PFR SPTS No. 21743

Sustainable vegetable systems – Quarterly report for July–September 2021

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November 2021

Summary

This report summarises activity carried out by The New Zealand Institute for Plant and Food Research Limited (PFR) from 1 July to 30 September 2021, across the different workstreams of the Sustainable Vegetable Systems (SVS) project.

Workstream 1:

- We completed final harvests of broccoli and oats in the Lincoln rotations, and pak choy in the Hawke's Bay rotation.
- Lettuces and onions were sown in Hawke's Bay, and onions in Lincoln. Land is being prepared for potato planting at Lincoln.
- Buried suction cups were installed in all rotations at both sites.
- A framework to describe a nitrogen (N) balance is developed for further discussion and illustrated with the broccoli crop data. The net change in soil N across the potato – wheat – broccoli rotation is also discussed.

Workstream 2:

- Regional field data continues to be collected, and data are being collated for N balance discussions.

Workstream 3:

- An SVS modelling workshop attended by modellers working in science and industry identified some key issues to consider in developing useful tools from modelling. Key steps for interactive exchange of information and grower input were identified.
- Modelling simulations are being updated with data from crops that have been recently harvested in the rotations. Work continues to refine soil parameters for accurate estimation of soil water as this determines accurate prediction of drainage and leaching.

Workstream 4:

- Grower interviews to understand the practices, knowledge and issues faced with N management of crops were conducted by phone or video conference because of COVID-19 restrictions.
- A report is being prepared from the interviews to help inform modelling discussion and tool development.
- A plan to continue with information sharing is being developed, with COVID-19 restrictions affecting the ability of focus groups to meet and field days to be held.

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1 Workstream activity

1.1 Workstream 1: Field experiments

Activity this quarter focused on completing harvests and establishing next crops in the rotation. Lockdown due to COVID-19 this quarter delayed some of the work in the field and lab, but we were ultimately able to get crops sown within the planting window. We also completed installation of the buried suction cups to collect drainage for leachate estimates at 60 cm and 120 cm.

More details of the experiment are outlined in the Year 1 annual report (Searle et al. 2021), but briefly, the treatments are four rates of nitrogen fertiliser (N1, N2, N3, N4) and two irrigation rates (I1, I2). These are replicated four times in a split plot randomised block, with irrigation as the main treatment.

The N rates aim to ensure that, where possible, a growth response to N is obtained with the optimum rate being provided at the N3 treatment. But the primary aim is to ensure that there are differences in soil N over time and in leaching between the N treatments, as these are the data needed for modelling and developing a farmer-facing tool. The irrigation rates aim to provide a non-limiting amount of water to the crop (I1) and to irrigate to field capacity (I2) so that there is increased likelihood of drainage and leaching during growth of a crop.

The exact rates of N and irrigation for each treatment will vary depending on the crop that is being grown.

1.1.1 Canterbury Potato–Onion rotation

During this quarter, we completed harvesting of the broccoli crop and sowing of onions, the next crop in the rotation (Figure 1).

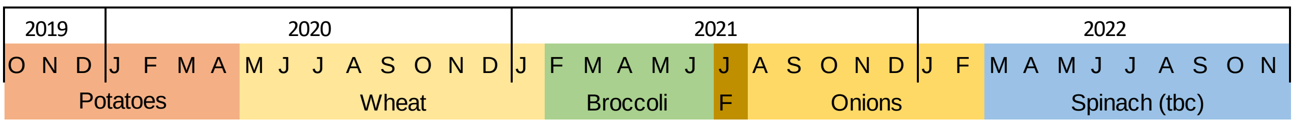

Figure 1. Canterbury potato–onion rotation crops. The final spinach crop is to be confirmed, the alternative is a ryegrass to follow the onion crop. A fallow period (‘F’) occurs between the broccoli and onion crops.

Broccoli harvest

- The final harvest occurred on 28 June 2021, or 120 days after planting (DAP). We graded broccoli floret heads along a 2 m length of two sowing beds (an area of 5.76 m^2) as marketable or unmarketable, and recorded fresh and dry weight. Marketable heads were 125 mm in diameter or more, and had tight beading. Fresh and dry weight biomass of leaf, stem/petiole and dead plant material were also recorded to obtain a measure of the amount of residue. After drying, plant material was ground and sent to the PFR Soils Lab for analysis of N content using a LECO C and N analyser.

- Temperature during growth averaged 12.1°C, which was 0.9°C warmer than the 30-year average.

- Total rainfall during growth was 250 mm. Of this, only 70 mm fell in the first 87 days after planting. During these 87 days, 85 mm of irrigation was also applied at four different times, giving a total of 155 mm applied in the period. Irrigation treatments were kept the same in the first period of growth. The last month of growth had significant rainfall with 122 mm over 3 days starting on day 88 after planting, and again a rainfall event of 42 mm between 107 and 110 DAP. This gave a total of 164 mm in the last month of growth; and so irrigation treatment differences were not implemented, as there was likely to have been leaching occurring due to the heavy rainfall. While there may have been some leaching over this last month, the drainage modelling and calculation to quantify this is being completed.

