Agriculture, Ecosystems and Environment 184 (2014) 21–33

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

CO_2 emissions following cultivation of a temperate permanent pasture

S. Rutledge[a,*], P.L. Mudge[a,b], D.F. Wallace[a,c], D.I. Campbell[a], S.L. Woodward[d], A.M. Wall[a], L.A. Schipper[a]

[a] Department of Earth and Ocean Sciences, University of Waikato, Private Bag 3105, Hamilton, New Zealand
[b] Landcare Research Manaaki Whenua Ltd., Private Bag 3127, Hamilton, New Zealand
[c] Plant and Food Research, Private Bag 1401, Havelock North, New Zealand
[d] Dairy NZ, Private Bag 3221, Hamilton, New Zealand

ARTICLE INFO

Article history:
Received 18 July 2013
Received in revised form 1 October 2013
Accepted 9 November 2013
Available online 12 December 2013

Keywords:
Carbon dioxide
Grassland
Pasture
Cultivation
Plowing
Disturbance
Soil carbon

ABSTRACT

It is well known that frequent cultivation of cropped soils leads to increased soil respiration and loss of soil carbon (C). In contrast, little is known about the impact of occasional cultivation of permanent grasslands on soil C and CO_2 dynamics. Occasional cultivation of pastures is common if a pasture is part of an arable-ley rotation, or as part of pasture renewal.

Here we report on the CO_2 balance following three cultivation events of temperate permanent pasture in New Zealand. For two experiments, one during a drought during late summer/autumn 2008 and one under moist soil conditions in spring 2008, CO_2 losses following cultivation were measured using the closed chamber technique. During the spring 2008 experiment, two soils with different clay mineralogy and drainage were studied. During a third cultivation event in autumn 2010 CO_2 exchange was measured using eddy covariance.

Measured short-term respiratory losses following cultivation across the three experiments ranged from 151 to 329 g C m^{-2} over 39 to 43 days. Rates of CO_2 loss measured during non-drought conditions were generally higher than those previously reported from studies in Europe and North America, presumably because of generally high soil temperatures, non-limiting moisture conditions and high organic carbon availability at our study site. The 'net impact of cultivation' (taking into account both direct respiratory losses of CO_2 and the lack of photosynthetic carbon input following cultivation) across the three experiments ranged between 77 and 406 g C m^{-2} over 39–43 days. Both direct CO_2 respiratory losses and the net impact of cultivation appeared highly dependent on soil moisture status, with lowest losses measured during a severe drought and highest losses measured in spring when ample moisture was present. Rates of respiratory CO_2 losses did not decrease over the duration of our experiments (39–43 days).

Our results suggest that when aiming to reduce C losses resulting from cultivation of permanent grassland, it is preferable to cultivate when conditions for soil microbial activity and photosynthesis are sub-optimal; for our study site this meant in autumn instead of spring because of lower soil moisture availability. We also recommend minimising the duration of the period between spraying the old sward and establishment of the new sward or crop.

1. Introduction

Globally, soils are the largest terrestrial pool of actively cycled carbon (C) and are therefore an important part of the global carbon cycle (Lal, 2008). In addition, soil C is the backbone of soil organic matter which is crucial for maintaining soil quality and production through maintaining water holding capacity, cation exchange capacity, soil aggregate stability and nutrient storage (Conant et al., 2001). Changes in the soil carbon store occur when inputs of C (e.g. photosynthesis and organic matter imports) are not in balance with C outputs (e.g. ecosystem respiration, produce export, leaching and erosion). Climate variability and management practices that alter these inputs and outputs can cause a change to the soil C store, which in turn has the potential to significantly modify the carbon dioxide (CO_2) concentration of the atmosphere (Schlesinger and Andrews, 2000; Amundson, 2001).

Globally, grazed grasslands cover about 26% of the ice free land area (Steinfeld et al., 2006) and are important stores of C because of their inherently high soil C contents (Conant et al., 2001; Tate et al., 2005). Studies of changes in soil carbon under grassland globally have reported gains, losses or no change in soil C (Bellamy et al., 2005; Meersmans et al., 2009; van Wesemael et al., 2010; McSherry and Ritchie, 2013).

* Corresponding author. Tel.: +64 7 838 4055.
E-mail address: s.rutledge@waikato.ac.nz (S. Rutledge).

0167-8809/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agee.2013.11.005

Table 1
Summary of seasons, periods, moisture conditions, soils and methods for the three cultivation events at Scott Farm.

Exp	Season	Year	Period	Length of measurement period (days)	Soil moisture conditions	Method cultivated paddocks	Soil of cultivated paddocks	Uncultivated pasture control
1	Late summer/autumn	2008	27 January–5 March	39	Drought	Chamber	Matangi	Chamber over Matangi + EC over Matangi
2	Spring	2008	15 October–25 Nov	42	Moist	Chamber	Te Kowhai and Horotiu	EC over Matangi
3	Autumn	2010	22 February–5 April	43	Moist	EC	Matangi	Model based on EC over Matangi

EC, eddy covariance.

