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CAN FULL INVERSION TILLAGE DECREASE SOIL AND PLANT CADMIUM CONCENTRATIONS IN TWO CONTRASTING SOILS?

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Abstract

In this study, tillage treatments, including full inversion tillage (FIT), shallow tillage (ST) and no tillage (NT), were established at two trial sites, in the Manawatū region on a Pallic soil and the Taranaki region on an Allophanic soil, to explore the effect of these treatments on soil total and extractable Cd concentration and on Cd uptake by plants. After tillage, all treatment plots were sown with turnip, as a summer crop, followed by the autumn re-grassing (ryegrass/white clover). Based on the short-term research, for the Pallic soil, soil Cd concentrations were low (0–5 cm: 0.22 and 0.016 mg Cd/kg for the total and extractable fractions, respectively) before tillage and were not significantly ($p > 0.05$) affected by tillage treatments. For the Allophanic soil, soil Cd concentrations were moderately high before cultivation (0–5 cm: 0.42 and 0.031 mg Cd/kg for the total and extractable fractions, respectively). For this soil, the FIT treatment decreased the total Cd by 40% and the extractable Cd by 58% in the 0–5 cm soil depth, compared to the pre-tillage treatment, and subsequently resulted in lower plant Cd concentration, compared to the ST and NT treatments.

Introduction

Cadmium (Cd) is a non-essential trace element that has been unintentionally added into New Zealand (NZ) pasturelands due to the historical applications of phosphate fertilisers containing Cd (Syers et al., 1986). Although the mean total soil Cd level in NZ agricultural systems remains at approximately 0.45 mg Cd/kg (Abraham, 2020), some pasture farms with excessive soil Cd concentration have been identified. For example, the Waikato Regional Council estimated that 11% of the Waikato's pastoral soils and 17% of its horticultural soils have already exceeded 1 mg/kg soil Cd (Kim, 2008), and a few locations reported with higher than 1.8 mg Cd/kg in this area (Abraham, 2020). Previous research reports have highlighted that about 90% of added Cd was recovered in the soil, and approximately 93% of this Cd accumulated within the top 12 cm soil depth (Loganathan and Hedley, 1997). In addition, the reduction of topsoil Cd concentrations, via leaching or plant uptake, was minimal for a pasture system even after 22 years, in spite of negligible new Cd inputs from phosphate fertiliser (Gray et al., 2020). This implies that Cd accumulation in grazing systems can result in long-term elevated Cd concentrations in top soils, which ultimately impact on animals and humans because of the increased uptake by plants. Therefore, mitigating topsoil Cd concentrations and its availability for plant uptake is vital to minimise the risks associated with Cd in NZ pasture systems.

Pasture renewal is periodically performed in intensively managed grazed pastures, like those in New Zealand, to restore or improve pasture productivity (Glassey et al., 2010; Kerr et al., 2015). Recent studies in NZ have focused on the use of infrequent full inversion tillage (FIT) at pasture renewal as a practical approach to improve soil organic carbon (SOC) storage, which reduces the emission of atmospheric CO_2 from pasture systems (e.g. Beare et al., 2020; Calvelo Pereira et al., 2020; Lawrence-Smith et al., 2020, this issue). Those studies have demonstrated that the use of FIT for pasture renewal can provide an opportunity to increase SOC stocks by burying carbon-enriched topsoil into subsoil, alongside transferring carbon-depleted subsoil into the surface, which allows the growth of new pasture favouring C accumulation. However, this process altering the vertical distribution of SOC also can cause unintended redistribute of other elements with soil depth, like as Cd. Moreover, corresponding changes in general soil chemical properties affecting Cd bioavailability (e.g. organic matter and soil pH) may also occur and, thus, influence on the uptake and accumulation of soil Cd in plant tissues. Therefore, the aim of this study was to closely examine the effect of FIT, at pasture renewal, on Cd distribution with soil depth and on Cd uptake by plants.

