

# Soil Nitrate Dynamics: Tracking Temporal Changes and Rapid-Test Performance in Vegetable Systems

An assessment of nitrogen changes, depth distribution, and rapid field-testing accuracy in bedded and ridge–furrow vegetable systems under variable environmental conditions.



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Lauren Hutchinson

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## Executive summary

This field trial investigated nitrogen availability patterns following fertiliser application in Pukekohe vegetable production systems and validated rapid field-testing methods against laboratory analysis. The research examined soil samples across 52 days following two Calcium Ammonium Nitrate (CAN) applications under contrasting weather conditions to address critical knowledge gaps in fertiliser timing protocols and on-farm nitrate monitoring technology.

### Key Findings

- Nitrate availability was driven primarily by fertiliser timing and rainfall; early sampling captured transient or leached nitrate rather than agronomically meaningful availability.
- Under more standard summer weather conditions, peak nitrate levels occurred 10-14 days after fertiliser application, indicating this is the best testing timeframe.
- Dynamic environmental conditions masked nitrogen processes across depths and cultivation types, with rainfall overwhelming soil structural or profile effects.
- Quick nitrate tests showed strong correlation with laboratory analysis but had concentration-dependent bias; laboratory analysis remains necessary for accurate quantification.
- High variability and strong environmental influences prevented robust detection of nitrification rates and patterns.
- Single site, single season, extreme weather, and methodological constraints limit extrapolation beyond the trial conditions.

### Bottom Line

Management strategies should prioritise timing over system configuration. Rainfall-driven variability can rapidly override intended fertiliser placement, cultivation type, or depth-related nitrogen processes, meaning management decisions based on poorly timed soil testing risk misrepresenting plant-available nitrogen and environmental loss potential. Quick testing methods are cost effective tools that can help make fast on farm management decisions, but should not be used as a complete replacement for laboratory analysis.

# 1. Background

## 1.1 Project scope

Although fertiliser types, uses, and effects are extensively researched worldwide, there is limited information on the specific timeframes over which nitrogen becomes plant-available following application. This is partly because dissolution and nitrification rates vary greatly with climate, soil type and soil conditions. While it is generally assumed that ammonium is nitrified to nitrate within 7–10 days, this is based on broad agronomic assumptions rather than specific studies. This project aims to quantify nitrogen availability across various depths and cultivation structures after two fertiliser applications. Multiple nitrate measurement techniques will be used to determine if timeframes are significantly different from the assumed period. Significant deviations would promote further specific study on timeframes in varying conditions.

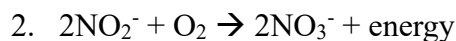
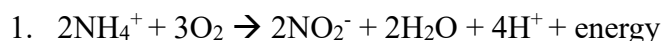
Objectives:

- Determine the temporal pattern of nitrate availability following fertiliser application under Pukekohe conditions.
- Compare nitrate availability rates between bedded and ridge-furrow systems to assess whether structure influences nitrogen availability.
- Validate rapid field-testing methods (Horiba LAQUA twin meters and Supelco® Nitrat-Quick Test strips) against laboratory mineral nitrogen analysis to improve grower confidence in on-site nitrate measurement technology.
- Provide data to support the development and refinement of the Sustainable Vegetable Systems (SVS) nitrogen-management tool.
- Generate evidence-based guidance on fertiliser application timing to assist growers in making informed nitrogen-management decisions.

## 1.2 Nitrogen and nitrification

In many cropping and pasture systems, nitrogen is often the most limiting growth factor when soil moisture is adequate, as it is a key component of amino acids, chlorophyll, and numerous enzymes (McLaren & Cameron, 1996). It is absorbed by plants primarily as nitrate ( $\text{NO}_3^-$ ) or ammonium ( $\text{NH}_4^+$ ), both of which are typically supplied in commercial fertilisers.

Because  $\text{NH}_4^+$  is positively charged, it binds tightly to negatively charged soil particles, making it less accessible to plants; consequently,  $\text{NO}_3^-$  is preferentially taken up (McLaren & Cameron, 1996). Ammonium slowly becomes more plant available via a process called nitrification, where  $\text{NH}_4^+$  is converted into the preferential  $\text{NO}_3^-$ . Nitrification occurs over two stages and is driven by autotrophic bacteria, which gain their energy source from the process (McLaren & Cameron, 1996). Firstly, ammonium is converted to nitrite ( $\text{NO}_2^-$ ) primarily by *Nitrosomonas* bacteria, and then nitrite is oxidised to nitrate ( $\text{NO}_3^-$ ) by *Nitrobacter* bacteria (McLaren & Cameron, 1996).



Nitrification rates are optimal under a pH of 4.5 to 7.5, as this is within the preferred range of the bacteria (McLaren & Cameron, 1996). Soil moisture is also critical for nitrification, with field capacity (-10kPa) resulting in the fastest rates. Saturated soils have little oxygen to support bacteria, and dry soils tend to have less microbial activity (McLaren & Cameron, 1996). The optimum temperature range for nitrification is between 25 and 30°C, with minimum activity occurring below 5°C and above 40°C (McLaren & Cameron, 1996). Trace elements, agricultural chemicals (pesticides) and the mobilisation of toxic elements due to low pH have also been found to limit nitrification rates (McLaren & Cameron, 1996).

As the dissolution of fertiliser and nitrification occurs, an availability curve of nitrate is created. The peak of this is best time for nitrogen testing to be carried out, as it represents the maximum amount of nitrate available to plants. As described, this curve is dependent on

fertiliser type, soil type and soil properties; there is variability in nitrification rates, and therefore variability in availability curves. The timelines that these curves occur over is currently not well quantified, resulting in the need for further study like the work done in this project.

### 1.3 Soil nitrate testing

Determining soil nitrate levels is essential for informed fertiliser management, particularly in intensive cropping systems. Accurate nitrogen data enables growers to optimise fertiliser application rates, improve efficiency, and minimise environmental impacts. While traditional laboratory analyses are often carried out pre-season, they are too costly and time consuming to be carried out for continual monitoring (Parks et al., 2012). As a result, rapid on-farm nitrate testing methods are increasingly being adopted because they provide fast, reliable, and cost-effective assessments of soil nitrogen status (Parks et al., 2012).

This trial assessed nitrate levels using both laboratory analysis and quick on-site methods to compare accuracy and make recommendations to growers. The methods used include: laboratory mineral-N analysis by Hill Labs, nitrate concentration measurement with a Horiba LAQUAtwin  $\text{NO}_3^-$  ion meter, and Supelco® quick Nitrat-Test strips.

$\text{CaCl}_2$  (quick testing) and KCl (Hill Labs) are used to extract soil nitrate because their cations displace bound ammonium and stabilise nitrate in solution, providing a more accurate measure of plant-available nitrogen than water alone (Li et al., 2012).

### 1.4 Fertiliser

The fertiliser used in this trial was Calcium Ammonium Nitrate (CAN) which consists of 14% ammonium, 14% nitrate and 8% calcium. It is widely used because it has a minimal impact on soil pH compared with ammonium-only fertilisers, making it suitable for a wide range of soils and crops (NSW DPI, 2020). In this trial, CAN was chosen because it represents a common, “growers standard” side-dressing fertiliser that is relevant in a commercial setting.

## 2. Methods

### 2.1 Site details and dates

The trial was conducted at the Pukekohe demonstration farm (Cronin Road) on a 24 m × 30 m area, divided into two 12 m × 30 m plots: one bedded, one ridge–furrow. No crop was present during the trial.

Baseline soil samples were collected before the first fertiliser application on 18 November 2025, with subsequent samples taken every 3–4 days over 52 days. A 6 × 4 m area was left unfertilised as a control. A second fertiliser application on 11 December 2025 was applied to compare nitrate release under differing weather conditions.

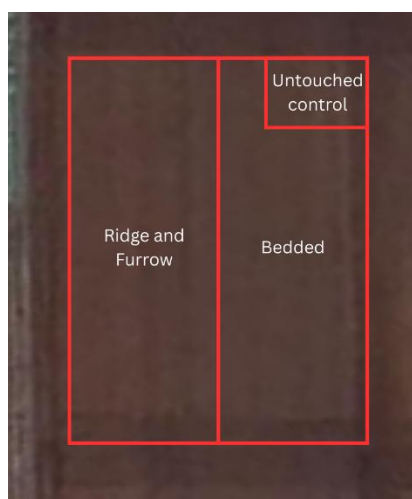


Figure 1: Trial layout and sampling areas

### 2.2 Fertiliser application

Two, 300 kg/ha applications of CAN fertiliser were applied to both plots via a side dressing on the 28<sup>th</sup> of November and the 11<sup>th</sup> of December. A Vicon pendulum spreader was used. This equated to 21.6kg of fertiliser per application. From this, 6.048kg of direct nitrogen was applied, consisting of 3.024kg of ammonium and 3.024kg of nitrate. A tarpaulin was used to stop fertiliser being applied on the control plot.

### 2.3 Sample collection and handling

In each treatment area, two soil samples were collected, one at 0–15cm depth and one at 15–30cm depth. Six soil cores for each sample were collected across a diagonal transect and at

different elevations across the beds/furrows using a Dutch auger to get representative samples.

Each of the six samples were then individually passed through a 4mm sieve, thoroughly mixed and stored in the refrigerator. A portion of each sample was used for quick on-site nitrate testing, while the rest was bagged, chilled, and sent to Hill Labs (Hamilton) for mineral nitrogen testing.

## 2.4 Sample processing

### 2.4.1 CaCl<sub>2</sub> solution preparation

A 1.5L bottle was rinsed with distilled water and zeroed on a scale. 1L of water was weighed and added to the bottle along with 1.47g of CaCl<sub>2</sub> powder to create a 0.0147 M extractant solution.

