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

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Abstract

The one-off (or infrequent) use of full inversion tillage (FIT) for pasture renewal has been identified as a promising option to increase soil C stocks. FIT relies on burying C-rich topsoil at depth while C depleted subsoil is brought to the surface, where the C inputs from new pasture production may accelerate C sequestration. Results are reported from two field trials on imperfectly drained Pallic soils in Canterbury and the Manawatu to assess the effects of FIT renewal in the autumn on soil C, dry matter production, nitrogen losses and agronomic costs. The trials consisted of replicated plots where ryegrass/clover pasture was renewed via FIT, no-tillage (NT) or shallow tillage (ST) compared to continuous pasture (no renewal). Additional treatments at Lincoln included plots sown to a mix of forage oats and Italian ryegrass following either FIT or NT. All treatments were established in March 2018.

As expected, FIT resulted in a redistribution of C in the top 30 cm of soil but did not change the total C stock immediately after cultivation or one year after pasture renewal. Total dry matter (DM) production during the first 19 month was similar under all three (FIT, NT, ST) pasture-pasture renewal treatments, which were, on average, about 3 t/ha higher than the continuous pasture. Total DM production in the pasture-crop-pasture renewal system over the same period was greater for FIT (≈ 31 t/ha) than NT (≈ 28 t/ha), which produced 12-16 t/ha more DM than the pasture-pasture renewal practices. At both sites, accumulation of mineral N following FIT-renewal increased the risk of NO_3^- leaching losses in winter-spring, but this was partially mitigated at Lincoln in the oat/Italian ryegrass treatments. Our results showed that the additional agronomic costs (e.g. tillage, fertiliser) associated with FIT can be offset by the increase in DM production in the first year after renewal. Longer-term trials are needed to demonstrate the effects of FIT-renewal on soil C stocks.

Introduction

Developing strategies to increase soil organic carbon (SOC) and thereby offset the increase in global GHG emissions is of increasing importance (Rumpel et al., 2018). Although the topsoil (e.g. 0-15 cm) of long-term pastures in New Zealand tends to be saturated in SOC, subsoils have lower SOC concentrations and hence a much greater capacity to store additional SOC (Beare et al., 2014). Modern pasture species typically have shallow root systems that do not generally supply enough C at depth to increase SOC stocks in subsoils.

Pasture renewal is periodically performed in New Zealand to improve pasture performance and/or modify pasture composition (Glassey et al., 2010). The one-off or infrequent (once every 30-50 years) use of full inversion tillage during pasture renewal has been proposed as an opportunity to increase SOC stocks (Lawrence-Smith 2020; Calvelo Pereira et al., 2018). The objective of full inversion tillage is to bury carbon-rich topsoil and bring low carbon subsoil to the surface where it can store more carbon from the vigorous growth of new pasture. However, the effective adoption of FIT pasture renewal for soil C sequestration requires that we understand and can manage the agronomic and environmental benefits and risks of this practice. The objective of this paper is to report results from field trials designed to assess some of the agronomic and environmental benefits and risks of autumn pasture renewal with full inversion tillage compared to traditional methods of renewal or continuous pasture.

Methods

Two field trials were established on imperfectly drained Pallic soils to assess the effects of FIT-renewal in the autumn on soil C, dry matter production, nitrogen losses and agronomic costs; one at Lincoln (Canterbury) and one in Palmerston North (Manawatu).

The Lincoln trial consisted of 6 replicated plots where perennial ryegrass/white clover pasture was renewed (grass-grass renewal) using FIT, shallow tillage (ST) or no-tillage (NT) compared to continuous pasture (no renewal). Additional treatments at this site included plots sown to a break crop of forage oats/Italian ryegrass following FIT or NT. The forage oats/Italian ryegrass was harvested at the green-chop stage in October 2018 and then re-sown into perennial ryegrass/white clover pasture, via direct drill, immediately after the crop harvest (grass-crop-grass renewal). Superphosphate (20 kg P ha^{-1}, 22 kg S ha^{-1}) and Cropmaster15 (30 kg N ha^{-1}) fertilisers were applied to all treatments at sowing followed by 3 subsequent applications of urea (30 kg N ha^{-1} each). Further details of the trial establishment and management can be found in McNally et al. (2019).

