Application of spent mushroom compost to a riverine silt loam at the time of pasture renewal and its effect on soil infiltration rate

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Abstract
Pasture renewal is an important strategy for maintaining pasture production. While cultivation during pasture renewal can improve soil macropores in the short term, these benefits do not necessarily persist. Evidence from previous studies indicates that compost applied to agricultural soils can improve soil physical properties and increase earthworm numbers. We assessed whether adding mushroom compost at the time of pasture renewal would have further benefits on soil infiltration. We applied commercial mushroom compost to a riverine silt soil that had low soil infiltration and regularly ponded temporarily during irrigation events. The experimental treatments were assigned to replicated field plots (5m x 6m) and included: A) no pasture renewal, no cultivation, B) pasture renewal, no cultivation, C) pasture renewal, cultivated, D) pasture renewal, cultivated, 50t/ha compost applied, E) pasture renewal, cultivated, 100t/ha compost applied, and F) pasture renewal, cultivated, 150t/ha compost applied. Soil infiltration rates measured 2 months after initiating treatments indicated no difference between plots that were cultivated and amended with compost compared with those plots left under the original pasture (and without cultivation). However, for pastures that were renewed via direct drill (i.e., without cultivation), soil infiltration rates were significantly ($P<0.05$) lower than all other treatments and likely reflected surface soil damage that was caused by heavy rainfall soon after drilling new seed rather than the absence of compost. After 14 months none of the management approaches for renewing pastures that we assessed were found to have a lasting effect on soil infiltration rate. Earthworm numbers and total earthworm biomass measured after 7 months were not significantly different across treatments across all compost rates evaluated. However, earthworm biomass tended to be lower in the cultivated soils compared with the non-cultivated treatments ($P<0.10$). This experiment indicates that a single application of mushroom compost during the renewal of pasture had limited benefit in improving soil infiltration rates or increasing earthworm numbers within 14 months after pasture renewal.

Keywords: Earthworms, mushroom compost, Pasture renewal, soil health, soil infiltration rate

Introduction
On New Zealand dairy farms, pasture renewal is considered an important strategy for maintaining pasture production and is routinely carried out when pasture composition shifts towards less-productive species and existing pasture growth, density, and persistence decline (Dodd et al. 2018). Two common methods are used to re-establish the pasture; cultivation followed by drilling of the seed, or directly drilling the seed with limited mechanical intervention (Thom et al. 2011). In both instances, the existing pasture is first removed using herbicide prior to seed placement. Direct drilling of seed rather than cultivation has become more common across New Zealand as it is thought to provide a number of benefits for soil health including reducing nitrogen leaching (Whitmore et al. 1992), conservation of carbon and less destructive pressure on soil aggregates compared with more intensive mechanical interventions (Blanco-Canqui and Ruis 2018).

The context for this study was a dairy farm in Canterbury, New Zealand that is located on silt soils overlying river sands and gravels (Manaaki Whenua Landcare Research 2019). The high silt content and low levels of organic matter in these soils mean that they are vulnerable to structural degradation under external pressures such as cultivation, heavy rainfall/irrigation and grazing activities (Renard et al. 1991; Hewitt and Shepherd 1997). The objective of our study was to assess whether mushroom compost would improve the soil physical properties that are directly associated with soil infiltration. Our study was conducted in conjunction with that of Moss et al. (2022) who reported the effect of compost amendment on a mixed-species pasture following renewal of the 5-year-old pasture sward.

Previous research on this farm has identified significant ponding issues associated with irrigation practices (Taylor et al. 2021). It was believed that very low soil permeability rates (i.e., unsaturated hydraulic conductivity measured at -40 mm head ranged between 3.40 to 12.0 mm/hr) in combination with the high irrigation intensity (peak irrigation intensity 65-75 mm/