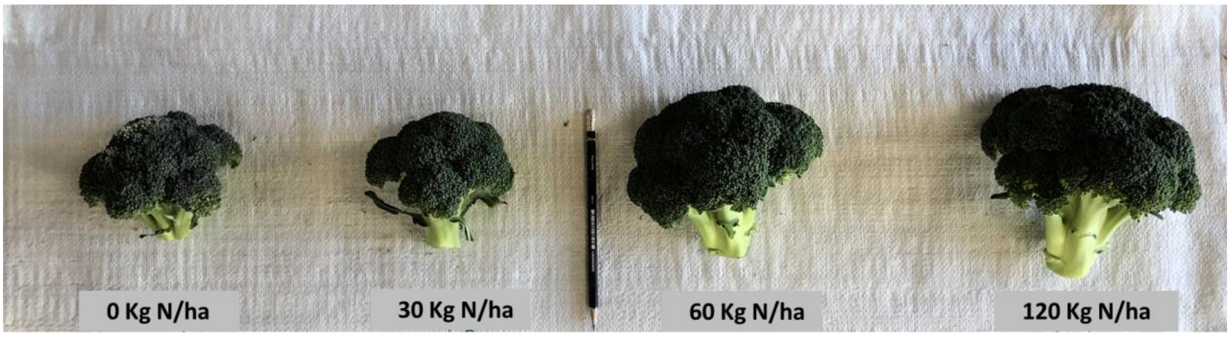

Figure 2. Broccoli head size for the different applied N fertiliser rates to broccoli grown at the PFR Lincoln research site.

- Broccoli head size increased with applied N (Figure 2). Head fresh weights increased Figure 2from 337 g with no applied N to 395 g when 60 kg N/ha were applied (Figure 3a). Applying additional N to 120 kg N/ha had no effect on head weight (Figure 3a).
- The number of marketable heads harvested averaged 1.5 /m2, equivalent to 39% of established plants being of marketable grade (Figure 3c, d). The average value is low, and this likely reflects the single harvest time used. There was significant variation in the percentage of marketable heads, ranging from 10 to 80% across plots, and this variation likely contributed to the low yields and lack of response of marketable yield to N rates.

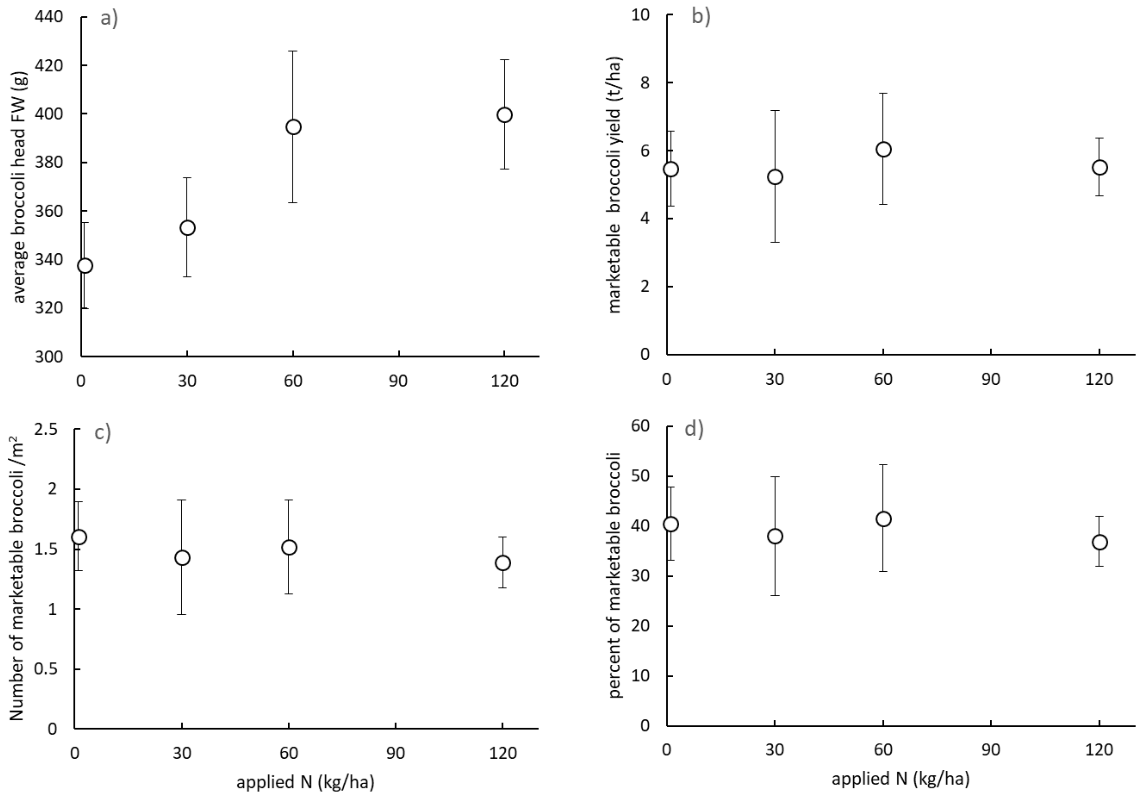

Figure 3. Response to applied N fertiliser of broccoli a) marketable head fresh weight (FW), b) marketable head yield, c) number of marketable heads per m2, and d) percentage of plants with marketable heads. Broccoli grown at the PFR Lincoln research site. Error bars are one standard deviation.

