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FULL INVERSION TILLAGE PASTURE RENEWAL OFFERS GREENHOUSE GAS MITIGATION OPTIONS: THE CANTERBURY EXPERIENCE

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Abstract
Soils under long term pastures hold large amounts of organic carbon (SOC) though there usually is limited opportunity to further increase the SOC content. A one-off full inversion tillage (FIT) event during pasture renewal provides an opportunity to increase the stock of SOC by altering the vertical distribution of SOC. A field trial at Lincoln (complementing the North Island trials outlined in Calvelo Pereira et al., 2019, this issue) demonstrated that FIT alters the SOC distribution. Autumn pasture renewal in a grass-grass rotation resulted in similar dry matter production (DMP) compared to continuous pasture after 10 months. However, autumn renewal using a grass-crop-grass rotation significantly increased DMP with approximately twice the DMP produced over the same 10 month period. An autumn grass-grass renewal using FIT potentially increases the risk of nitrogen leaching through mineralisation of the buried topsoil SOC. The use of a catch crop in the grass-crop-grass rotation reduced this increased risk of N leaching. The agronomic costs associated with FIT pasture renewal are also offset by the increased DMP.

Introduction
Soil organic carbon (SOC) sequestration has been proposed as one method to reduce atmospheric CO_2 concentrations (Rumpel et al., 2018) and in turn help offset agricultural greenhouse gas emissions. Although the topsoil (e.g. 0-15 cm) of long-term pastures tend to be saturated in soil organic C (SOC), subsoils tend to have lower SOC concentrations and hence a much greater capacity to store additional SOC (Beare et al., 2014). Increasing SOC in subsoils would require an increase in C inputs at depth primarily through the use of deeper rooting plant species. However, pasture species that are favourable in New Zealand systems are typically shallow rooted (Dodd et al., 2011) which makes increasing C inputs at depth challenging. Therefore, a one-off modification to the distribution of SOC in the soil profile whereby subsoil material is brought to the surface (i.e. through the use of deep ploughing or full inversion tillage, FIT) would allow subsoils to have greater contact with plant C inputs and hence provide a mechanism to increase SOC.

This re-distribution of SOC using FIT would be best implemented during a pasture renewal event where cultivation is commonly implemented. Pasture renewal is periodically performed in New Zealand pasture systems, often to either improve pasture performance or to resolve pasture persistence issues (Glassey et al., 2010). However, for FIT to be attractive to farmers, the renewed pasture following FIT would need to remain productive and the associated agronomic costs be reasonable. Therefore, the objective of this study was to establish a field trial in the South Island (Lincoln) to assess the effectiveness of FIT on increasing the SOC stock and investigate the agronomic effects (e.g. dry matter production and agronomic costs). Please refer to Calvelo Pereira et al., (2019) for additional information on the North Island field sites.

Methods

A field trial was established on an imperfectly drained Pallic soil near Lincoln, Canterbury complementing similar field trials established in the Manawatu region (refer to Calvelo Pereira et al., 2019). The trial at Lincoln consisted of 6 replicated plots where perennial ryegrass and white clover pasture was renewed (grass-grass renewal) via FIT, no-tillage (NT) or shallow tillage (ST) compared to continuous pasture (no renewal). Additional treatments included plots sown to a break crop using a mix of forage oats and Italian ryegrass following either FIT or NT cultivation (Figure 1, Table 1).

