Report for Our Land and Water Rural Professionals Fund

Strip-till Fodder Beet to Improve Land and Water Outcomes

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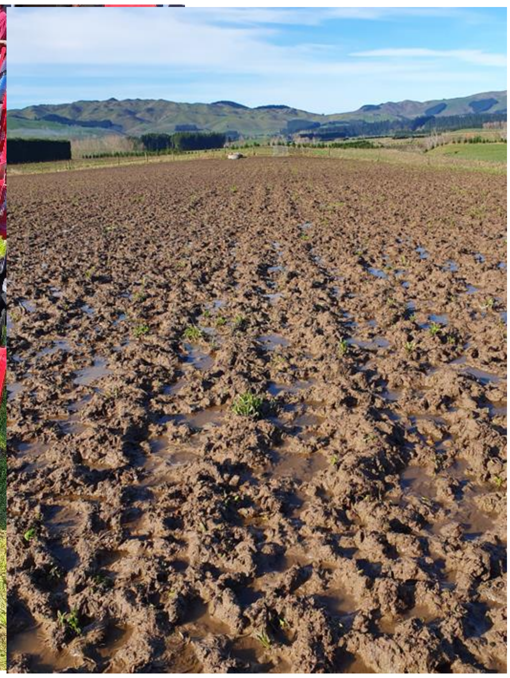

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Executive summary

Fodder beet is an important crop for wintering in New Zealand farming systems. It keeps well through winter providing a high dry matter feed. However, high stocking rates on water-logged soils can create adverse environmental effects that have been in the public eye in recent years.

Despite a national decline in the area of fodder beet sown, it is anticipated that through improved management it will remain an important winter feed. Namely, being less susceptible to pests and diseases than other popular winter feeds are, a lower requirement of N inputs to achieve high yields, and emerging research that indicates animals when grazing fodder beet produce less methane.

Fodder beet requires a fine, clean, and even seed bed with good seed to soil contact. Conventional tillage is predominately used to achieve this, requiring upwards of five passes with different cultivation equipment. This is costly as it requires more labour and machine hours. No-tillage is often used as an alternative cultivation method, however as fodder beet requires a clean seed bed it is actively discouraged for fodder beet.

Strip tillage is a well-established cultivation method used in wide row spaced crops. Cultivation, fertiliser, and seeding are done in one pass. Additionally, only strips where the seed is placed is cultivated, typically 150-100 mm wide and the space between these, approximately 350 mm, is left uncultivated. International literature has found some environmental benefits of this approach, including a decrease in runoff, and improved yield which was attributed to improvements in soil structure.

To ascertain if there was less run off created in strip till cultivation compared to conventional, sites on each treatment were set up on similar slopes. These sites were hydrologically isolated from the paddock via a wooden box that had a metal flume at the downmost point of the slope. These flumes drained into 20 l buckets that were vigorously stirred before a sample was collected and frozen until the end of the trial.

Throughout the trial period, from the end of May to the end of August 2023, three rainfall events occurred that caused runoff. A total of 27 samples were sent to Hills Laboratory in Christchurch. They were sampled for total suspended sediment (SS), total P (TP), total N (TN), dissolved reactive P (DRP), Nitrate-N (NO3), ammoniacal-N (NH3), dissolved organic C (DOC), total kjeldahl N (TKN), and chloride (Cl). The results were analysed using a one-way ANOVA test and significant levels were tested to $P > 0.05$.

Analysis of SS, TN, NO3, DRP, and TP found no significance between treatments, that cultivation, given the parameters of this research, showed no significant impact of cultivation method on runoff. Most metrics (SS, TN, DRP, and TN) decreased after each runoff event, indicating there could be some effect of trampling to consolidate the soil.

The financial analysis had a slight saving in favour of the strip tillage, 0.5% cheaper per hectare. It is important to note that both the strip tillage and conventional tillage were in the same paddock so for the ease of management the treatments received the same fertilisers, herbicides, and pesticides. A previous study of using strip tillage in fodder beet had significantly higher savings (15% cheaper /ha (Beef and Lamb New Zealand, 2017)). However, in that study they managed the agronomy of the treatments separately, with the main saving coming from reduced fertiliser usage.

Conversations with key industry stakeholders implied there are some limitations to using strip tillage for fodder beet. As strip tillage is a one-pass cultivation method it requires easier soil conditions to create a seed bed in one pass compared to the multiple passes and opportunities to correct seed bed in conventional tillage. This includes it not being too wet nor being too stoney. Additionally, some people have observed greater requirements for pesticides as the uncultivated sections can harbour slugs.

It is important to note some limitations with this research. This includes a small sample size and collection only occurring for one season. Collecting a larger sample size across a range of soil types and over a number of years will help distinguish if there is in fact any significant difference. Additionally, there is an opportunity to manage inputs separately with inter-row spray and precision fertiliser application. Further research could explore the opportunities for agronomic management to reduce the environmental impact of fodder beet as it remains a key part of the New Zealand farming system.

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1 Introduction

Fodder beet is an important crop for winter feed in Aotearoa New Zealand. Fodder beet reliably produces a high yield of dry matter per hectare enabling farmers to run more stock over a smaller area and increase their profitability per hectare. Fodder beet maintains its feed quality over winter months when production from other feed sources is tight. Compared to other brassica crops, less nitrogen (N) inputs are required for production (Chakwizira et al., 2014; Ministry for Primary Industries, 2018) and it is not affected by common brassica diseases such as club rot.

However, fodder beet has created challenges with land and water outcomes with high stocking rate on waterlogged winter soils creating challenges with run off and sediment loss (Thomas, Beare, Francis, Barlow, & Hedderley, 2008). Runoff contributes to N and P moving into freshwater and causing worse freshwater outcomes. This has created pressure to reduce the use of fodder beet.

It was estimated that in 2018 approximately 60,000 hectares of fodder beet was grown in New Zealand (Ministry for Primary Industries, 2018). Jim Gibbs estimates the area to now be around 40-50,000 hectares (personal communication, October 20, 2023). He expects the use of fodder beet to remain steady into the future due to the potential methane reductions and lower nitrogen input requirements compared to other winter crops. Therefore, any improvement in environmental outcomes could have significant impact on land and water quality. This is a large enough scale to create national improvements on land and water quality.

Fodder beet needs a fine high quality seed bed. To achieve this, multiple passes are used to cultivate the whole soil surface. No-tillage is often used as a less impactful cultivation method, unfortunately due to fodder beet's need for a clean seed bed, fodder beet planted under a no-tillage system struggles. An alternative method, strip tillage cultivation is growing in popularity.

Strip tillage is a well-established cultivation method internationally and predominately used in maize cultivation. It generally requires one pass of the strip tiller and seeder to cultivate, plant, and fertilise the seed. The cultivator works a small strip of soil where the seed is placed and leaves the areas between rows uncultivated. Benefits include providing a fine seedbed whilst leaving behind an uncultivated area. International literature has reported that this improves soil structure and moisture retention and long-term trials have measured increases in yield attributed to better soil outcomes.

There are a growing number of contractors offering this service in New Zealand with claims that strip tillage could result in better environmental outcomes. International research also indicates that strip tillage significantly reduces run off and sediment loss. A handful of farmers are planting their fodder beet with strip-till and have observed less compaction and maintained yields compared to their conventionally tilled fodder beet crops.

The challenge is that these claims have not been substantiated by research. This project will assess the difference in environmental impact when winter grazing on strip tilled versus conventionally tilled fodder beet. It will measure the volume of runoff created and establish if there is any difference in sediment, Nitrogen (N), and Phosphorus (P) concentrations between treatments to assess if the cultivation method impacts runoff.

Lastly, this project will consider the financial cost between the cultivation methods, including input costs, and carry out a feasibility analysis on the ability for strip-till technology to be more widely adopted in Aotearoa New Zealand farming systems.

1.1 Te Ao Māori

Matauranga Maori is underpinned by tikanga (being honest and just), whakawhanaungatanga (making good in relationships) and whakapapa. Whakapapa binds people to each other and the soil, air, and water (Kepa et al., 2021). This world view is critical for finding pathways to Aotearoa New Zealand farm systems that have a minimal impact on the environment whilst protecting food security and livelihoods of those connected to the land. This project closely aligns with this approach, investigating a less impactful way of carrying out winter grazing that meets the needs of the environment and people.

2 Literature Review

This literature review explores academic literature and industry information methods to prepare the seed bed for fodder beet. It focuses on the common practice of conventional tillage and a small but growing practice in New Zealand, strip tillage. There is some research which has investigated the difference between these types of cultivation methods. This review will draw attention to observed environmental differences and explore if there are any impacts on yield.

2.1 Cultivation methods for fodder beet

Fodder beet requires precision drilling into a firm and fine seed bed for good germination (Specialty Seeds, n.d.; PGG Wrightsons, 2017; Ravensdown, 2020). Power/disc harrowing is typically the first pass to break down the clods of the previous crop and is often followed by deep ploughing (Khaembah, et al., 2020; Specialty Seeds, n.d.; Burrows, 2017). Another pass of power/disc harrowing may follow ploughing and/or Cambridge rolling (Chakwizira, de Ruiter, & Maley, 2014; Khaembah, et al., 2020). The seed bed is then left to sit for a while to ensure there is minimal weed competition for fodder beet seedlings (DairyNZ, 2023), following which the seeds are precision drilled at a rate of 90,000 to 100,000 seeds per hectare. Conventional cultivation requires many passes of heavy equipment, resulting in high fuel usage, soil compaction, and cost (Jaskuska, et al., 2020). Consistent use of ploughing can create soil pans which decrease water permeability, lower yields (Triplett & Dick, 2008), and decrease soil organic matter (Gorski, Gaj, Ulatowska, & Miziniak, 2022; Triplett & Dick, 2008; Jaskuska, et al., 2020). However, conventional tillage does produce a uniform seed bed with reduced weed competition.

An alternative to conventional tillage is no-till. Seed is sown directly into the sprayed-off previous crop. No-till has risen in popularity as it reduces energy inputs, labour, and machinery inputs compared to conventional tillage (Triplett & Dick, 2008). However, management of weeds and pests (such as slugs) can become a challenge (Triplett & Dick, 2008), to a degree where no-tillage is discouraged for fodder beet field preparations (Specialty Seeds, n.d.).