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hr; Laurenson et al. *unpublished*) were responsible for the ponding issues that were occurring immediately after irrigation events. Initial work ruled out depth of irrigation as a key driver of ponding. The low soil infiltration rates observed at this site were surprising given the riverine location and apparent free-draining nature of the soils. Measurements that were carried out to determine the cause of ponding indicated that soil surfaces had low permeability; yet, at depth in the soil profile, this was not apparent. For instance, at a depth of 500 mm in the soil profile unsaturated (-40 mm head) hydraulic conductivity was in the order of 50 to 80 mm/hr (Laurenson et al. *unpublished*). Therefore, it was hypothesised that infiltration rates may be impacted by aggregate slaking processes near the soil surface. If so, cultivation of these surface soils as part of the farm's pasture renewal programme was expected to promote slaking and therefore contribute to the low infiltration rates. Cultivation temporarily increases the abundance of large macropores that enable rapid drainage soon after being worked. However, the physical damage of cultivation on aggregate stability and pore connectivity has been shown to reduce soil infiltration rates over time, especially under repeated tillage (Klute 1982; Connolly et al. 1997; McGarry et al. 2000).

The establishment of permanent pastures can improve soil physical conditions (McLenaghen et al. 2017). Also, applying compost and manures is generally associated with improvements in soil physical properties, including soil infiltration (Edmeades 2003). Fulvic acids, humic acids and polysaccharides, contained in composts and manures, help to bind particles together into aggregates, thereby forming pores that promote the flow of water (Boyle et al. 1989). Some studies speculate that these processes become evident only when large inputs of such organic matter are applied over several years (Edmeades 2003), while other studies show short-term improvements in some physical properties such as aggregate stability and delayed soil crust formation in weakly aggregated soils (Bresson et al. 2001; Annabi et al. 2007; Mamedov et al. 2014; Gümüş and Şeker 2017). Compost and manure applications have been attributed to a higher abundance of earthworms in grasslands (Curry 1976; Edwards 2004) and improved soil structure and aggregate stability with cultivation (Bertrand et al. 2015). Mushroom compost was used in this study because it was locally available in large volumes. Mushroom compost is a by-product of the mushroom industry and contains a mix of lignocellulosic biomass, gypsum, and nutrients (Stewart et al. 2000; Jordan et al. 2008).

In the present study, we assessed whether adding fresh mushroom compost at the time of pasture renewal would benefit infiltration rates and earthworm populations. We utilised the research site described by Moss et al. (2022) to assess our hypothesis in parallel to the research objectives that were being explored by those authors, which were focused on pasture production and pasture species composition in response to compost applications and cultivation.

Materials and methods

Site description

The dairy farm where this study was carried out is located on Rakaia Island, Central Canterbury. The study site was on an area of the farm receiving regular irrigation, via a centre-pivot irrigator, between October to April. In March 2018, the 5-year-old perennial ryegrass (*Lolium perenne* L.) sward that was growing at the study site was selected for pasture renewal.

Thirty plots, measuring 5 m x 6 m, were established at the research site. Six treatments undergoing varying degrees of pasture renewal and receiving different rates of compost (described in) were identified and five replicates per treatment were assigned to each of the 30 plots. These treatments included A) no pasture renewal, no cultivation, B) pasture renewal, no cultivation, C) pasture renewal, cultivated, D) pasture renewal, cultivated, 50t/ha compost applied, E) pasture renewal, cultivated, 100t/ha compost applied, and F) pasture renewal, cultivated, 150t/ha compost applied (compost application rates determined on a wet weight basis). All plots, with exception of Treatment A, were sprayed with *Glyphosate360* herbicide at 4 L/ha on 17 March 2018 prior to compost being applied. The experimental area was then fenced to prevent cattle from accessing the plots. Sowing of treatments B-F occurred on 20 April, 34 days after herbicide application and 20 days after compost application (see below). The seed mix consisted of perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.) and plantain (*Plantago lanceolata* L.) at a rate of 21, 3, and 2 kg/ha respectively. Seed was sown using a direct drill followed by a Cambridge roller.

A weather station was installed approximately 80 m from the trial site. Due to the presence of trees immediately surrounding the pivot circumference, it was decided to install the weather station under the pivot. Combined rainfall and irrigation were collected from a tipping bucket mounted on the weather station. The daily precipitation values were retrospectively categorised as either rainfall or irrigation based on the farm's irrigation diary and verified using a second rainfall gauge mounted at another location on the farm, outside the irrigated zone. Total drainage volume was estimated using a daily soil water balance model as described by Scotter et al. (1979) and Woodward et al. (2001).