The Palmerston North trial also consisted of replicated plots where the pasture was renewed (grass-grass renewal) following FIT or by no-tillage (NT) compared to continuous pasture (no renewal). DAP and Potassium Sulphate fertiliser were applied at sowing to deliver 28, 31, 28 and 15 kg ha^{-1} of N, P, K and S, respectively. In both trials the plots designated for renewal were sprayed off in February 2018 before cultivation and seeding in March 2018.

Stocks of SOC (0-45 cm) was measured by soil coring (45 mm diameter, N=6) both pre- and post-renewal to assess the redistribution of SOC following FIT and to quantify and short-term changes in SOC stocks as a result of pasture renewal. Dry matter production and N uptake of both the pasture-pasture and pasture-crop-pasture treatments were monitored during the 19 months that followed trial establishment.

At Lincoln, the vertical distribution of soil mineral N was measured at approximately monthly intervals between March and November 2018 (8 months) to assess the risk to N leaching over the winter-spring period. At the Palmerston North site, drainage and NO_3 leaching losses were measured directly from hydrologically isolated plots. Nitrous oxide (N_2O) emissions were measured during pasture destruction (spray-of) and the first 1-3 months following reseeding of the pasture-pasture treatments using static chambers. The N_2O emissions from urine and N-fertiliser applied to FIT and NT renewal and CP treatments at both sites are reported separately (McNally et al. 2020).

Results and Discussion

SOC stocks

At both trial sites, FIT was effective at burying C-rich topsoil below 15 cm and bringing low-C subsoil to the surface, creating a gap in soil C (relative the original topsoil) that can be filled by C inputs from the roots of new pasture (Figure 1). At Lincoln, there were no differences in the total soil C stocks (0-45 cm; expressed on an equivalent mass basis) of FIT and NT renewal treatments compared to CP, both shortly after renewal (April 2018) and one year later (April 2019). Similar results were obtained at the Palmerston North site. Longer-term monitoring of soil C stocks will be required to detect the increases expected from FIT pasture renewal over 10-20 yrs.