### 2.4.2 NO<sub>3</sub><sup>-</sup> extraction from soil

The fine earth fraction of each sample was well mixed to ensure homogeneity. For one sample, 30mL of CaCl<sub>2</sub> solution was added to two 50mL tubes respectively. In each tube, 10mL of soil was added, ensuring each addition of soil was equally split between the two tubes, minimising variation. The tubes were then shaken vigorously for 1 minute and then left to settle until a clear fraction was present. This was repeated for the remaining 5 samples, resulting in a total 12 tubes.

## 2.5 Horiba LAQUA twin meter



Figure 2: LAQUA NO<sub>3</sub><sup>-</sup> twin ion meter with calibration solutions

### 2.5.1 Calibration

The LAQUA twin meter was calibrated on every day of sampling to ensure consistent and accurate readings. Calibration was carried out using dual standard solutions with nitrate concentrations of 150ppm and 2000ppm.

### 2.5.2 Nitrate measurement

The sensors were rinsed with distilled water and dried until the meter was zeroed and ready for measurement. A syringe was rinsed with the clear fraction of a sample and then was used to place approximately 0.3 mL of sample solution onto the meter, ensuring both sensors were covered. Once stabilized, the nitrate concentration was recorded (ppm). The meter was then rinsed with distilled water and dried before the next measurement. This was repeated for each of the remaining 11 tubes.

## 2.6 Supelco® quick Nitrat-Test



Figure 3: Quick nitrate strips and colourimetric scale

One colourimetric test strip was dipped in the clear fraction of each tube for 1 second, then left to develop for 1 minute. After a minute, the colour of the strip was compared with the colour key on the side of the container to get a nitrate concentration in ppm.

## 2.7 Soil moisture correction

Fresh soil samples were tested without prior drying, resulting in excess moisture that diluted the  $\text{CaCl}_2$  solution, reducing its effective concentration. This lowers nitrate extraction

efficiency, resulting in an underestimation of nitrate levels. To correct this, the readings from both Nitrat-Test strips and the LAQUA twin meters were adjusted via a calculation.

$$kg\ NO_3N/ha = \frac{NO_3(ppm)}{moisture\ factor} \times \frac{soil\ depth(cm)}{10} \times bulk\ density\left(\frac{g}{cm^3}\right)$$

The moisture factor varies greatly depending on the soil type, season, and irrigation scheme. The Ministry for Primary Industries (MPI) and Foundation of Arable Research (FAR) provides a table with different soil types and textures which can be used to estimate the soil moisture factor. This estimation can be inaccurate at times and potentially introduce error. The soil texture used in the trial was a clay loam, and the moisture depended on recent weather activity.

The soil depth is included in the calculation to adjust for the volume of soil in the sample. The bulk density accounts for the mass of soil in a relative volume, with a greater density meaning more soil per unit volume. Overall, the equation converts a nitrate reading in ppm to the amount of nitrate present in kilograms per hectare of soil.

## 2.8 Hill Labs mineral nitrogen procedure

Any root particles or rocks were removed from the sample. A field-moist subsample of 2 mm material was then taken for extraction. Hill Labs reported nitrogen values as  $NO_3^-N$  or  $NH_4^+-N$ . This is because laboratory analyses commonly report nitrogen on a standardized nitrogen-equivalent basis, rather than as the full ion, allowing direct comparison of plant-available nitrogen across samples and consistent interpretation for fertiliser management.

To convert  $NO_3^-$  to  $NO_3^-N$ , the value was divided by 4.42 because this factor represents the ratio of the molecular weight of nitrogen ( $14\ g\ mol^{-1}$ ) to the molecular weight of the nitrate ion ( $62\ g\ mol^{-1}$ ).

### 2.8.1 Ammonium N

Ammonium was determined using a 0.1M KCl extraction followed by Berthelot colourimetry (Hill Labs, 2026).

### 2.8.2 Nitrate N

Nitrate was determined via a 0.1M KCl extraction, followed by Cd reduction and NED colourimetry (Hill Labs, 2026).

## 3. Results

### 3.1 T tests

Across pooled sampling dates, soil NO<sub>3</sub> concentrations were substantially higher and more variable in the fertilised bedded and ridge–furrow systems than in the control, with mean concentrations of ~38–40 ppm in fertilised treatments compared with <9 ppm in the control across both depths (**Table 1**). Standard deviations were low in the control and markedly higher in the fertilised treatments, indicating greater variability in soil NO<sub>3</sub>–N concentrations following fertiliser application. The relatively small standard errors in the control compared with larger standard errors in the bedded and ridge–furrow systems reflect more consistent concentrations in unfertilised soils and greater uncertainty around the mean under fertilised conditions. Variability was low in the control (CV ≈24–26%) but high in fertilised treatments (CV ≈58–75%), reflecting pronounced temporal and spatial heterogeneity following CAN applications.

Paired t-tests by sampling date showed that LAQUA measurements moderately differed from Hill Labs, whereas nitrate strips showed consistent and significant departures from Hill Labs on most dates (**Table 2**). Where there are no statistically significant differences, nitrate concentrations are low.

When pooled by treatment and depth, **Table 3** shows LAQUA agreed with Hill Labs in the control at both depths but differed significantly in bedded and ridge–furrow soils, while nitrate strips differed significantly from Hill Labs across all treatment/depth combinations. Depth comparisons in **Table 4** indicates a significant decline in NO<sub>3</sub><sup>-</sup> with depth in the control only ( $p = 0.0045$ ), with no depth effect detected in bedded or ridge–furrow systems. No significant differences in NO<sub>3</sub><sup>-</sup> concentrations were detected between bedded and ridge–furrow systems at any depth when data were pooled across fertiliser applications (**Table 5**).

Table 1: Descriptive statistics for soil NO<sub>3</sub><sup>-</sup> concentrations (kg/ha) by treatment (control, bedded, ridge and furrow) and sampling depth (0–15 cm and 15–30 cm). Values summarise pooled observations across sampling dates of Hill Labs data.

	Control		Bedded		Ridge and Furrow	
	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Count (n)	12.00	12.00	12.00	12.00	12.00	12.00
Minimum (kg/ha)	5.99	5.99	6.58	6.58	6.58	6.58
Maximum (kg/ha)	15.56	13.17	107.73	92.17	77.81	129.28
Mean ± Standard error (kg/ha)	10.47±0.77	8.78 ± 0.60	47.13 ± 7.56	44.44 ± 7.83	46.03 ± 7.36	45.84 ± 9.68
Standard deviation (kg/ha)	2.66	2.06	26.18	27.14	25.50	33.55
Median (kg/ha)	10.77	8.38	43.09	38.90	47.88	38.30
Range (kg/ha)	9.58	7.18	101.15	85.59	71.22	122.69
Coefficient of variation (%)	25.38	23.50	55.54	61.06	55.39	73.20

Table 2: Results of paired t-tests comparing LAQUA and nitrate strip measurements with Hill Labs analyses by sampling date, reported in kg ha<sup>-1</sup>. P-values and corresponding null hypothesis decisions ( $\alpha = 0.05$ ) are shown for each method and unit. The null hypothesis tested was that field method measurements do not differ from Hill Labs values on a given sampling date.

	P Value (kg/ha)		Null Hypothesis	
	LAQUA	Strips	LAQUA	Strips
18/11/2025	0.795	0.082	Fail to reject	Fail to reject
1/12/2025	0.071	0.007	Fail to reject	Reject
4/12/2025	0.013	0.003	Reject	Reject
8/12/2025	0.002	0.001	Reject	Reject
12/12/2025	0.026	0.014	Reject	Reject
15/12/2025	0.041	0.028	Reject	Reject
18/12/2025	0.049	0.013	Reject	Reject
22/12/2025	0.021	0.008	Reject	Reject
24/12/2025	0.037	0.015	Reject	Reject
30/12/2025	0.074	0.015	Fail to reject	Reject
5/01/2026	0.086	0.011	Fail to reject	Fail to reject
8/01/2026	0.088	0.017	Fail to reject	Reject

Table 3: Paired *t*-test results comparing LAQUA (kg/ha) and nitrate strip (kg/ha) measurements with Hill Labs analyses (kg/ha) by treatment and sampling depth. *P*-values and corresponding null hypothesis decisions ( $\alpha = 0.05$ ) are reported for each field method. The null hypothesis tested was that field method measurements do not differ from Hill Labs values within a given treatment–depth combination.

	P Value		Null Hypothesis	
	LAQUA	Strips	LAQUA	Strips
Control 0-15cm	0.369	2.59E-08	Fail to reject	Reject
Control 15-30cm	0.296	4.11E-07	Fail to reject	Reject
Bedded 0-15cm	3.17E-04	1.62E-04	Reject	Reject
Bedded 15-30cm	4.69E-04	2.60E-04	Reject	Reject
Ridge and Furrow 0-15cm	1.23E-04	9.04E-05	Reject	Reject
Ridge and Furrow 15-30cm	2.04E-03	9.90E-04	Reject	Reject

Table 4: Paired *t*-test results comparing soil  $\text{NO}_3^-$  concentrations (kg/ha) between sampling depths (0–15 cm and 15–30 cm) within treatments. Data was pooled across both fertiliser applications. *P*-values and null hypothesis decisions are reported ( $\alpha = 0.05$ ).

	P Value	Null Hypothesis
Control	0.0045	Reject
Bedded	0.6647	Fail to Reject
Ridge and Furrow	0.9760	Fail to Reject

Table 5: Paired *t*-test results comparing soil  $\text{NO}_3^-$  concentrations (kg/ha) between bedded and ridge–furrow systems at fixed sampling depths. Data was pooled across both fertiliser applications. *P*-values and null hypothesis decisions are reported ( $\alpha = 0.05$ ).

	P Value	Null Hypothesis
0-30cm	0.8166	Fail to Reject
0-15cm	0.7152	Fail to Reject
15-30cm	0.9595	Fail to Reject

### 3.2 Temporal changes in Nitrate

**Figure 4** illustrates temporal nitrate changes across different systems for the first fertiliser application (18/11/2025 → 08/12/2025). Nitrate levels for most systems peaked on the 1/12/2025, four days after application, with a maximum of 33.516 kg/ha (Bedded 0-15cm).