Compost material

Fresh compost (i.e., < 1 week since removal from the mushroom production system) was sourced from a local mushroom farming business. It comprised of spent growing bed material that was pasteurised and pH neutralised (pH 6.5) prior to delivery to prevent pathogen and weed contamination. Compost, (37% dry matter, 37.5% total carbon (C), 2.58% total nitrogen (N), 0.72% total phosphorus (P), 1.79% total potassium (K), 2.51% total sulphur (S), 0.25% total sodium (Na), all dry weight-basis, and carbon to nitrogen ratio of 15:1), was applied to three of the five treatment plots at the three different rates (Table 1), 14 days after herbicide treatment. Compost was spread by hand according to treatment allocation, based on its wet weight. Compost application rates, corresponding dry weight and nutrient loading are summarised in . All treatments except the no compost, no cultivation treatment, were cultivated 6 days after compost application. Cultivation consisted of three passes of a rototiller with a '*crumbler*' attached that incorporated the compost within the top 150 mm of soil.

Pasture management

A detailed description of the pasture management approach is provided in Moss et al. (2022). Briefly, pastures were irrigated via a centre pivot system as per farm requirements. Grazing animals were removed from the trial site from February 2018 onwards, including for the duration of this trial. Pastures were mowed regularly with a rotary lawn mower that cut the sward at 30 mm above ground level. Harvests were carried out approximately every 35 days (ranging between 25 to 42 days) during the spring, summer and autumn periods. For those pasture plots that were not renewed, pastures were mown on 16 March 2018, with clippings discarded outside the study site, one day before all other treatment areas received herbicide. The first measurement on this treatment was made on 26 June 2018. All plots were mown simultaneously at intervals from 11 September. Clippings were discarded from the first two mowing events but were returned to the plots for the following mowing events.

Soil infiltration

Soil infiltration was measured in-situ on two occasions, on 5 June 2018 and 14 June 2019 which corresponded to 2 and 14 months after compost was applied, respectively. At each measurement date, five measurements were carried out per plot (n=25 per treatment). Infiltration measurements were made using the single ring infiltrometer method (Bouwer 1986). At each sampling location within the plots, an area of grass (~400 x 400 mm) was trimmed to soil height, and leaf material was removed. Then, a steel ring, 300 mm diameter and 200 mm height, was pressed 5 mm into the soil surface using a rubber mallet and block of wood whilst ensuring soil disturbance was minimal. Once the ring was in place, 706 mL of water (equivalent to 10 mm application depth) was applied to the soil within the ring and the time required for this volume to infiltrate the soils was recorded. This process was repeated consecutively until the time taken for water to infiltrate into the soil became constant across three successive infiltration volumes. Generally, 4 to 8 applications of water (i.e., 40 to 80 mm) were applied to soils before a final iteration was conducted from which an infiltration measurement was recorded. The final reading was used in subsequent statistical analysis.

Earthworm sampling

Soil samples were collected on 6 November 2018, corresponding to 7 months after compost was applied. Duplicate samples (200 x 200 x 200 mm) were collected using a spade from diagonally opposite corners of the plot and at 1 m from the plot edge. A total of 60 samples were collected and hand-sorted in the laboratory for earthworms. Species were identified, and total earthworm abundance and biomass were recorded (Satchell 1971; Sims and Gerard 1985).

Statistical analysis

For soil infiltration rates, a simple linear model was fitted to the log of the infiltration measurements using R (version 3.6.3). The treatments and sampling dates and the interaction between the two effects were modelled. Visual inspection of the residuals indicated that the assumptions (i.e., normality and homoscedasticity) for the analysis were met.

Earthworm numbers and earthworm biomass were analysed and compared using a generalised linear model (GLM) with negative binomial distributions through a log link function. The GLM consisted of three single factors to compare between either Treatment, Cultivation, or Compost. All GLM analyses were carried out with statistical software SAS version 9.3.

Results

Climate and irrigation

The research site received a total of 535 mm of water (399 mm rainfall and 136 mm irrigation) between March and December 2018 and 324 mm (236 mm rainfall and 88 mm irrigation) between January and June 2019 (Figure 1). For both the 2018 and 2019 seasons, estimated drainage was consistently greatest during the months of March to June, while for the period between July and November drainage was comparatively lower. Estimated drainage during April and May 2018 (i.e., immediately prior and post renewal) was significant and accounted for 40% of the total drainage for the entire experimental period.