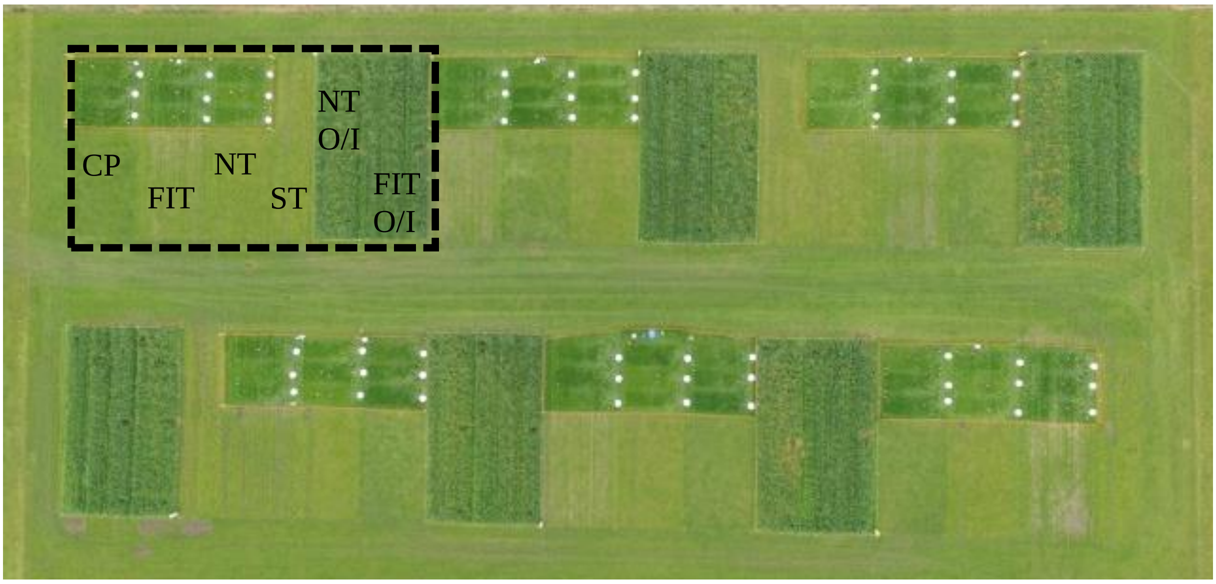

Figure 1 Aerial view of the Lincoln trial site demonstrating the general layout of the trial and blocking of the 6 replicates. The dashed box indicates 1 block with the respective treatments. CP = continuous pasture, FIT = full inversion tillage, NT = no tillage, ST = shallow tillage, O/I = oats/Italian ryegrass.

Table 1 Overview of the trial establishment phase and fertiliser applications.

Event	Date	CP N=6	FIT N=6	NT N=6	FIT N=6	NT N=6	ST N=4
Spray	15/2/18	No	Yes	Yes	Yes	Yes	Yes
Spray	8/3/18	No	Yes	Yes	Yes	Yes	Yes
Cultivation	19/3/18	No	Inversion plough	Direct drill	Inversion plough	Direct drill	Maxitill
Sowing	21/3/18	No	RC	RC	O/I	O/I	RC
Fertiliser[1]	9/4/18	Yes	Yes	Yes	Yes	Yes	Yes
Re-sow post crop	4/11/18	n/a	n/a	n/a	RC	RC	n/a
Fertiliser[2]	30/11/18	Yes	Yes	Yes	Yes	Yes	Yes

CP = continuous pasture, NT = no tillage, FIT = full inversion tillage, ST = shallow tillage.
RC = sown to perennial ryegrass and white clove, O/I = sown to forage oats and Italian ryegrass.
1. Fertiliser applied as Cropmaster15 and superphosphate at rate of 200 kg ha^{-1}.
2. Urea applied at a rate of 30 kg N ha^{-1}.

The stock of SOC (0-45 cm) was measured following soil coring (45 mm diameter, N=6) throughout each plot pre- and post-FIT to assess the redistribution of SOC following FIT.
Dry matter production was monitored prior to- and following cultivation to assess the performance of the renewed pasture.

Nitrogen dynamics were monitored to assess the potential for losses of nitrogen. Mineral nitrogen content in the soil profile (0-80 cm) was monitored regularly throughout the year by soil coring. Nitrous oxide emissions were quantified during cultivation and throughout the year using static chambers and emission factors were determined following addition of urine and fertiliser at the time of the first grazing. As the nitrous oxide data are still in the process of being analysed, they will not be presented here.

Results and Discussion

SOC stocks

Cultivation using FIT resulted in a redistribution of the SOC in the top 30 cm of soil but did not change the total C stock to 45cm. The total C stock of the soil profile to 45 cm in the FIT plots, calculated using an equivalent soil mass approach, was not different to the baseline sampling in the 3 months after cultivation (data not shown). FIT deposited C rich topsoil below 10 cm and brought low C subsoil to the surface providing an opportunity to increase C stocks at the surface (Figure 2).

The consequent change in the SOC distribution and stock under the various treatments will be monitored through time and, as such, Figure 2 represents the immediate change in the SOC distribution as a direct result of the FIT cultivation.