Strip-till cultivation is a method of cultivation that works well for crops that have a wide row spacing (Jaskuska, et al., 2020). Fodder beet is one such plant, requiring 0.5 m between rows and 0.25 m between plants to get an optimal yield (DairyNZ, 2023). It involves tilling the soil in the seed rows and leaving the inter-row soil undisturbed. It is carried out with specialised equipment that can cultivate, sow seed, and apply fertiliser in one pass, often referred to as a strip-till-one-pass (STOP). The sowing rate is the same as conventional at 90,000 to 100,000 seeds per hectare.

Figure 1 illustrates the differences between conventional cultivation, strip tillage, and no till, showing what parts of the soil surface are cultivated.

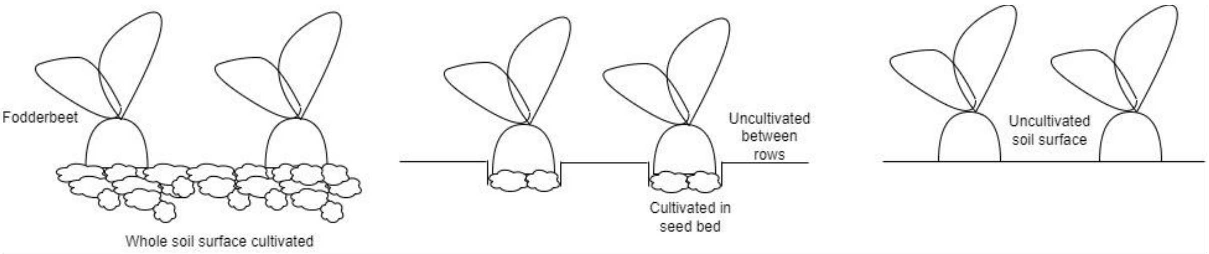


Figure 1. Different types of cultivation methods across the drilling rows

There is little literature that has studied strip tillage as a cultivation method for fodder beet. International studies have investigated strip tillage on sugar beet and found that the cultivation causes no change in yields or quality (Gorskiet al., 2022). In New Zealand, the majority of strip till research is related to maize cultivation and carried out by the Foundation for Arable Research (FAR). Currently, the only research project that relates to strip till fodder beet in the New Zealand context is a project facilitated by Beef and Lamb NZ in 2017. North Island farmers, the Linklater's, as part of the Beef and Lamb Innovation Farm programme, found that strip tillage could be used to successfully establish fodder beet. Their project concluded that there could be advantages in areas prone to wind erosion and water stress and observed little impact on yield (Beef and Lamb New Zealand, 2017).

Ravensdown (2020) also mentions strip tillage as a successful cultivation method. Strip tillage for fodder beet has been used on farms all over New Zealand. However, there is no academic research investigating strip-till fodder beet in New Zealand and many of the findings are anecdotal.

2.2 Cultivation method impacts on yield

The Linklater's trial with Beef and Lamb NZ saw very little difference in yields between the cultivation methods, with their fodder beet yield ranging across both treatments from 17.3-21 t DM/ha (Beef and Lamb New Zealand, 2017). As the study only spanned one-year, yield trends could not be ascertained.

New Zealand-based studies on maize have showed varying impacts on yield. Most studies have found no statistical difference in yield between full cultivation, strip tillage and direct drill (Parker, Johnstone, & Wallace, 2008; Foundation for Arable Research, 2009a). A Grower Leading Change group found a reduction in plant emergence under strip tillage compared to conventional tillage, this trial is still ongoing as of August 2023, so final yield results have not been collected (Growers Leading Change, 2023). Past research has found that yields eventually equalise because of lower germination results in lower competition for resources therefore plants undergo compensatory growth (Parker, Johnstone, & Wallace, 2008). Studies comparing plant emergence in silty loam found that strip tillage had improved plant emergence compared to no tillage (Licht & Al-kaisi, 2005). Soil moisture conservation, reduced penetration resistance, and increased soil temperatures provided a more ideal seedbed than no till. The Foundation for Arable Research (2009b) identified that maintaining the yield was dependant on good management practices such as pest control, and accurate GPS.

Year one of a two-year study using strip till to establish radish seed has produced similar results to those observed in the fodder beet and maize trials, that there is no significant difference in yield (Rolston et al., 2023). Farmers interviewed as part of this study noted that pre-emptive slug management was required.

An international two-year study found strip-till sugar beet had a 6.6% increase in root yield compared to conventional till (Gorski et al., 2022). Results indicated that correct variety selection given agronomic constraints had a greater impact on yield than cultivation method.

There are several international studies that have researched the impacts of using strip till cultivation over a longer period of time. Jaskuska et al., (2020) found that yields of winter wheat and winter rape seed increased over the eight-year test period compared to those grown in conventional and no tillage systems. Fernandez et al., (2015) measured soil properties and changes in yield over a five-year period. Grain yields averaged 9% greater for strip till than no till. Both studies linked improved yields due to the improvement in soil properties caused by different cultivation methods.

2.3 Strip tillage impacts on the environment

Strip tillage in international studies has been shown to improve soil properties and in turn, improve environmental outcomes compared to conventional tillage. Observations have been made regarding runoff sediment (Truman et al., 2007; Endale et al., 2017), soil properties (Jaskuska, et al., 2020), and CO_2 emissions (Sraruskis, et al., 2017).

Truman et al., (2007) carried out tests on cotton under strip- and conventional tillage. Their research found that strip till reduced runoff by 2.5-fold, sediment loss by 3.5-fold and carbon losses by 7-fold. Endale et al., (2017, p. 31) found that sediment loss in conventional tillage fields was almost 8 times that from the paired strip tilled field. Results also showed a statistically significant difference between the total organic nitrogen and total organic carbon loads of the sediment, indicating less losses from the soil in strip till.

Strip till has shown an improvement in key soil properties in studies that span longer periods. Jaskuska et al., (2020) measured changes in soil properties of sandy loam soil in Poland over eight years. They measured more earthworms, available phosphorus, potassium, and organic carbon content in the strip till treatment compared to no-till and conventional tillage. The study also observed an improvement in yield under strip till and attributed it to the improvement in soil properties.

Fernandez et al., (2015) carried out a comparison study over five years between no-till and strip-till. They found in fine textured, poorly drained soils, strip tillage increased soil organic matter by 8.6%, reduced bulk density by 4% and reduced penetration resistance by 18%.

Over the five-year study there were inconsistent results regarding water aggregate stability and infiltration rate. They hypothesised a longer study may be needed to observe any differences in these properties.

Strip tillage results in variation within the field between non-cultivated inter-row and cultivated planter rows (Jaskuska, et al., 2020; Foundation for Arable Research, 2021). Figure 2 measurements were taken after one year of trial in New Zealand. Soil density between strip till and planter rows is greater than in the planter row. These observations align with Jaskuska, et al., (2020) who stated that tilled zones of lower compaction result in water being absorbed faster, creating a favourable root zone. Additionally, in the unloosened interrow, the higher density and greater mulch on the surface lowered water loss. Jaskuska, et al., (2020) measured 13% greater soil moisture in the root zone compared to conventional and reduced tillage systems. Overstreet and Hoyt (2008) measured greater bulk density in the inter-row space which supported greater biological activity, there was no distinguishing difference between soil C and N levels.

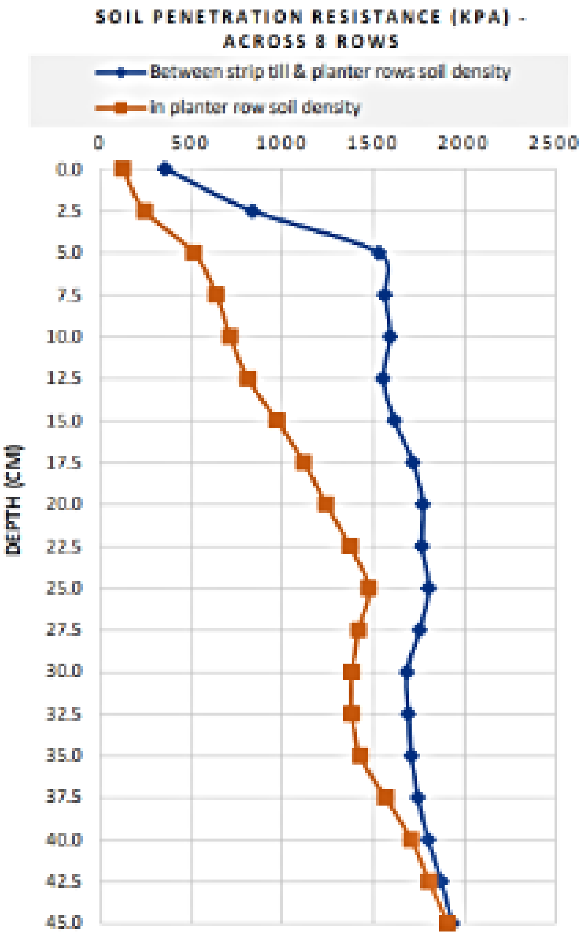


Figure 2. Soil density soil profile comparing cultivated rows to non-cultivated rows.

Retrieved 29 October 2023 from https://assets.far.org.nz/blog/files/e41d80c8-ab93-53d9-9c0b-c9d8de7cab0d.pdf pg. 8

Compared to conventional tillage, strip tillage can result in 18-53% reduction in CO_2 emissions through less tractor passes and reduced energy requirements (Sraruskis, et al., 2017). The variation in reduction can be influenced by the strip tillage settings such as working depth, row cleaners, and working speed. This study will not measure CO_2, however the literature indicates that there are environmental benefits beyond what will be investigated in this current research.

Strip tillage can be a one pass cultivation method. The weight of the seed, additional cultivation equipment, and fertiliser means a heavy piece of equipment passing once over a specific area. Foundation for Arable Research (2021) measured soil compaction and found that the average soil density was below acceptable maximum levels (2500 kPa) in every row.

3 Materials and Methods

There is little research that has investigated the impact of cultivation method on sediment and nutrient loss from soil in New Zealand fodder beet. Specifically, there has been even less research on the use of strip tillage as a cultivation method for fodder beet as it is used in the New Zealand wintering system. Research such as Truman et al., (2007) indicated that changing the cultivation method could result in a reduction of sediment, N, and P losses. This could help get better land and water outcomes whilst maintaining the productivity.