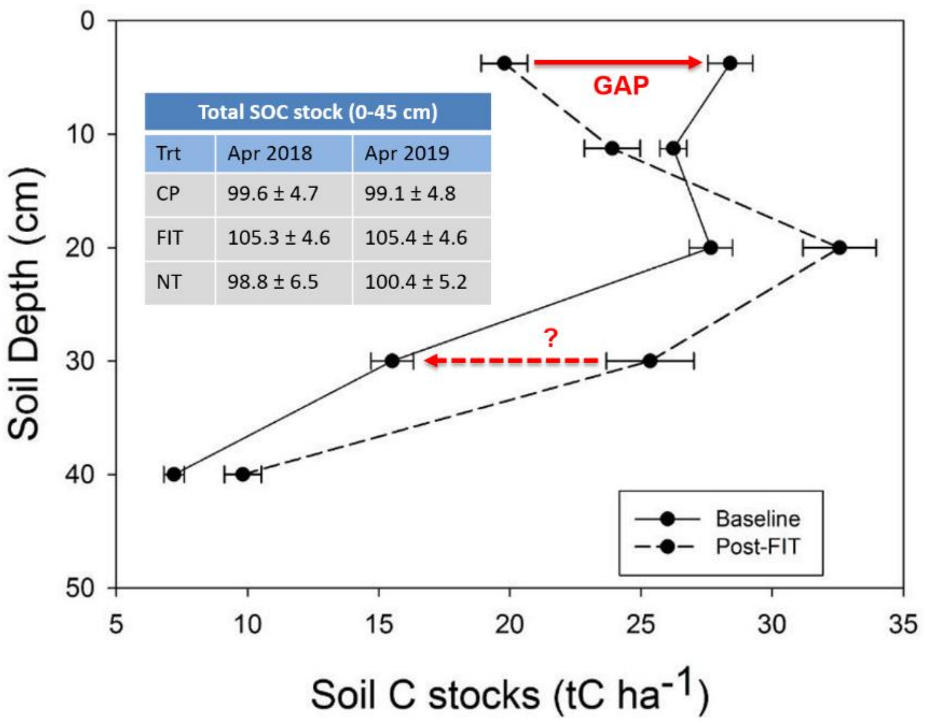

Figure 1. The vertical distribution of soil organic carbon (SOC) stock pre- and post- full inversion tillage presented on a fixed depth basis (Lincoln trial site). The plotted points represent the mid-point of the sampling depth and error bars are ± 1 SE. The inserted table gives stocks of SOC on an equivalent mass basis (to ≈ 45 cm) measured approximately 2 months (April 2018) and 14 months (April 2019) following NT and FIT pasture-pasture renewal compared to continuous pasture (CP).

Pasture and crop production

At Lincoln, total dry matter (DM) production over the first 19 months following pasture-pasture renewal (mean = 18 t/ha) exceeded that of CP by about 3 t ha^{-1}, but there were no differences between the three renewal treatments (i.e. NT, ST and FIT) (Figure 2). While establishment of ryegrass-clover pasture in the FIT plots was slower than the other renewal treatments (NT and ST), the DM production equalled that of CP within 10 months of renewal (~ 10 t DM ha^{-1}, 2). At Palmerston North, the total DM produced (19 months) from FIT and NT renewal treatments averaged (13.6 t ha^{-1}), which exceeded that of CP by about 1 t ha^{-1} (data not shown).

In the pasture-crop-pasture renewal treatments at Lincoln, the oats/Italian ryegrass crop produced much more DM than the pasture-pasture plots and the DM at green chop harvest (15 Oct 2018) was 3.4 t ha^{-1} higher following FIT (18.5 t ha^{-1}) compared to NT (15.1 t DM ha^{-1}). There were no differences in the pasture DM produced (Oct 2018 to Oct 2019; 12.7 t ha^{-1}) from FIT and NT following harvest of the oats/Italian crop. The total DM produced (19 months) from the FIT (31.2 t DM ha^{-1}) and NT (27.8 t DM ha^{-1}) pasture-crop-pasture renewal systems was 12.1-15.5 t DM ha^{-1} greater than the CP treatment. The N removed in the oats/Italian ryegrass harvested from the FIT (264 kg N ha^{-1}) and NT (207 kg N ha^{-1}) treatments greatly exceeded the average N removed (164 kg N ha^{-1}) in the pasture DM by Oct 2018.