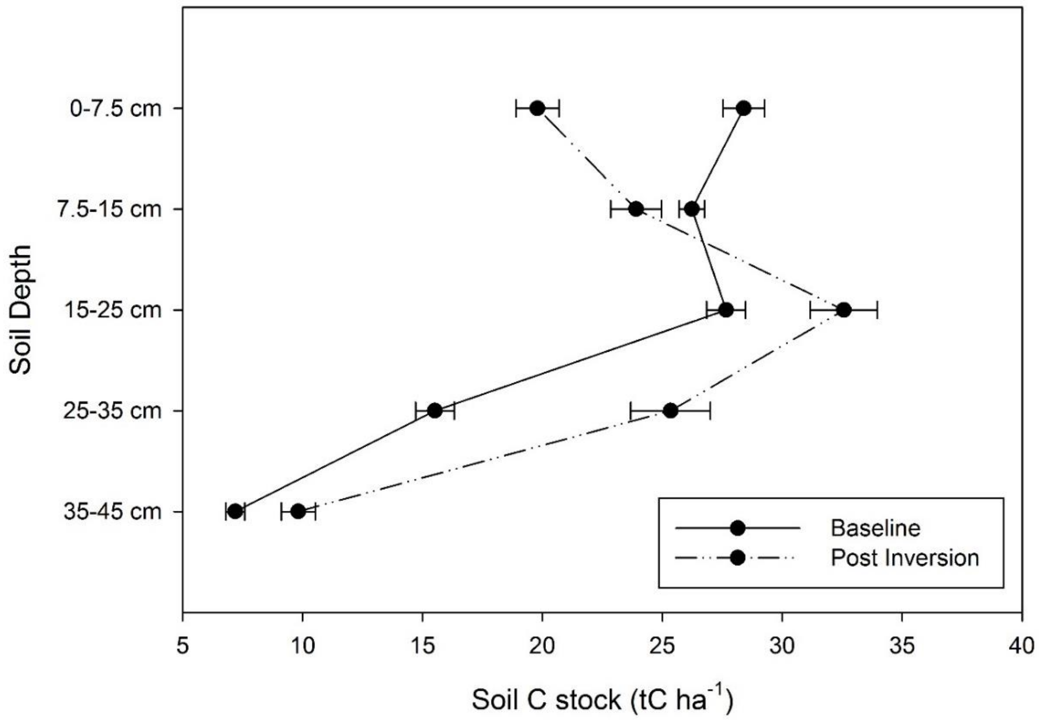

Figure 2 The vertical distribution of soil organic carbon (SOC) stock pre- and post- full inversion tillage presented on a fixed depth basis. The filled in circles represent the mid-point of the sampling depth and error bars represent 1 SE. Please note the figure is preliminary and total C stock to 45 cm was not different between baseline and post-inversion sampling (approximately 3 months).

Pasture production

Pasture renewal increased the DM production under the NT and ST treatments (~ 11 t DM ha$^{-1)}$ where the cumulative pasture production exceeded that of CP (~ 10 t DM ha^{-1}) within 10 months (

***Figure** 3). While the establishment of ryegrass-clover pasture in the FIT plots was slower than the other cultivation treatments (NT and ST), the DM production had also reached that of the CP within 10 months (~ 10 t DM ha^{-1},*

***Figure** 3). However, the green chop oats/Italian ryegrass crop produced much higher DM than the pasture plots with between 15 - 18 t DM ha^{-1} produced by October 2018. Furthermore, the DM of the green chop crop had a 30% higher yield following FIT (18 t DM ha^{-1}) compared to NT (15 t DM ha^{-1},*

Figure 4). The annual DM production from the oats/Italian plots is expected to be even greater with the additional production of the re-sown ryegrass-clover pasture.