This research will measure and analyse the runoff from a fodder beet paddock grazed by mixed age ewes in the winter of 2023 to assess if there is any difference in runoff, nutrient, and sediment concentration.

3.1 Experimental site

Figure 3 shows the location of the study near Greta Valley, North Canterbury. Figure 4 shows an aerial of the trial location with the dots showing where the plots are located. Prior to the trial, the paddock was in Italian ryegrass which was sprayed out on 28 September 2022 and 5 October 2022, hoggets grazed the paddock out.

Across both treatments the fodder beet variety was Robbos (*Beta vulgaris*) planted at 90,000 seeds/ha. It is known as a relatively soft bulb that is suitable for grazing all stock types as it sits high out of the ground (Barenbrug, 2023).

On 18 October 2022, 3.5 ha of the paddock was strip tilled and planted in one pass using a Falc 3000 row crop rotary tiller with a Valderstat precision seeder. One pass created 6 rows of 150 mm cultivated and 350 mm uncultivated, equating to 30% of the area being cultivated to a depth of 200 mm. A crop-start fertiliser mix (14:6:12) was put through the precision seeder and spread just in the cultivated areas.

On 19 October 2022, the remaining 1.5 ha of the paddock was deep-ripped and disked, rotor spiked, harrowed and Cambridge rolled over three passes to achieve an even seed bed. These passes were done by the farmer. The 1.5 ha was precision drilled by a contractor on 27 October 2022 with a John Deere 12 row. This cultivation method resulted in 100% of the area being worked to a depth of 500 mm. A crop-start fertiliser mix (14:6:12) was broadcast over the conventional tillage area post drilling.

Both treatments followed the same spray plan for herbicide, pesticide, and fungicide control. This included a pre-emerge on 29 October and four post emerge applications. The last post emergence application was made on 1 February 2023. On 1 December 2022, 46 units (100 kg) per ha of N was spread. Plantain was present and persistent in both treatments requiring additional herbicide applications.

Following the conclusion of the trial, both treatments were disked and sown with barley.

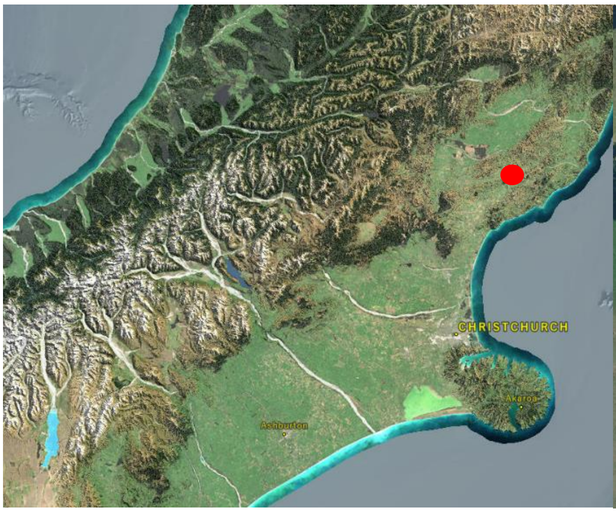


Figure 4. Location of the study.

Red dot shows location.

Figure 3. Paddock treatments.

Purple is strip till, and Red is conventional till. Dots depict the location of the plots.

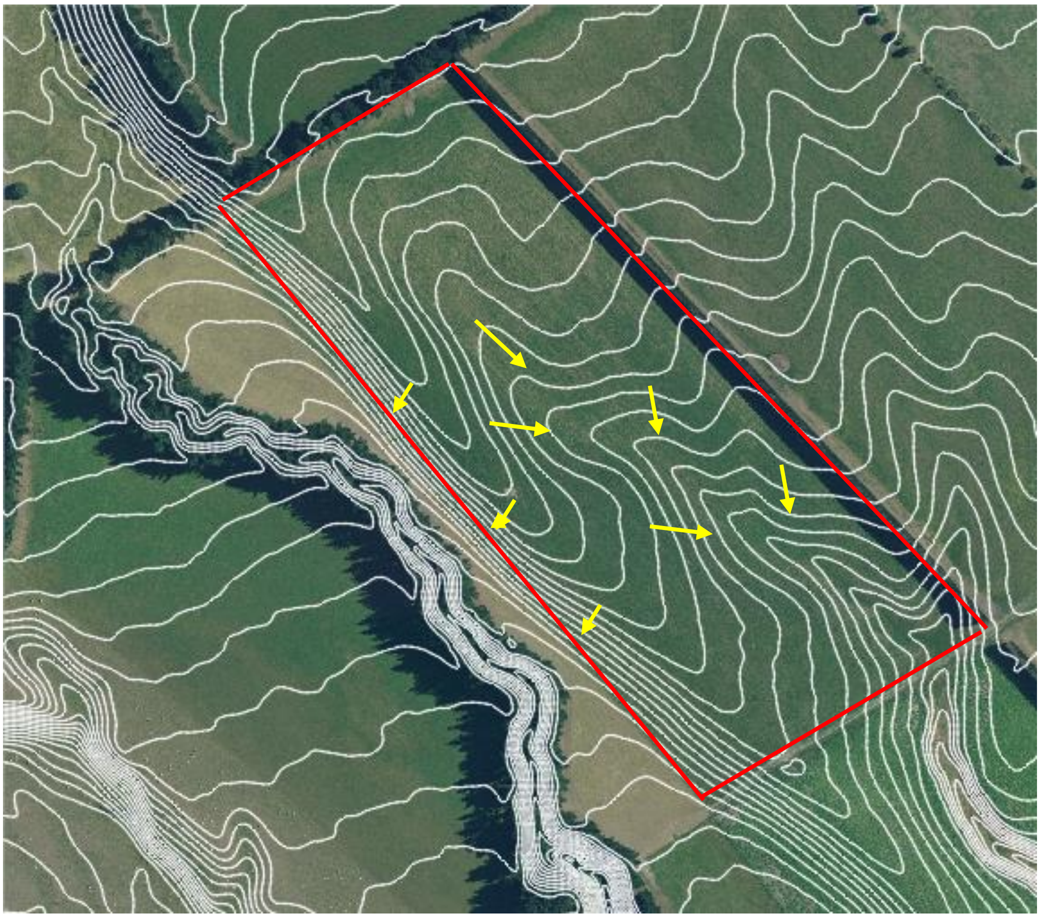


Figure 5. Surface water flow for study location.
White lines show 0.5m contours and yellow arrows depict surface drainage direction.

The slope of the plots average 5.2% for the conventional cultivation plots and 7.0% of the strip till plots. New national policy standards require grazing to be done on less than 10% gradient, therefore these plots reflect realistic conditions that winter grazing occurs in.

Figure 6 is retrieved from S-Maps and indicates the trial paddock (marked by the red square) has a soil order of Pallic and soil composition of 70% Waipara, 20% Mairaki, and 10% Pahau (retrieved 19 May 2023). For a 4°-7° slope Waipara and Pahau have a medium relative runoff and Mairaki has a high risk. These soils are described as moderately deep, poorly drained, silt over clay. There is no artificial drainage on site.

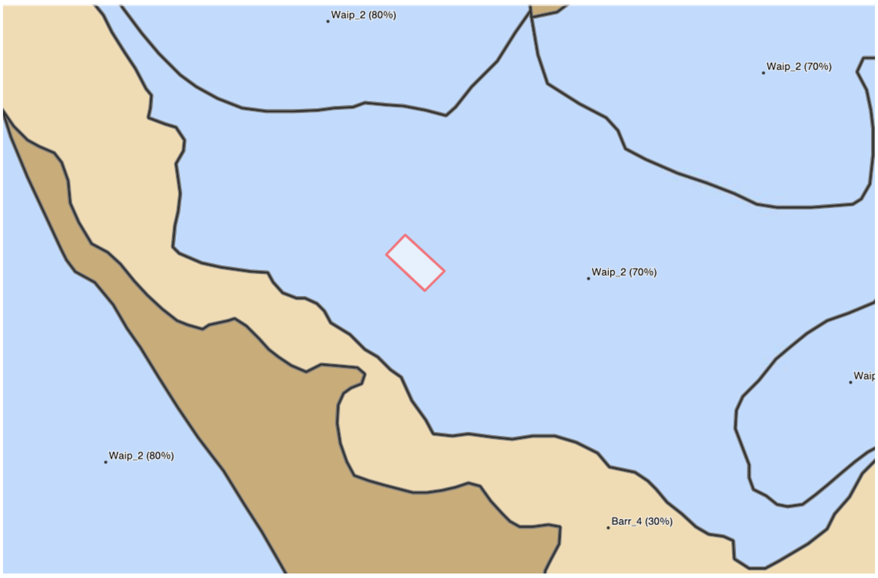


Figure 6. Soil composition of trial location and surrounding area.

3.2 Experimental design

Grazing started on 25 June 2023 with 1,000 mixed age, in-lamb ewes. The ewes were put on the paddock at 8 am each day and taken off at 1 pm, giving them five hours of grazing per day. It is estimated the average fodder beet intake per ewe per day was 0.8 kg DM. The balance of their diet was comprised of standing Italian ryegrass fed in the runoff paddock and baleage. The management objective of these ewes was to maintain condition pre lambing. All the fodder beet was grazed by 2 August 2023.

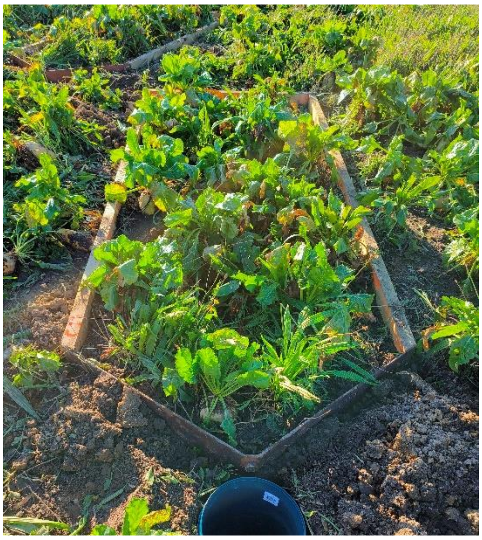


Figure 7. A plot after just being installed.