Broccoli N uptake

- Total crop N uptake increased from 91 to 154 kg N/ha with an increase in applied N from 0 to 120 kg N/ha (Figure 4a). On average, 78% of the total N uptake was found in the residues and 22% in the marketable heads (Figure 4a). N uptake by marketable heads was 23.1 kg N/ha when no N fertiliser was applied, increasing to 29.4 kg N/ha when 60 kg N/ha was applied. Further increasing fertiliser application to 120 kg N/ha did not increase the amount of N in marketable heads (Figure 4a).
- N in total crop residues (unmarketable heads, leaves, stems and petioles) increased with applied N fertiliser from 68.3 to 126 kg N/ha (Figure 4a). When broken down into the residue components, on average 46% was found in leaf material, 30% in the stem and the reminder in the reject heads (Figure 4b). The amount of N in senesced plant material and roots to a 30 cm depth was less than 1.5 kg N/ha and are not included in Figure 4.

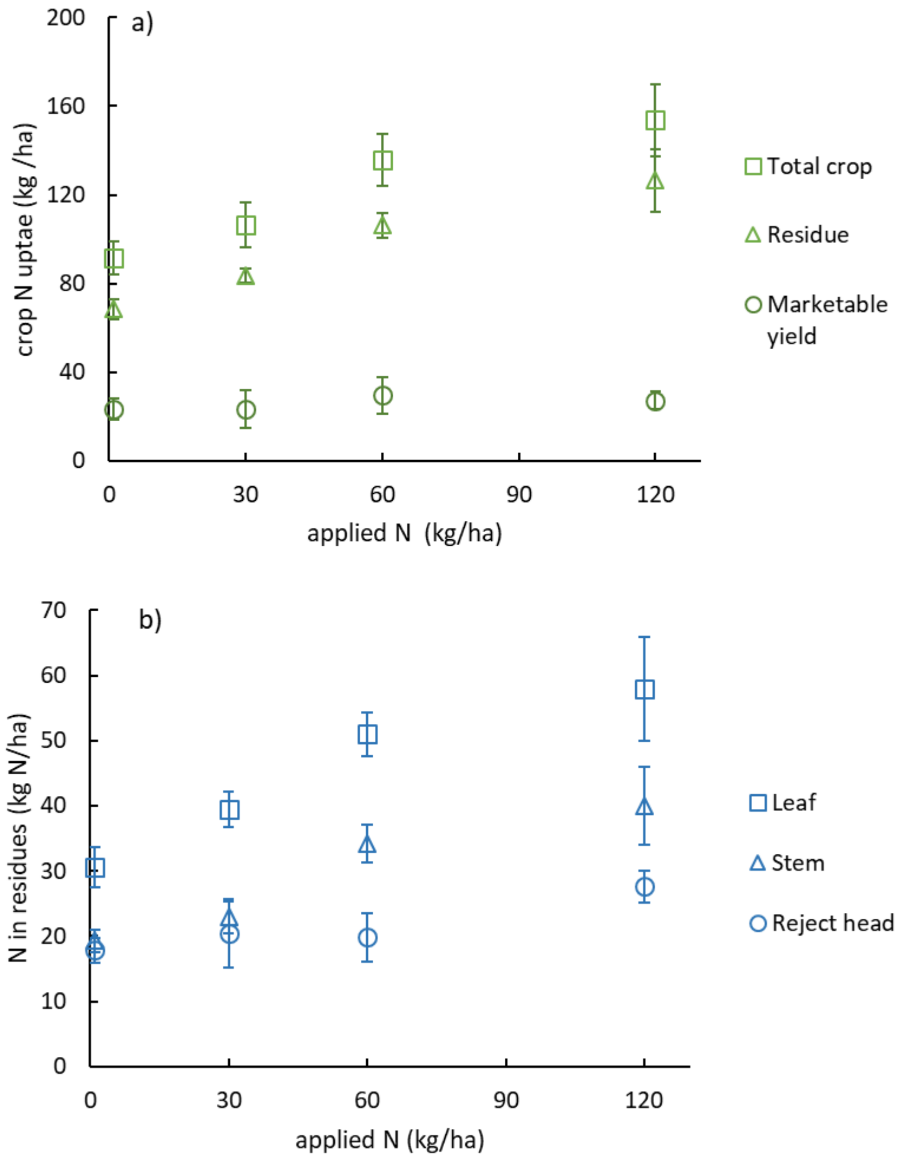

Figure 4. a) N uptake by marketable heads, crop residues and total crop uptake, and b) N content of residue components, reject heads, stems including petioles, and leaf of broccoli crop sown at the PFR Lincoln research site.