Nitrate levels for the ridge and furrow 15-30cm treatment peaked on the 4/12/2025, seven days after application at 21.54 kg/ha.

**Figure 5** shows temporal nitrate changes across different systems for the second fertiliser application (08/12/2025 → 08/01/2026). Most treatments exhibited a primary nitrate peak on 15/12/2025, four days after application with a maximum of 129.27 kg/ha. There was a secondary collective peak on the 24/12/2025, 14 days after application with a maximum of 107.73 kg/ha (Bedded 0-15cm).

**Figure 6** summarises nitrate dynamics over both applications with daily rainfall (mm) overlaid. There was a total of 60.9 mm of rain following the first fertiliser application. The second application saw 98mm of rain in the 29 days post application. It also shows higher rainfall associated with decreasing nitrate peaks.

**Figures 7 and 8** show the sum of nitrate (kg/ha) across each area and depth. The maximum total nitrate levels reached in the bedded system was 184 kg/ha (24/12/2025), and 204 kg/ha in the Ridge and Furrow system (15/12/2025). Across the entire trial, the maximum total nitrate reading (when all systems are summed) was 361 kg/ha (24/12/2025).

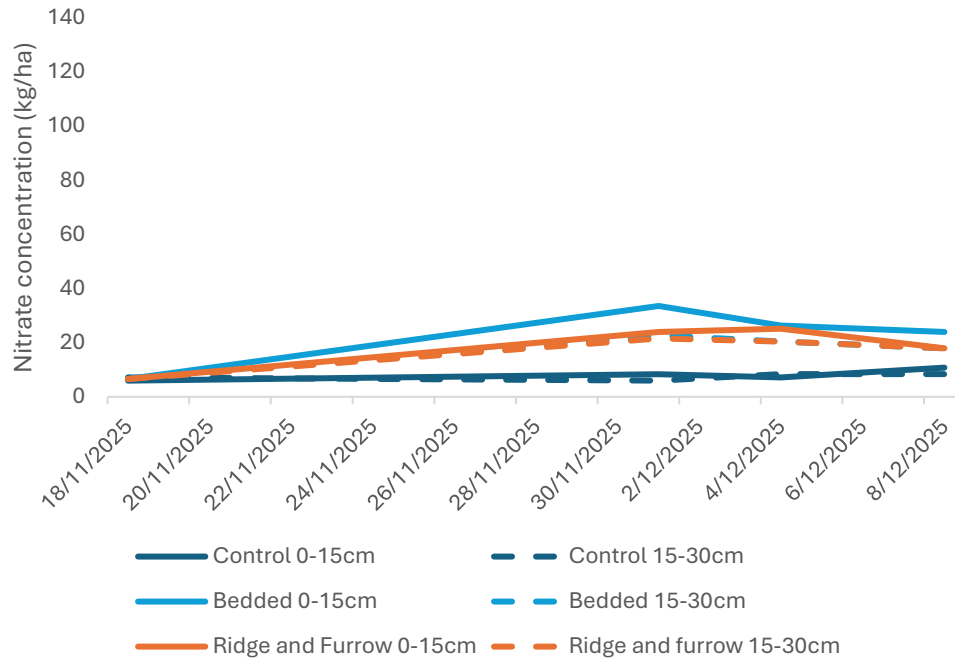


Figure 4: Temporal changes in nitrate (kg/ha) as measured by Hill Labs across the first application of CAN fertiliser.

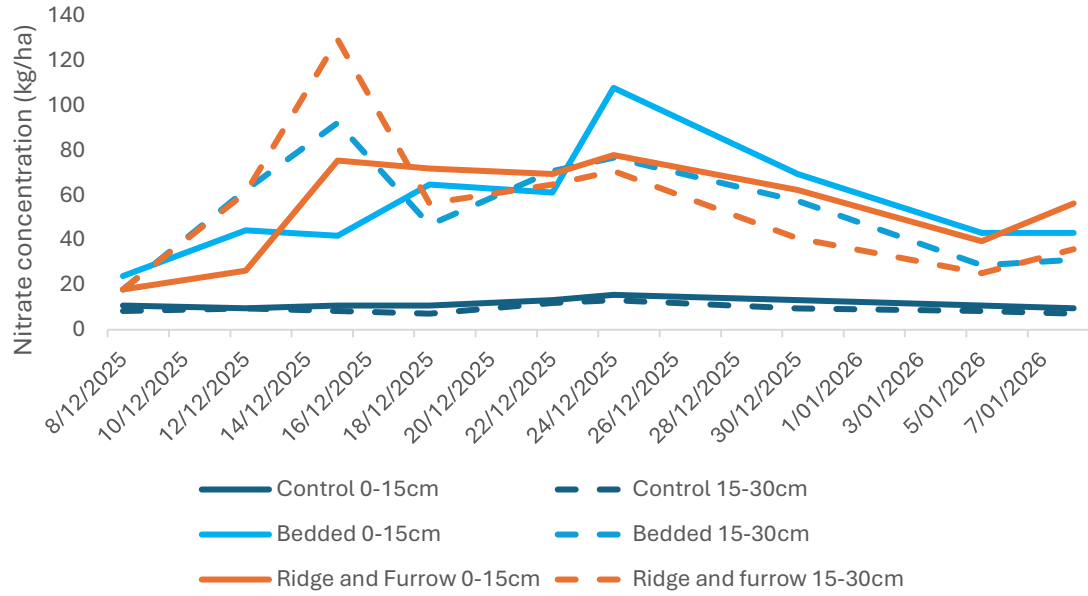


Figure 5: Temporal nitrate dynamics following the second CAN fertiliser application.

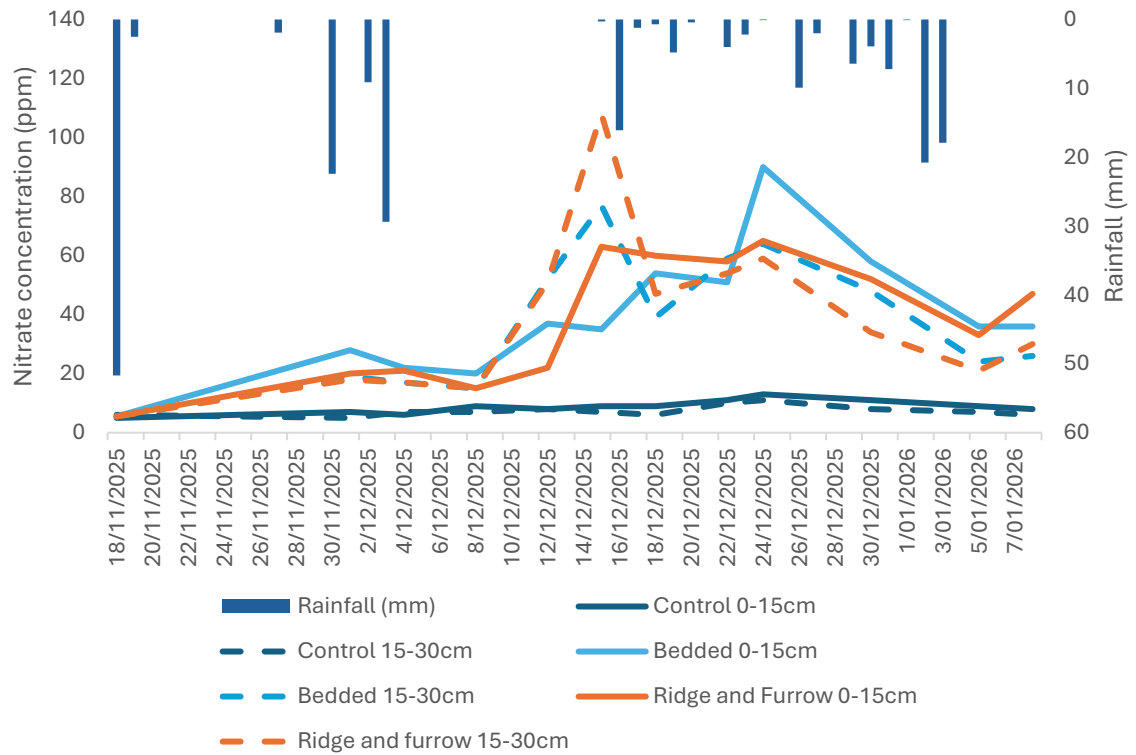


Figure 6: Nitrate dynamics across both applications, with rainfall overlaid on a secondary axis.

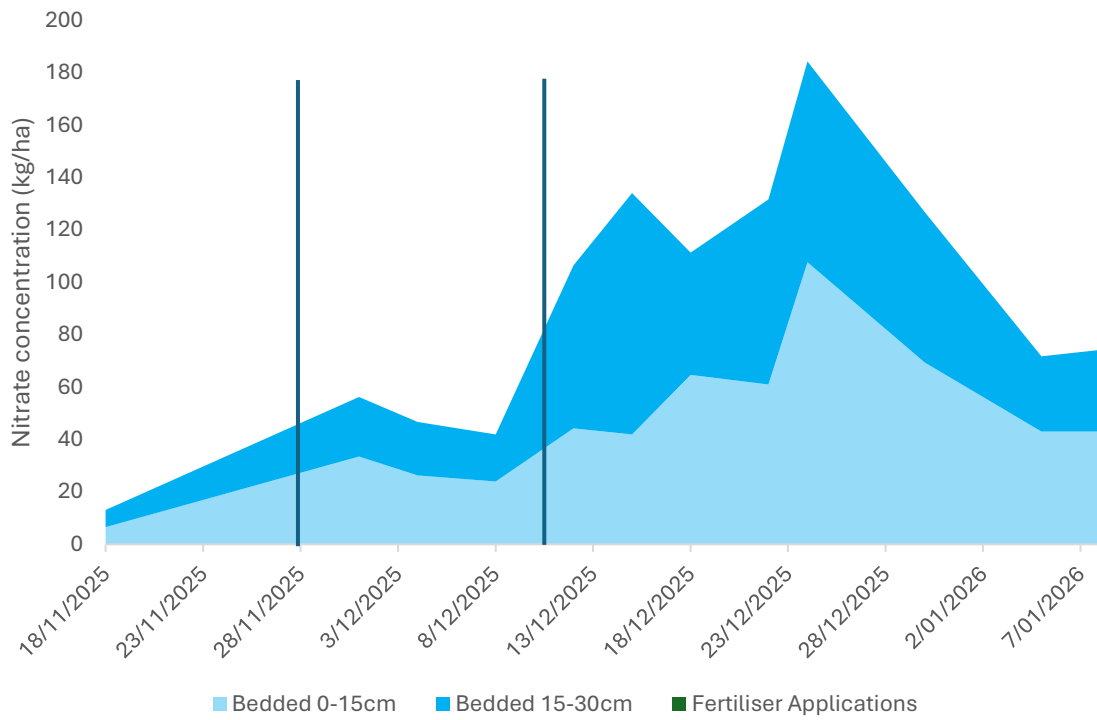


Figure 7: Stacked area graph showing nitrate concentrations across different depths in the bedded system, and cumulative nitrate concentrations for the whole area (kg/ha). Timing of fertiliser applications is also indicated with bars.

