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WHERE, WHEN AND HOW - PRACTISE GUIDELINES FOR SUCCESSFUL INTRODUCTION OF FULL INVERSION TILLAGE TO INCREASE SOIL CARBON STOCKS UNDER PASTURE

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Abstract

Where? Permanent pastures on dairy and intensive sheep and beef farms in New Zealand reach an equilibrium with topsoils (0 - 15 cm) rich in but subsoils (15-30+ cm) low in soil organic carbon (SOC). Even pastures renewed regularly with minimum tillage practices retain this strong vertical stratification of SOC.

When? Practical experience from our research shows that pasture renewal is time to introduce full inversion tillage (FIT). FIT increases the depth of SOC, and allows the new grass to build new SOC in the low carbon (C) subsoil exposed at the surface after tillage. A renewal sequence of FIT applied in spring, followed by a seasonally-active crop before direct drilling new pasture is recommended for weed control and to minimise the risk of soil N loss to water. Little or no spray-off period is required with FIT, which reduces mineral N accumulation and N_2O emissions prior to new pasture establishment. Increased crop yields after FIT make it cost neutral compared to no-till pasture renewal.

How? Select a pasture due for renewal that has not been deep (> 15 cm) ploughed in the last 10 years. Take soil cores to 0 - 30 cm, cut and place the topsoil (0 - 7.5 cm) in a separate bag to the subsoil (7.5 - 30 cm depth). On receiving the soil test results if the SOC value for the topsoil is at least twofold greater than that of the subsoil then proceed with FIT. Lime and fertiliser may be applied after FIT where soil pH, P or K status is in the deficient range for the crop to be sown.

A standard plough fitted with a disc coulter and a trash-burying, skimmer in front of each mouldboard is best suited for burying topsoil in the furrow bottom. The point of the skimmer share should be set at 7.5 cm below the soil surface of the herbicide-treated pasture, with the main share of the mouldboard set to 25 - 35 cm depth depending on the vertical stratification of SOC. Plastic mouldboards or mouldboard slats are best suited to heavy and Allophanic soils.

Introduction

There is interest from farmers and scientists in management techniques that can increase soil carbon stocks as a one-off way of removing CO_2 from the atmosphere to partially mitigate climate warming. If such procedures can be proven successful, measurable and sustainable then the New Zealand government may accept soil C sequestration as a greenhouse gas offsetting procedure. In this paper, we present guidelines for a tillage technique that creates the opportunity for increased C storage in permanent pastures.

Permanent pastures on dairy and intensive sheep and beef farms in New Zealand reach an equilibrium with topsoils (0-15 cm) rich in but subsoils (15-30+ cm) low in soil organic carbon (SOC) (e.g. Mclntosh et al., 1997; Schipper and Sparling, 2011; Mudge et al., 2017; Calvelo-Pereira et al., 2018; Stafford et al., 2018). Under these circumstances SOC stocks in pasture soils change little over time (Schipper et al., 2017) because the topsoil SOC content has reached saturation (Pravia et al.2019; Six et al., 2002). Evidence from the stratification of SOC after pasture soils are cropped using no-till (NT) and shallow tillage systems (Home et al., 1992; Curtin et al., 2015; Pravia et al., 2019), and from our trials (e.g. Figure 1) comparing tillage techniques for pasture renewal (Beare et al. 2020; Calvelo-Pereira et al. 2020), shows that pastures renewed regularly with minimum tillage practices will retain this strong vertical stratification of SOC. Lawrence-Smith et al. (2020) proposed that if pastures are renewed using full inversion tillage (FIT) the potential to increase SOC stocks under pasture can be realised. FIT of the old pasture buries C-rich topsoil at the furrow bottom and brings subsoil unsaturated in C to the surface (Beare et al., 2020; Calvelo-Pereira et al., 2020). Litter, dung and roots generated by the newly sown pasture then builds SOC stocks in the new topsoil over the following years (e.g. Hedley et al., 2009; Schipper and Sparling, 2011; Calvelo-Pereira et al., 2018).