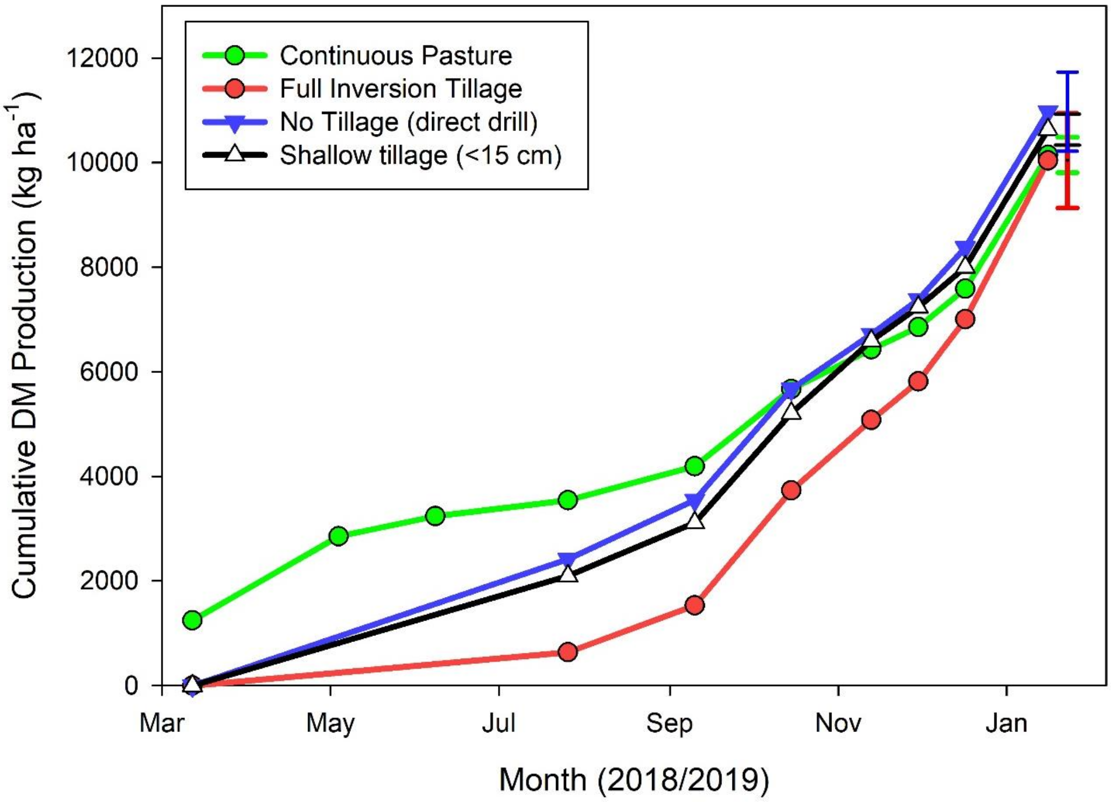

Figure 3 Cumulative dry matter (DM) production (kg ha^{-1}) of perennial ryegrass and white clover pasture following pasture renewal by FIT, NT and ST compared to continuous pasture (no renewal). Data presented is the preliminary mean DM production from 6 replicated plots per treatment for CP, NT and FIT and 4 plots for ST. Error bars represent 1 SE and refer to the last sampling.