N balance of broccoli crop

We estimated the N balances for the broccoli grown with different rates of applied N using the framework illustrated in Figure 5. There are two questions addressed by this framework:

1. What is the best way to do a N balance that contributes to improved understanding of losses and management for growers and industry? This N balance framework is a starting point for further development and discussion as more examples are explored across the different workstreams, and a 'farmer – facing' tool is developed in this programme. It also provides a framework for wider discussion regarding N use in cropping systems.
2. Where does the N go in the system? The framework provides an approach to examining the allocation to different N pools to the 'surplus' N needed for yield. Every crop exports a certain amount of N off the field in the sold product, but there is more N applied than is exported. This

N, that is 'surplus' to the export requirements becomes part of different pools of N in the crop system that are susceptible to loss. The N balance aims to identify what the fate of the 'surplus' N is as a way of understanding N use in the system and risk of losses from the system. In this programme of work, we have a particular emphasis on leaching losses, so this is a focus of the framework.

A N balance is simply the difference between N inputs and outputs of the system. This balance does not take into account gaseous losses, or atmospheric N inputs, so in this regard it must be considered a partial balance only.

The inputs for this are:

- Mineralisable N – the amount of N that becomes available to the crop over time from mineralisation of the organic N pool. This value is ideally obtained from the Potential Mineral N test (PMN), but needs correcting based on average soil temperature and moisture during the period of crop growth.
- Mineral N – the amount of nitrate and ammonium N that is immediately available to the crop, measured at planting.
- Crop residue N – the amount of N that is returned to the soil in residue from the previous crop. This can be significant in vegetable crops. The release rate of N from this residue needs to be determined and is the subject of a separate project; therefore, an assumption is made that all of the N in the residue becomes available to the subsequent crop.
- Fertiliser N – the amount of N applied as fertiliser.

Outputs are:

- N in marketed crop yield – the amount of N that is exported from the field in sold yield.
- The N 'surplus', which is the difference between the total inputs and the N in marketed crop yield. What makes up this surplus is then determined as either:
  - N in the residue of the crop.
  - N in the soil mineral N pool at harvest of the crop: this is a pool that is at risk of leaching.
  - N in the leached amount from the field.
  - N that is otherwise unaccounted for ('missing' in Figure 5). When there are large amounts of unaccounted for losses, some further evaluations of likely reasons will need to be explored.

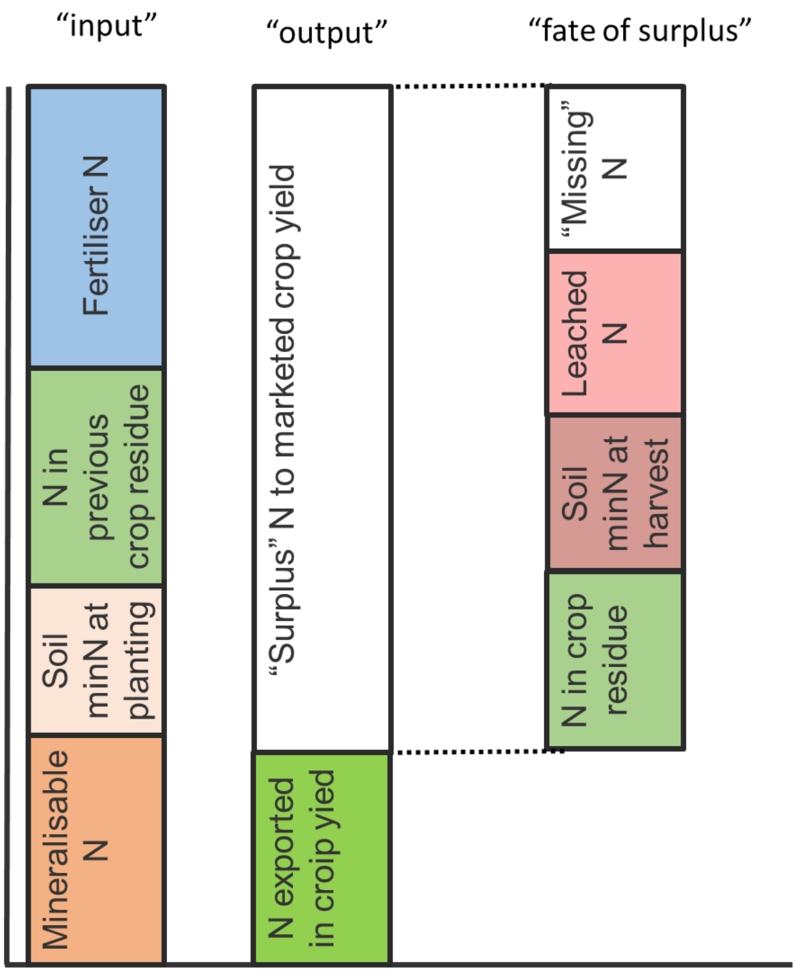

Figure 5. Framework for N balance. This balance identifies the 'surplus' N over and above that exported in marketable yield, and where that 'surplus' N is allocated within the system, what has leached and what is at risk of leaching.

We applied this framework to the broccoli crop (Figure 6). To develop this balance we first calculated the mineralisable N available to the crop. The PMN (Potential Mineralisable N) value was 285 kg N/ha that could potentially be mineralised from the soil. To get an estimate of the mineralisable N actually available to the crop, the PMN test needs to be adjusted by factors that take account of soil temperature and moisture content. This was done using average long-term temperature for the site, and assuming that the crop was fully irrigated during March and April and rain fed during May and June. On this basis, the estimated mineralisable N for the crop is 86 kg N/ha. This is the value used in the calculation of the N balance.