It is common practise for intensively grazed pastures to be renewed every 5-10 years. Well-managed pasture renovation is profitable (Kerr et. al., 2015; Stevens et. al., 2000) compared to continued farming of older permanent pastures; plus renovation allows the introduction of new grasses and clovers with plant and animal disease resistance (Burggraaf and Thom, 2000). There can be additional benefits of including a forage crop in the pasture renewal sequence to provide additional winter or summer feed (Bryant et al., 2010). Increased forage crop yields can be realised in some situations if no-till (NT) is replaced with FIT (Beare et al., 2020; Calvelo-Pereira et al., 2020).

In the sections that follow we present guidelines that would allow a farmer to identify *where* – there is stratified soil C under a pasture, which when renewed with FIT would increase SOC stocks, and *when* to undertake the pasture renewal and *how* to manage the tillage operations, crop and pasture agronomy.

Guidelines

Where does SOC stratification exist in soils suited to full-inversion tillage?

Firstly, all cultivation practices should be confined to land use capability (LUC) classes and slope categories as specified in local regional council land management regulations (e.g. Bay of Plenty Regional Council, 2020; Horizons Regional Council 2020). In general, this is restricted to LUC class 1-3 land on a <15^{o} slope. View farm records and select paddocks in permanent pastures that have not been deep (> 15 cm) ploughed in the last 10 years.

Figure 1. Soil cores taken one year after an old pasture was renewed using FIT or NT to establish a new seed bed for grasses. CP = continuous pasture. NT and CP show topsoils (0 - 7.5 cm) rich in C and FIT shows the buried topsoil from 10 to 30 cm.

When to undertake reconnaissance soil testing

At least three weeks prior to undertaking the ploughing for pasture renewal, walk across the cultivatable area in a zig-zag pattern and take 20 soil cores to 0 - 30 cm, cut and place the topsoil (0 - 7.5 cm) in a separate bag to the sub-soil (7.5 - 30 cm depth). Send both samples to a soil testing laboratory for a “Basic soil test” plus organic matter (i.e. SOC) and anion storage capacity (P retention). On receiving the soil test, results if the SOC value for the topsoil is at least two-fold greater than that of the subsoil then proceed with FIT. Table 1 shows some soil C results for examples of permanent pastures growing on the common soil orders in NZ.

Table 1. The %C content and bulk density of the 0 - 7.5 cm and 7.5 - 30 cm layers of soils under permanent pastures and the potential C stock increase after pasture renewal with FIT.

	Soils under permanent pasture						
		0- 7.5 cm		7.5 - 30 cm		Potential C [1]increase
Soil Type (Smap sibling)	Soil order	Carbon (%)	Bulk Density (t/m^3)	Carbon (%)	Bulk Density t/m^3	(t/ha)
[2]Kereone silt loam (Otorohanga_1d.3)	Allophanic	9.0	0.80	5.5	0.80	11
[3]Edendale rolling deep (Waikiwi_30a.1)	Brown	5.2	0.92	3.5	1.08	-1
[4]Tokomaru silt loam	Pallic	4.4	1.10	1.6	1.35	11
[5]Topehaehae clay loam (Taitapu_17a.1)	Gley	5.2	0.90	1.6	1.20	12
[6]Taupo sandy loam (Makiekie_6a.1)	Pumice	6.3	0.72	1.7	0.73	16

[1]The calculated increase assumes that the topsoil C content returns to its original value and 75% of the buried topsoil C remains. (Data sources [2,5] Stafford et al., 2018; [3]McIntosh et al., 1997; [4] Calvelo-Pereira et al., 2018; [6] Sparling et al., 2014 or Smap online).

The potential increase in SOC stocks was calculated using bulk density values published in the source literature or available in Smap online. The calculation (Eq.1) assumes that the FIT plough is set up to replace the 0-7.5 cm of C rich topsoil with 7.5 cm of C poor subsoil. This creates a “C gap” in the topsoil, which is filled (to the original topsoil C content) when the new permanent pasture reaches an organic matter content equilibrium again. At this stage the calculation assumes that 75% of the buried topsoil C remains.

$$C\ stock\ increase\ (t\ C\ ha^{-1}) = 750 \times \frac{((T_{\%C} \times T_{BD} \times F) - (S_{\%C} \times S_{BD}))}{100} \qquad \text{Eq.1}$$

Where the 7.5 cm slice of soil has a volume of *750 m^3 ha^{-1}* and $T_{\%C}$, T_{BD} and $S_{\%C}$, S_{BD} are the % C content and bulk densities *(BD t m^{-3})* of the soil layers at 0-7.5cm and 7.5-30 cm, respectively. F is the fraction of original topsoil C remaining when the new permanent pasture reaches an organic matter content equilibrium again.