Materials and Methods

Site description and sample collection

Two field trial sites with contrasting soil types were established in the Manawatū and Taranaki regions of the North Island of New Zealand to assess the effect of FIT, following spring renewal, on soil chemical properties (e.g. organic matter and soil pH), Cd level in soil and plant, dry matter production, nitrogen losses and agronomic costs. The Manawatū trial site, with a Pallic soil, was commenced in October 2016 (see detailed description in Calvelo Pereira et al., 2019, 2020). Another trial site at Taranaki region, with an Allophanic soil, was established in October 2017, on a commercial farm (Gerard Lynch) near Maxell.

In the original study, spring pasture renewal was established in both experimental sites using common cultivation practices (Fig. 1). The tillage treatments in both sites comprised the use of either FIT (~25 cm soil depth), shallow tillage (~5 cm soil depth, ST) and no tillage (NT) to cultivate long-term pasture soil, with at least four replicates of each treatment used. After tillage, all treatment plots were sown with turnip as a summer crop, which was grazed as part of each farm's grazing rotation. In the next autumn, soils were sprayed with herbicide and re-grassing (using ryegrass/white clover) was conducted by direct drill in all plots.

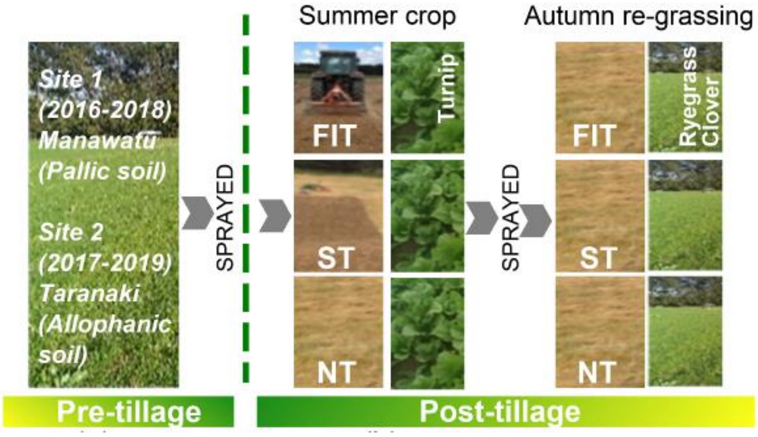

Fig.1 Brief summary of spring pasture renewal practices used at both trial sites, Manawatū and Taranaki (Calvelo Pereira et al., 2020)

At both trial sites, soils were core sampled (0–40 cm) before cultivation (pre-tillage) and after about five months of turnip growth and grazing (post-tillage). Soil cores were sliced into 0–5, 5–10, 10–15, 15–20, 20–25, 25–30, 30–40 cm soil depths, and samples were stored for further analysis. Soil (~ 1g, 0–40 cm soil depth) was digested with conc. HNO_3 (10mL) and diluted up to 25 mL with deionised water to analyse the total soil Cd concentration using GFAAS (Perkin Elmer 900z, Germany). A sub-soil sample (~ 5g, 0–15 cm soil depth) was extracted with 30 mL 0.05 M $Ca(NO_3)_2$, and extractable soil Cd concentration was measured using GFAAS (McLaren et al., 2005).

To evaluate changes in plant Cd uptake after tillage treatments, for each plot, herbage samples were collected periodically during the crop (by using quadrats) and pasture (by using grab samples) phases. Bulk samples were oven-dried (65°C) and ground to < 1 mm, and then underwent Cd determination (for methods see https://www.hill-laboratories.com).

Data analysis and statistics

In this study, a one-way ANOVA test was employed to statistically assess the influences of pasture renewal practices (FIT, ST and NT) on soil Cd levels for each soil depth, including total and extractable soil Cd concentration. This analysis was completed via the OriginPro 8.0 software package.