Further inputs were obtained from soil mineral N tests and crop N uptake values.

The PMN test is usually estimated in samples taken to 15 or 30 cm depth. In these experiments, leachate is measured at 60 cm depth, and so the budget is constructed using inputs of soil mineral N from the 0–60 cm depth, and assuming that mineralisation below 30 cm is minimal.

Some observations using this N balance approach:

- The broccoli was sown after a wheat crop. The wheat straw was removed from the field and not incorporated into the soil, so it is not included as a contributor to the N input into this budget.
- For this example, surplus N is allocated to either the residual soil mineral N at harvest, the N in broccoli residue (stalk, petioles, leaves and unmarketable heads), and an ‘unaccounted’ N pool. Part of this ‘unaccounted’ pool could be the amount of N leached, which is in the process of being calculated for this crop. The heavy rainfall events in the last month of growth may have contributed to some leaching.
- This approach (Figure 6) shows that the ‘surplus’ of N increased from 105 to 232 kg N/ha when the N fertiliser rate increased from 0 to 120 kg N/ha.
- Of this surplus, approximately 65% was in the crop residue pool for the 0, 30 and 60 kg N/ha treatment. For the high N treatment (120 kg N/ha), 55% of the ‘surplus’ N was in the crop residue pool.
- N in the soil mineral N pool ranged from 10 to 14% of the ‘surplus’ N pool, and in the 0, 30 and 60 kg N/ha treatments was 15–16 kg of N/ha on the top 60 cm of soil. For the 120 kg N/ha treatment, the soil mineral N pool increased to 28 kg N/ha in the top 60 cm of soil. These values are relatively low and could either be due to good use of available N by the crop or losses (e.g. due to leaching). Given the size of the ‘unaccounted’ for pool, it is possible that leaching may be a contributor to these low soil mineral N values.
- The ‘unaccounted’ pool increased markedly in the 120 kg N/ha treatment; interestingly this value increases where excess fertiliser N to crop requirement is applied, at least in this example. Leaching calculations may yet show a contribution to this ‘unaccounted’ pool, particularly in the highest N treatment.
- This N balance shows that under the best management application rate for this crop (60 kg N/ha), additional N applied as fertiliser can be accounted for in the residual soil mineral N at harvest and N in crop residue. However, there is still a significant amount in the ‘unaccounted’ for pool. If this proves to be leaching loss, it would not be unexpected given the high rainfall events (over 160 mm rain) in the last month of growth. This highlights the importance of environmental conditions during crop growth on crop N use outcomes.

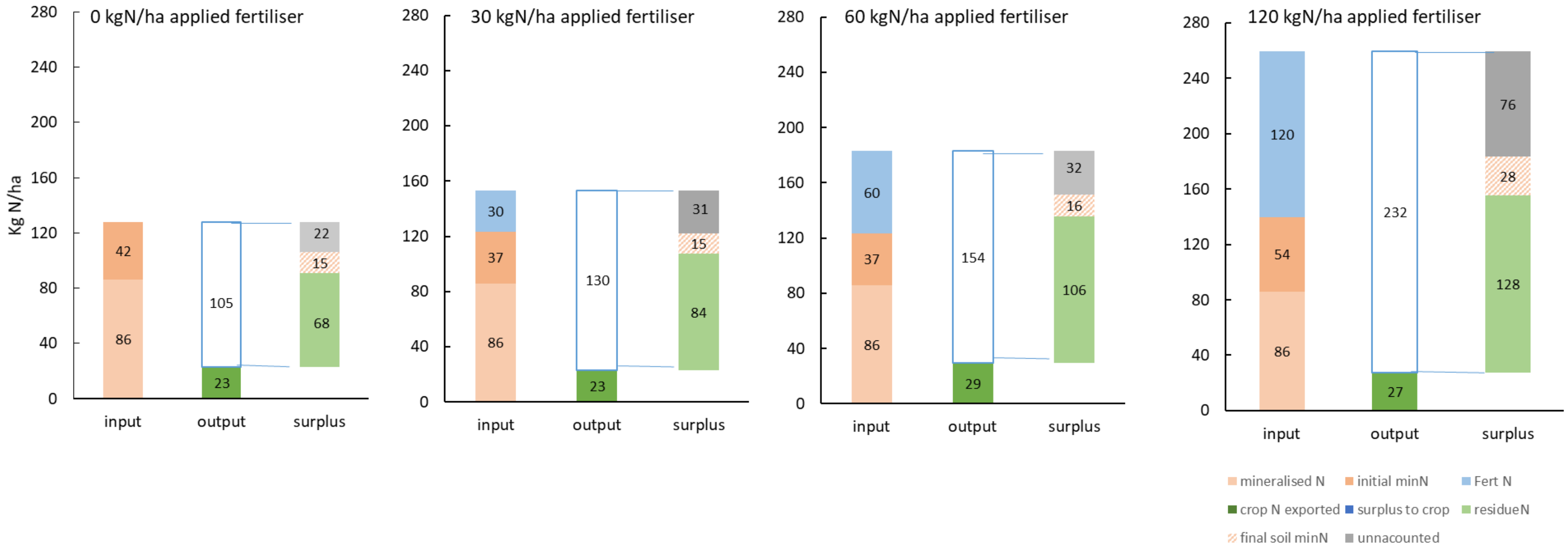

Figure 6. N balance for a broccoli crop grown under the different fertiliser treatment rates.