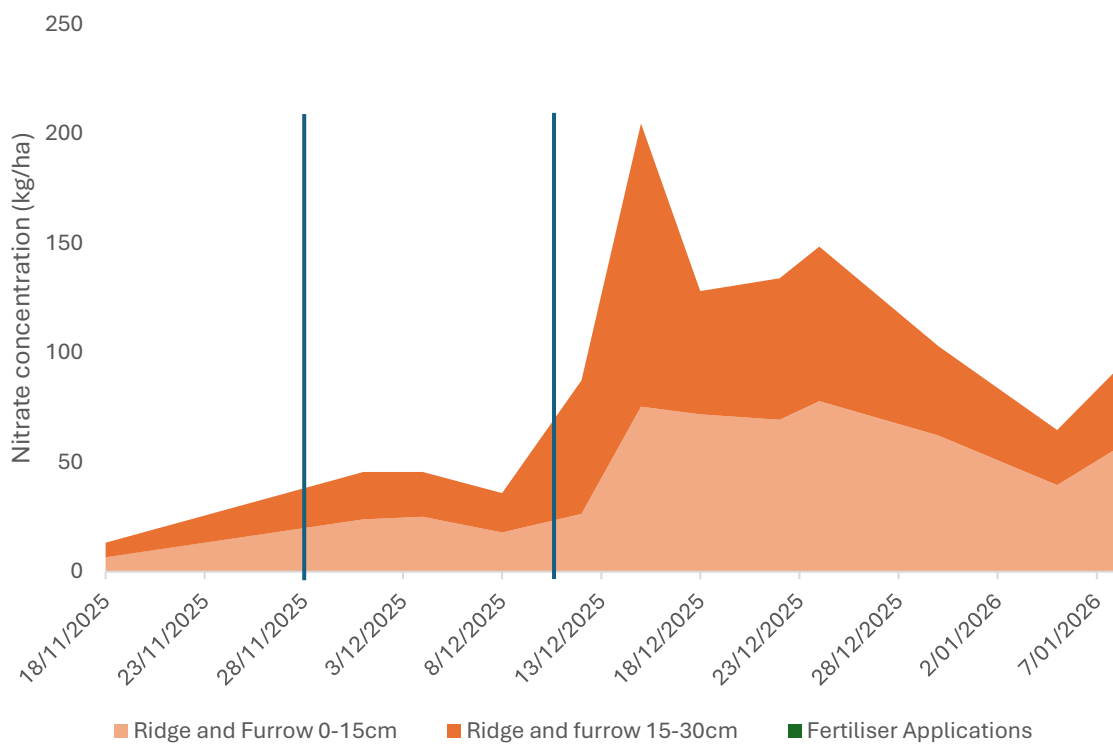


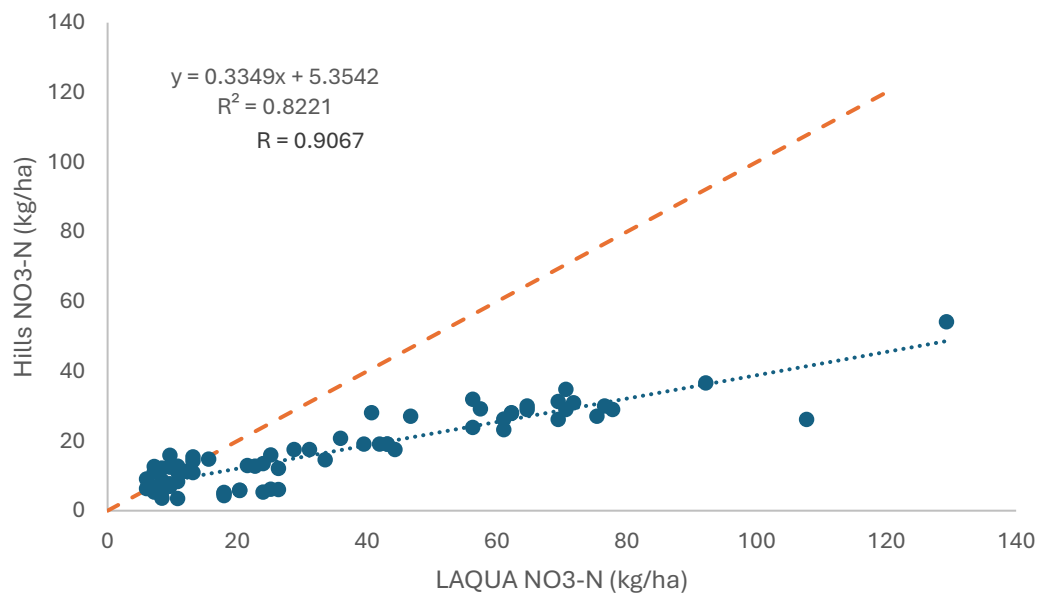
Figure 8: Stacked area graph showing nitrate concentrations across different depths in the Ridge and Furrow system, and cumulative nitrate concentrations for the whole area (kg/ha). Timing of fertiliser applications is also indicated with bars.

### 3.3 Correlation analysis between quick testing and Hill Labs results

**Figure 9** demonstrates that the LAQUA twin meter has relatively strong correlation with Hill Labs results, as 82% of variance in LAQUA is explained by Hill Labs measurements.

Despite this, LAQUA systematically underestimates Hill Labs results, with underestimation increasing as nitrate concentration increases. At low concentrations, LAQUA readings overestimate Hill Labs results (+ 5.3542).

**Figure 10** shows that the colourimetric nitrate strips also correlate strongly with Hill Labs results ( $R^2 = 0.8334$ ). However, they underestimate nitrate more than LAQUA ( $0.2305 < 0.3349$ ), with underestimation increasing at higher concentrations.



*Figure 9: Comparison of LAQUA and Hill Labs nitrate concentrations across paired sampling dates following two fertiliser applications. The orange dotted line indicates 1:1 agreement.*

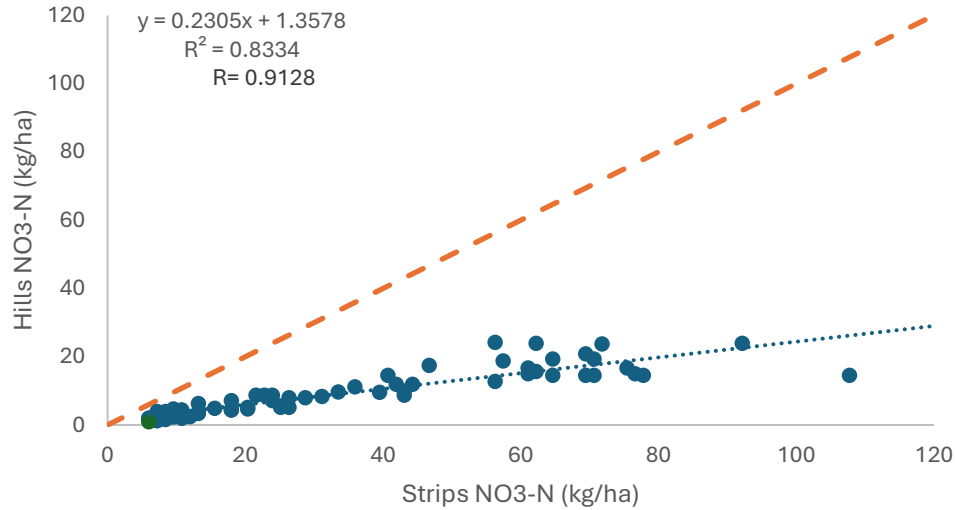


Figure 10: Comparison of Strips and Hill Labs nitrate concentrations across paired sampling dates following two CAN fertiliser applications. The orange dotted line indicates 1:1 agreement.

### 3.4 Nitrate differences between depths and soil structure

**Figure 11** shows nitrate concentrations at different depths (0-15cm, 15-30cm) across Control, Bedded, and Ridge and Furrow systems. A statistically significant difference between depths was observed only in the Control system ( $P = 0.0045$ ), with slightly higher nitrate in the surface layer. No significant differences between depths were detected in Bedded or Ridge and Furrow, indicating relatively uniform nitrate distribution in these systems.

**Figure 12** compares nitrate concentrations between Bedded and Ridge and Furrow systems. Both systems had similar mean nitrate concentrations at each depth indicating that cultivation structure had minimal effect on total nitrate levels.

