The short-term effects of topsoil inversion tillage on soil carbon storage, New Zealand

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ABSTRACT

There is an interest in the potential of increasing soil organic carbon (SOC) stocks in soils, as this increase may contribute to mitigate the impact of climate change. Pastoral soils as those of New Zealand accumulate large amounts of SOC in the topsoil because of C input from grass is concentrated in the root zone. Deep ploughing or topsoil inversion tillage at pasture renewal (TIT-renewal) has been proposed as a technique to accelerate SOC storage in pastoral soils. This study focuses on short-term effects of contrasted cultivation (tillage) practices at pasture renewal, shallow tillage and TIT, in soil C stocks. Six months after cultivation, the effect of deep ploughing was to redistribute C in the profile and no C changes were detected till a depth of 40 cm, when compared to shallow tillage.

Keywords

Pasture soils; deep ploughing, Carbon storage, Climate change mitigation,

INTRODUCTION

Farmers in New Zealand and other places in the world are more and more required to increase their outputs in the changing market (Clark et al., 2007). This requirement causes more pressure on productive soils. At the same moment governmental organizations and researchers try to find ways to mitigate greenhouse gas emissions (GHGs) and climate change. There is an interest in the potential of increasing soil organic carbon (SOC) stocks in pastureland. Soils are a keystone in climate regulation so right management of pasture may contribute to the GHG mitigation (Minasny et al., 2017).

In an undisturbed soil, soil organic matter content (SOM) normally decreases with depth (Franzluebbers, 2002), since soil organic matter inputs in the soil are root material and litter (Calvelo Pereira, 2017). Organic matter supply takes place mainly in the upper few centimetres of a soil. Soil organic carbon is a significant part of the soil organic material and therefore carbon shows similar stratification with depth. Vegetation in soils has, because of its roots and litter, a big influence on the SOC stratification in the soil; clay content and climate are of less influence (Lorenz and Lal, 2005; Rasse et al., 2005). SOM, and thus SOC, in the soil is affected by different processes like decomposition, immobilisation and mineralisation.

Pastures in New Zealand are renewed on average every 5 or 10 years (Kemp et al., 2010). The most common type of cultivation during pasture renewal is shallow tillage (ST) which is limited to the topsoil, up to 10 cm, which may lead to enhanced loss of soil carbon (Rutledge et al., 2014). Recent research has shown that a deeper ploughing may contribute to increase SOC storage. (Alcántara et al., 2016). An effective transference (i.e. inversion) of topsoil organic matter into depth by using a modified mouldboard plough, might transfer SOC from the topsoil to a deeper layer where different chemical conditions could promote the permanence of SOC in the soil (Alcántara et al., 2016; Calvelo Pereira et al. 2018).

At the same time, an effective inversion caused by deep tillage, may favour that the new mixed topsoil stores more SOC because of the actual low SOC concentration (Chung et al., 2010). It is hypothesized that the TIT at pasture renewal may lead to an increase in SOC stock for the entire soil profile with time.

Objective

The objective of this research was to determine the short-term effect of deep ploughing or topsoil inversion tillage (TIT), in order to increase the carbon storage, on C distribution and carbon storage.

METHODS

The experiment was carried out in Palmerston North (New Zealand) at Paddock 35 of Massey experimental farm Dairy 4 (40^{o} 23’46.79” S; 175^{o}36’35.77” E). The dominant soil in the area is a Tokomaru silt loam soil (Typic Fragiaqualf; Soil Survey Staff, 2014), with an average slope of 3% (Hanly et al., 2017) at an altitude of approximately 80 meter above sea level (Massey, 2017). For the comparison of treatments, 8 plots were used. 4 of these plots were cultivated by using shallow tillage (approx. 10 cm depth) and 4 using topsoil inversion tillage (deeper mouldboard ploughing, around 25/30 cm depth) as described in detail elsewhere (Calvelo Pereira et al., 2019).

Each plot was sampled at two periods: 1) in October 2016, prior to any pasture renewal (baseline) and 2) in March 2017, approx. 6 months after pasture renewal and growth of a crop prior to re-seeding pasture (Calvelo Pereira et al 2019)

At each plot, three soil core samples up to 40 cm depth were taken.Each core was sliced at 5 cm depth intervals till 30 cm and the last slice comprised 30-40cm depth. Samples were stored and processed for determining the C concentrations, by using the Vario MACRO cube CHNS elemental analyser (Elementar Analysensystem GmbH, Hanau, Germany).

The soil cores were also used to determine bulk density (BD; kg cm^{-3}) for each of the samples considered, these values combined with C concentrations were used to calculate C stocks (t ha^{-1}) at fixed depth intervals.

A t-test was used to compare the mean differences between the two treatments; tests were carried out in SPSS (IBM Statistics SPSS 24). Plots under ST treatment are in this case seen as the reference situation which is compared with the situation under TIT treatment.

RESULTS

Figure 1 shows changes in C concentration with depth and cultivation type either before (October 2016) or 6 months after (March 2017) the treatments were applied. At the start of the experiment (October 2016) the soils (i.e. both the ST and the TIT treatments) showed a characteristic decrease in soil carbon concentration with depth (Fig. 1a). After six months of cultivation, the C concentrations profile under ST treatment was similar to that at the beginning of the experiment (Fig. 1b), whereas TIT treatment showed lower ($P < 0.001$) C in the 0-5 cm layer and an higher ($P < 0.05$) C in the layers between 5 and 15 cm depth when compared to ST treatment.. Both treatments showed similar C distribution below 15 cm (Fig. 1b).