The trial plots both within and between treatments were hydrologically isolated and placed close together and on similar slopes as to minimise variation between sites. Each treatment had five plots as shown in Figure 7. The plots measured 2 m x 3 m, with the metal V shaped catcher at the bottom of the slope. The wooden box was made of 200 mm by 50 mm treated pine and dug in so 150 mm was below the soil surface and 50 mm remained above.

The metal V shaped catcher had a hole located 150 mm that was dug to sit flush with the ground. The addition of pipe fittings directed the runoff from the plot into 20 litre buckets. The buckets were fitted with lids so only the runoff was collected.

Rainfall at the site was measured using a manual rain gauge. Moisture probes were installed in the centre of each plot and readings were taken weekly from 25 May 2023 to 27 July 2023 and fortnightly from then until 30 August 2023.

4 Sampling and Analysis

4.1 Soil and plant measurements

Soil samples were taken at 15 locations around the strip till plots and 15 locations around the conventional tillage plots to a depth of 150 mm. A summary of the soil properties are listed in Table 1.

Table 1. Soil analysis results summary

Soil property	Strip tillage	Conventional tillage	% Difference between test sites
pH (pH Units)	5.8	6.1	5%
Olsen phosphorus (mg L^{-1})	34	32	6%
Potassium (me 100 g^{-1})	0.39	0.26	40%
Calcium (me 100 g^{-1})	8.5	8.6	1%
Magnesium (me 100 g^{-1})	1.18	1.09	8%
Sodium (me 10 $0g^{-1}$)	19	24	23%
Cation exchange capacity (me 100 g^{-1})	16	15	6%
Total base saturation (%)	64	71	10%
Volume weight (g mL^{-1})	1.04	0.99	5%
Potentially available N (kg Ha^{-1})	224	227	1%
Anaerobically mineralizable N (µg g^{-1})	143	154	7%
Organic matter (%)	5.3	4.9	8%
Total Carbon (%)	3.1	2.9	7%

Soil property	Strip tillage	Conventional tillage	% Difference between test sites
Total Nitrogen (%)	0.28	0.27	4%
C/N ratio	11.0	10.7	3%
Soil texture - Sand 0.06-2 mm (%)	15	15	0%
- Silt 0.002-0.06 mm (%)	59	60	2%
- Clay <0.002 mm (%)	25	25	0%

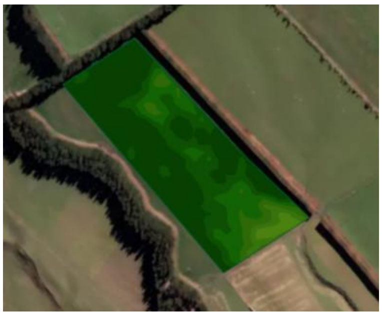
Soil moisture measurements were taken weekly by a neutron probe, with a recording site in each of the plot sites. The probes measured millimetres per 100 metres at the depth of 0-15 mm and every 10 mm till a depth of 55 mm. Measurements were averaged across the five plots.

The fodder beet yield test was taken on 15 June 2023. Three, four-metre strips of fodder beet were lifted in each treatment and leaf was separated from bulb to measure wet weight. Yield was calculated by multiplying the wet weight against 11.5% DM for leaf and 15.2% for the bulb. Calculations returned 19 t DM/ha ± 1 t DM/ha for both the strip till and conventional till.

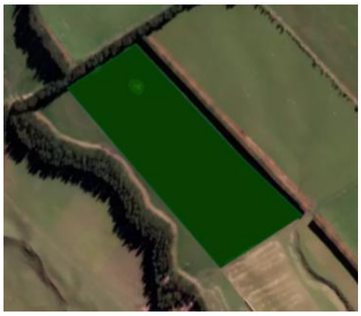
Figure 8 shows the variation in biomass of the paddock throughout the duration of the trial. Yara AtFarm was the source data which creates these maps based on Normalised Difference Vegetation Index (NDVI) taken via satellites that pass over New Zealand every five days. The satellites measure the reflection of red and near-infrared light from the vegetation (Yara, 2023). To get accurate measurements requires clear skies, no data has been included that was comprised by cloud.

The data indicates no significant difference in the rate of canopy closure between treatments. The variation in growth in the 9 December measurement more closely aligns with the slope map rather than areas associated with different treatments. Slower growth aligns with lower parts of the paddock which was visually observed to produce less fodder beet. The results also show that treatments reached canopy closure around the same time.

14 November 2022

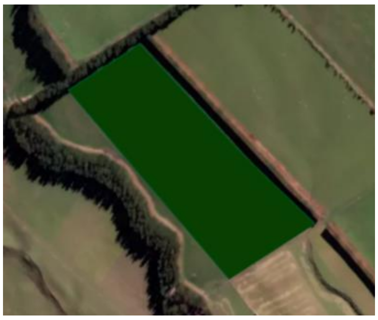


9 December 2022



18 January 2023

17 February 2023



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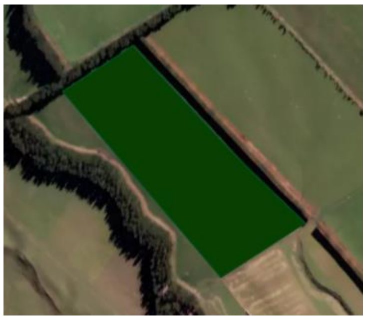


23 April 2023

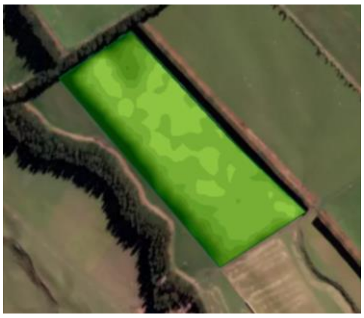
No Data

- May 2023

No Data

- June 2023

12 July 2023



11 Aug 2023

Key:

Figure 8. NDVI map of trial paddock from planting to trial finish.

Data sourced via Yara AtFarm. Data can be accessed through https://www.at.farm/

4.2 Surface runoff

Samples were collected on an events basis within 24 hours of an event creating surface runoff. The volume of water in the bucket was recorded, stirred vigorously to minimise the risk of sediment settling, and a sample of approximately 500ml was taken. If the volume of water did not exceed 500 ml, all water was collected. Samples were labelled and frozen until bulk analysis could be done.

Analysis was carried out by Hills Laboratory to measure the total suspended sediment, total P, total N, dissolved reactive P, Nitrate-N, ammoniacal-N, dissolved organic C, total kjeldahl N, and chloride. A total of 27 samples were tested, collected from three runoff events that happened on 24 July (nine samples – no plot 4), 27 July (10 samples), and 16 August (eight samples, no plot 1 and plot 8). Samples from trial plots 1, 3, and 8 collected on 27 July and 2, 4, and 5 on 16 August did not have enough volume to be measured for suspended solids.

Details of testing procedure and raw results as presented by Hills Laboratory can be found in Appendix B.

4.3 Feasibility assessment

The ease of accessing strip till technology and the financial analysis was collected through informal discussions with key stakeholders.

4.4 Statistical analysis

Total suspended solids, nitrogen, nitrate, dissolve reactive phosphorus, and total phosphorus were analysed by a one-way Analysis of Variance (one-way ANOVA). Significant levels were presented at the $P < 0.05$ level of significance.

5 Results and Discussion

The trial period of 25 May 2023 to 30 August 2023 had a total of 256 mm of rain and was considered by the farmer to be a wet season. A major rainfall event happened on 22 and 23 July 2023. Over these two days, 89 mm fell followed by 13 and 11 mm on 24 and 25 July, respectively. These four days account for 44% of the total rainfall during the research period. Another rainfall event that triggered runoff was 19 mm on 16 August 2023. All other rainfalls totalled less than 11 mm over a 24-hour period.

Runoff events occurred on 23 and 25 July and 16 August. Runoff events appeared to occur when rainfall exceeded 19 mm within a 24-hour period. The exception being 25 July when only 11 mm fell, however the large amount of water that fell in the days beforehand likely had a strong influence on this runoff event occurring. Gray et al., (2022) observed that runoff events generally happened after sustained rainfall events when the soil moisture content exceeded 45% v v^{-1}, typical of that soil's field capacity.

Unfortunately, due to the scale of the rainfall event on the 22 July, all buckets were at capacity at the time of collection. Therefore, we predict that the catchment buckets overflowed, and it was not possible to gauge how much runoff was actually produced during that time. Figure 9 demonstrates the amount of water left at the bottom of the plots indicating the overflow.

Figure 9. Trial plot 10 (strip till) post major rainfall event.

