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PLANNING FOR CHANGES IN TOPSOIL C AND N STOCKS – SIGNIFICANCE IN C AND N BUDGETS

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Abstract

New Zealand has a history of rapid land use change as trends in global commodity markets influence primary sector financial sustainability. Traditionally, low sheep and beef returns accelerate extensive pastoral land use change to forest, particularly if supported by afforestation schemes (*e.g.* AGS and ETS). High dairy payout accelerate forest change to intensive pasture. Current debate around the agricultural sector participating in a carbon (C) economy is spreading in New Zealand, coincident with debate on de-intensification to reduce impacts on water quality. Farms including planted forest lands may be rewarded if they are able to show a decrease in nitrogen (N) loss to water and an increase in the terrestrial sink of C. While soil carbon change is not accounted for in the ETS a change from forest to pasture penalises the landowner for the reduction in biomass C with no reward or penalty for change in soil organic matter C and N. To account for soil carbon change, protocols to measure and monitor topsoil organic C and N storage at the farm level are needed. Evidence for consistent quantifiable change is required to support inclusion of soil organic matter change in both C and N accounting. Previous research in the Taupo (Central North Island) area has shown that conversion of forest land back to productive permanent pasture caused a fast accumulation of soil organic C (6.1 t C/ha/year) and of N (450 kg N/ha/year) as a response to fertiliser addition and plant productivity. In this paper we provide a case study of topsoil organic matter change in a forest to pasture conversion in the Taupo region. 42 paddocks from three sites (Tainui, Tauhara and Waimana; Wairakei Estate, Taupo) were monitored in 2017. The paddocks are currently under pasture management after recent (2-11 years ago) conversion from former planted forest. Marked differences in the storage of C (38 to 51 t C/ha_{15cm}) and N (1.8 to 3.4 t N /ha_{15cm}; Waimana site) were detected. The relevance of these changes to C and nutrient budgeting are discussed in relation to how such large and important changes can be accounted for.

Introduction

Land use change in New Zealand is very dynamic as trends in global commodity markets influence primary sector financial sustainability. Traditionally, low sheep and beef returns accelerate extensive pastoral land use change to forest, particularly if supported by afforestation schemes, *e.g.* either afforestation grant scheme, AGS (Ministry for Primary Industries, 2016) or the New Zealand emissions trading scheme, NZ ETS (Ministry for the Environment, 2018).

The forest-to-farm land-use change has impacted New Zealand's greenhouse gas accounting because forests planted since 1990 can be included as "forest sinks", *i.e.* net consumers of carbon dioxide under the first commitment period of the Kyoto Protocol and hence included in the NZ ETS (Ministry for the Environment, 2018). The consequences of this land-use change on C and N budgets are therefore currently based on the consequences of tree removal (Ministry for Primary Industries, 2016). Significant disruption of the soil profile occurs as trees are harvested and stumps removed to be replaced by pasture. Pasture has then to be established in soil profiles that can be highly variable over a distance of only a few metres. Significant inputs of nitrogen (N) and phosphorus (P) fertilisers are required to build soil fertility in these soils (Hawke, 2004), which may have been under forest for several decades.

The global soil carbon (C) pool is double that of the vegetation or atmosphere (Batjes, 2014). Therefore, it is important to quantify impacts of deforestation on soil C storage. In New Zealand, comparing forest and pasture on different soil Orders, studies generally report a greater amount of C under pasture than under forest or scrub (Giddens *et al.*, 1997; Schipper and Sparling, 2011; Hewitt *et al.*, 2012). A limited number of studies in New Zealand (Hedley *et al.*, 2009; Mudge *et al.*, 2014; Sparling *et al.*, 2014) described consistent increases in soil C and N after land use change from plantation pine to pasture. In this sense, some Pumice soils may rapidly increase their C (up to 6.1 kg C/ha/year) and N content (up to 450 kg N/ha/year) especially in the topsoil (*i.e.*, 0-15 cm depth;) after conversion from forest to managed pasture (Hedley *et al.*, 2009). The greater the length of time since conversion to pasture, the greater the amounts of C and N stored in the soil (Sparling *et al.*, 2014).