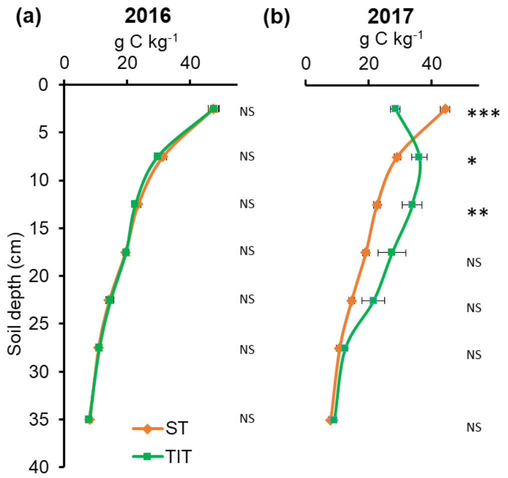

*Figure 1 Average ± standard error of the mean (SEM) soil C concentration with depth in the Tokomaru silt loam at the trial site (a) before cultivation, i.e. shallow tillage (ST) or topsoil inversion tillage (TIT) (October 2016) and (b) six months after cultivation (March 2017). The differences between the treatments (ST vs TIT) were investigated independently at each date and for each depth using a t-test. * P <0.05, ** P < 0.01, *** P < 0.001.*

As can be seen in Table 1, at the start of the experiment (October 2016). C stocks in both treatments were the same when comparing each depth or the cumulative C stock till 40 cm depth. In March 2017, TIT showed changes in C stocks with depth. Considering the total cumulative C stocks for the 0-40 cm depth soil layer, no change was detected ($P>0.05$).

*Table 1 Changes in soil C stock (average +- SD) with depth in the Tokomaru silt loam before (2016) and after (2017) cultivation for shallow tillage or topsoil inversion tillage (TIT). The differences between the treatments (ST vs TIT) were investigated independently at each date and for each depth using a t-test. * P <0.05, ** P < 0.01, *** P < 0.001.*

Variable	Depth (cm)	ST	TIT	*P*-value
Soil C stocks (t ha^{-1}) (October 2016).	0-5	24.3 ± 2.33	24.1 ± 1.06	0.792
	5-10	20.4 ± 2.10	19.6 ± 1.22	0.260
	10-15	16.0 ± 1.80	15.7 ± 1.14	0.590
	15-20	13.5 ± 1.92	13.7 ± 1.10	0.771
	20-25	10.5 ± 2.31	10.8 ± 2.12	0.713
	25-30	8.06 ± 2.15	8.51 ± 2.10	0.634
	30-40	12.9 ± 3.18	12.4 ± 2.37	0.691
Cumulative C stocks		**106 ± 12.53**	**105 ± 8.60**	0.860
Soil C stocks (t ha^{-1}) (March 2017).	0-5	26.5 ± 1.74	19.7 ± 2.69	0.000
	5-10	19.8 ± 1.73	22.1 ± 3.59	0.052
	10-15	15.6 ± 2.22	19.3 ± 4.40	0.010
	15-20	13.6 ± 2.66	16.1 ± 6.65	0.208
	20-25	10.6 ± 2.03	13.6 ± 5.55	0.076
	25-30	8.17 ± 2.16	9.85 ± 2.12	0.044
	30-40	12.4 ± 3.11	13.9 ± 2.80	0.313
Cumulative C stocks		107 ± 11.8	**115 ± 16.6**	0.158

DISCUSSION

The Typic Fragiaqualf soil used in this study showed a contrasted stratification of C, as is common in pasture soils (Lorenz and Lal, 2005). As expected, deep ploughing (i.e. TIT) modified the soil C stratification, and this change was still visible six months after (Fig. 1b). At the same time, C stocks changed accordingly (Table 1), which suggests that TIT inverts the topsoil C and, thus, creates a low-C zone that may increase C storage in future because of C input from the pasture growth (roots and litter) (Machmuller et al., 2015).

Soil C stocks, up to 40 cm depth, were the same 6 months after deep cultivation (Table 2) when compared with shallow cultivation, as C was redistributed. The results show that deep ploughing (i.e. TIT) did not cause a loss of carbon in the soil profile when compared with shallow tillage. A recent study in the same soil showed a net soil C mass increase at least four years after topsoil inversion tillage with mouldboard ploughing up to a depth of 25 cm (Calvelo Pereira et al.,2018).

Contrastingly, other studies using shallow cultivation have found that ST can accelerate the decomposition of the soil organic matter (Rutledge et al., 2014, Davidson and Ackerman, 1993).

Determination of C distribution in the different plots took place only six months after cultivation. This might have been not enough time to cause any significant differences in C stocks as new plants/pasture had no time to act as C input to the soil (Rasse et al 2005).

Future research will focus on evaluate long-term changes in soil C stocks after TIT. Moreover, more understanding on how deep ploughing will also influence the redistribution of plant available nutrients and hence pasture performance is also needed.

CONCLUSION

This study found that the cultivation using deep ploughing (TIT) caused a redistribution of SOM, and that total C stock was the same when comparing to deep ploughing and shallow tillage 6 months after cultivation.

ROLE OF THE STUDENT

Jorn Dijkstra was a BSc student working under the supervision of Klaas Metselaar (WUR), Dave Horne and Roberto Calvelo Pereira (Massey University) when the research in this report was performed. The results shown in this paper are only a selection out of the authors undergraduate research thesis. The processing and analysing of soil samples, processing of the results as well formulation of the conclusions and the writing were all done by the student.

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