In New Zealand, pastoral agriculture is the dominant land use with 41% of the land area being used for grazing. Recently, Schipper et al. (2010) identified that C stocks in New Zealand soils under grazed pasture were more dynamic than previously thought with relatively large losses on some flat land and gains on hill country. The causes of the C gains and losses were unclear. Over the last few decades, there has been intensification in the management of dairy farmland in New Zealand (MacLeod and Moller, 2006; Clark et al., 2007), and several management practices common to dairy farming can be hypothesised to have contributed to the losses of C from these soils, e.g. increased fertiliser inputs, higher stocking rate, increased use of fodder crops, better pasture utilisation, increased product export and increased frequency of pasture renewal.

Pasture renewal offers the opportunity to remove weeds and pests, improve drainage, aeration and contour of the land, replace low producing pasture, and introduce improved pasture varieties, thereby improving pasture production (Stevens et al., 2007). To improve dairy farm profitability, farmers in New Zealand are increasingly advised to increase the rate of pasture renewal (Clark et al., 2007; Stevens et al., 2007). Pasture renewal involves killing the entire existing sward by spraying it with a general herbicide and resowing the new sward (Stevens et al., 2007). Although farmers may decide to direct-drill the seed into the old sprayed-off sward, cultivation before sowing is still a common practice because it may help control weeds and improve aeration, or because a crop (e.g. brassicas, chicory or maize) was planted between the old and the new pasture sward.

It is well known that frequent cultivation or tillage results in a decline in soil C storage (Lal, 2004; Baker and Richie, 2007; Smith et al., 2008). This loss of soil C can be a consequence of (i) increased loss of C through accelerated decomposition resulting from increased aeration and/or the breakdown of soil aggregates that previously provided physical protection to C from microbial decomposition; (ii) increased erosion; and (iii) decreased input of C caused by the absence of photosynthesis before plants emerge (Six et al., 2004; Grandy and Robertson, 2006; Baker and Richie, 2007; Willems et al., 2011). Numerous studies have reported a decline in soil C over time in agricultural soils under conventional (i.e. frequent) tillage in croplands. In contrast, the number of studies quantifying the impact of occasional tillage on soil C storage is very limited (Conant et al., 2007; Govaerts et al., 2009).

In a modelling study, Conant et al. (2007) found that infrequent (or periodic) tillage of soils after long periods of no-till caused declines in soil C stocks: even a one-off tillage event caused between 1 and 11% of soil C to be lost. However, only a few studies have examined how periodic cultivation affects the CO_2 exchange and C balance of permanent pasture (Eriksen and Jensen, 2001; Yamulki and Jarvis, 2002; Grandy and Robertson, 2006; MacDonald et al., 2010; Willems et al., 2011). Permanent pastures generally have relatively high soil C contents compared to soils used for cropping (Conant et al., 2001; Tate et al., 2005) so may be susceptible to greater C losses following cultivation.

This study aims to quantify the impact of periodic cultivation on the CO_2 balance of permanent dairy pasture in New Zealand. Three cultivation events on one farm were studied. For two cultivation events in 2008, CO_2 losses were measured using chambers during two seasons and for three different soil types. Net ecosystem CO_2 exchange (NEE) was also measured using eddy covariance (EC) over paddocks on the same farm that were not cultivated (i.e. uncultivated ‘control’ paddocks), and this information was combined with the chamber data to estimate the net impact of cultivation on CO_2 exchange. During a third cultivation most of the area in the footprint of the EC system was cultivated. Comparison of results from the cultivation events during different seasons and for three different soil types allowed us to investigate the controlling factors of CO_2 loss following cultivation.

2. Methods

This paper reports on results from three cultivation events. Experiments 1 and 2 were cultivation events in summer-early autumn (January–March 2008) and spring (October–November 2008), respectively, during which CO_2 respiratory losses were measured using a chamber. During a third cultivation event in autumn (February–April 2010; Experiment 3), CO_2 exchange was measured using eddy covariance. The seasons, periods, moisture conditions, soils and methods for the three cultivation events have been summarised in Table 1.

2.1. Site description

Measurements for all three cultivation events were made at Scott Farm, a research dairy farm owned and operated by the New Zealand dairy industry research organisation DairyNZ. The farm is situated close to Hamilton city in the Waikato region on the North Island of New Zealand (37.46°13.62′S, 175.22°40.64′E, 41 m.a.s.l.) and has been used for dairying for at least 95 years. Paddocks are rotationally grazed year-round with an average stocking density of 3 dairy cows/ha. Paddocks generally receive 150 kg N ha^{-1} y^{-1}.

The climate is temperate with an average annual rainfall of 1126 mm and average annual temperature of 13.8 °C. A range of soil types are present on the farm. Measurements for the summer-autumn cultivations in 2008 and 2010 (Exp’s 1 and 3) were made over the Matangi silt loam (Typic Orthic Gley Soil, Hewitt, 1993). For the spring cultivation (Exp 2) measurements made over two soils were compared: the Te Kowhai (Typic Orthic Gley Soil) and the Horotiu (Typic Orthic Allophanic Soil; Hewitt, 1993). The three soils were formed from the same alluvium parent material of rhyolitic sand, silt and gravel deposited by the ancient Waikato River (Singleton, 1991). Well drained sandy and gravely soils (Horotiu soil) occur where the braided river system formed levees or higher ridges, whereas gley soils (Te Kowhai and Matangi soils) have developed in the lower lying swales. The soils in the swales are made of similar material as those on the levees but they are generally finer