High dairy payouts have accelerated the forest change to intensive pasture. The current debate in New Zealand is whether the area of intensive pasture should decrease to reduce impacts on water quality. At the same time, politicians are discussing whether the pastoral and arable agricultural sectors should directly participate in a carbon economy. Beyond direct impacts on soil C and N stocks, conversion from forest to pasture will modify the fate of other greenhouse gases, as consequence of increasing methane and nitrous oxide emissions associated with the introduction of grazing ruminants (Kirschbaum *et al.*, 2012; Kirschbaum *et al.*, 2013). In addition, nitrate leaching through the soil may increase, primarily due to urine excreted by ruminants. (Monaghan *et al.*, 2007). To fully account for the change in environmental footprint associated with land use change and in particular in C and N stocks after conversion from forest to managed pasture, a key initial step is hence to plan for robust measurement and monitoring of topsoil organic C and N storage at the farm level.

In this paper we provide a case study of topsoil organic matter change in a forest to well managed ryegrass/clover pasture conversion in the Taupo region. For this, we used data from the monitoring of 42 paddocks from three sites on Pumice soils at Wairakei Estate, Taupo. The paddocks are currently under pasture management after recent (2-11 years ago) conversion from former planted forest. Additionally, we applied the OVERSEER® nutrient budgets model including real farm data to assess changes in the fate of N as consequence of recent land use change.

Materials and Methods

Site selection; soil sampling and chemical analyses

Three sites were selected on sheep/beef areas that had been converted from pine plantation to well managed ryegrass/clover pasture in the Wairakei State, Taupo, Central North Island, New Zealand (Figure 1; Table 1). The study areas were on Pumice soils (Rijkse and Vucetich, 1980; Hewitt, 2010). Each of the three study sites included two clusters of 7 paddocks, each cluster covering an area of 19.3 ha on average. The paddocks are currently under pasture management after recent (2-11 years ago) conversion from former planted pine forest. Sites followed a similar fertiliser regime, with approx. 168 kg N/ha/year applied in September (as Pasturezeal G2 10K, 30 kg N/ha) and October, April, December (as urea, 46 kg N/ha per application). Phosphorus, potassium and sulphur were applied yearly in September (as Pasturezeal G2 10K, 22 kg P/ha, 40 kg K/ha, and 26 kg S/ha).

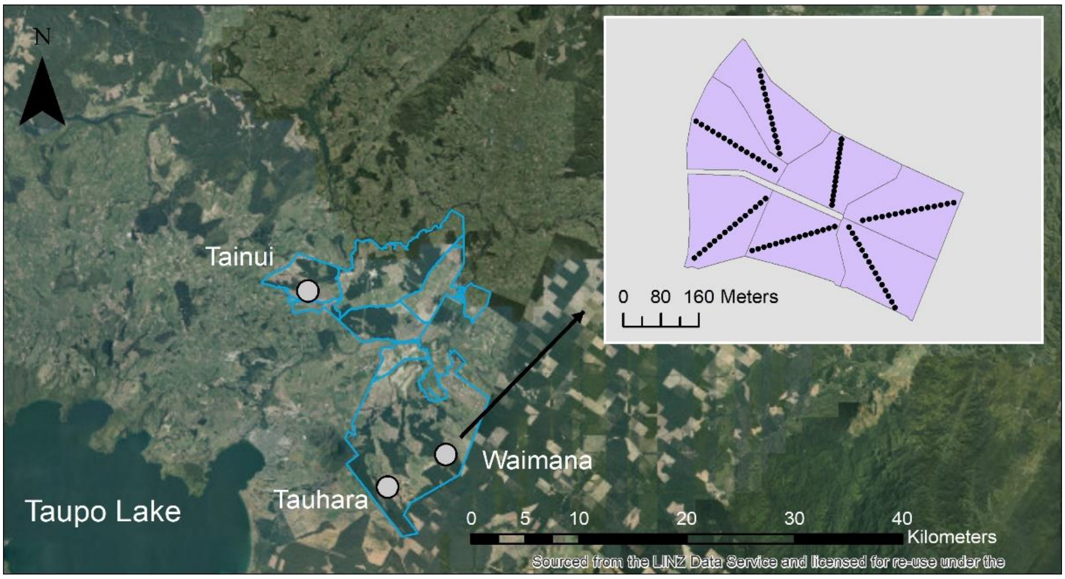

Figure 1 Study area, Wairakei Estate, Taupo, Central North Island, and paddocks monitored (*i.e.*, Tainui, Tauhara and Waimana sites). Inset: layout of transects and individual soil sampling points (example: Waimana cluster B; 7 paddocks)

Soil sampling occurred in Summer 2017. At each study site and cluster, for each paddock, a transect was laid out and 15 samples were taken at intervals along each transect. Topsoil samples (0-15 cm depth) were taken using a hand-driven soil corer and bulked every 5 sampling points; a total of 3 bags per paddock were available for chemical analysis. Topsoil samples were prepared and analysed following published methods (Blakemore *et al.*, 1987; Morton and Roberts, 2012). Soil chemical properties as total C, total N, C/N ratio, available N, mineralisable N, pH, Olsen P, major cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}, $cmol_c/kg$), cation exchange capacity (CEC, $cmol_c/kg$), and base saturation, which are common parameters assessing farm fertility status, were used.