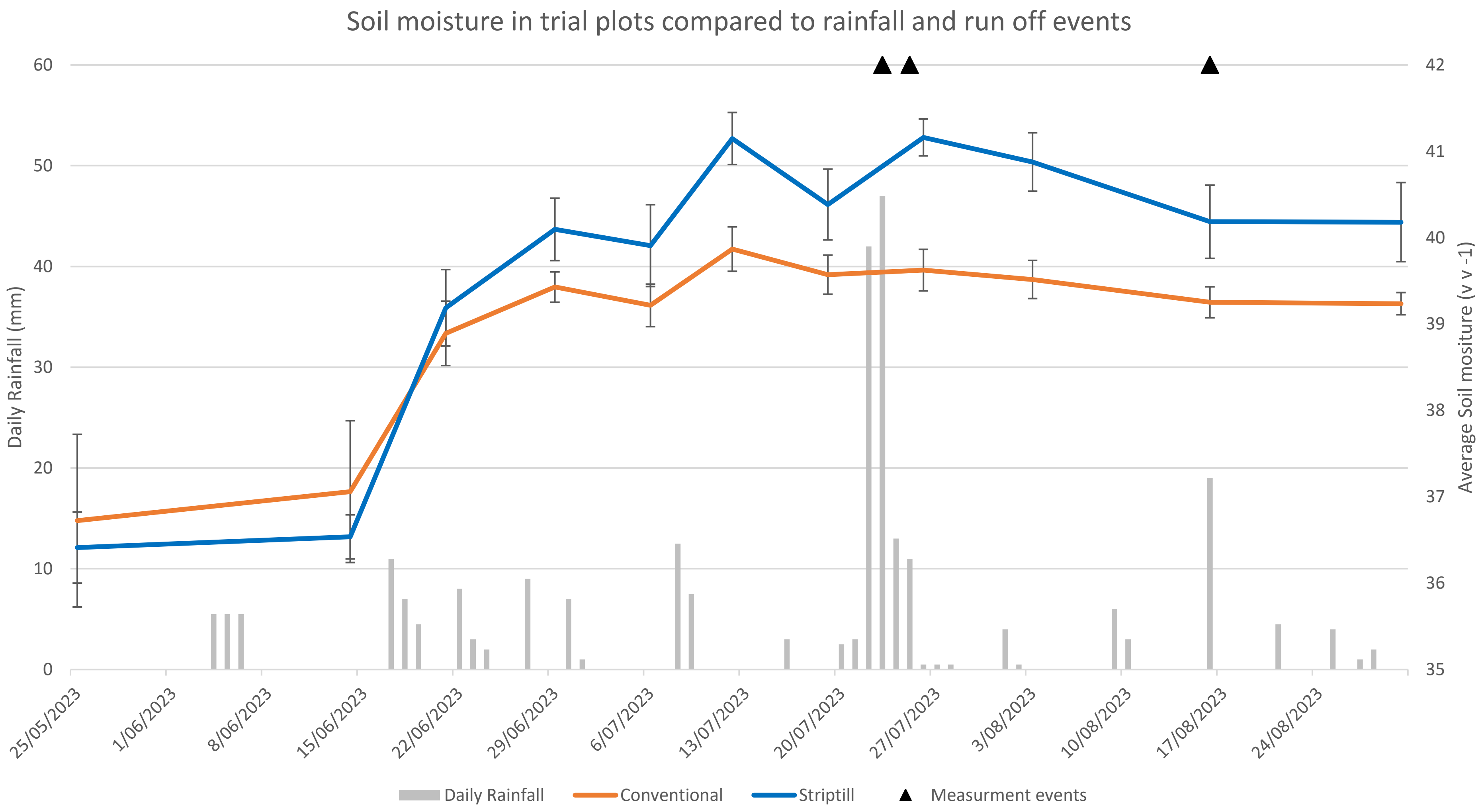


Figure 10. Soil moisture in trial plots compared to rainfall and runoff events.

The soil cultivation method under the conditions of this research provided no significant difference between conventional or strip till treatments ($p < 0.05$). Figure 11 shows box plots of the data generated by the three runoff events by conventional or strip tillage.

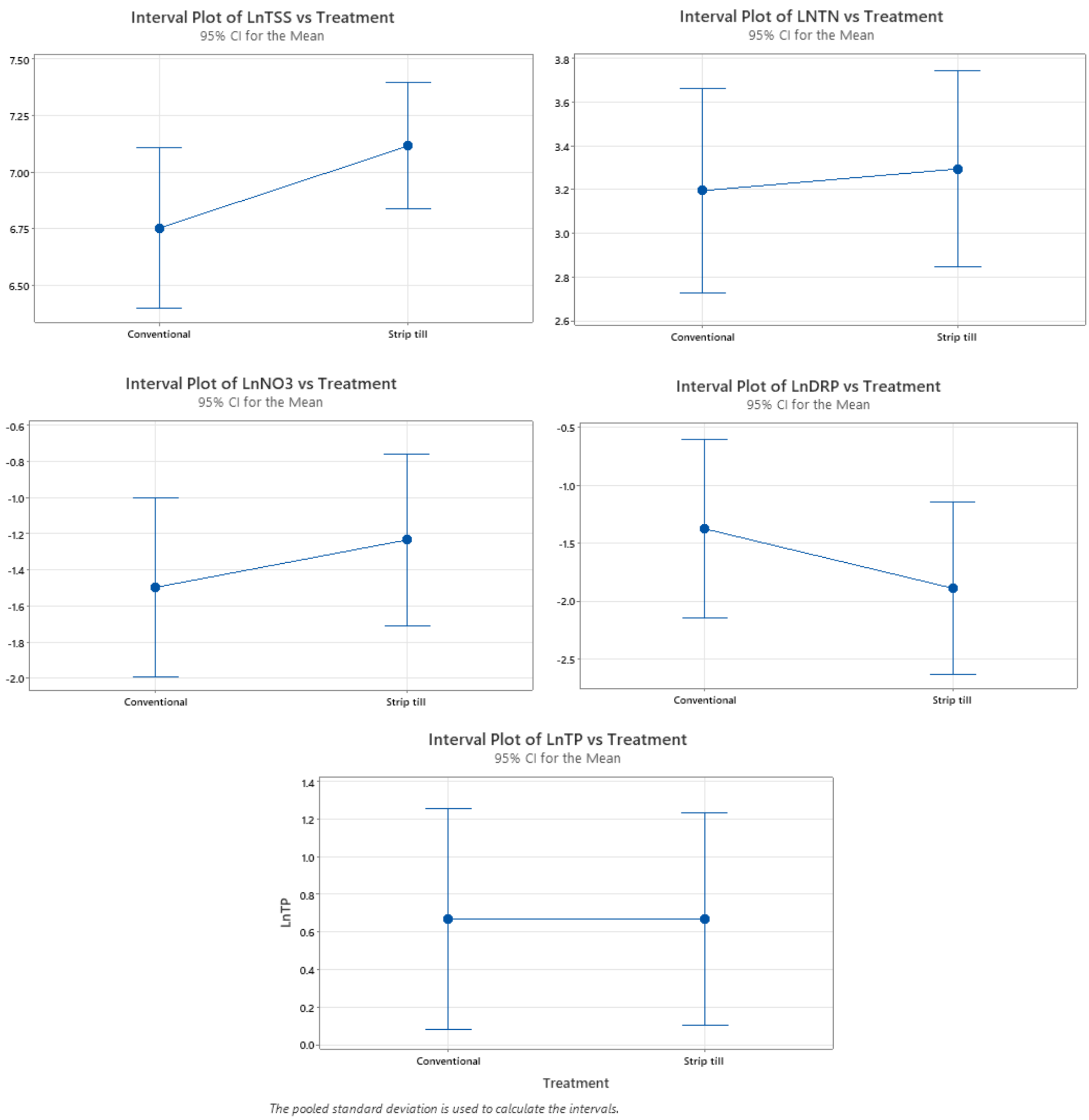


Figure 11 Runoff measurements; Total suspended solids (TSS), suspended sediment (TSS), total nitrogen (TN), Nitrate (NO3), dissolved reactive phosphorus (TDRP), and total phosphorus (TP)

Data was transformed for log natural and used pooled standard deviation to present the data in Figure 11. Table 2 summarises the models and presents standard deviation by treatment. TSS had greatest relationship of those measured, however, at a $p < 0.05$ the null hypothesis across all measurements is rejected given the research conditions.

Table 2. Statistical summary of log natural of measurements

		Treatment	
		Conventional tillage	Strip till
LnTSS	**n**	8	13
	Mean	6.75	7.11
	StDev	0.34	0.544
	r^2	12.88%	
	***p*-value**	0.110	
LnTN	**n**	13	14
	Mean	3.19	3.29
	StDev	0.88	0.74
	r^2	0.40%	
	***p*-value**	0.754	
LnNO3	**n**	13	14
	Mean	-1.49	-1.23
	StDev	0.38	1.13
	r^2	2.44%	
	***p*-value**	0.437	
LnDRP	**n**	13	14
	Mean	-1.37	-1.89
	StDev	1.16	1.49
	r^2	3.77%	
	***p*-value**	0.332	
LnTP	**n**	13	14
	Mean	0.68	0.67
	StDev	0.77	1.21
	r^2	0.00%	
	***p*-value**	0.997	

Figure 12, TSS and TN show a downward trend in the g/m^3 measured across the three runoff events for both treatments. This follows trends observed by (McDowell, et al., 2003) showed that in cultivated soils, the loss of sediment decreases as more treading occurs. It was hypothesised that treading acted to increase the soil strength and cohesion. Equally, as the grazing front of the winter crop moved forward, animals were less likely to pass over the trial plots therefore decreasing the volume of nutrients deposited. McDowell, (2006) observed that the volume of contaminates from sheep dung decreased in surface runoff 12 days after it was deposited.

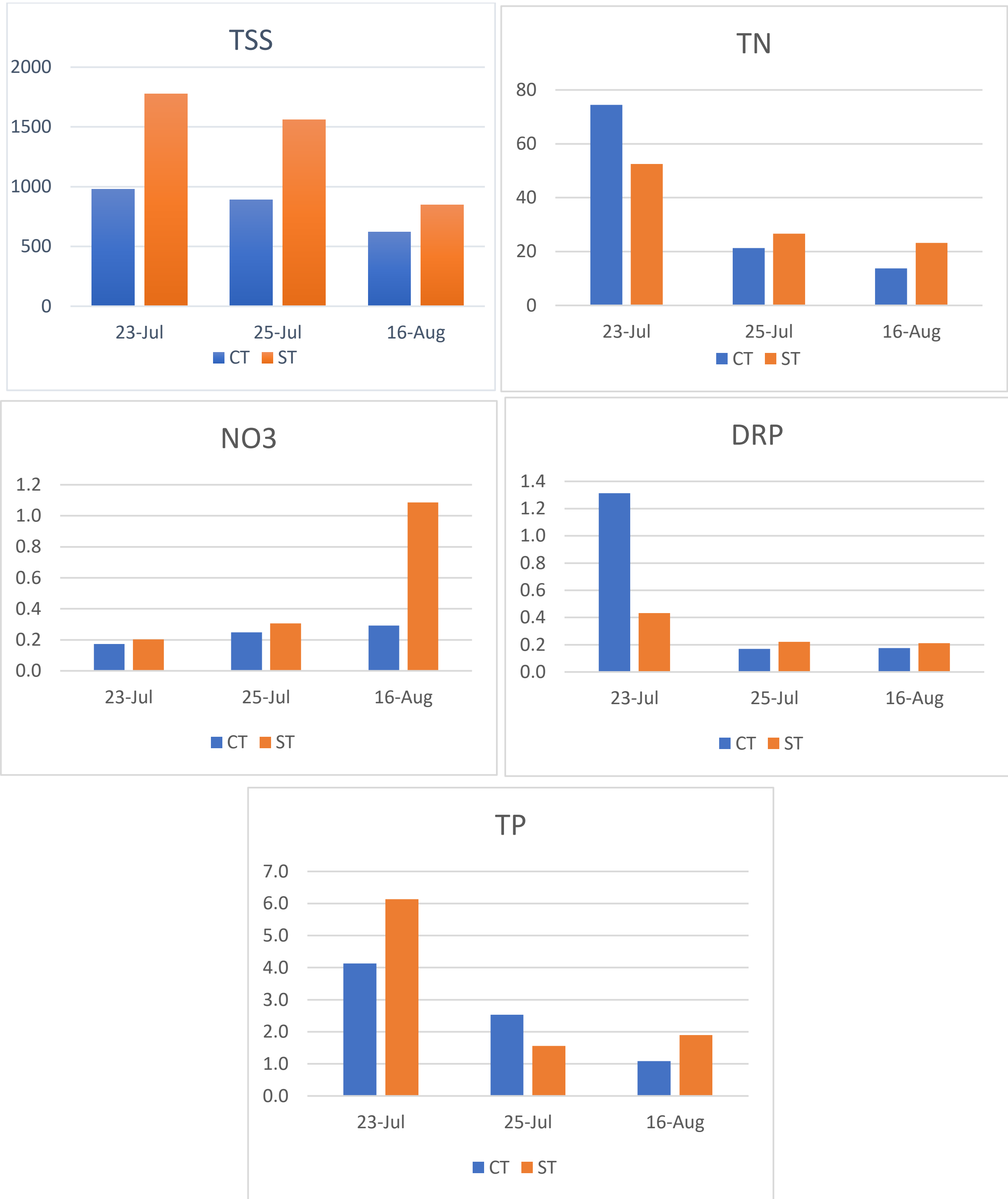


Figure 12. Average of plot results by treatment type and date of runoff event. All units g/m^3.