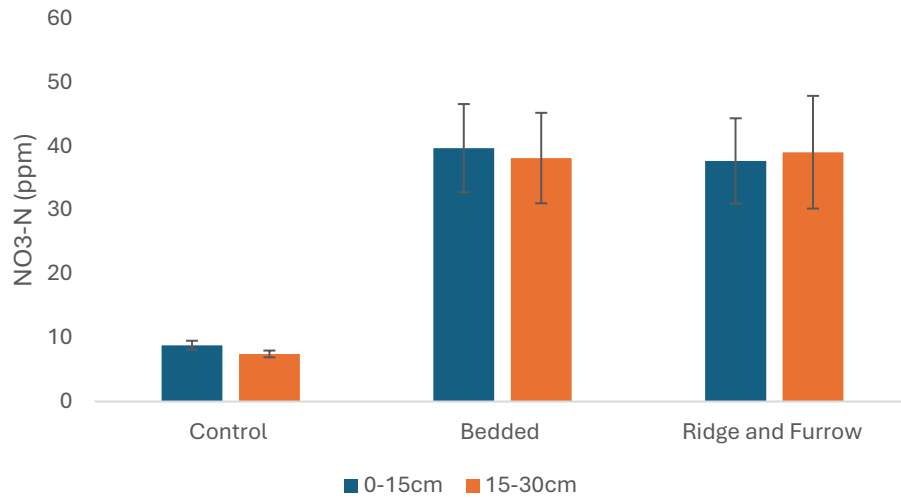


Figure 11: Comparison of nitrate concentrations at different depths across three different systems: Control, Bedded and Ridge and Furrow.

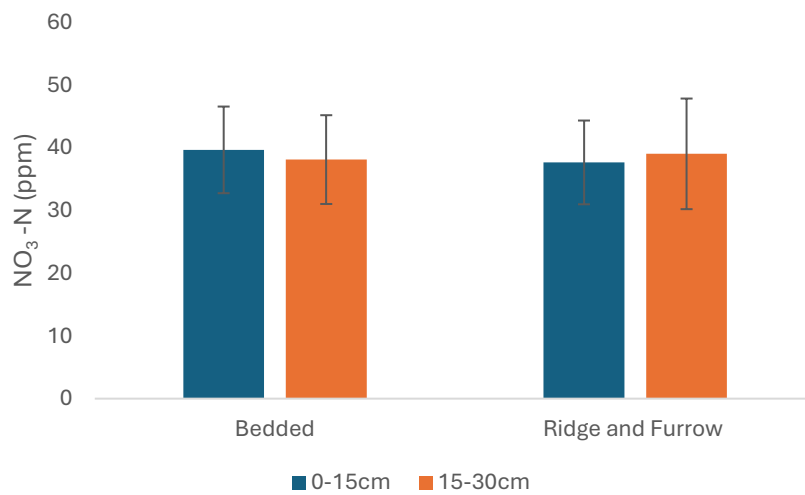


Figure 12: Comparison of nitrate concentrations across Bedded and Ridge and Furrow systems at different depths: 0-15cm and 15-30cm.

## 4. Discussion

### 4.1 Temporal nitrate trends

#### 4.1.1 First application

CAN was applied on 28/11/2025, with the first post-application soil sampling on 1/12/2025, capturing the highest measured nitrate concentrations. These levels likely do not represent a true peak from complete prill dissolution or nitrification; instead, they reflect the nitrate present before substantial leaching occurred. Heavy rainfall likely drove rapid nitrate leaching below 30 cm, with 22 mm falling between application and the first sampling, and a further 38.5 mm between 1/12 and 4/12 (Min et al., 2011).

The slight decline following the peak is attributable primarily to continued microbial immobilisation, as no further rainfall occurred (McLaren & Cameron, 1996). Overall, the data largely reflects nitrate's high mobility in the absence of plant uptake rather than a true availability curve, consistent with observations in other summer vegetable systems (Min et al., 2011). This highlights the importance of timely soil testing and accounting for rainfall events when assessing fertiliser efficiency or environmental risk (Quemada et al., 2013).

#### 4.1.2 Second application

The second CAN application on 11/12/2025 produced two distinct sets of nitrate peaks. Early measurements on 12/12 and 15/12 illustrate the high variability that occurs when sampling too soon after application. On 12/12, no rain had fallen, so prills remained largely undissolved and nitrate levels were lower than expected (YARA, 2017). By 15/12, only 0.3 mm of rain had fallen, providing patchy moisture that likely allowed some prill dissolution but limited migration, resulting in highly variable readings (FAR, 2020). The notable peak in Ridge and Furrow 15–30 cm likely reflects undissolved prills included in sampled soil (YARA, 2017).

The second set of peaks occurred 13 days after application when adequate rainfall (29.7 mm over 9 days) facilitated complete prill dissolution and microbial nitrification (McLaren & Cameron, 1996). These peaks more accurately represent maximum nitrate concentrations that can be used to make fertiliser management decisions. Similar delayed nitrate peaks following a period of dry conditions and subsequent rainfall have been observed in other intensive vegetable systems, where early post-application measurements were highly variable and

maximum concentrations were only reached several days after wetting (Norton & Ouyang, 2019).

## 4.2 Comparison between Bedded and Ridge and Furrow systems

Nitrate dynamics were similar between bedded and ridge–furrow systems at all depths (**Table 5**), suggesting that under Pukekohe conditions, soil structure had little observable effect on mineralisation or nitrification following fertiliser application. The likely reason for this is both plots experienced the same dynamic environmental conditions over the course of both applications (Norton & Ouyang, 2019). Rainfall, wind, and prolonged hot, dry periods, had a greater influence on nitrate dynamics than the differences in soil structure or moisture retention between systems, effectively masking any structural effect (Norton & Ouyang, 2019). **Figure 12** illustrates that the temporal and spatial variability of nitrate was similar across both systems, indicating that any effect of bed form on nitrate availability was minor relative to other field conditions.

## 4.3 Nitrate changes with depth

Nitrate concentrations varied with depth depending on treatment (**Table 4**). In control plots, higher nitrate was generally observed in the upper soil profile, likely reflecting natural nitrogen processes such as mineralisation and nitrification (**Table 1**). Nitrification rates are typically highest in the upper soil layers, where oxygen, temperature, moisture, organic matter, and microbial activity are greatest (McLaren & Cameron, 1996).

The high concentrations of nitrate and ammonia meant that depth differences in nitrogen processes in fertilised treatments were likely masked by leaching processes. Heavy rainfall shortly after both CAN applications likely redistributed nitrate throughout the soil profile, effectively homogenising concentrations across depths (Environment Canterbury, 2025). The large fertiliser inputs overwhelmed the natural surface-to-depth gradient, showing that fertiliser application, rather than inherent soil processes, was the main driver of nitrate distribution in these treatments.

## 4.4 Comparison of Quick testing with Laboratory analysis

### 4.4.1 LAQUA vs Hill Labs

The overestimation of nitrate at low concentrations is likely related to the meter's measurement range. The HORIBA meter is calibrated for 6.8–140 mg NO<sub>3</sub>-N L<sup>-1</sup>, while the

measured data ranged from 4.977 to 76.923 mg L<sup>-1</sup> (HORIBA, 2026). 13% of the readings fell below the meter's minimum, which helps explain the high variability and overestimation at low concentrations. Since all values were well below the maximum of 140 mg L<sup>-1</sup>, any overestimation at higher values must be due to a different factor, likely the use of a CaCl<sub>2</sub> extractant (Parks et al., 2012).

Chloride is not recommended as an extractant because it can interfere with ion-selective electrode measurements (HORIBA, 2026; Parks et al., 2012). At low nitrate levels, excess chloride may be misread as nitrate, causing overestimation, while at higher nitrate levels, the high ionic strength of CaCl<sub>2</sub> reduces nitrate activity and flattens the electrode response, lowering sensitivity (Parks et al., 2012). This explains why discrepancies between LAQUA and Hill Labs measurements vary with treatment and nitrate concentration.

When pooled by treatment (**Table 3**), control plots showed relatively stable nitrate levels, while fertilised plots exhibited larger fluctuations. This likely arises because nitrate concentrations in the control are low, where chloride interference and high ionic strength effects from the CaCl<sub>2</sub> extract are minimal, having a minimal impact on accuracy (Parks et al., 2012). In fertilised treatments, higher nitrate levels and increased ionic strength reduce electrode sensitivity and introduce nonlinear response, contributing to observed deviations from reference measurements. (Parks et al., 2012). **Table 2** indicates that LAQUA results aligned more closely with Hill Labs values at the start and end of the trial, when nitrate concentrations were lowest, highlighting a concentration-dependent bias in the meter readings (Parks et al., 2012).

#### 4.4.2 Strips vs Hill Labs

All data from the test strips falls into the reported measurement range of 2-113 NO<sub>3</sub>-N (ppm), meaning underestimation at high concentrations is unlikely to be a range limitation. The most likely explanation is that the strips are semi-quantitative, meaning they have discrete colour steps (10–500 mg/L NO<sub>3</sub><sup>-</sup>) and are read by matching the reaction zone to the closest colour. At low nitrate (~15 mg/L), this gives readings close to the true value, but as nitrate increases, the spacing between colour steps cause the strips to increasingly underestimate concentrations (Parks et al., 2012). This underestimation at high concentrations explains differences between lab results and strip results.

When pooled by treatment, strip results consistently differed from Hill Labs measurements, while pooling by date shows closer agreement early in the experiment, when nitrate

concentrations were lowest (**Tables 2–3**). Both quick methods had a similar correlation to Hills results, however strips had slightly more accuracy at lower concentrations. This difference is likely because of the semiquantitative nature of the strips (Parks et al., 2012). At low nitrate concentrations, these steps approximate true values closely, giving good accuracy. At higher concentrations, systematic underestimation accumulates, producing significant differences in t-tests despite similar correlation and better low-concentration performance (Parks et al., 2012).