The important aspects to note (Table 1) are: (i) when the original % C in the topsoil (0 - 7.5 cm) is approximately two fold greater than the % C in the sub-soil (7.5 - 30 cm depth), the potential increase in soil carbon stocks is >10 t C/ha, and (ii) the Edendale soil (Brown) has a deeper topsoil, does not obey the 2:1 rule, and FIT will not lead to an increase in soil carbon stocks.

Therefore, it is important to carry out soil testing prior to implementing FIT if the main goal is to increase SOC stocks. If the goals are improved weed control at cultivation and the potential of higher crop yields, then FIT can be undertaken irrespective of SOC stock changes.

Adjust soil fertility at seed-bed preparation if needed

The soil test will also provide information on soil fertility. It is quite common that the subsoil nutrient status under permanent pasture (PP) is significantly lower than the topsoil nutrient status (Figure 2, PP).

After FIT low-fertility subsoil exposed in the new seedbed (Figure 2, FIT) can pose a risk to germination and subsequent crop or pasture growth. Our recommendation is that where soil pH, P or K status is in the deficient range for the crop or pasture to be sown, sufficient lime and fertiliser may be applied after FIT, during seed-bed preparation, to meet the needs of the crop. In our experience, after five trials on different soil types (e.g. Pallic soil Figure 2), capital applications of lime, phosphorus and potassium are not generally required to raise the topsoil nutrient status to that of the original topsoil.

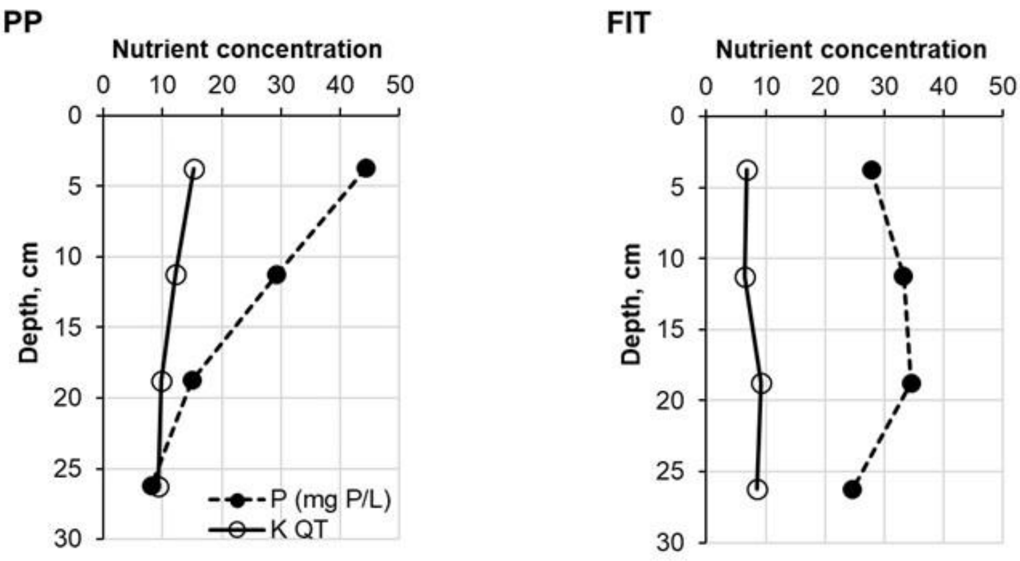

Figure 2. Olsen extractable P and exchangeable K profiles from soil cores taken 1 year after an old pasture (PP) growing on a Pallic soil was renewed using FIT.