Net nitrogen supply during the rotation (potato–wheat–broccoli)

The net N supply was calculated for each crop in the rotation for each date where both soil mineral N and crop N uptake were measured. This was done using the following equation:

$$\boldsymbol{Net\ N\ supply} = (\boldsymbol{R} + \boldsymbol{U}) - (\boldsymbol{I} + \boldsymbol{A})$$

Where:

- ***R*** represents the amount of residual soil mineral N (kg/ha) measured at 0–60 cm depth on the date of sampling;
- ***U*** the amount of N (kg/ha) taken up by the crop up to the date of sampling;
- ***I*** the initial amount of residual soil mineral N (kg/ha) measured at 0–60 cm depth at planting for that crop;
- ***A*** the amount of N (kg/ha) added as fertiliser up to the date of sampling.

The net N supply is not a direct measure of N losses or gains through the system, but it is a useful proxy to identify potential changes of N within the system. A positive value indicates a net addition of N to the system (for example, through mineralisation and/or N fixation, or over application of fertiliser). On the other hand, a negative value indicates a net loss of N by the system (for example, through leaching and/or gaseous losses and/or immobilisation). The net N supply thus provides a framework to assess how management practices might influence the overall N balance for a crop. The net N supply is shown in Figure 7 and Figure 8.

Key observations

During the potato crop:

- There were similar trends between both irrigation treatments but lower net N supply under excessive irrigation (I2), which indicates higher potential losses from the system. This was expected because drainage is one of the main vehicles through which losses can occur.
- Early in the season (mid-December), the net N supply ranged from −47 (N2) to −123 kg N/ha (N4), which indicates that the supply of N through fertiliser and by the soil (mineralisation) exceeded the uptake by the crop.
- Late in the season (late February), the net N supply increased to a positive value of 20 (N1) and to −26 and −25 kg N/ha for N2 and N3, respectively. For N4, it remained similar to the mid-December measurement. This indicates that N supply from the N2 and N3 treatments was a better match for crop uptake, still in excess for N4 and lacking for N1 (no fertiliser applied during the season).
- At final harvest, the net N supply decreased for N3, while it remained the same for N1, N2 and N4. This is because the crop did not take up more N since the previous sampling. It is important to note also that this harvest was delayed slightly because of the COVID-19 restrictions (February – March, 2020), which meant a delay in sowing the following wheat crop and more chances for N losses to occur.

During the wheat crop:

- During winter (June, July and August), the net N supply for the high N treatment (N4) indicated more potential losses under non-limiting irrigation (I1) than under excessive irrigation (I2). It is important to note that the wheat was a mop-up crop in the rotation and so irrigation and N fertiliser inputs were managed the same across all treatments. This meant that differences observed during this crop are more likely to be attributed to the preceding potato crop management. Under excessive irrigation, it is possible that most of the soil mineral N was lost before the wheat crop was sown, while the losses in the non-limiting irrigation treatment occurred in the early stages of the wheat crop.

- From mid-spring onwards (mid-October), the net N supply was similar for all the treatments and progressively increased to 0 or positive values. This indicates that the wheat crop slowly took up N from the soil and that N fertiliser inputs were not in excess as the crop was managed the same across all the treatments.

During the broccoli crop:

- There were no differences in net N supply between the treatments (both N rate and irrigation) until the final harvest of the crop.
- Net N supply was positive during the growth of the crop, which indicates that, in addition to N supplied by fertiliser, further N was added to the system (through mineralisation and/or fixation for example). It could also be because of the fact that N uptake was measured for the whole plant during those harvests and brassicas (such as broccoli, cabbage, cauliflower) can take up high amounts of N during their growth.
- At final harvest, the net N supply decreased for all the treatments, and was the lowest for the N4 treatment (both irrigation treatments). For the final harvest, only marketable broccoli heads were harvested and the rest of the crop was left behind as residual. This meant that N uptake was lower as most of the biomass was left behind.

  It is important, however, to note that:

  - In a commercial situation, sequential harvests occur once the crop is ready, compared with a single final harvest here, which meant more N would have been removed rather than left as residual.
  - The calculation for the net N supply is an indication of what could be lost from the system and does not account for crop residue breakdown, which occurs progressively through time (i.e. not all the N contained within the crop residue is released at once) and is dependent on soil temperature. This meant that the net N supply at final harvest is only an indicator for the residual N left behind. Further sampling through the following crop in this rotation (onions) will provide a more accurate trend.