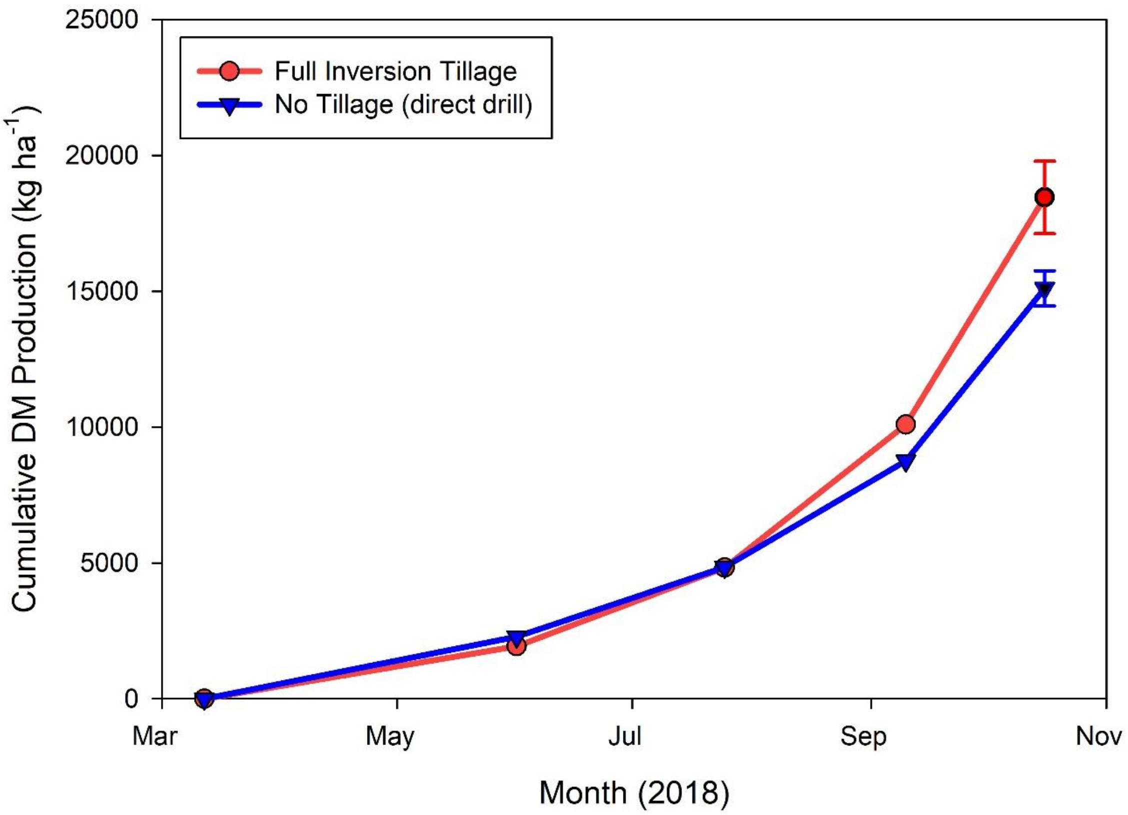

Figure 4 Cumulative dry matter (DM) production (kg ha^{-1}) of oats and Italian ryegrass break crop. The final sampling point represents the harvested yield at the green chop stage. Data presented is the preliminary mean DM production from 6 replicated plots per treatment. Error bars represent 1 SE.

Nitrogen characteristics

Mineral nitrogen was assessed at regular increments down the soil profile (0-80 cm) prior to cultivation and approximately monthly following cultivation and pasture renewal. An accumulation of mineral N lower in the soil profile (> 30 cm depth) over the winter months in the FIT-renewal treatment suggests that an autumn grass-grass renewal might increase the potential risk of NO_3^- leaching over the winter period (data not shown). However, the use of a break crop (i.e. oats/Italian ryegrass) resulted in increased DM production throughout the winter months and consequently increased the uptake of mineral N in the herbage. The greater production over this winter period decreased the mineral nitrogen content down the soil profile which would help to mitigate some of the risk of nitrogen loss (data not shown).

Preliminary results demonstrated that N_2O emissions and emission factors from applied urine and fertiliser were lower under FIT compared to no tillage and continuous pasture plots (data not shown). The length that these reduced emissions/emission factor values persist for is unknown and would require further investigation.

Agronomic costs

Accounting for the value of the DM produced by the continuous pasture, the renewed ryegrass-clover pasture treatments were less profitable in the first 8 months (due to the greater establishment costs). However, the increased daily DM production rates that are being observed in the pastures that have been renewed should result in greater profitability. A different scenario is achieved when a break crop is used through a grass-crop-grass renewal as the additional agronomic costs (e.g. tillage, fertiliser) associated with FIT (or NT) are easily offset by the increase in dry matter production of the break crop (Table 2). The establishment costs of FIT compared to other methods of pasture renewal are also relatively small when increased pasture production can offset these costs.

Table 2 An overview of the establishment costs compared to the dry matter (DM) value for continuous pasture (CP) compared to the renewed treatments (FIT and NT) established with ryegrass-clover or oats/Italian ryegrass. The values presented are preliminary and only cover the period up until the harvest of the oats/Italian ryegrass crop (i.e. 8 months).

Treatment	Establishment cost ($ ha^{-1})	DM value ($ ha^{-1})*	DM Value – Cost ($)
CP – Ryegrass-clover	250	1500	1250
NT – Ryegrass-clover	820	1620	800
FIT – Ryegrass-clover	1300	1300	0
NT – oats/Italian RG	1650	4500	2850
FIT – oats/Italian RG	2300	5500	3200

* DM valued at $0.22 kg DM^{-1}, Supplement valued at $0.3 kg DM^{-1}. Costs calculated up to the harvest of the green chop crop (i.e. late October).

Summary

Early signs of the data analysis are promising and indicate that the use of FIT creates an opportunity to increase SOC in the surface soil without causing any adverse effects on pasture performance. We want to reiterate that FIT would be used as a one-off event (ca. once every 30 years) with any subsequent pasture renewal events being through no tillage. It should also be pointed out that we are not advocating the use of FIT in all scenarios, on all soils, and it is our intention to highlight scenarios/guidelines for where FIT would be the most suitable in due course.

Acknowledgements

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