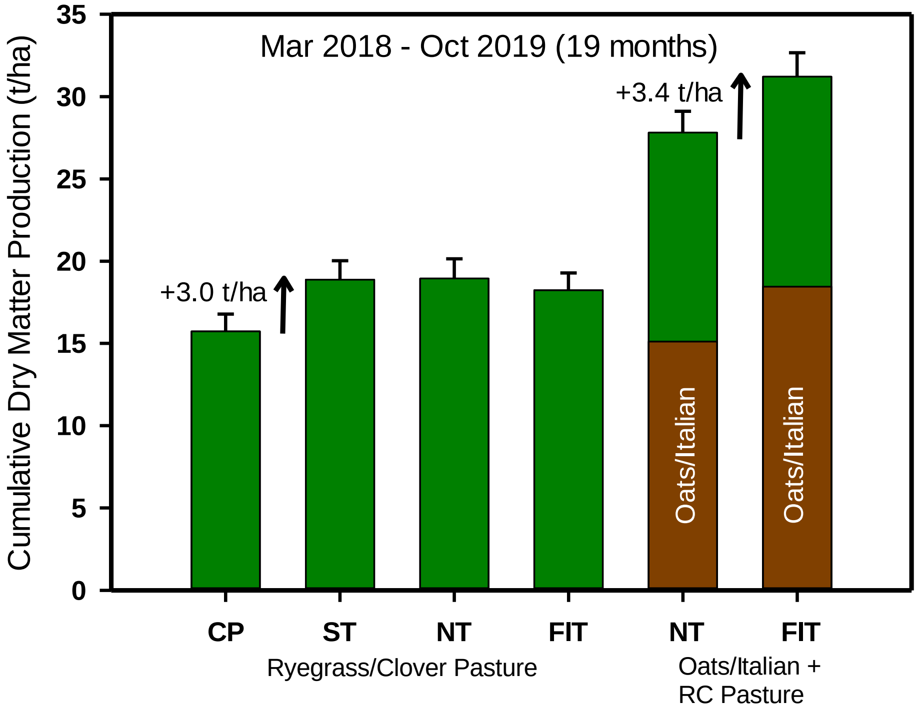

Figure 2 Cumulative dry matter (DM) production (t ha^{-1}) of ryegrass/clover pasture following ST, NT and FIT renewal (pasture-pasture) and oats/Italian plus ryegrass/clover pasture following NT and FIT renewal (pasture-crop-pasture) compared to continuous pasture (CP, no renewal) at the Lincoln trial site. Data presented are mean values ± 1 SE.

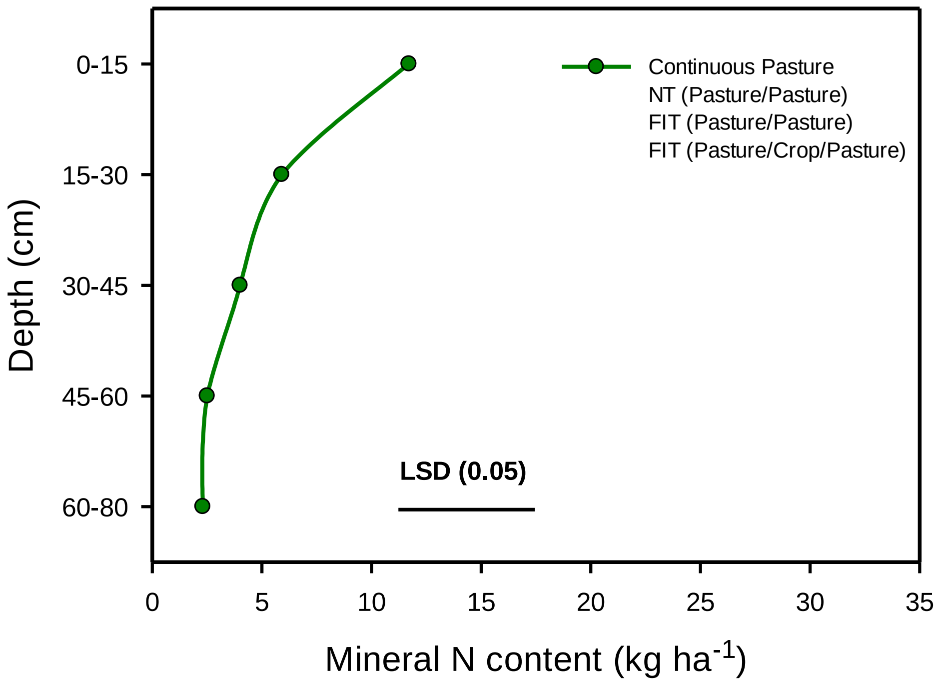

Figure 3 Cumulative dry matter (DM) production (t ha^{-1}) of ryegrass/clover pasture following ST, NT and FIT renewal (pasture-pasture) and oats/Italian plus ryegrass/clover pasture following NT and FIT renewal (pasture-crop-pasture) compared to continuous pasture (CP, no renewal) at the Lincoln trial site. Data presented are mean values ± 1 SE.