Infiltration rates

Cultivation of pastures during the renewal process did not have a significant adverse effect on soil infiltration

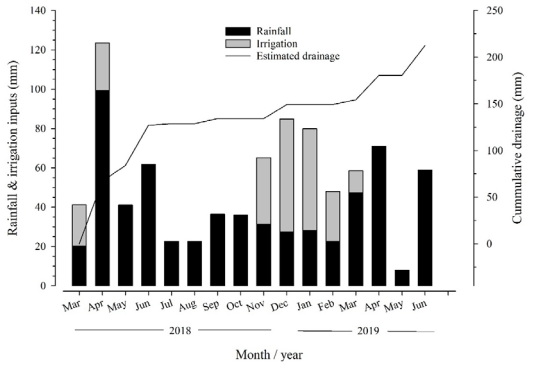


Figure 1 Rainfall and irrigation measured at the research site (bars) and estimated cumulative drainage (line) calculated using a soil water balance.

rates when compared against the original pasture i.e., soil infiltration rates remained similar (Figure 2). However, in the first year of the study, 2 months after pasture renewal, soil infiltration rates in the direct drilled plots were significantly lower than those that had been cultivated and, surprisingly, lower than the original pasture. When comparing those plots that had been cultivated with and without compost, there was no significant difference between treatments, regardless of compost application rate.

In the second year of the trial, 14 months after compost application, there were no significant differences across all treatments including the comparisons made with the original pasture.

Earthworm abundance

Earthworm numbers and total earthworm biomass were not significantly different across treatments (Figure 3). However, earthworm biomass (but not numbers) tended to be lower in the cultivated soils compared with the non-cultivated treatments ($P<0.10$). *Aporrectodea caliginosa* and *Lumbricus rubellus* were the dominant species observed across all treatments. *L. rubellus,* an epigeic earthworm, tended to be less abundant in plots receiving compost to those receiving no compost ($P=0.065$).

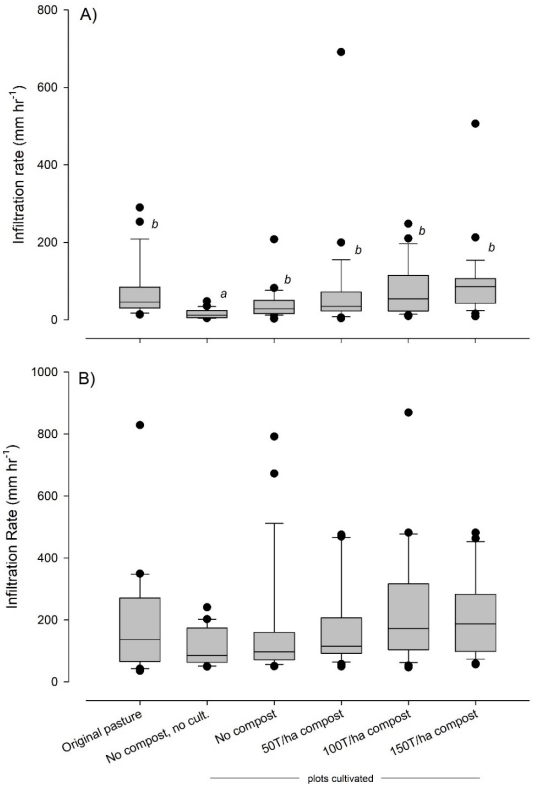


Figure 2 Soil infiltration rate in June 2018 and 2019, A) 2 months and B) 14 months after compost application. Treatments with differing letters are significantly different ($P<0.001$). No significant differences were found in 2019. The bottom, middle line, and top of each box indicate the lower quartile, median and upper quartile of the dataset for each treatment.

