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THE AGRONOMIC AND ENVIRONMENTAL BENEFITS AND RISKS OF SPRING PASTURE RENEWAL WITH FULL INVERSION TILLAGE

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Abstract

Increasing soil organic carbon (SOC) stocks could offset farm net greenhouse gas emissions by reducing global atmospheric CO_2 concentrations and, thereby, slow climate warming. New Zealand's long-term pastures commonly create topsoils (0–10 cm) rich in SOC but the subsoils (10–30 cm) often contain less than half as much SOC. Lowland farmers are advised to renew their pastures every 7–10 years to improve pasture production. Pasture renewal practices typically involve herbicide spraying in spring or late summer-autumn to (i) directly establish new pasture or (ii) sow a forage crop for summer or winter grazing prior to sowing new pasture. Minimum till or direct drilling maintains the vertical stratification of SOC, limiting the scope to increase SOC under new pasture. Trials have been established to test whether a one-off (or infrequent) use of full inversion tillage prior to pasture renewal (FIT-renewal) could accelerate SOC storage in soils by both exposing low SOC subsoil to carbon inputs from new pasture and transferring carbon-rich topsoil deep into the subsoil (potentially slowing its decomposition).

During 2016–2017, two trials were established, one at Massey University (Pallic soil) and one on a commercial farm in the Taranaki/Whanganui area (Allophanic soil) to assess the effects of spring FIT-renewal on SOC stocks and crop/pasture agronomic performance. In both trials, FIT-renewal involved ploughing to approx. 30 cm depth and sowing a summer Brassica crop followed by autumn re-grassing. Other renewal treatments included were no-till (direct drill) and shallow till. Changes in SOC vertical distribution, plant growth, herbage quality (at both sites) and nitrogen leaching (Massey site only) were monitored.

At both sites, FIT effectively buried SOC below 0–10 cm depth and increased crop yield compared to no-till treatment. Pasture production was similar among all treatments. In the Massey trial, N leaching losses were consistently lower under FIT than the other practices. These results highlight the potential agronomic and environmental benefits of FIT-renewal; however, longer-term studies are needed to verify the effects on SOC storage. The benefits of spring FIT-renewal may depend on timely application and the inclusion of a crop phase.

Keywords: full inversion tillage; soil carbon sequestration; spring renewal; deep ploughing; greenhouse gas emissions.

Introduction

Increasing soil organic carbon (SOC) stocks is currently targeted as a strategy to offset agricultural greenhouse gas emissions and thus slow climate warming (Rumpel *et al.*, 2020). The topsoil (0–10 cm) of high producing permanent pastures accumulate large amounts of SOC (Schipper *et al.*, 2017), highly stratified with depth and the scope for additional increases of SOC stocks may be limited (McNally *et al.*, 2017; Whitehead *et al.*, 2018).

Lowland farmers in New Zealand rely on intensively managed grazed pastures supporting year-round animal production. These farmers are advised to renew the pastures every 7–10 years because of direct economic benefits (Kerr *et al.*, 2015) derived from improvements in pasture performance and animal productivity after re-grassing. Pasture renewal practices typically involve herbicide spraying in spring or late summer-autumn to (i) directly establish new pasture or (ii) sow a forage crop for summer or winter grazing prior to sowing new pasture (Hanly *et al.*, 2017; Trolove *et al.*, 2019).

Minimum till or direct drilling maintains the vertical stratification of SOC, limiting the scope to increase C storage under new pasture. The modification of SOC stratification with depth can be achieved by a one-off (or infrequent) use of full inversion tillage [or deep ploughing, below 25 cm depth; Alcántara *et al.* (2017); Calvelo Pereira *et al.* (2018)] prior to pasture renewal (FIT-renewal). Both exposing low SOC subsoil to carbon inputs from new pasture as well as transferring carbon-rich topsoil deep into the subsoil (potentially slowing its decomposition) could accelerate SOC storage in the soil profile.

Beyond positive effects on SOC storage, the adoption of FIT-renewal may as well promote other benefits because of the establishment of the new vigorous sward. Both method and timing (spring vs autumn) of pasture renewal influence agronomic yield and nutrient cycling (Velthof *et al.*, 2010). Currently, the use of FIT-renewal is being tested in New Zealand at the farm-scale (Calvelo Pereira *et al.*, 2019; McNally *et al.*, 2019), following best management practices to fully evaluate the contribution of FIT to enhance SOC storage.