## 4.5 Nitrification rates

Nitrification data was extracted from  $\text{NO}_3^-$  and  $\text{NH}_4^+$  ratios and differences between consecutive sampling dates. Control plots showed minimal change in nitrate-to-ammonium ratios and  $\Delta t\text{NO}_3/\Delta t\text{NH}_4$  values, indicating little measurable nitrification. Fertilised treatments displayed large fluctuations, with both positive and negative changes and no consistent temporal trend. These swings suggest that soil heterogeneity and environmental factors likely influenced the observed differences (Stange, Neue, 2009).

**Figures 7 and 8** show a maximum combined nitrate concentration of 361 kg/ha on 24/12/2025, occurring shortly after the second fertiliser application (300 kg/ha). The measured nitrate exceeded the amount applied, suggesting that nitrification may have occurred. As ammonium is a cation and therefore less prone to leaching, the nitrate observed may have originated from ammonium remaining from the first application, although contribution from the second application cannot be excluded; consequently, no specific nitrification timeline can be inferred from this data. **Figures 7 and 8** also show a small uptick in nitrate concentrations at the end of the measurement period, which may reflect the onset of nitrification from the second application or background mineralisation.

Overall, the results do not provide robust quantitative evidence of treatment-specific nitrification, and any interpretation should be limited to qualitative observations of occasional nitrate production in fertilised plots.

## 4.6 Implications for grower decision making

As this trial only represents one soil type in one climatic region over one season, the results are only an indication of nitrate availability over time and should not be exclusively used to determine nitrate management decisions.

The most significant conclusion of this trial that can be implemented is an indication of when the best time to sample is. The second application strongly shows that sampling should not be carried out within one to six days after applying fertiliser. This is because limited dissolution, nitrification and nitrate dispersion create highly variable results that do not give an accurate representation of the nitrate dynamics that will support crop growth (FAR, 2020). **Figure 5** illustrates the best time to test in a clay loam under the same climatic conditions is 10-14 days after fertiliser application. This period is long enough to allow for sufficient nitrification to occur, complete dissolution of prills and adequate dispersal of nitrate throughout the soil profile, to give a representative idea of available nitrogen (Norton & Ouyang, 2019).

The first application does not give adequate data to suggest a sampling timeline as highly wet conditions resulted in rapid leaching of  $\text{NO}_3^-$  below the measured profile (Min et al., 2011). From this, growers can take a different conclusion: do not apply fertiliser on fallow plots when heavy rain is forecasted in the following days. **Figure 4** demonstrates this clearly, by the time the crop is planted, there will be inadequate nitrate levels in the rooting depth to support any type of enhanced growth as most nitrate would have leached below 30cm (Norton & Ouyang, 2019). Applications before heavy rain also increases the likelihood of excess nitrate reaching local waterways and contributing to eutrophication (Murphy et al., 2024).

Although **Figure 11** demonstrates little difference in depth testing across fertilised systems, sampling should still be carried out across different depth levels. Dynamic environmental conditions masked depth differences within this trial (YARA, 2017). Under more stable weather, differences would likely be detectable, providing better information to the grower on nitrate dynamics (Norton & Ouyang, 2019).

**Figure 12** strongly shows there is no difference between ridge and furrow and bedded systems when testing. This suggests that growers do not require an adapted methodology when testing different structural systems, however these results may differ under different soil structures, soil types and locations.

**Figures 9 and 10** show quick nitrate tools can be informative and helpful for making fast fertiliser decisions, especially when paired with the SVS tool. However, growers should not rely solely on quick testing as the accuracy is limited at different concentrations and are best suited to show trends (Parks et al., 2012). A laboratory soil test before planting is recommended to get an accurate and reliable picture of nitrogen levels.

When selecting a quick test, both LAQUA and nitrate strips showed very similar correlations with Hill Labs results ( $R^2 = 0.82\text{--}0.83$ ). However, LAQUA measurements exhibited greater uncertainty at both low and high nitrate concentrations, require calibration and setup, have higher costs and operational complexity (Parks et al., 2012). Nitrate strips are cheaper, easier to use, and more reliable at lower concentrations, but are only semi-quantitative and rely on visual interpretation, which can reduce accuracy (Parks et al., 2012). This limitation can be partially addressed by using the MQuant® strip reader to standardise colour interpretation. It should be noted that both LAQUA and strips results require conversion into kg/ha for comparison with Hill results, as lab data is reported on a dry weight basis (FAR, 2020; Hill Labs, 2026).

## 4.7 Limitations

### 4.7.1 Scope

As previously highlighted, this trial was carried out on one plot, in one location over one season, with one type of fertiliser across only two replications. Due to this, the most significant limitation of the trial is how representative the results are of nitrate dynamics across the wider area and country. Soil is well-known to be highly heterogeneous, and New Zealand climates are characteristically variable, even across small areas. As a result, the findings cannot be applied as blanket assumptions across New Zealand, and further multi-site, multi-season studies with different fertiliser types are required to confirm their broader applicability.

The experimental design also limits interpretation of the results. The trial was conducted in the absence of a crop, meaning plant nitrogen uptake was not represented; as a result, nitrate dynamics reflect bare or lightly cropped conditions rather than realistic commercial production systems. If a crop was present, there would also be lower soil moisture and soil temperature due to plant uptake of water and canopy shade. Differences in moisture and temperature would impact nitrification rates and overall results (McLaren & Cameron, 1996).

The small plot size and limited replication increase the influence of spatial variability and raise the potential for edge effects between fertilised and control areas, particularly given their proximity.

### 4.7.2 Weather dominance

Over the 52 days of the trial there was extreme variation in weather conditions, with hot dry periods, extensive rain, storm events, windy periods and calm conditions. Heavy rain directly after the first application resulted in rapid leaching below testing level and inadequate data to draw temporal conclusions. A mix in weather extremes across both applications meant nitrate levels were highly impacted, and the effects of depth and soil structure (cultivation type) on nitrogen were likely masked.

### 4.7.3 Sampling and processing

Sampling was confined to the upper 30 cm of the soil profile and conducted at fixed intervals, which may not have captured short-lived nitrate peaks or deeper leaching losses under highly dynamic conditions.

There was potential for soil contamination through the sampling equipment (Dutch auger, bucket). During soil processing, wet conditions made it difficult to pass samples through the 4 mm sieve. In several cases, material clumped after sieving, meaning the fine fraction used for extraction may not have been fully representative of the more clay rich fraction.

### 4.7.4 Method limitations

When correcting for moisture during conversion from ppm to kg/ha, a general correction factor for a clay loam was used (wet = 1.3, moist = 1.4, dry = 1.7). The water content of the soil was estimated based on previous weather and soil feel during sampling. These correction factors were estimated and introduced a large factor of inaccuracy.

The extractant used to measure nitrate levels for quick tests was CaCl<sub>2</sub>, whereas the extractant used in Hill Labs methodology was KCl. This difference means different ionic strength of extractants and systematic variability.

Supelco® strips used a colourimetric system making the results subjective and introducing error in readings.

## 5. Conclusions

Fertilised plots consistently showed higher and more variable soil nitrate concentrations than the control, with transient peaks occurring 4–14 days after application. Rainfall strongly influenced nitrate distribution and temporal patterns, often masking depth and cultivation

effects. No major differences were observed between bedded and ridge–furrow systems, indicating soil structure had minimal impact on nitrate availability under the conditions studied. Depth differences were only evident in the control, highlighting that high fertiliser inputs and environmental variability can homogenise nitrate throughout the profile.

Quick-test methods (LAQUA and Supelco® strips) correlated strongly with laboratory results ( $R^2 \approx 0.82\text{--}0.83$ ) but exhibited concentration-dependent biases, limiting their accuracy for absolute measurements. Nitrification rates were highly variable and inconsistent, providing only qualitative evidence of ammonium conversion to nitrate in fertilised plots.

For growers, these results indicate that soil sampling should be conducted 10–14 days after fertiliser application to capture representative nitrate levels, and fertiliser applications should be avoided prior to heavy rainfall to minimise leaching. While quick-test methods can inform short-term decisions, laboratory analysis remains essential for accurate nitrogen assessment. Future studies should expand across multiple sites, seasons, and crop systems to confirm the generality of these findings and refine nitrogen-management recommendations.

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## 7. Appendices

### Appendix A: Raw Data

Table 6: Sampling dates and corresponding nitrate data. Each treatment includes two replicates. Nitrate concentrations were initially measured as  $\text{NO}_3^-$  for each rapid testing method and subsequently converted to  $\text{NO}_3\text{-N}$  by dividing by 4.42. All values reported in ppm.

Date	Treatment	LAQUA ( $\text{NO}_3^-$ )	Strips ( $\text{NO}_3^-$ )	LAQUA ( $\text{NO}_3\text{-N}$ )	Strips ( $\text{NO}_3\text{-N}$ )
18/11/2025	Control 0-15 (1)	32	10	7.2398	2.2624
	Control 0-15 (2)	33	10	7.4661	2.2624
	Control 15-30 (1)	34	10	7.6923	2.2624
	Control 15-30(2)	34	10	7.6923	2.2624
1/12/2025	Control 0-15 (1)	44	10	9.9548	2.2624
	Control 0-15 (2)	45	10	10.1810	2.2624
	Control 15-30 (1)	46	10	10.4072	2.2624
	Control 15-30(2)	48	10	10.8597	2.2624
	Bedded 0-15 (1)	77	50	17.4208	11.3122
	Bedded 0-15 (2)	74	50	16.7421	11.3122
	Bedded 15-30 (1)	66	45	14.9321	10.1810
	Bedded 15-30 (2)	66	45	14.9321	10.1810
	R/F 0-15 (1)	70	45	15.8371	10.1810
	R/F 0-15 (2)	69	45	15.6109	10.1810
	R/F 15-30 (1)	67	40	15.1584	9.0498
	R/F 15-30 (2)	67	50	15.1584	11.3122
4/12/2025	Control 0-15 (1)	25	5	5.6561	1.1312
	Control 0-15 (2)	26	7	5.8824	1.5837
	Control 15-30 (1)	26	10	5.8824	2.2624
	Control 15-30(2)	27	5	6.1086	1.1312
	Bedded 0-15 (1)	29	25	6.5611	5.6561
	Bedded 0-15 (2)	29	25	6.5611	5.6561
	Bedded 15-30 (1)	28	20	6.3348	4.5249
	Bedded 15-30 (2)	28	25	6.3348	5.6561
	R/F 0-15 (1)	29	25	6.5611	5.6561
	R/F 0-15 (2)	30	25	6.7873	5.6561
	R/F 15-30 (1)	28	25	6.3348	5.6561
	R/F 15-30 (2)	27	25	6.1086	5.6561
8/12/2025	Control 0-15 (1)	22	25	4.9774	5.6561
	Control 0-15 (2)	22	20	4.9774	4.5249
	Control 15-30 (1)	23	20	5.2036	4.5249