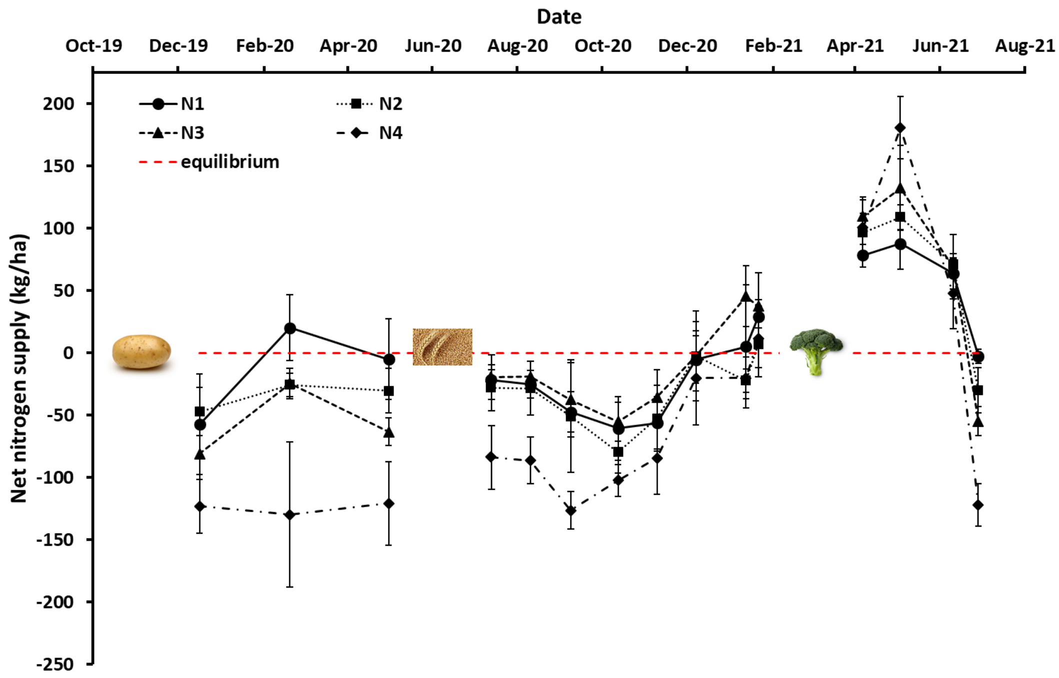

Figure 7. Net nitrogen supply (kg/ha) during the potato–wheat–broccoli rotation grown under the different N fertiliser treatment rates and under non-limiting irrigation (I1) at Lincoln, Canterbury. Vertical bars indicate standard error.

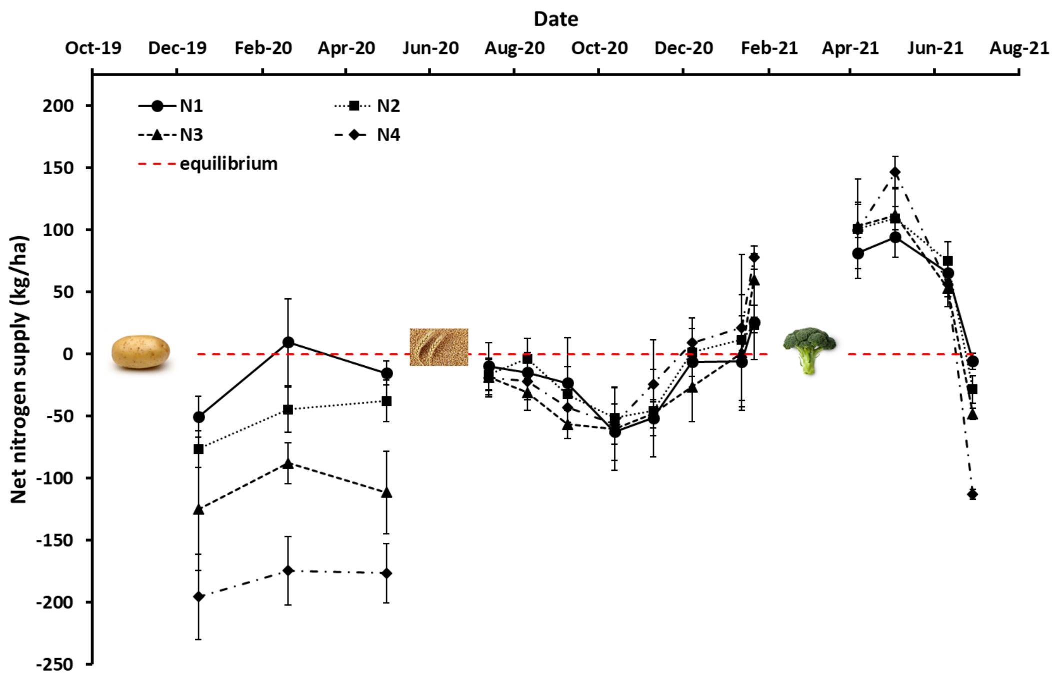

Figure 8. Net nitrogen supply (kg/ha) during the potato–wheat–broccoli rotation grown under the different N fertiliser treatment rates and under excessive irrigation (I2) at Lincoln, Canterbury. Vertical bars indicate standard error.

Onion sowing

- Onion seed of variety 'Tillbury' were sown on Thursday 7 September 2021 (Figure 9), using 2–3 mm seed, coated with Apron®, Fludioxonil and Captan to ensure no insect or disease loss during establishment.

Figure 9. Onion experiment sowing.