The objective of this study was to assess the short-term effects of spring pasture renewal using contrasting tillage treatments (either no-till, shallow till or FIT) on two soils under permanent pasture. During 2016–2017, two trials were established, one at Massey University [Trial 1; Pallic soil; Calvelo Pereira *et al.* (2019)] and one on a commercial farm in the Taranaki/Whanganui area (Trial 2; Allophanic soil). At both trials, all tillage treatments involved spring sowing of a summer brassica crop followed by autumn re-grassing. This article provides a summarised assessment of the effects of spring FIT-renewal on SOC stocks and crop/pasture agronomic performance for trial 1 (2 years after renewal) and trial 2 (1 year after renewal). This research in the Manawatu region complements other field trials established to assess autumn pasture renewal (Beare *et al.*, 2020) as well as the impact of FIT on nitrous oxide emissions (McNally *et al.*, 2020).

Materials and Methods

Field trials description

The current study focuses on two on-going field trials on spring pasture renewal including full inversion tillage (Figure 1) in the North Island of New Zealand: (i) Trial 1, on a Pallic soil, dairy farming; and (ii) Trial 2, on an Allophanic soil, sheep and beef farming. The following text provides a description of each trial. Trial 1 has been presented in greater detail elsewhere (Calvelo Pereira *et al.*, 2019).

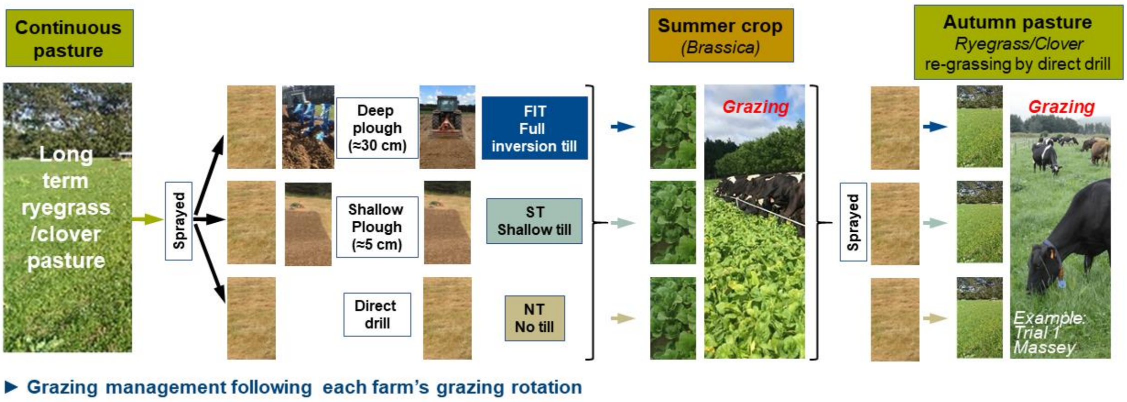

Figure 1 Brief description of spring pasture renewal practices described in this study.

Trial 1: grass-crop-grass rotation on a Pallic soil under dairy farming

The trial site was located on Massey University's Dairy 4 farm near Palmerston North, Manawatu (40° 23′ 46.79″ S; 175° 36′ 35.77″ E) on a mole-pipe drained Tokomaru silt loam, a Pallic soil (Hewitt, 2010). Prior to commencement of this trial, all plots were under a mixed pasture of predominantly perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) which was grazed by dairy cows. Details on initial soil fertility and fertiliser application have been presented elsewhere (Calvelo Pereira *et al.*, 2019).

The trial design consisted of three tillage treatments in spring to establish a summer fodder crop followed in autumn by re-sowing permanent pasture by direct drilling into the fodder crop stubble (Figure 1): (i) direct drill-no till (NT); (ii) shallow (approx. 5 cm depth) till (ST); and (iii) deep ploughing (approx. 30 cm depth; FIT) using a modified mouldboard plough. Treatments were assigned randomly to existing experimental plots (approx. 0.09 ha each). Leafy turnip (*Brassica campestris spp rapa*, var Hunter) was sown on all plots on 29 November 2016. Crop yield was monitored during summer and the crop was grazed by dairy cows as part of the farm's grazing rotation. On April 2017, a mix of perennial ryegrass and white clover was sown by direct drilling. Following re-grassing, pasture growth was monitored and all treatments in the trial area were grazed by dairy cows as part of the farm's grazing rotation.