Complementary deep soil cores (0-40 cm depth) were collected from the same paddocks in August 2017 (3 soil cores per paddock; total = 126 soil profiles). These samples provided information about the bulk density at a depth of 0-15 cm, allowing the calculation of the corresponding C and N masses (at a fixed depth).

Table 2 General information of sites considered in this study on Pumice soils in Wairakei Estate, Taupo, Central North Island.

Site	Cluster	Paddocks	Area (ha per cluster)	Pasture age (years)	Soil type	Soil order
Tainui	A	7	16.8	2	Oruani hill soils	Pumice soils
	B	7	21.2	2	Oruani sand	Pumice soils
Tauhara	A	7	20.2	8-11	Atiamuri sand	Pumice soils
	B	7	19.7	8-11	Taupo sand	Pumice soils
Waimana	A	7	19.7	8	Taupo sand	Pumice soils
	B	7	18.4	2	Atiamuri sand	Pumice soils

Data analysis and statistics; OVERSEER® nutrient budgets model

Maps were obtained by using ArcGIS Desktop (version 10.5.1; Esri Inc., California, USA), to organise georeferenced information provided by Wairakei Estate Farm. Statistical analyses were conducted with Statistica version 8 software package (Stat Soft. Inc., Tulsa, OK, USA). The effect of site (*i.e.,* Tainui, Tuhara, and Waimana) and that of time since conversion from forest to pasture (*i.e.*, contrasted pasture age) on the chemical properties (*e.g.* total C, total N, pH, etc.) were statistically analysed using a factorial ANOVA test for each property independently; a P value of less than 0.05 was regarded as being significant. In general, site (*i.e.*, Tainui, Tauhara and Waimana) had little or no effect on the variation of soil chemical properties, including the amount of total C and N (data not shown). Also, time since conversion from forest to pasture was similar for Tainui and Tauhara sites (see Table 1), which limited the comparison including the effect of time since land use change. The study focussed on results from the only site, Waimana, with contrasting time since land use change to pasture (Figure 1; Figure 2; Table 2). The effects of time since conversion on the different chemical parameters and the C and N stocks were further analysed statistically using a paired t-test with two-sided $P < 0.05$ considered significant.

OVERSEER® Nutrients Budget model online version 6 was used to simulate impact that conversion from forest to pasture had farm N leaching. OVERSEER® is a long-term annual average model currently used in New Zealand to estimate the impact of farm and nutrient management on impacts on nutrient losses from individual farms (see references in Hanly *et al.*, 2017). All simulations used input and production information from Wairakei Estate farm (*e.g.* fertiliser use, animal stock changes, and so on) for a dairy heifer grazing system on Waimana site after 2 years of pasture conversion. The main aim was to model N allocation to the different N pools under simple scenarios considering variable N immobilisation rates and contrasting contribution from clover pasture to N input as main variables. The three scenarios modelled thus considered the following combinations: (i) standard N immobilisation and medium clover contribution; (ii) high N immobilisation and medium clover contribution; and (iii) high N immobilisation and very high clover contribution.

Results and Discussion

Major changes in topsoil chemistry

At the Waimana site, the time since conversion from forest to pasture (gap of a minimum of 6 years) had an effect on general properties of the topsoil (0-15 cm depth). Soils under ryegrass/clover pasture increased (at $P < 0.001$) total C concentration from 3.34% to 4.90%, and N concentration from 0.16 % to 0.32%, after 2 and 8 years of time since conversion

(Table 2). Available N, mineralisable N, exchangeable Ca and Mg, as well as CEC also increase (at $P < 0.05$) with time after land use conversion from forest to pasture (*i.e.*, when comparing 2 years and 8 years pasture growth; Table 2). In these Pumice soils, the topsoil pH was lower, and CEC was higher with time since conversion ($P < 0.05$; Table 2). Similar trends were described by Hedley *et al.* (2009) in Pumice soils recently (3-5 years) converted from pine forest. The lower soil pH is consistent with the acid input caused by nitrification of fertiliser N, with legume-based pastures potentially enhancing this effect (Bolan *et al.*, 1991).