Table 3 is the average concentrations of SS. The majority of previous of research has studied runoff created by grazing pasture (Cournane, 2010; McDowell, et al., 2003). Pasture tends to have a lower loss of sediment compared to cultivated soils. Concentrations for previous studies for lambs grazing on cultivated soil range from 0.621 to 1.327 g L^{-1} (McDowell & Houlbrooke, 2009). The research was within this range of 0.855 to 1.229 g L^{-1}.

Pallic soils, the same soil order as this trial at 90% soil moisture had the greatest SS concentration and load in surface runoff compared to brown, melanic and recent gley (Cournane, 2010). This might explain while, despite using best practice grazing techniques the concentration of SS in this trial was on par with those of previous studies where lambs were grazed at 4,300 lambs/ha for three days (McDowell & Houlbrooke, 2009).

Table 3 Average suspended sediment (TSS), total nitrogen (TN), Nitrate (NO3), dissolved reactive phosphorus (TDRP), and total phosphorus (TP) measured in surface runoff from conventional and strip-till treatments.

Treatment	TSS ($g\ L^{-1}$)	TN ($g\ L^{-1}$)	NO3 ($mg\ L^{-1}$)	TDRP ($mg\ L^{-1}$)	TP ($mg\ L^{-1}$)
Conventional	0.855	0.024	0.223	0.252	1.950
Strip-till	1.229	0.026	0.290	0.150	1.948

TP losses across treatments are very similar. McDowell & Houlbrooke (2009) suggested that TP was more strongly affected by the P available for leaching. In this study the animals grazed the plots and had the same fertiliser applied to it. This would indicate the same amount of P is applied and therefore available for leaching, consistent with these results.

5.1 Feasibility of strip-till technology for fodder beet

The financial analysis is based on actuals from the strip till and conventional till trials. Please note these costs are specific to this trial, and while are considered on par with the 2022/23 growing season, actual costs will be dependent on location, cost of running own gear, contractor prices, and what spraying and fertiliser plans the farmer follows.

A financial analysis of the costs associated with this trial and the ground preparation is summarised in Table 4. This trial only had a 0.5% difference in total costs with strip till being marginally cheaper than conventional tillage. As there was no difference in yield there is almost no difference in cost of production per kg dry matter at $0.150 ($2,845/ha for conventional) and $0.147 ($2,785/ha for strip till).

A Beef+Lamb NZ-funded farm innovation trial in 2014 showed that strip till cost $2,088.40/ha ($0.12 /kg DM) to establish and conventional tillage $2,471.04/ha ($0.14 /kg DM) (Beef and Lamb New Zealand, 2017). This is a 15% cost saving. In the Beef+Lamb trial, less fertiliser and chemicals were applied in the strip till treatment as they placed it via banding. This reduction in inputs potentially explains the larger cost saving.

Table 4. Costs for different cultivation methods for the trial

	$/Ha		
	Conventional tillage	Strip tillage	% Difference
Ground Prep			
Deep ripped, disked and Rotary spiked*	$400	-	
Drilling			
Precision Drilling	$200	-	
Strip tillage	-	$550	
Cultivation costs	**$600**	**$550**	**2.2%**
Seed	**$425**	**$425**	**0.0%**
Broadcast costs Crop Start	$10	-	
Capital Fert, Side dressing, and fodder beet base	$760	$760	
Fertiliser costs	**$770**	**$760**	**0.3%**
Spray Programme incl. application cost	$1,050	$1,050	
Spray costs	**$1,050**	**$1,050**	**0.0%**
Total cost	**$2,845**	**$2,785**	**0.5%**
Yield t/ha	19	19	
$/Kg Dm	$0.150	$0.147	0.5%

* The farmer used his own equipment for this cultivation and estimated the cost for all passes, including fuel, repairs, and maintenance etc to be $400/ha.

While financial savings are important to farmers, there have been some limitations to when strip till can be used. Limitations include when the soil is too wet or too stoney. Farmers have found that if it is too wet, they observed smearing which compromised the quality of the cultivated area. The soil in the tilled rows often does not break down as well in wet conditions. In conventional tillage this can be corrected for in subsequent passes however, as strip tillage is one pass, the optimum seed bed needs to be achieved on the first go. Stoney soil compromises the ability to create an even seed bed as well, and can cause damage to the precision gear. As a result, stony paddocks are not suitable for strip tillage.

The first 90 days are the most important for fodder beet establishment. In this trial both the conventional and strip tillage was managed with the same chemical and grazing programme. It was observed in the strip till area that more feed grew in the inter-row area and there was no compromise of fodder beet yield. Some people have found that the additional feed can harbour more pests and diseases which require additional management.

6 Conclusion

Previous studies indicate that there could be potential environmental benefits from cultivating with strip tillage verses conventional tillage. However, given the conditions of this trial there was no significant relationship between cultivation method and runoff. Results from suspended sediment, nitrogen, and phosphorus were statistically the same.

As this project only spanned one year and a small sample size it is difficult to establish if cultivation method has an effect on runoff or if it had any lasting effect on soil conditions.

Strip tillage did save on cultivation costs per hectare and resulted in less cultivation passes being done. A limitation to this research was the sample size, both in terms of runoff events, and the number of different soil types.

Studies that have found an improvement in soil properties and reduced runoff have used strip tillage for many years. This project only provided a small sample size. It would be recommended to re-do this study at a larger scale and investigate a suite of management practices that could result in a lower environmental impact of fodder beet on the environment. This includes things such as precision fertiliser and herbicide use.

There are a number of contractors claiming that strip till fodder beet is better for the environment, and looking at other studies for different crop types it could be extrapolated that this should be expected. However, this study has indicated that using strip tillage for fodder beet in a wintering system caused no significant difference in runoff, N losses or P. Therefore, it is highly recommended that more research is carried out to establish if these results are repeatable with a larger sample size.

7 Acknowledgments

The authors would like to acknowledge the Our Land and Water (Toitū te Whenua, Toiora te Wai) National Science Challenge - Rural Professional Fund 2023-24, for the opportunity to carry out this research. We would also like to thank the farmers and industry professionals involved in bringing this project together.

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Appendix A Soil Samples – Report from Hills Laboratory

Hill Labs

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Certificate of Analysis

Page 1 of 5

Client:	Tambo New Zealand Limited	**Lab No:**	3328439 shvpv1
Address:	PO Box 39039	**Date Received:**	25-Jul-2023
	Harewood	**Date Reported:**	07-Aug-2023
	Christchurch 8545	**Quote No:**	
		Order No:	
		Client Reference:	
		Submitted By:	Megan Fitzgerald

Sample Name: Strip Till **Lab Number:** 3328439.1
Sample Type: SOIL Arable (S56)

Analysis	Units	Level Found	Medium Range*
pH	pH Units	5.8	5.7 - 6.2
Olsen Phosphorus	mg/L	34	20 - 30
Potassium	me/100g	0.39	0.30 - 0.60
Calcium	me/100g	8.5	5.0 - 12.0
Magnesium	me/100g	1.18	0.60 - 1.20
Sodium	me/100g	0.39	0.00 - 0.30
CEC	me/100g	16	12 - 25
Total Base Saturation	%	64	50 - 85
Volume Weight	g/mL	1.04	0.60 - 1.00
Potentially Available Nitrogen (15cm Depth)*	kg/ha	224	100 - 150
Anaerobically Mineralisable N*	µg/g	143	
Organic Matter*	%	5.3	7.0 - 17.0
Total Carbon	%	3.1	
Total Nitrogen	%	0.28	0.30 - 0.60
C/N Ratio*		11.0	
Anaerobically Mineralisable N/Total N Ratio*	%	5.1	3.0 - 5.0
Soil Sample Depth*†	mm	0-150	
Sand (0.06-2mm)*	%	15	
Silt (0.002-0.06mm)*	%	59	
Clay (<0.002mm)*	%	25	

Base Saturation %	K 2.4	Ca 52	Mg 7.2	Na 2.4
MAF Units	K 8	Ca 11	Mg 28	Na 19

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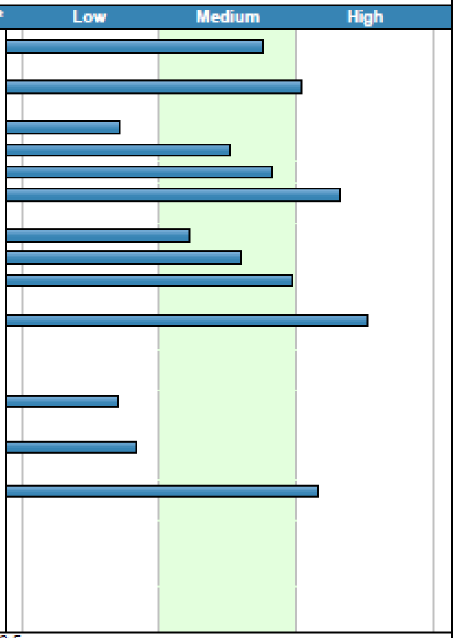
Certificate of Analysis