Trial 2: grass-crop-grass rotation on an Allophanic soil under sheep and beef farming

The trial site was located on commercial sheep and beef farm near Maxwell, in the Taranaki/Wanganui area (39° 47' 46.50"S; 174° 54' 1.62" E) on an Allophanic soil (Hewitt, 2010). Prior to commencement of this trial, all plots were under a mixed pasture of predominantly perennial ryegrass and white clover which was grazed by sheep and beef. Soil was characterised for fertility; subsoil fertility levels were satisfactory for meeting crop needs (data not shown). The re-grassing trial design consisted of three tillage treatments, the same as described for Trial 1 (Figure 1). Treatments (NT, ST, and FIT) were assigned to experimental plots (approx. 0.03 ha; 5 replicates) along a slope gradient. Following a similar practice as that described for the Manawatu site, the pasture on all plots was sprayed, then cultivated following the same treatments (i.e. NT, ST and FIT), to sow leafy turnip (*Brassica campestris spp rapa*, var Hunter) on all plots. All plots received basal fertiliser at the following rates: 48 kg N/ha and 53 kg P/ha (as DAP); 1.5 kg B/ha (as sodium borate). Crop yield was assessed during summer period and plots were grazed following the farm's grazing rotation. On April 2018, a mix of perennial ryegrass and white clover was sown by direct drilling. Following re-grassing, pasture growth was monitored, and the trial area was grazed by sheep and rising 1 y Friesian bulls as part of the farm's grazing rotation.

Monitoring of field trials

Herbage and early N uptake monitoring (Trial 1 and Trial 2)

At both sites, crop yield was assessed by sampling 3 replicate quadrats (0.8 x 0.5 m) in each plot (5 plots per treatment). Following re-grassing, pasture growth was monitored by using a plate-meter.

Soil sampling for short-term carbon stocks change (Trial 1 and Trial 2)

At both trial sites, soils were cored at two different times: (i) baseline or pre-renewal, before the starting of each trial and prior to pasture renewal; and (ii) post-renewal or approx. 5 months after renewal practice and growth of crop. A 43.5 mm diameter percussion corer was used to obtain a representative core to depth of 30 cm. Soil columns were sliced to obtain representative samples at depth intervals of 0–5, 5–10, 10–15, 15–20, 20–25, and 25–30. Soil samples were dried and stored for elemental C analysis. The soil bulk density of each core obtained from each depth interval was calculated by dividing the sample masses (corrected for the soil mass dried at 105°C in an oven by using a subsample) by the corresponding core volume. Soil C stocks were calculated using an equivalent soil mass approach (Calvelo Pereira *et al.*, 2018).

Additional assessment of drainage and N loses during year 2 (Trial 1 only)

In Trial 1, each plot had its own internal pipe and mole drainage system, allowing the quantification of drainage volume and losses of NO_3-N. In this report, drainage data for 2018 are discussed.

Agronomic costs model

The input data and results from the Trial 1 and Trial 2 was used to develop guidelines for cost-effective and practical application of FIT-renewal. A prototype spreadsheet calculator was developed [modelled on the PRCT Dairy Calculator developed by Stantial and Brazendale (2009)], recording the agronomic cost of successfully establishing a vigorous pasture sward (costs of sprays, tillage, fertiliser and drilling operations). Fertiliser inputs are based on site-specific chemical soil fertility tests and target values (Roberts and Morton, 2012) for optimum crop and pasture establishment.

Data analysis and statistics

Statistical analyses were conducted with the Statistica version 8 software package (Stat Soft. Inc., Tulsa, OK, USA). For each trial independently, the effect of pasture renewal practice (i.e. NT, ST and FIT) on different variables was statistically analysed using a one-way ANOVA test. When depth was included in the statistical analysis, the one-way ANOVA test was calculated independently for each depth considered. If a significant ($P < 0.05$) main effect was detected, difference between treatment means was tested using the least significant difference.