Results and Discussion

Effects of FIT on soil Cd concentration and vertical distribution

The changes in soil total and extractable Cd concentrations with soil depth, for both Pallic and Allophanic soils (pre-tillage and post-tillage), as a function of pasture renewal (FIT, ST and NT) are shown in Figure 2. Before tillage, there was a general trend of soil total Cd concentration decreasing with soil depth at both trial sites, which caused the topsoil (0–5 cm) containing an approximately 3 times higher Cd than the subsoil (Fig. 2a and c). This characteristic of Cd variation with soil depth is in agreement with Stafford et al. (2018), which has reported 3–10 times higher Cd concentration at the 0–5 cm soil depth compared to the subsoil. Additionally, the Pallic soil had lower soil total Cd concentration (0–5 cm: ~ 0.22 mg Cd/kg, on average, Fig. 2a) than the Allophanic soil (0–5 cm: ~ 0.42 mg Cd/kg, on average, Fig. 2c) before cultivation.

The Allophanic soil also had higher extractable Cd in the 0–5 cm soil depth (~ 0.031 mg Cd/kg, on average) than in the 5–15 cm soil depth (~ 0.024 mg Cd/kg, on average) before tillage (Fig. 2d). However, soil extractable Cd concentration (pre-tillage) showed a different vertical distribution trend compared to total Cd for the Pallic soil (Fig. 2a and b). The Pallic soil had lower extractable Cd in the 0–5 cm soil depth (~ 0.016 mg Cd/kg, on average) than in the 5–15 cm soil depth (~ 0.026 mg Cd/kg, on average). Loganathan et al. (1997) also has reported lower extractable Cd concentration in top soil for a Pallic soil in the Manawatū region, which is probably linked to the higher Cd adsorption in the upper soil as a result of higher organic matter content and soil pH compared to the subsoil. While the Allophanic soil had a soil organic matter content significantly higher than Pallic soil before tillage (Calvelo Pereira et al., 2020), its higher extractable Cd concentration in this upper soil is probably associated with the moderately high soil total Cd concentration in current study. It has been demonstrated that total soil Cd concentration is a foremost factor determining plant-available Cd concentration in the soil (Gray et al., 1999).

For the Pallic soil, vertical distribution of soil Cd concentration was not significantly ($p > 0.05$) affected by tillage treatments (Fig. 2a and b). The FIT treatment had slightly lower soil total Cd concentration but relatively higher extractable Cd concentration in the topsoil compared to the ST and NT treatments (Fig. 2a and b). However, for the Allophanic soil, the FIT treatment significantly decreased total Cd by 40% and extractable Cd by 58% at the 0–5 cm soil depth, compared to the pre-tillage values (Fig. 2c and d). There was also an increase in total Cd for the FIT treatment below the 0-10 cm soil depth, which supports a redistribution of Cd, from the topsoil to the subsoil, after FIT at Taranaki trial site.

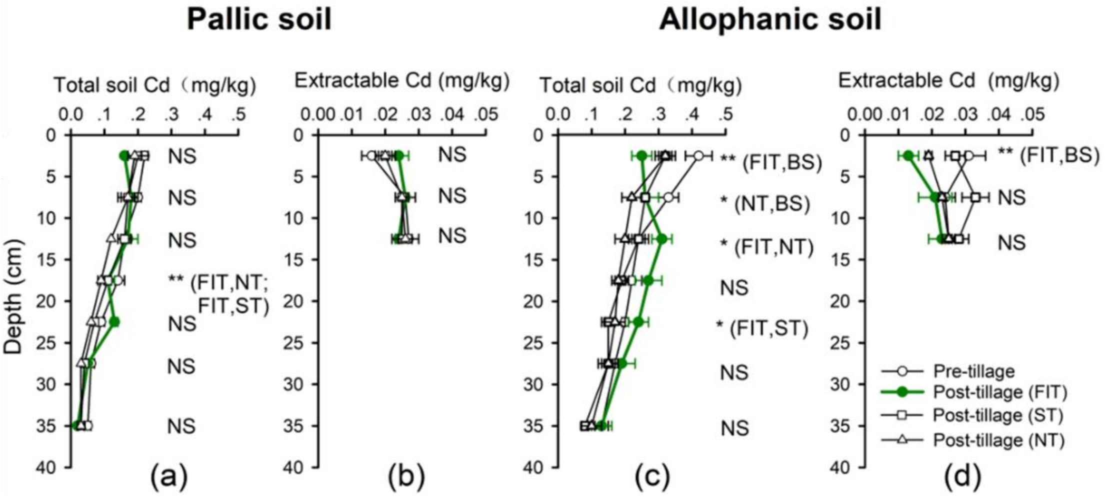

Fig.2 Soil Cd levels at two trial sites (Date are means ± S.E.M. and results in brackets represent ANOVA at $^{**}p < 0.001$ or $^{*}p < 0.05$. NS denotes no difference at $p > 0.05$)