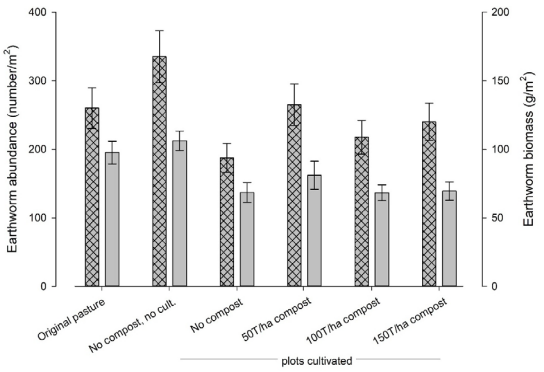


Figure 3 Earthworm abundance (grey hatched bars) and earthworm biomass (grey solid bars) measured 7 months after pasture renewal and initiation of treatments. Error bars indicate standard error of the mean (providing an indication of variability within treatment replicates). No significant differences between treatments were found.

Discussion

In this study compost was applied to soils in a single application, ranging from 50 to 150 T/ha. We estimate that the compost would have increased total organic C in the top 150 mm of soil by approximately 5, 9 and 14%, respectively (Table 1) for the 50, 100 and 150 T/ha treatments. Despite these additions, there was no improvement in infiltration relative to cultivation without compost. The process of incorporating the compost, through cultivation, had a far greater influence on soil infiltration rates than the compost itself. Improvements in soil physical properties,

Table 1 Description of the treatments that were assigned to the different plots (n=5 per treatment)

Treatment	Pasture renewed[1]	Pasture sprayed[2]	Cultivated[3]	Rate of compost (T/ha)[4]	Calculated increase to SOC[5] (%)	Nutrients applied (based on concentration of compost)[6] (kg/ha)			
						N	P	K	S
Original pasture	No	No	No	-	-	-	-	-	-
No compost, no cult.	Yes	Yes	No	-	-	-	-	-	-
No compost	Yes	Yes	Yes	-	-	-	-	-	-
50T/ha compost	Yes	Yes	Yes	50	5	477	133	331	464
100T/ha compost	Yes	Yes	Yes	100	9	955	266	662	929
150T/ha compost	Yes	Yes	Yes	150	14	1,432	400	993	1,393

[1] Plots sown post herbicide and post compost application. Seed mix consisted of perennial ryegrass (*Lolium perenne* L.), white clover (*Trifolium repens* L.) and plantain (*Plantago lanceolata* L.) at a rate of 21, 3, and 2 kg/ha respectively.
[2] Original pastures sprayed with herbicide (glyphosate, 4 L/ha) prior to re-seeding.
[3] Soil cultivation, 6 days post compost application, involved 3 passes of a rototiller with 'crumbler'. Cultivation incorporation depth was 150 mm.
[4] Loading rates are based on a wet weight basis (dry matter content 37% $_{w/w}$)
[5] SOC =soil organic carbon, % increase refers to the relative increase in organic carbon in the top 150 mm from compost compared to the unamended soil and is calculated based on soil bulk density of 1.39 g/cm^3, compost incorporation depth of 150 mm, estimated organic carbon in soil 6%, organic carbon content of spent mushroom compost 37.5%.
[6] N= total nitrogen, 2.58%$_{dw}$, P= total phosphorus, 0.72%$_{dw}$, K= total potassium, 1.79%$_{dw}$, S= total sulphur, 2.51% $_{dw}$. No other forms of nutrients were applied to plots during the trial.

including soil infiltration and aggregate stability, in response to applications of compost and manure are widely reported in pastures and other agricultural systems (Le Bissonnais and Arrouays 1997; Edmeades 2003; Gümüş and Şeker 2017; Kranz et al. 2020). However, generally these reported outcomes arose after several repeat applications over several years. Other short duration studies exploring the impacts of both compost and tillage on soil infiltration rates conclude a similar lack of effect from single compost applications (Mohammadshirazi et al. 2016; Obalum et al. 2019).

The addition of compost did not significantly affect total earthworm numbers or total earthworm biomass when measured seven months after treatments were imposed. Epigeic *L. rubellus,* an earthworm feeding on surface organic matter, was less abundant 7 months after compost application, showing that either the application of the mushroom compost did not have long-term effects or was not an organic matter resource preferred by these earthworms. Cultivation tended to cause a decline in earthworm biomass (but not numbers) compared with the non-cultivated treatments. This observation aligns with several other reported studies such as Bell et al. (2009) who showed earthworm populations within one year of cultivation were half of control populations, and Tozer et al. (2015) who suggest it may take 12 months for earthworm populations to recover post cultivation.