	Control 15-30(2)	22	15	4.9774	3.3937
	Bedded 0-15 (1)	32	40	7.2398	9.0498
	Bedded 0-15 (2)	35	50	7.9186	11.3122
	Bedded 15-30 (1)	32	50	7.2398	11.3122
	Bedded 15-30 (2)	33	40	7.4661	9.0498
	R/F 0-15 (1)	27	25	6.1086	5.6561
	R/F 0-15 (2)	27	30	6.1086	6.7873
	R/F 15-30 (1)	31	30	7.0136	6.7873
	R/F 15-30 (2)	31	25	7.0136	5.6561
12/12/2025	Control 0-15 (1)	41	15	9.2760	3.3937
	Control 0-15 (2)	46	15	10.4072	3.3937
	Control 15-30 (1)	49	20	11.0860	4.5249
	Control 15-30(2)	48	15	10.8597	3.3937
	Bedded 0-15 (1)	110	75	24.8869	16.9683
	Bedded 0-15 (2)	110	75	24.8869	16.9683
	Bedded 15-30 (1)	190	150	42.9864	33.9367
	Bedded 15-30 (2)	160	150	36.1991	33.9367
	R/F 0-15 (1)	76	50	17.1946	11.3122
	R/F 0-15 (2)	76	50	17.1946	11.3122
	R/F 15-30 (1)	160	100	36.1991	22.6244
	R/F 15-30 (2)	170	110	38.4615	24.8869
15/12/2025	Control 0-15 (1)	51	15	11.5385	3.3937
	Control 0-15 (2)	54	10	12.2172	2.2624
	Control 15-30 (1)	53	15	11.9910	3.3937
	Control 15-30(2)	54	10	12.2172	2.2624
	Bedded 0-15 (1)	120	75	27.1493	16.9683
	Bedded 0-15 (2)	120	75	27.1493	16.9683
	Bedded 15-30 (1)	230	150	52.0362	33.9367
	Bedded 15-30 (2)	230	150	52.0362	33.9367
	R/F 0-15 (1)	170	100	38.4615	22.6244
	R/F 0-15 (2)	170	110	38.4615	24.8869
	R/F 15-30 (1)	360	200	81.4480	45.2489
	R/F 15-30 (2)	320	200	72.3982	45.2489
18/12/2025	Control 0-15 (1)	57	15	12.8959	3.3937
	Control 0-15 (2)	59	15	13.3484	3.3937
	Control 15-30 (1)	57	10	12.8959	2.2624
	Control 15-30(2)	58	10	13.1222	2.2624
	Bedded 0-15 (1)	150	100	33.9367	22.6244
	Bedded 0-15 (2)	160	100	36.1991	22.6244
	Bedded 15-30 (1)	140	100	31.6742	22.6244

	Bedded 15-30 (2)	140	80	31.6742	18.0995
	R/F 0-15 (1)	170	125	38.4615	28.2805
	R/F 0-15 (2)	150	120	33.9367	27.1493
	R/F 15-30 (1)	160	125	36.1991	28.2805
	R/F 15-30 (2)	170	125	38.4615	28.2805
22/12/2025	Control 0-15 (1)	55	15	12.4434	3.3937
	Control 0-15 (2)	58	20	13.1222	4.5249
	Control 15-30 (1)	55	10	12.4434	2.2624
	Control 15-30(2)	62	15	14.0271	3.3937
	Bedded 0-15 (1)	120	75	27.1493	16.9683
	Bedded 0-15 (2)	120	80	27.1493	18.0995
	Bedded 15-30 (1)	170	100	38.4615	22.6244
	Bedded 15-30 (2)	190	100	42.9864	22.6244
	R/F 0-15 (1)	130	75	29.4118	16.9683
	R/F 0-15 (2)	140	75	31.6742	16.9683
	R/F 15-30 (1)	150	75	33.9367	16.9683
	R/F 15-30 (2)	150	75	33.9367	16.9683
24/12/2025	Control 0-15 (1)	74	25	16.7421	5.6561
	Control 0-15 (2)	79	25	17.8733	5.6561
	Control 15-30 (1)	72	15	16.2896	3.3937
	Control 15-30(2)	76	25	17.1946	5.6561
	Bedded 0-15 (1)	130	75	29.4118	16.9683
	Bedded 0-15 (2)	140	75	31.6742	16.9683
	Bedded 15-30 (1)	160	80	36.1991	18.0995
	Bedded 15-30 (2)	150	75	33.9367	16.9683
	R/F 0-15 (1)	150	75	33.9367	16.9683
	R/F 0-15 (2)	150	75	33.9367	16.9683
	R/F 15-30 (1)	150	75	33.9367	16.9683
	R/F 15-30 (2)	150	75	33.9367	16.9683
30/12/2025	Control 0-15 (1)	73	30	16.5158	6.7873
	Control 0-15 (2)	75	30	16.9683	6.7873
	Control 15-30 (1)	76	20	17.1946	4.5249
	Control 15-30(2)	76	25	17.1946	5.6561
	Bedded 0-15 (1)	150	100	33.9367	22.6244
	Bedded 0-15 (2)	150	100	33.9367	22.6244
	Bedded 15-30 (1)	130	80	29.4118	18.0995
	Bedded 15-30 (2)	150	100	33.9367	22.6244
	R/F 0-15 (1)	130	75	29.4118	16.9683
	R/F 0-15 (2)	140	75	31.6742	16.9683
	R/F 15-30 (1)	130	60	29.4118	13.5747

	R/F 15-30 (2)	140	80	31.6742	18.0995
5/01/2026	Control 0-15 (1)	80	25	18.0995	5.6561
	Control 0-15 (2)	80	30	18.0995	6.7873
	Control 15-30 (1)	75	25	16.9683	5.6561
	Control 15-30(2)	78	25	17.6471	5.6561
	Bedded 0-15 (1)	120	50	27.1493	11.3122
	Bedded 0-15 (2)	120	60	27.1493	13.5747
	Bedded 15-30 (1)	110	50	24.8869	11.3122
	Bedded 15-30 (2)	110	50	24.8869	11.3122
	R/F 0-15 (1)	120	60	27.1493	13.5747
	R/F 0-15 (2)	120	60	27.1493	13.5747
	R/F 15-30 (1)	100	35	22.6244	7.9186
	R/F 15-30 (2)	100	35	22.6244	7.9186
8/01/2026	Control 0-15 (1)	77	20	17.4208	4.5249
	Control 0-15 (2)	80	25	18.0995	5.6561
	Control 15-30 (1)	79	25	17.8733	5.6561
	Control 15-30(2)	80	25	18.0995	5.6561
	Bedded 0-15 (1)	120	60	27.1493	13.5747
	Bedded 0-15 (2)	120	65	27.1493	14.7059
	Bedded 15-30 (1)	110	55	24.8869	12.4434
	Bedded 15-30 (2)	110	50	24.8869	11.3122
	R/F 0-15 (1)	150	80	33.9367	18.0995
	R/F 0-15 (2)	150	80	33.9367	18.0995
	R/F 15-30 (1)	130	70	29.4118	15.8371
	R/F 15-30 (2)	130	70	29.4118	15.8371

Table 7: Dates with corresponding treatments showing moisture factor used and calculated values for LAQUA and Hills in (kg/ha). Conversion equation = (ppm value/moisture correction factor) x 0.798 (bulk density) x 1.5 (depth factor).

Date	Sample	Moisture correction	LAQUA (kg/ha)	Strips (kg/ha)
18/11/2025	Control 0-15	1.4	6.2868	1.9344
	Control 15-30	1.4	6.5769	1.9344
1/12/2025	Control 0-15	1.4	8.6080	1.9344
	Control 15-30	1.4	9.0916	1.9344
	Bedded 0-15	1.4	14.6046	9.6719
	Bedded 15-30	1.4	12.7670	8.7048
	R/F 0-15	1.4	13.4440	8.7048
	R/F 15-30	1.4	12.9604	8.7048

4/12/2025	Control 0-15	1.3	5.3121	1.2499
	Control 15-30	1.3	5.5204	1.5624
	Bedded 0-15	1.3	6.0412	5.2080
	Bedded 15-30	1.3	5.8329	4.6872
	R/F 0-15	1.3	6.1454	5.2080
	R/F 15-30	1.3	5.7288	5.2080
8/12/2025	Control 0-15	1.7	3.5047	3.5843
	Control 15-30	1.7	3.5843	2.7878
	Bedded 0-15	1.7	5.3366	7.1686
	Bedded 15-30	1.7	5.1773	7.1686
	R/F 0-15	1.7	4.3012	4.3808
	R/F 15-30	1.7	4.9384	4.3808
12/12/2025	Control 0-15	1.7	6.9297	2.3895
	Control 15-30	1.7	7.7262	2.7878
	Bedded 0-15	1.7	17.5233	11.9477
	Bedded 15-30	1.7	27.8780	23.8954
	R/F 0-15	1.7	12.1070	7.9651
	R/F 15-30	1.7	26.2849	16.7268
15/12/2025	Control 0-15	1.7	8.3634	1.9913
	Control 15-30	1.7	8.5227	1.9913
	Bedded 0-15	1.7	19.1163	11.9477
	Bedded 15-30	1.7	36.6396	23.8954
	R/F 0-15	1.7	27.0814	16.7268
	R/F 15-30	1.7	54.1629	31.8605
18/12/2025	Control 0-15	1.4	11.2195	2.9016
	Control 15-30	1.4	11.1227	1.9344
	Bedded 0-15	1.4	29.9830	19.3439
	Bedded 15-30	1.4	27.0814	17.4095
	R/F 0-15	1.4	30.9502	23.6963
	R/F 15-30	1.4	31.9174	24.1799
22/12/2025	Control 0-15	1.4	10.9293	3.3852
	Control 15-30	1.4	11.3162	2.4180
	Bedded 0-15	1.4	23.2127	14.9915
	Bedded 15-30	1.4	34.8190	19.3439
	R/F 0-15	1.4	26.1143	14.5079
	R/F 15-30	1.4	29.0158	14.5079
24/12/2025	Control 0-15	1.4	14.7981	4.8360
	Control 15-30	1.4	14.3145	3.8688
	Bedded 0-15	1.4	26.1143	14.5079
	Bedded 15-30	1.4	29.9830	14.9915