Table 2 Average values of total C (%), total N (%), C/N ratio, available N (kg/ha), mineralisable N (mg/kg), mineralisable N/total N (%), pH, Olsen P (mg/L), major cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}, $cmol_c$/kg), cation exchange capacity (CEC, $cmol_c$/kg), and base saturation (%) measured in topsoil (0-15 cm depth) samples from Waimana site as a function of time since conversion from forest to ryegrass/clover pasture. Results (*P* value) from a paired t-test are included; NS, not significant ($P > 0.05$).

Variable		Waimana		*P* value
	Approx. pasture age Units	2 years	8 years	
Bulk density	kg/dm^3	0.77	0.70	NS
Total C	%	3.34	4.90	< 0.001
Total N	%	0.16	0.32	< 0.001
C/N ratio	-	20.6	15.2	< 0.001
Available N	kg/ha	45.57	73.38	< 0.001
Mineralisable N	mg/kg	48.52	81.67	< 0.001
Mineralisable N /Total N	%	3.02	2.60	0.004
pH	-	5.80	5.57	< 0.001
Olsen P	mg/L	18.33	17.19	NS
Na^+	$cmol_c$/kg	0.11	0.12	NS
K^+	$cmol_c$/kg	0.43	0.49	NS
Ca^{2+}	$cmol_c$/kg	3.10	3.80	0.035
Mg^{2+}	$cmol_c$/kg	0.30	0.46	0.002
CEC	$cmol_c$/kg	11.90	15.71	< 0.001
Base saturation	%	34.00	30.90	NS

Total C and N gain in the topsoil

Total soil C and N stocks increased after conversion of these soils from plantation forest to well managed pastoral soils (Table 2; Figure 2). Soil C (0-15 cm depth) in the Pumice soil at Waimana increased from 38.3 t C/ha$_{15cm}$ 2 years after conversion to 51.4 t C/ha$_{15cm}$ 8 years after conversion, a significant 34% increase in soil C stock (Figure 2). Average soil C increase in the present study was then 2.2 t C/ha/year in the top 150 mm of soil, for the period between 2 and 8 years since conversion being compared. As time from conversion increased, changes in the mass of total N at the study site showed a similar pattern to those described for total C (Table 2; Figure 2). Soil N (0-15 cm depth) in the Pumice soil at Waimana increased from 1.8 t N/ha$_{15cm}$ 2 years after conversion to 3.4 t N/ha$_{15cm}$ 8 years after conversion, a significant 82% increase in topsoil N stock at a fixed depth (Figure 2). Average soil N increase in the present study was then 253 kg N/ha/year in the top 150 mm of soil, for the period between 2 and 8 years since conversion under comparison.

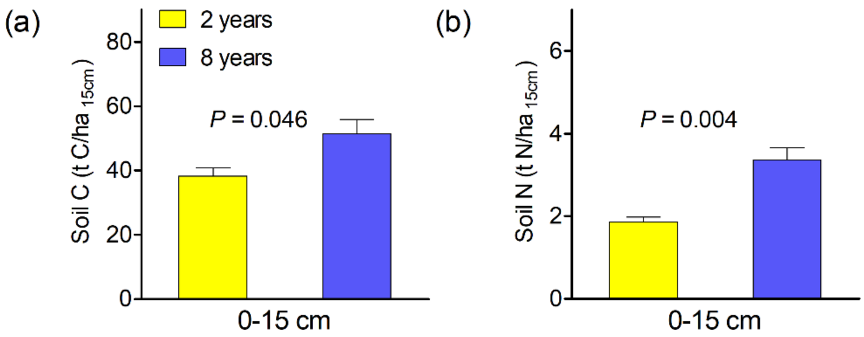

Figure 2 Average changes in (a) soil C stocks (t/ha) and (b) soil N stocks (t/ha) in the Pumice soil (0-15 cm depth) at Waimana as a function of time since conversion from forest (2 years, 8 years). Results (*P* value) from a paired t-test are included.

Data presented in this study appear consistent with national (Hedley *et al.*, 2009; Mudge *et al.*, 2014; Sparling *et al.*, 2014) and international (Conant *et al.*, 2001; Murty *et al.*, 2002) data for forest-to-pasture conversions in temperate zone. Overall, the cited studies found no net change in C contents or significant increases in topsoil C when conversion included the introduction of improved pasture species, fertiliser application and grazing management. In this sense, the data presented here are consistent with a fast rate of C and N accumulation after recent conversion from forest to ryegrass/clover pasture. This short-term relatively fast rate of C accumulation is similar to that described in a variety of soils either after land use change to pastoral management (Barrow, 1969; Hedley *et al.*, 2009), or also for soils where new pastures were sown in topsoil with initial low C content (Walker *et al.*, 1959; Machmuller *et al.*, 2015). This relatively rapid rate of C storage in the new pastoral topsoil is partly related to the new C input (roots and litter and their decomposition products) promoting the accumulation of particulate organic matter (Angers and Chenu, 1998). However, due to considerable soil disturbance caused by operations associated to removing trees, soil sampling of converted pastures should consider greater depths (*e.g.*, 30 or 60 cm), as suggested by others (Hedley *et al.*, 2009; Sparling *et al.*, 2014).