Risk of N losses

At Lincoln, there was significant accumulation of mineral N deeper in the soil profile (> 30 cm depth) following FIT pasture-pasture renewal that indicated an increased risk of NO_3^- leaching over the winter/spring period compared to NT renewal or continuous pasture (Figure 3).

However, the higher DM production and N uptake of the FIT oats/Italian ryegrass crop greatly reduced the mineral N content of the deeper soil compared to FIT pasture-pasture renewal and, thereby, reduced the risk of NO_3^- leaching over the same period.

At the Palmerston North site, drainage from the FIT (160 mm) pasture renewal treatment was ≈ 48 mm less than that of the NT and CP treatments between May and September 2018 (Data not shown). However, despite lower drainage, the N leaching losses from FIT (24 kg N ha^{-1}) were higher than those of NT (13 kg N ha^{-1}) and CP (9 kg N ha^{-1}). The potential benefits of an autumn sown break crops were not evaluated at this site.

Nitrous oxide emissions were elevated during pasture destruction (spray-off) and the first 1-3 months following cultivation and reseeding in the pasture-pasture renewal systems compared to continuous pasture at both sites. Whereas there were no differences in N_2O emissions from FIT and NT renewal practices at Lincoln, emissions from NT were more than two-fold higher than the emissions from FIT at Palmerston North (data not shown).

Agronomic costs

Accounting for the value of the DM produced, the FIT and NT pasture-pasture renewal treatments were less profitable than CP over the first year (due to greater establishment costs) at both the Lincoln (Table 1) and Palmerston North (data not shown) sites. However, the higher DM production rates of the renewed treatments were sufficient to offset the additional establishment cost incurred at renewal. In contrast to pasture-pasture renewal, the additional agronomic costs (e.g. tillage, fertiliser) associated with the pasture-crop-pasture renewal system were easily offset by the much greater DM production of the oat crop and the FIT renewal was most profitable. Compared to other renewal practices the establishment costs of FIT are relatively small when increased pasture production can offset these costs.

Table 1 An overview of the establishment costs compared to the dry matter (DM) value for continuous pasture (CP) compared pasture-pasture (FIT vs NT) and pasture-crop-pasture (FIT vs NT) renewal treatments. The values presented include the costs and dry matter production value from the first 12 months of the trial at Lincoln.

Treatment	Establishment cost ($ ha^{-1})	DM value ($ ha^{-1})*	DM Value – Cost ($)
CP – Ryegrass-clover	250	2800	2550
NT – Ryegrass-clover	820	3100	2280
FIT – Ryegrass-clover	1300	3030	1730
NT – oats/Italian RG	1650	6480	4830
FIT – oats/Italian RG	2300	7490	5190

* DM valued at $0.22 kg DM^{-1}, Supplement valued at $0.3 kg DM^{-1}.

Conclusions

Our initial findings from two trials investigating autumn pasture renewal indicate that FIT can achieve high levels of pasture DM production that are equivalent to those of ST and NT renewal practices and greater than that of CP. However, pasture-pasture renewal with FIT in the autumn increases the risk of NO_3^- leaching over the subsequent winter-spring period. In contrast, the oat/Italian ryegrass crop used in the pasture-crop-pasture renewal system was effective at mitigating the risk of NO_3^- leaching with FIT compared to other practices. Pasture-crop-pasture renewal with FIT was also the most profitable renewal system. The benefits and risks of spring pasture renewal with FIT are discussed by Calvelo Pereira et al. (2020). Preliminary guidelines for the effective use of FIT pasture renewal to enhance soil C sequestration are given by Hedley et al. (2020).

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