Results and Discussion

Trial 1 and Trial 2 monitoring

Dry matter production (Trial 1 and Trial 2)

In both trials, the average turnip crop yield was influenced by the intensity of tillage at pasture renewal, and accumulation of dry matter was greater under FIT-renewal treatment (Table 1). Particularly, in Trial 2, the average yield in plots was higher ($P < 0.05$) under FIT treatment (9817kg DM/ha) than under NT (7066kg DM/ha) and ST (7352 kg DM/ha) treatments (Table 1). The average pasture accumulation of the re-sown swards (Trial 1 and Trial 2; Table 1) for the FIT treatment was not significantly different to that for the NT and ST treatments in any of the periods studied.

Table 1 Average herbage dry matter (kg/ha) accumulated at both trial sites for each renewal practice (i.e. NT, ST and FIT).

Trial	Accumulated DM	Tillage treatment			*P* value
		NT	ST	FIT	
Trial 1	kg DM/ha				
Crop phase	Mar 2017	6535b	7963ab	8957a	*0.014*
Pasture phase	Apr 2017 – Nov 2019	33930a	33804a	34359a	*NS*
Trial 2					
Crop phase	Jan 2018	7066b	7352b	9817a	*0.022*
Pasture phase	Apr 2018- Jun 2019	7176a	7706a	6868a	*NS*

Nitrogen losses during year 2 (Trial 1 only)

In Trial 1, reductions ($P < 0.10$) in the loss of NO_3-N under FIT treatment compared to the NT treatment were detected during the crop phase (Calvelo Pereira *et al.*, 2019).

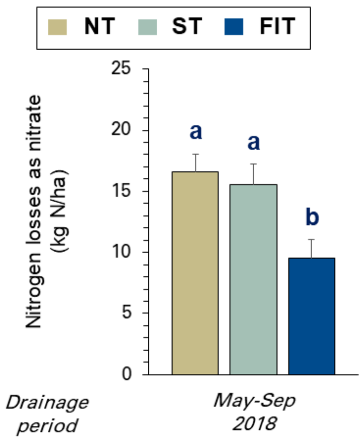

Figure 2 Average NO_3-N leached for Trial 1 during 2018 as dependent on tillage treatment (i.e. NT, ST and FIT).

During 2018 (pasture phase) drainage season, the average loss of NO_3-N was reduced ($P < 0.05$) under FIT treatment (9.5 kg NO_3-N/ha) compared to NT (16.6 kg NO_3-N/ha) and ST (15.6 kg NO_3-N/ha) treatments (Figure 2). These results confirm that at least during year 2 after pasture renewal, FIT treatment continued mitigating the risk of nitrogen loss.

Changes in soil C stocks five months after pasture renewal

At the start of both trials (Trial 1: October 2016; Trial 2: October 2017) the soils showed a distinct stratification of C soil organic matter (data not shown), as expected for long-term pasture. Five months post tillage, at the end of the forage crop grazing, all renewal treatments showed no major differences in total C stocks down to a nominal depth of 30 cm (on average, 98 and 148 Mg C/ha for the Pallic and Allophanic soils respectively; Figure 3). The NT and ST treatments showed strong SOC stratification, like that found in the long-term pasture. Five months after renewal and crop growth, the FIT treatment showed a modified SOC stratification in both the Pallic and Allophanic soils (Figure 3).