Insight on the fate of N

The average value of C/N ratio was 20.6 after 2 years of pasture growth, being reduced ($P < 0.001$) to 15.2 after 8 years (Table 2). This consistent reduction in C/N ratio with time since conversion may reflect improved fertility status, and imply that in initial years of pasture establishment, N leaching to freshwater may be limited due its immobilisation into soil organic matter (Schipper and Sparling, 2011) given that the system is able to store further N as soil organic matter. This would suggest that conversion from forest to pasture, with adequate inputs of N, P, K and S to soils, allows significant increase in soil C and N storage for at least 8 years after conversion (Waimana site).

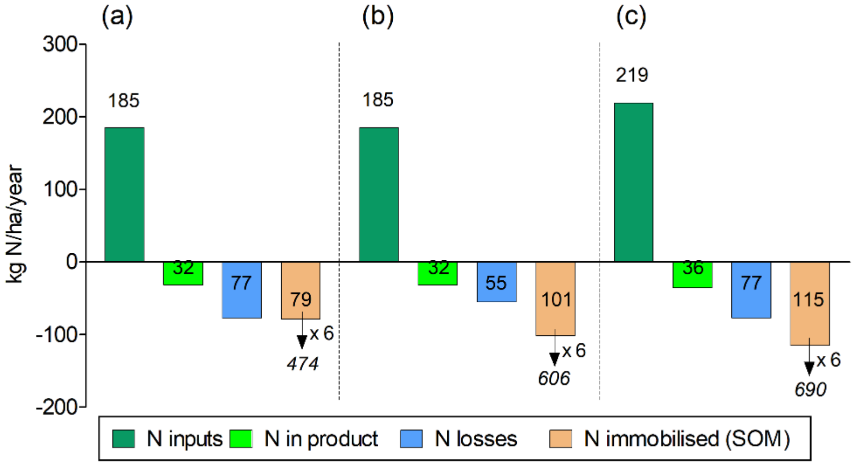

Figure 3 OVERSEER® N budgeting (kg N/ha/year) for a pastoral block at Waimana site 2 years after conversion from forest considering (a) standard N immobilisation and medium clover contribution; (b) high N immobilisation and medium clover contribution; and (c) high N immobilisation and very high clover contribution.

The farm system for Waimana 2 years after conversion from forest to pasture was also simulated using OVERSEER® Nutrients Budgets model (Figure 3). Three situations were considered: (i) standard N immobilisation and medium clover contribution; (ii) high N immobilisation and medium clover contribution; and (iii) high N immobilisation and very high clover contribution. Model used "business-as-usual" farm management details from Wairakei Estate, adapting parameters to the real data provided for Waimana site topsoil characterisation. This simple exercise indicated that both potential N immobilisation and additional N input from clover (Ledgard, 2001) will determine the N budgeting after conversion from soil forest, as modelled in OVERSEER® (Figure 3). Overall, the different OVERSEER® estimates indicated that a pasture block recently converted (2 years) from forest to well managed ryegrass/clover pasture would immobilise as soil organic matter, on average, between 79-115 kg N/ha/year, less than half the actual value measured in the Pumice soils (253 kg N/ha/year; Figure 2; Figure 3). The great ability of these Pumice soils to store N reinforces the suggestion that a large proportion of the N fertiliser application and biologically fixed N is being immobilised into soil organic matter, unaccounted for OVERSEER®. This observation also indicates that N leaching losses are likely to be low, especially in recent years after conversion from forest to pasture, and this needs further investigation.

Conclusion

While soil C change is unaccounted for in the NZ ETS, a change from forest to pasture penalises the landowner for the reduction in biomass C with no reward or penalty for rapid changes soil C and N stocks. To account for soil carbon change, further discussions are required between soil scientists and environmental policy makers to plan robust protocols to measure and monitor topsoil organic C and N storage at the farm level. Evidence for consistent quantifiable change, well down in depth (*i.e.*, 30 cm depth), is required to support inclusion of soil organic matter change in both C and N accounting.

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