	R/F 0-15	1.4	29.0158	14.5079
	R/F 15-30	1.4	29.0158	14.5079
30/12/2025	Control 0-15	1.3	15.4156	6.2496
	Control 15-30	1.3	15.8322	4.6872
	Bedded 0-15	1.3	31.2478	20.8319
	Bedded 15-30	1.3	29.1646	18.7487
	R/F 0-15	1.3	28.1230	15.6239
	R/F 15-30	1.3	28.1230	14.5823
5/01/2026	Control 0-15	1.7	12.7442	4.3808
	Control 15-30	1.7	12.1867	3.9826
	Bedded 0-15	1.7	19.1163	8.7616
	Bedded 15-30	1.7	17.5233	7.9651
	R/F 0-15	1.7	19.1163	9.5582
	R/F 15-30	1.7	15.9303	5.5756
8/01/2026	Control 0-15	1.7	12.5053	3.5843
	Control 15-30	1.7	12.6646	3.9826
	Bedded 0-15	1.7	19.1163	9.9564
	Bedded 15-30	1.7	17.5233	8.3634
	R/F 0-15	1.7	23.8954	12.7442
	R/F 15-30	1.7	20.7093	11.1512

Table 8: Raw data from Hill Labs showing nitrate and ammonium concentrations reported in NO<sub>3</sub>-N then converted into kg/ha. Conversion equation = ppm value x 0.798 (bulk density) x 1.5 (depth factor).

		Hills (NO <sub>3</sub> -N)	Hills NH <sub>4</sub> -N	NO <sub>3</sub> -N (kg/ha)	NH <sub>4</sub> -N (kg/ha)
18/11/2025	Control 0-15	5	2	5.985	2.394
	Control 15-30	6	2	7.182	2.394
1/12/2025	Control 0-15	7	1	8.379	1.197
	Control 15-30	5	1	5.985	1.197
	Bedded 0-15	28	19	33.516	22.743
	Bedded 15-30	19	22	22.743	26.334
	R/F 0-15	20	9	23.94	10.773
	R/F 15-30	18	20	21.546	23.94
4/12/2025	Control 0-15	6	1	7.182	1.197
	Control 15-30	7	1	8.379	1.197
	Bedded 0-15	22	7	26.334	8.379
	Bedded 15-30	17	10	20.349	11.97
	R/F 0-15	21	8	25.137	9.576
	R/F 15-30	17	6	20.349	7.182
8/12/2025	Control 0-15	9	1	10.773	1.197

	Control 15-30	7	1	8.379	1.197
	Bedded 0-15	20	5	23.94	5.985
	Bedded 15-30	15	16	17.955	19.152
	R/F 0-15	15	3	17.955	3.591
	R/F 15-30	15	10	17.955	11.97
12/12/2025	Control 0-15	8	1	9.576	1.197
	Control 15-30	8	1	9.576	1.197
	Bedded 0-15	37	8	44.289	9.576
	Bedded 15-30	52	47	62.244	56.259
	R/F 0-15	22	1	26.334	1.197
	R/F 15-30	51	33	61.047	39.501
15/12/2025	Control 0-15	9	1	10.773	1.197
	Control 15-30	7	2	8.379	2.394
	Bedded 0-15	35	19	41.895	22.743
	Bedded 15-30	77	78	92.169	93.366
	R/F 0-15	63	41	75.411	49.077
	R/F 15-30	108	102	129.276	122.094
18/12/2025	Control 0-15	9	1	10.773	1.197
	Control 15-30	6	2	7.182	2.394
	Bedded 0-15	54	32	64.638	38.304
	Bedded 15-30	39	56	46.683	67.032
	R/F 0-15	60	41	71.82	49.077
	R/F 15-30	47	67	56.259	80.199
22/12/2025	Control 0-15	11	1	13.167	1.197
	Control 15-30	10	1	11.97	1.197
	Bedded 0-15	51	9	61.047	10.773
	Bedded 15-30	59	68	70.623	81.396
	R/F 0-15	58	6	69.426	7.182
	R/F 15-30	54	30	64.638	35.91
24/12/2025	Control 0-15	13	1	15.561	1.197
	Control 15-30	11	1	13.167	1.197
	Bedded 0-15	90	18	107.73	21.546
	Bedded 15-30	64	26	76.608	31.122
	R/F 0-15	65	8	77.805	9.576
	R/F 15-30	59	19	70.623	22.743
30/12/2025	Control 0-15	11	1	13.167	1.197
	Control 15-30	8	1	9.576	1.197
	Bedded 0-15	58	16	69.426	19.152
	Bedded 15-30	48	33	57.456	39.501
	R/F 0-15	52	21	62.244	25.137

	R/F 15-30	34	39	40.698	46.683
5/01/2026	Control 0-15	9	1	10.773	1.197
	Control 15-30	7	1	8.379	1.197
	Bedded 0-15	36	12	43.092	14.364
	Bedded 15-30	24	29	28.728	34.713
	R/F 0-15	33	16	39.501	19.152
	R/F 15-30	21	17	25.137	20.349
8/01/2026	Control 0-15	8	1	9.576	1.197
	Control 15-30	6	1	7.182	1.197
	Bedded 0-15	36	14	43.092	16.758
	Bedded 15-30	26	33	31.122	39.501
	R/F 0-15	47	6	56.259	7.182
	R/F 15-30	30	19	35.91	22.743

## Appendix B: Weather data

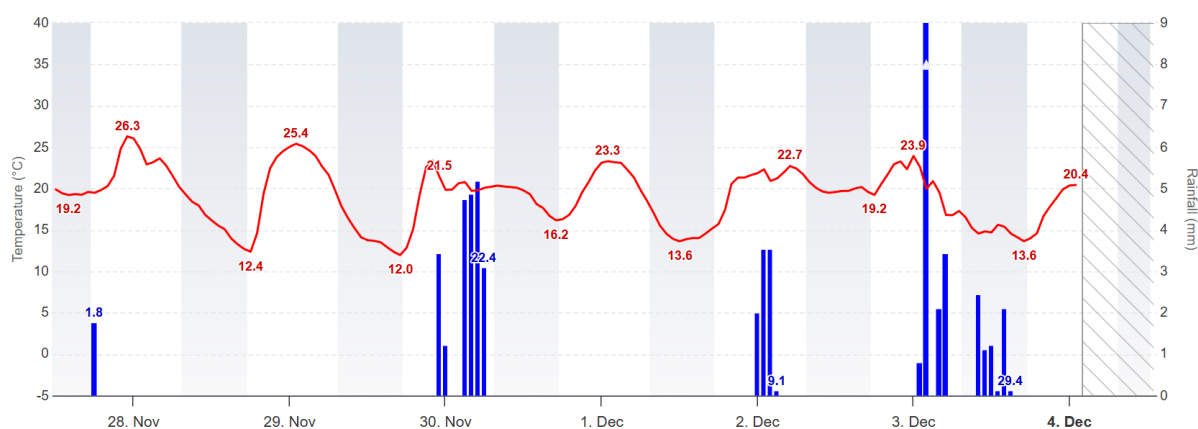


Figure 13: Climate data obtained from the Vegetables New Zealand Inc. (VNZI) Weather & Disease portal, using records from the Pukekohe Research Farm weather station. Weather data shows the entire trial period (18/11/25 à 08/01/26), with blue bars showing rainfall (mm), and the red line showing temperature (°C).

## Appendix C: Site details

Table 9: Location details

Name:	Pukekohe Research and Demonstration Farm
Coordinates:	37°12'18"S 174°51'50"E

Elevation (m):	80
Landscape position	Plain
Mean annual rainfall (mm)	1,200mm
Mean annual temperature (°C)	15.86

Table 10: Soil physical and chemical properties. Note: Bulk density of 0.798 was used to calculate conversion of nitrate into kg/ha, as this is consistent with the SVS tool calculation.

Bulk density	<b>1.03</b>
Texture	Clay loam
Soil name	Patumahoe clay loam
pH	6.1-6.4
C:N Ratio:	8.6 – 10.2

## Appendix D: FAR soil moisture correction table

Table 11: FAR moisture correction table based on texture

Texture	Dry	Moist	Wet
<b>Clay</b>	1.8	1.5	1.3
<b>Clay loam</b>	1.7	1.4	1.3
<b>Loam</b>	2.0	1.5	1.3
<b>Loamy sand</b>	1.8	1.5	1.4
<b>Sand</b>	1.8	1.5	1.4
<b>Sandy clay</b>	1.8	1.4	1.3
<b>Sandy clay loam</b>	1.9	1.6	1.4
<b>Sandy loam</b>	2.1	1.8	1.5
<b>Silt</b>	1.9	1.4	1.3
<b>Silt loam</b>	1.7	1.4	1.3
<b>Silty clay</b>	1.9	1.6	1.4
<b>Silty clay loam</b>	1.9	1.5	1.4