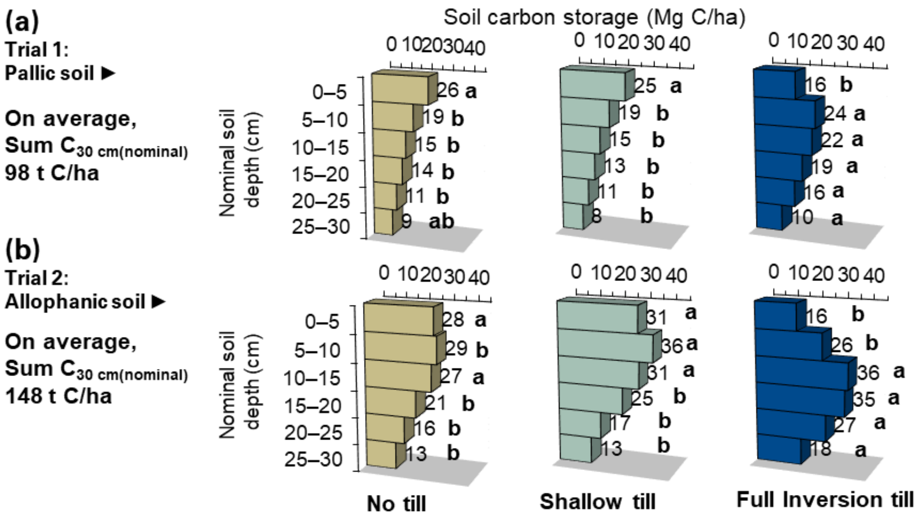

Figure 3 Average soil carbon stocks calculated at equivalent soil mass per tillage practice 5 months after renewal and growth of crop for (a) Trial 1, Pallic soil, and (b) Trial 2, Allophanic soil.

In the Pallic soil, average carbon stocks in the 0–5 cm nominal depth under FIT (16 Mg C/ha) was lower ($P < 0.001$) than the C stocks under the NT and ST treatments, which were on average 26 and 25 Mg C/ha, respectively (Figure 3a). The soil profile of the FIT treatment had a higher ($P < 0.05$) C stock than either of the other two treatments, at 5–10, 10–15, 15–20, 20–25, and 25–30 cm nominal depths (Figure 3a). In the Allophanic soil, average carbon stocks in the 0–5 cm nominal depth under FIT (16 Mg C/ha) was lower ($P < 0.001$) than the C stocks under the NT and ST treatments, which were on average 28 and 31 Mg C/ha, respectively (Figure 3b). The soil profile of the FIT treatment had a higher ($P < 0.05$) C stock than either of the other two treatments at 15–20, 20–25, and 25–30 cm nominal depths (Figure 3b).

Overall, these results demonstrate that FIT inverts the topsoil C and, thus, creates an unsaturated C topsoil root zone (i.e. a SOC ”gap”; 12 Mg C/ha, Pallic soil and 18 Mg C/ha, Allophanic soil). Because of FIT, former subsoils, now transferred into the topsoil, will have greater contact with plant C inputs from grass litter, roots and dung. Longer-term monitoring of changes in soil carbon storage is needed to verify benefits of FIT for soil carbon sequestration, i.e. assess whether buried topsoil material decomposed more slowly than the SOC gap is filled in the initially C poor new topsoil (Alcántara *et al.*, 2017).

Agronomic costs assessment

Table 2 summarises main outcome of the calculation of agronomic costs for Trial 1 and Trial 2. Differences in initial fertiliser applied also influenced costs of FIT at crop establishment at Trial 1.The higher costs associated with crop establishment (more tillage passes for shallow tillage (ST, 2 passes) and full inversion tillage (FIT, 3 passes) and increased fertiliser costs (FIT) are more than offset by the increased value of the summer crop (Table 2). However, the similar accumulated pasture yields offer no feed value differences between tillage treatments (see Table 1).

Table 2 A summary of the costs, associated with three tillage methods at Trial 1 (Pallic soil, dairy farming) and Trial 2 (Allophanic soil, sheep and beef farming). DM value: Ryegrass/clover = \$0.22 / kg DM; Supplement = \$0.30 / kg DM. For Trial 1, DM value as at 7/11/2019 (approx. 36 months post-tillage); for Trial 2, DM value as at 19/6/2019 (approx. 19 months post-tillage).

Trial	Treatment	Establishment cost (Crop and Pasture) (\$/ha)	DM value (\$/ha)	Feed value – cost (\$/ha)
Trial 1	NT	1640	9425	7785
	ST	1910	9826	7915
	FIT	2225	10286	8061
Trial 2	NT	1339	3699	2359
	ST	1609	3901	2291
	FIT	1789	4456	2667

Summary and conclusion

The modified plough successfully transferred SOC below the 0–10 cm soil depth in both the Pallic and Allophanic soils. At both trials, crop yield was higher under the FIT treatment, and pasture production was similar among all treatments. In the Massey Trial 1, N leaching losses were consistently lower under FIT than the other practices. The increased costs of tillage and seed-bed preparation with FIT can be neutralised by the value of higher summer crop yields prior to autumn re-grassing. Further evaluation of the trial sites over time will confirm whether FIT can then offset farm net greenhouse gas emissions over the long-term. These results highlight the potential agronomic and environmental benefits of spring FIT-renewal, which may depend on timely application and the inclusion of a crop phase.

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