-drill approach gained popularity between 1990 and 2008 (Beare et al., 2012), and in 2012 pasture renewal was performed using direct drilling in 46% of pasture renewal events (Statistics New Zealand, 2012a).

Rutledge et al. (2014) monitored CO_2 exchange during three pasture renewal events in New Zealand via ploughing that led to short-term losses of CO_2 of between 151 and 329 $g\,C\,m^{-2}$ in the period between spraying and seedling emergence (approximately 40 days). When compared to a non-renewed control block, the 'net impact of pasture renewal' (taking into account both direct respiratory losses of CO_2 and the lack of photosynthetic carbon input following cultivation) was between 77 and 406 $g\,C\,m^{-2}$. The moisture status of the soil was the main driver of the rate of CO_2 loss, with largest losses observed during relatively moist soil conditions (Rutledge et al., 2014).

The aim of the current study was to quantify the impact of pasture renewal (PR) via direct drilling (i.e. in the absence of full cultivation) on the CO_2 and C balance of an intensively grazed, permanent pasture in warm-temperate northern New Zealand. We conducted a 1-year before to 1-year after-control-impact field study. We established three experimental blocks on one farm, two of which underwent pasture renewal. The third block did not undergo any treatment and served as a control. Here, we describe the CO_2 and C balance for the year before PR, and the year including PR. The experimental design allowed for comparisons of the CO_2 and C balance both within-block-between-years (comparing the before-PR and the PR-year for the two renewed blocks separately) and between-blocks-within-year (comparing the PR-year between the renewed blocks and the Control block). We hypothesised that the net effect of PR would be CO_2 and C losses in comparison to the Control, mostly resulting from the period without photosynthetic input between spray-off of the old sward and establishment of the new sward. We compare our findings to the results of earlier work which focussed on quantifying the impact of PR including a full cultivation (ploughing) on the CO_2 and C balance (Rutledge et al., 2014, 2015). We expected CO_2 and C losses due to PR via direct drilling would be smaller than those due to PR including ploughing, because there would be less physical disturbance and aeration of the soil, and the soil would be left unvegetated for a shorter period.

2. Methods

2.1. Site, soils and climate

This study took place on Troughton Farm (37.77°S, 175.8°E, 54 m elevation), which is situated in the Waikato region on the North Island of New Zealand. The landscape is relatively flat, with soils on the farm formed on parent material of rhyolic and andesitic ash deposited on alluvial sediments (McLeod, 1992). A complex of several soils formed, depending on the deposition environment and drainage condition. On the three experimental blocks, the dominant soil type was the Te Puninga soil. This loamy soil, imperfectly drained and moderately gleyed (McLeod, 1992), has