How to set up the plough for FIT

A standard plough fitted with a disc coulter and a trash-burying, skimmer in front of each mouldboard is best suited for burying topsoil in the furrow bottom. Standard mouldboards set to a working width of approximately 47 cm should be able to achieve a working depth of 30 cm. The point of the skimmer share (Figure 3) should be set at 7.5 cm below the soil surface of the herbicide-treated pasture, with the main share of the mouldboard set to 25 - 35 cm depth depending on the vertical stratification of SOC. (A mouldboard with deeper body depth may be necessary to plough deeper than 30 cm; consult your farm machinery dealership). Plastic mouldboards or mouldboard slats are best suited to heavy and Allophanic soils because they minimise soil sticking to the plough

Figure 3. Skimmer share set 22.5 cm above mouldboard share point and 7.5 cm below the soil surface.

Recommended sequence for pasture renewal (grass to grass or grass- crop – grass)

In summer dry climates, except where spray irrigation is available, new ryegrass-clover based pastures are best established in autumn when a prolonged period of adequate soil moisture can be better guaranteed. To avoid a feed shortage on farm however, the initial ploughing is best timed for a period of feed surplus e.g. mid to late spring. This allows a forage crop to be established in spring, providing valuable supplementary feed that can be conserved or grazed off prior to the autumn grass reseeding. Forage crops can be more effective than new pasture at taking up soil N, which was mineralised during the spray off and tillage period. This minimises the risk of N leaching from the cultivated soil. If spray irrigation is available, cultivation timing is not limited by drought. Irrigation can be used to control the soil moisture content at tillage and seedbed preparation. The ground can be either re-sown immediately in grass or, a summer or winter crop. Deficit irrigation should be practiced to avoid leaching loss of mineralised soil N.

We recommend spraying the old pasture with herbicide. Climate permitting keep the interval between spray-off and ploughing short, < 10 days. Plough with the configuration shown in Figure 3. Use a rotatiller to prepare the crop seed bed and incorporate any lime and fertiliser that has been recommended. Our experience with leafy rape sown in mid-October, in summer dry Manawatu, is that FIT can deliver 2 t DM/ha more than no-till at grazing, 85 days after sowing. High yielding brassica crops (> 8 t DM/ha) when strip grazed by cattle present an N leaching risk. Duration-controlled grazing (stock return to pasture after crop allocation) will lessen the nitrogen (N) load on the brassica stubble and lessen the risk of N loss to water during the subsequent drainage season. After grazing is complete, direct drill the new pasture into the crop stubble following a light rain (e.g. 20 mm on a silt loam soil) or irrigation. Less fertiliser N (with urease inhibitor) is typically required once the new grass is established after forage crop grazing (< 25 kg N/ha) than after removal of a conserved feed crop (< 50 kg N/ha). As with any new grass up to two light grazings are recommended to assist sward development before resuming the normal grazing round and maintenance fertiliser regime (Roberts and Morton, 2012).

The research team's experience and analysis of four grass-crop-grass trials, (Manawatu, Southern Taranaki and two trials at Lincoln in Canterbury) show that increased crop yields after FIT make it cost neutral compared to no-till pasture renewal (Beare et al., 2020; Calvelo-Pereira et al. 2020).

Auditing changes in soil C stocks

The time to re-measure soil C stocks will be three weeks prior to the next pasture renewal event in the same paddock. Currently the New Zealand government has not implemented a paddock scale soil C monitoring programme. In the future, the NZ government accepted SOC sequestration as part of the national effort to reduce GHG emissions, then soil sampling protocols similar to those developed by the FAO (2019) would have to be adhered to. In its most complicated form (farm specific), this is likely to involve a third party, certified, auditor taking soil cores to measure soil C and bulk density in the top 30 cm of soil prior to, and after a management change (i.e. pasture renewal with FIT replacing NT). In a simpler form (management and soil type specific), NZ agricultural scientists could, through regional trials, establish soil management protocols that if followed lead to an agreed increase in SOC stocks. Photographic evidence (GPS located and timestamped) and receipts (seed – fertiliser etc) would be all the farmer would need to provide. In the mean-time those interested in soil

C sequestration could join a voluntary international scheme such as those supported by VERRA 2018.

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