Client:	Tambo New Zealand Limited	**Lab No:**	3328439 shvpv1
Address:	PO Box 39039 Harewood Christchurch 8545	**Date Received:**	25-Jul-2023
		Date Reported:	07-Aug-2023
		Quote No:	
		Order No:	
		Client Reference:	
		Submitted By:	Megan Fitzgerald

Sample Name: Conventional Till **Lab Number:** 3328439.2
Sample Type: SOIL Arable (S56)

Analysis		Level Found	Medium Range*
pH	pH Units	6.1	5.7 - 6.2
Olsen Phosphorus	mg/L	32	20 - 30
Potassium	me/100g	0.26	0.30 - 0.60
Calcium	me/100g	8.6	5.0 - 12.0
Magnesium	me/100g	1.09	0.60 - 1.20
Sodium	me/100g	0.52	0.00 - 0.30
CEC	me/100g	15	12 - 25
Total Base Saturation	%	71	50 - 85
Volume Weight	g/mL	0.99	0.60 - 1.00
Potentially Available Nitrogen (15cm Depth)*	kg/ha	227	100 - 150
Anaerobically Mineralisable N*	µg/g	154	
Organic Matter*	%	4.9	7.0 - 17.0
Total Carbon	%	2.9	
Total Nitrogen	%	0.27	0.30 - 0.60
C/N Ratio*		10.7	
Anaerobically Mineralisable N/Total N Ratio*	%	5.8	3.0 - 5.0
Soil Sample Depth*‡	mm	0-150	
Sand (0.06-2mm)*	%	15	
Silt (0.002-0.06mm)*	%	60	
Clay (<0.002mm)*	%	25	
Base Saturation %		K 1.7 Ca 58 Mg 7.4 Na 3.5	
MAF Units		K 5 Ca 11 Mg 24 Na 24	



The above nutrient graph compares the levels found with reference interpretation levels. NOTE: It is important that the correct sample type be assigned, and that the recommended sampling procedure has been followed. R J Hill Laboratories Limited does not accept any responsibility for the resulting use of this information.
IANZ Accreditation does not apply to comments and interpretations, i.e. the 'Range Levels' and subsequent graphs.

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		Quote No:	
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		Client Reference:	
		Submitted By:	Megan Fitzgerald

Soil Analysis Results

Sample Name:		Strip Till	Conventional Till				
Lab Number:		3328439.1	3328439.2				
Sample Type:		SOIL Arable	SOIL Arable				
Sample Type Code:		S56	S56				
pH	pH Units	5.8	6.1	-	-	-	-
Olsen Phosphorus	mg/L	34	32	-	-	-	-
Potassium	me/100g	0.39	0.26	-	-	-	-
Potassium	%BS	2.4	1.7	-	-	-	-
Potassium	MAF units	8	5	-	-	-	-
Calcium	me/100g	8.5	8.6	-	-	-	-
Calcium	%BS	52	58	-	-	-	-
Calcium	MAF units	11	11	-	-	-	-
Magnesium	me/100g	1.18	1.09	-	-	-	-
Magnesium	%BS	7.2	7.4	-	-	-	-
Magnesium	MAF units	28	24	-	-	-	-
Sodium	me/100g	0.39	0.52	-	-	-	-
Sodium	%BS	2.4	3.5	-	-	-	-
Sodium	MAF units	19	24	-	-	-	-
CEC	me/100g	16	15	-	-	-	-
Total Base Saturation	%	64	71	-	-	-	-
Volume Weight	g/mL	1.04	0.99	-	-	-	-
Potentially Available Nitrogen (15cm Depth)*	kg/ha	224	227	-	-	-	-
Anaerobically Mineralisable N*	µg/g	143	154	-	-	-	-
Organic Matter*	%	5.3	4.9	-	-	-	-
Total Carbon	%	3.1	2.9	-	-	-	-
Total Nitrogen	%	0.28	0.27	-	-	-	-
C/N Ratio*		11.0	10.7	-	-	-	-
Anaerobically Mineralisable N/Total N Ratio*	%	5.1	5.8	-	-	-	-
Soil Sample Depth*†	mm	0-150	0-150	-	-	-	-
Sand (0.06-2mm)*	%	15	15	-	-	-	-
Silt (0.002-0.06mm)*	%	59	60	-	-	-	-
Clay (<0.002mm)*	%	25	25	-	-	-	-

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		Client Reference:	
		Submitted By:	Megan Fitzgerald

Analyst's Comments

† Customer supplied data. Please note: Hill Labs cannot be held responsible for the validity of this customer supplied data, or any subsequent calculations that rely on this information.

Samples 1-2 Comment:
For further information about this test, please refer to our Technical Note - Soil Texture Measurement as published on the Hill Laboratories website.

Samples 1-2 Comment:
The medium or optimum range guidelines shown in the histogram report relate to sampling protocols as per Hill Laboratories' crop guides and are based on reference values where these are published. Results for samples collected to different depths than those described in the crop guide should be interpreted with caution.
For pastoral soils, the medium ranges are specific for a 75mm sample depth, but if a 150mm sampling depth is used the nutrient levels measured may appear low against these ranges, as nutrients are typically more concentrated in the top of the soil profile. These soil profile differences are altered upon cultivation or contouring.
Further explanation of the derivation of the medium and optimum ranges is available on request.

Samples 1-2 Comment:
The Potentially Available Nitrogen (kg/ha) test above assumes the sample is taken to a 15 cm depth. If the depth is 7.5 cm, then the result reported above should be divided by two.
To calculate Potentially Available Nitrogen (as kgN/ha) for other sample depths use the reported Anaerobic Mineralisable Nitrogen (AMN) result in the following equation:
AN (kg/ha) = AMN (µg/g) x VW (g/ml) x sample depth (cm) x 0.1
Note that the AN and AMN results reported include the readily available Mineral N (NH4-N and NO3-N) fraction, which is typically quite low.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Labs, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Sample Registration*	Samples were registered according to instructions received.	-	1-2
Soil Prep (Dry & Grind)*	Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2mm screen.	-	1-2
pH	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH. In-house.	0.1 pH Units	1-2
Olsen Phosphorus	Olsen extraction followed by Molybdenum Blue colorimetry. In-house method.	1 mg/L	1-2
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-2
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-2
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 MAF units	1-2
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	2 MAF units	1-2
Potentially Available Nitrogen	Anaerobic incubation followed by extraction using 2M KCl followed by Berthelot colorimetry. (Calculation based on 15cm depth sample). Note that any Mineral N present is included in the AN/AMN result reported. In-house.	10 kg/ha	1-2
Anaerobically Mineralisable N*	As for Potentially Available Nitrogen but reported as µg/g.	5 µg/g	1-2

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Certificate of Analysis

Client:	Tambo New Zealand Limited	**Lab No:**	3328439 shvpv1
Address:	PO Box 39039 Harewood Christchurch 8545	**Date Received:**	25-Jul-2023
		Date Reported:	07-Aug-2023
		Quote No:	
		Order No:	
		Client Reference:	
		Submitted By:	Megan Fitzgerald

Sample Type: Soil

Test	Method Description	Default Detection Limit	Sample No
Organic Matter*	Organic Matter is 1.72 x Total Carbon.	0.2 %	1-2
Total Carbon	Dumas combustion. In-house.	0.1 %	1-2
Total Nitrogen	Dumas combustion. In-house.	0.04 %	1-2
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.01 me/100g	1-2
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.5 me/100g	1-2
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.04 me/100g	1-2
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.05 me/100g	1-2
Potassium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1-2
Calcium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	1 %BS	1-2
Magnesium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.2 %BS	1-2
Sodium	1M Neutral ammonium acetate extraction followed by ICP-OES. In-house.	0.1 %BS	1-2
CEC	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity. May be overestimated if soil contains high levels of soluble salts or carbonates. In-house.	2 me/100g	1-2
Total Base Saturation	Calculated from Extractable Cations and Cation Exchange Capacity.	5 %	1-2
Volume Weight	The weight/volume ratio of dried, ground soil. In-house.	0.01 g/mL	1-2
Sand (0.06-2mm)*	Sieve analysis after organic matter removal. In-house.	2 %	1-2
Silt (0.002-0.06mm)*	Sedimentation procedure by hydrometer after organic matter removal. In-house.	2 %	1-2
Clay (<0.002mm)*	Sedimentation procedure by hydrometer after organic matter removal. In-house.	2 %	1-2

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 26-Jul-2023 and 07-Aug-2023. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

W. M. Homewood

Wendy Homewood
Operations Support - Agriculture

Appendix B Water Samples – Report from Hills Laboratory

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Certificate of Analysis

SPv1

Client:	Tambo New Zealand Limited	**Lab No:**	3372193
Contact:	Megan Fitzgerald	**Date Received:**	26-Sep-2023
	C/- Tambo New Zealand Limited	**Date Reported:**	16-Oct-2023
	PO Box 39039	**Quote No:**	126375
	Harewood	**Order No:**	
	Christchurch 8545	**Client Reference:**	
		Submitted By:	Megan Fitzgerald

Sample Type: Aqueous

Sample Name:		27 July 1	27 July 2	27 July 3	27 July 4	27 July 5
Lab Number:		3372193.1	3372193.2	3372193.3	3372193.4	3372193.5
Total Suspended Solids	g/m³	-	770	-	1,070	830
Chloride	g/m³	1.6	2.7	17.7	11.8	8.4
Total Nitrogen	g/m³	6.0	21	42	16.5	21
Total Ammoniacal-N	g/m³	1.42	3.8	3.2	2.2	1.60
Nitrite-N	g/m³	0.026	0.024	0.025	0.022	0.024
Nitrate-N	g/m³	0.25	0.20	0.199	0.23	0.36
Nitrate-N + Nitrite-N	g/m³	0.28	0.23	0.22	0.26	0.39
Total Kjeldahl Nitrogen (TKN)	g/m³	5.7	21	41	16.2	21
Dissolved Reactive Phosphorus	g/m³	0.23	0.23	0.084	0.159	0.149
Total Phosphorus	g/m³	1.91	1.88	6.5	0.64	1.72
Dissolved Organic Carbon (DOC)	g/m³	8	< 5	14	8	7