Effects of FIT on plant Cd concentration and uptake

Cadmium concentration in turnip tissues was significantly higher ($p < 0.05$) than in ryegrass/white clover (Table 1). It is well established that brassica crops (e.g. turnip) can accumulate higher Cd levels than perennial ryegrass and clover, and the Cd concentration ranges in this study are similar to those reported by other researchers (e.g. Roberts et al., 1994; Loganathan et al., 1997; Stafford et al., 2016). However, the effect of tillage treatments on herbage Cd concentration was only significant at the Allophanic trial site. For this soil, FIT treatment showed the lowest Cd concentration in turnip (~ 0.69 mg Cd/kg DM) and ryegrass/white clover (~ 0.04 mg Cd/kg DM) compared to ST and NT treatments. It has also been previously shown that high plant-available Cd can cause high Cd concentration in plants (Loganathan et al., 1997). The lower extractable Cd concentration at the topsoil for the FIT treatment is likely to have resulted in the lowest plant Cd concentration for this soil. However, crop yield differences may also have influenced the herbage Cd concentration. The FIT treatment resulted in the highest turnip yield for the Allophanic soil (Table 1), which may have resulted in greater dilution of Cd in this plant. Because the turnip yield differential between treatments was greater than it was for the turnip Cd concentration, the FIT treatment resulted in the highest total turnip herbage uptake of Cd (~ 6.51 g DM/ha). This Cd uptake was 14% higher than the NT treatment and 17% higher than the ST treatment. However, Cd intake per kg of turnip DM for the FIT treatment was 14% lower than the NT treatment and 9% lower than the ST treatment.

Table 1 Plant Cd concentration and uptake at two trial sites (on average)

	Crop (turnip)								
	Cd concentration (mg/kg DM)			Accumulated dry matter (t DM/ha)			Accumulated Cd uptake (g DM/ha)		
	FIT	ST	NT	FIT	ST	NT	FIT	ST	NT
Pallic soil	0.92	0.79	0.95	6.78	5.65	3.9	6.29	4.41	3.59
Allophanic soil	0.69	0.76	0.8	9.58	7.35	7.07	6.51	5.57	5.72
	Grass (ryegrass/white clover)								
	Cd concentration (mg/kg DM)			Accumulated dry matter (t DM/ha)			Accumulated Cd uptake (g DM/ha)		
	FIT	ST	NT	FIT	ST	NT	FIT	ST	NT
Pallic soil	0.05	0.05	0.05	11.24	11.33	11.6	0.66	0.55	0.55
Allophanic soil	0.04	0.06	0.05	5.64	5.97	5.64	0.18	0.32	0.27

Note: Accumulated dry matter/Cd uptake was the sum of herbage productivity/Cd uptake during the crop and pasture phases, but herbage samples were collected at different time between the Pallic soil and the Allophanic soil.

Summary and Conclusion

The use of FIT at pasture renewal modified the vertical stratification of soil total and extractable Cd, but the extent of the effect was influenced by pre-tillage soil Cd concentrations and their vertical distribution. For the Pallic soil, soil Cd concentration was low and not significantly affected by tillage treatments. For the Allophanic soil, which had a higher topsoil total Cd concentration, the FIT treatment caused a decrease in topsoil total and extractable Cd concentration and, subsequently, resulted in lower Cd uptake by a summer crop (turnip) and pasture (ryegrass/white clover), compared to the ST and NT treatments. In this study, the results suggest that FIT at pasture renewal can successfully mitigate topsoil Cd concentrations through transferring low Cd subsoil into the topsoil and then reduce Cd uptake by forge plants, where total soil Cd levels are moderately high.

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