The absence of an immediate compost effect may reflect slow mineralisation due to the relatively high C:N ratio that encouraged short-term microbial immobilisation of N. The mineralisation rate of the mushroom compost was not analysed in this experiment so it is not possible to confirm the availability and leaching susceptibility of the various nutrient constituents during the experiment. In an earlier experiment, using mushroom compost Stewart et al. (2000) reported the slow release of nutrients from field lysimeters when applied at rates up to 80T/ha (wet weight) and measured over a 30-week period. The exception to this was sulphate, that was leached rapidly from lysimeters with recovery rates equivalent to 80% of applied. However, for potassium, calcium and magnesium, respective recovery rates were considerably less at 3-, 13- and 37% of the total amounts applied. Stewart et al. (2000) also reported low rates of inorganic-N leaching from soils amended with 80T/ha of mushroom compost i.e., approximately 15% of that applied. In the aligned study by Moss et al. (2022) compost had no significant effect on total dry matter production over a 2-year period. This lack of pasture response is despite the significant levels of nutrients being applied to compost treatment plots in a single application i.e., N loadings ranging from 477 to 1,430 kg N/ha. This supports the assessment that a single application of mushroom compost did not provide a functional improvement for renewed pasture, and wider outcomes of infiltration rates and earthworm abundance in the short-term (i.e., 2-<years).

Contrary to the original hypothesis, cultivation as part of a pasture renewal programme did not result in an immediate decline in soil infiltration rate. However, for plots that were sprayed and direct drilled without

cultivation, soil infiltration rates were adversely affected. We speculate that the decline in soil infiltration rate of these plots was caused by surface soil damage from rainfall and irrigation that occurred during the period when the original pasture was senescing and before the new sward had established. For instance, existing pasture was sprayed off on 17 March 2018 and 3 irrigation events (7.6-8.6 mm/event; peak intensity 65 mm/hr) occurred between the 1st to 4th of April 2018. In addition, 131 mm of rainfall (10 events; Figure 1) was recorded at this site between 22 March 2018, 5 days after herbicide application, and 23 May 2018, including single rainfall events of 20, 52 and 15 mm/event on the 10th and 29th of April and 17th May 2018, respectively.

Considerable kinetic energy from rainfall and irrigation would have been exerted on these soils during a period when pasture cover was declining following herbicide application. These riverine silts are vulnerable to this type of force because they typically lack stabilising agents such as clay, oxides and hydroxides (Levy and Mamedov 2002). These conditions may have increased the susceptibility of the soil surface to aggregate breakdown and pore blockage compared with the original pasture treatment (Awadhwal and Thierstein 1985). Sediments that are dislodged from aggregates are then able to block drainage pores near to the soil surface. Maintaining a vegetation cover would otherwise reduce the kinetic energy from rainfall and irrigation significantly (Christian et al. 1999; Basche and DeLonge 2019), and reduces soil slaking damage.

The cultivated plots maintained relatively high infiltration rates in year 1 despite the reduced pasture cover. Higher short-term macroporosity during the period immediately after cultivation is likely to have moderated any effect of aggregate degradation under rainfall and irrigation (Laurenson and Houlbrooke 2014). In general, infiltration rates for all plots were higher in year two compared with year one, presumably due to the absence of grazing at the trial site and the establishment of the grass sward. This was particularly apparent in the original pasture plots that remained high because the thick well-established sward was able to intercept the falling water.

Conclusion

The addition of mushroom compost did not improve infiltration rates or earthworm abundance when incorporated into soils as part of a pasture renewal programme. Cultivation was effective in maintaining soil infiltration rates at levels similar to the original pasture and presumably outweighed any adverse effect of damage to soils with reduced or bare soil cover. The process of renewing pasture without cultivation had an initial adverse effect on soil infiltration rate. This we expect was due to rainfall/irrigation damage that these soils received during the period after herbicide application and prior to establishment of the new sward.

Contrary to our hypothesis, after 14 months, none of the management options we assessed at the time of pasture renewal had a lasting effect on soil infiltration rate. This study, although limited to infiltration and earthworms, found no benefit of applying mushroom compost during pasture renewal. Further investigation of whether compost application within a pasture renewal strategy can provide successful outcomes is required.

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