Sample Name:		27 July 7	27 July 8	27 July 9	27 July 10	27 July 11
Lab Number:		3372193.6	3372193.7	3372193.8	3372193.9	3372193.10
Total Suspended Solids	g/m³	1,880	-	1,740	740	1,890
Chloride	g/m³	13.9	3.0	6.8	8.4	10.9
Total Nitrogen	g/m³	22	12.0	43	20	36
Total Ammoniacal-N	g/m³	1.29	2.4	1.92	2.4	4.4
Nitrite-N	g/m³	0.023	0.014	0.033	0.029	0.030
Nitrate-N	g/m³	0.44	0.20	0.40	0.38	0.21
Nitrate-N + Nitrite-N	g/m³	0.46	0.22	0.43	0.41	0.24
Total Kjeldahl Nitrogen (TKN)	g/m³	22	11.7	42	19.9	36
Dissolved Reactive Phosphorus	g/m³	0.047	0.015	0.189	0.31	0.55
Total Phosphorus	g/m³	0.66	1.11	2.5	1.01	2.5
Dissolved Organic Carbon (DOC)	g/m³	9	6	9	8	13

Sample Name:		16 Aug 2	16 Aug 3	16 Aug 4	16 Aug 5	16 Aug 7
Lab Number:		3372193.11	3372193.12	3372193.13	3372193.14	3372193.15
Total Suspended Solids	g/m³	-	620	-	-	870
Chloride	g/m³	4.5	22	20	19.1	19.4
Total Nitrogen	g/m³	18.9	13.5	11.9	10.6	27
Total Ammoniacal-N	g/m³	5.2	1.24	0.96	0.62	1.02
Nitrite-N	g/m³	0.026	0.018	0.022	0.017	0.018
Nitrate-N	g/m³	0.26	0.23	0.42	0.26	0.021
Nitrate-N + Nitrite-N	g/m³	0.28	0.25	0.44	0.28	0.040
Total Kjeldahl Nitrogen (TKN)	g/m³	18.7	13.2	11.4	10.3	27
Dissolved Reactive Phosphorus	g/m³	0.48	0.100	0.067	0.059	0.005
Total Phosphorus	g/m³	0.98	0.74	1.31	1.31	1.68
Dissolved Organic Carbon (DOC)	g/m³	7	21	23	25	30

Sample Type: Aqueous				
Sample Name:		16 Aug 9	16 Aug 10	16 Aug 11
Lab Number:		3372193.16	3372193.17	3372193.18
Total Suspended Solids	g/m^3	960	730	840
Chloride	g/m^3	27	28	25
Total Nitrogen	g/m^3	26	22	17.7
Total Ammoniacal-N	g/m^3	3.3	5.0	2.3
Nitrite-N	g/m^3	0.072	0.071	0.075
Nitrate-N	g/m^3	1.66	1.43	1.23
Nitrate-N + Nitrite-N	g/m^3	1.74	1.50	1.30
Total Kjeldahl Nitrogen (TKN)	g/m^3	24	20	16.4
Dissolved Reactive Phosphorus	g/m^3	0.092	0.40	0.35
Total Phosphorus	g/m^3	1.22	1.70	3.0
Dissolved Organic Carbon (DOC)	g/m^3	35	38	41

Analyst's Comments

Only plastic containers were supplied for these samples. Please note that glass containers should be used for DOC analysis to avoid possible plastic contamination.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request.
Unless otherwise indicated, analyses were performed at Hill Labs, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-18
Total Suspended Solids	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5µm), gravimetric determination. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2540 D (modified) : Online Edition.	3 g/m^3	2, 4-6, 8-10, 12, 15-18
Chloride	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) : Online Edition.	0.5 g/m^3	1-18
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3. In-house calculation.	0.05 g/m^3	1-18
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) : Online Edition.	0.010 g/m^3	1-18
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) : Online Edition.	0.002 g/m^3	1-18
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N. In-House.	0.0010 g/m^3	1-18
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) : Online Edition.	0.002 g/m^3	1-18
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) : Online Edition.	0.10 g/m^3	1-18
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) : Online Edition.	0.004 g/m^3	1-18
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H (modified) : Online Edition.	0.002 g/m^3	1-18
Dissolved Organic Carbon (DOC)	Filtered sample, Supercritical persulphate oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 C (modified) : Online Edition.	0.5 g/m^3	1-18

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 28-Sep-2023 and 16-Oct-2023. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

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Certificate of Analysis

SPv2

Client:	Tambo New Zealand Limited	Lab No:	3374082
Contact:	Megan Fitzgerald	Date Received:	28-Sep-2023
	C/- Tambo New Zealand Limited	Date Reported:	27-Oct-2023
	PO Box 39039	Quote No:	126375
	Harewood	Order No:	
	Christchurch 8545	Client Reference:	
		Submitted By:	Megan Fitzgerald

Sample Type: Aqueous

Sample Name:		1 22-Sep-2023	2 22-Sep-2023	3 22-Sep-2023	5 22-Sep-2023	7 22-Sep-2023
Lab Number:		3374082.1	3374082.2	3374082.3	3374082.4	3374082.5
Total Suspended Solids	g/m³	840	500	1,520	1,060	860
Chloride	g/m³	2.9	5.6	11.0	10.2	19.8
Total Nitrogen	g/m³	24	97	97	80	18.7
Total Ammoniacal-N	g/m³	2.2	3.5	3.9	1.87	1.28
Nitrite-N	g/m³	0.014	0.010	0.024	0.012	0.005
Nitrate-N	g/m³	0.094	0.145	0.163	0.29	0.165
Nitrate-N + Nitrite-N	g/m³	0.108	0.155	0.187	0.30	0.171
Total Kjeldahl Nitrogen (TKN)	g/m³	24	97	97	79	18.5
Dissolved Reactive Phosphorus	g/m³	0.51	3.1	1.20	0.44	0.090
Total Phosphorus	g/m³	1.53	5.9	4.2	4.9	4.7
Dissolved Organic Carbon (DOC)	g/m³	11	51	33	11	10.9

Sample Name:		8 22-Sep-2023	9 22-Sep-2023	10 22-Sep-2023	11 22-Sep-2023
Lab Number:		3374082.6	3374082.7	3374082.8	3374082.9
Total Suspended Solids	g/m³	670	2,600	1,150	3,600
Chloride	g/m³	0.9	12.3	8.7	15.9
Total Nitrogen	g/m³	5.9	90	46	102
Total Ammoniacal-N	g/m³	0.45	3.0	2.2	4.3
Nitrite-N	g/m³	0.005	0.023	0.012	0.032
Nitrate-N	g/m³	0.105	0.35	0.20	0.198
Nitrate-N + Nitrite-N	g/m³	0.110	0.37	0.22	0.23
Total Kjeldahl Nitrogen (TKN)	g/m³	5.8	90	46	102
Dissolved Reactive Phosphorus	g/m³	0.116	0.36	0.55	1.05
Total Phosphorus	g/m³	1.09	5.9	7.6	12.4
Dissolved Organic Carbon (DOC)	g/m³	< 5	15	13	29

Analyst's Comments

Only plastic containers were supplied for these samples. Please note that glass containers should be used for DOC analysis to avoid possible plastic contamination.

Summary of Methods

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively simple matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis. A detection limit range indicates the lowest and highest detection limits in the associated suite of analytes. A full listing of compounds and detection limits are available from the laboratory upon request. Unless otherwise indicated, analyses were performed at Hill Labs, 28 Duke Street, Frankton, Hamilton 3204.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Sample No
Filtration, Unpreserved	Sample filtration through 0.45µm membrane filter. Performed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch.	-	1-9

Sample Type: Aqueous			
Test	**Method Description**	**Default Detection Limit**	**Sample No**
Total Suspended Solids	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5μm), gravimetric determination. Analysed at Hill Laboratories - Chemistry; 101c Waterloo Road, Christchurch. APHA 2540 D (modified) : Online Edition.	3 g/m^3	1-9
Chloride	Filtered sample from Christchurch. Ion Chromatography. APHA 4110 B (modified) : Online Edition.	0.5 g/m^3	1-9
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N. Please note: The Default Detection Limit of 0.05 g/m^3 is only attainable when the TKN has been determined using a trace method utilising duplicate analyses. In cases where the Detection Limit for TKN is 0.10 g/m^3, the Default Detection Limit for Total Nitrogen will be 0.11 g/m^3. In-house calculation.	0.05 g/m^3	1-9
Total Ammoniacal-N	Filtered Sample from Christchurch. Phenol/hypochlorite colourimetry. Flow injection analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 H (modified) : Online Edition.	0.010 g/m^3	1-9
Nitrite-N	Filtered sample from Christchurch. Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (modified) : Online Edition.	0.002 g/m^3	1-9
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - Nitrite-N. In-House.	0.0010 g/m^3	1-9
Nitrate-N + Nitrite-N	Filtered sample from Christchurch. Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (modified) : Online Edition.	0.002 g/m^3	1-9
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} D (modified) 4500 NH_3 F (modified) : Online Edition.	0.10 g/m^3	1-9
Dissolved Reactive Phosphorus	Filtered sample from Christchurch. Molybdenum blue colourimetry. Flow injection analyser. APHA 4500-P G (modified) : Online Edition.	0.004 g/m^3	1-9
Total Phosphorus	Total phosphorus digestion, automated ascorbic acid colorimetry. Flow Injection Analyser. APHA 4500-P H (modified) : Online Edition.	0.002 g/m^3	1-9
Dissolved Organic Carbon (DOC)	Filtered sample, Supercritical persulphate oxidation, IR detection, for Total C. Acidification, purging for Total Inorganic C. TOC = TC -TIC. APHA 5310 C (modified) : Online Edition.	0.5 g/m^3	1-9

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Testing was completed between 30-Sep-2023 and 27-Oct-2023. For completion dates of individual analyses please contact the laboratory.

Samples are held at the laboratory after reporting for a length of time based on the stability of the samples and analytes being tested (considering any preservation used), and the storage space available. Once the storage period is completed, the samples are discarded unless otherwise agreed with the customer. Extended storage times may incur additional charges.

This certificate of analysis must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental

Appendix C Treatment Images

Conventional tillage treatments					
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
					
					

Strip tillage treatments					
	Plot 7	Plot 8	Plot 9	Plot 10	Plot 11