- Soil content of phosphorus (P) and potassium (K) were slightly moderate prior to planting (Table 1), so a base fertiliser application was recommended by the supporting agronomist, at rates of 27 kg/ha of P and 112 kg/ha of K using a mix of triple super and potassium sulphate.
- Soil mineral N content in the N3 plots (these are the plots for recommended optimum N rates) and the PMN soil test result are still to be completed. The final N rates are therefore to be determined, but an N rate at planting was recommended of 0, 15, 30 and 60 kg N/ha. Side dressing rates will be confirmed subject to the soil test results.

Table 1. Soil nutrient content for the onion crop of the Canterbury potato–onion rotation, grown at the *PFR Lincoln research site*.

pH	Olsen P (mg/L)	Potassium (me/100g)	Calcium (me/100g)	Magnesium (me/100g)	Sodium (me/100g)	Cation Exchange Capacity (me/100g)	Base saturation (%)
6.6	31	0.33	9.8	0.80	0.16	15	75

1.1.2 Canterbury Vegetable rotation

- During this quarter, the oat crop was harvested and potatoes are being prepared for sowing (Figure 10).

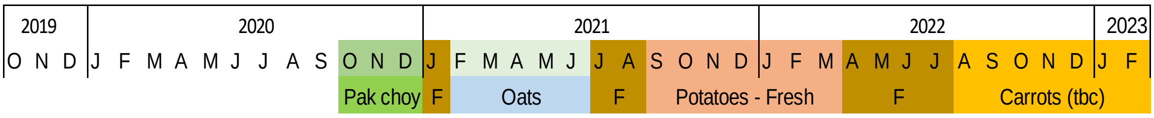

Figure 10. Canterbury vegetable rotation. The final crop is to be confirmed; the alternative is a ryegrass to follow the fresh potato crop. Fallows ('F') occur between the different crops.

Oat harvest

- Final harvest occurred on 26 July 2021. All above ground plant biomass was collected from a duplicated 0.5 m^2 from each plot.
- 30 July the remainder of oats were mown and baled, and crop residue removed from the field and not incorporated.
- N fertiliser was not applied to the oat crop and so growth and yield depended solely on soil N supply from mineral N and mineralisable N pools. There were also residue returns via pak choy (the previous crop) residues. Lab analysis of all crop material is delayed because of COVID-19 so that a N balance cannot yet be completed.
- Yield did not vary between N treatments (Figure 11a) and averaged 37.5 t/ha fresh mass across all treatments. However, N uptake did increase with N treatment (Figure 11). This means that the soil N present in the N1 treatment was enough to give optimum yield, but the crop was able to take up luxury N, thus acting as an effective catch crop.

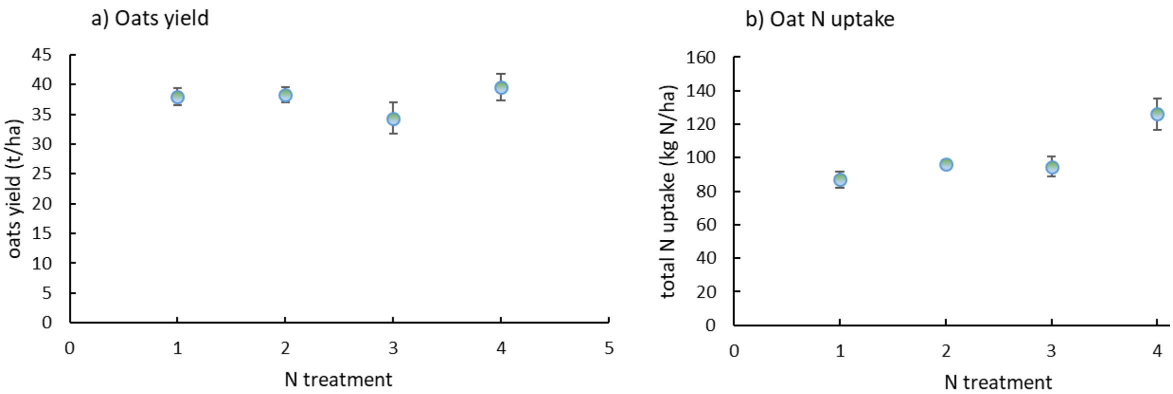

Figure 11. a) Oat fresh biomass yield at different N treatments, and b) total N uptake by the crop. Error bars represent one standard deviation.

Potato crop

- This crop will be sown in October. Fertiliser rates are being confirmed with agronomist input and SVS Technical Panel feedback.

1.1.3 Hawke's Bay Onion rotation

- This rotation starts with the sowing of the onion crop (Figure 12).

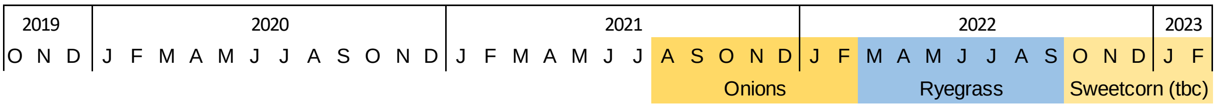

Figure 12. Hawke's Bay onion rotation. The final sweetcorn crop is to be confirmed; the alternative is that this rotation will finish with a ryegrass crop.

Onion sowing

- The onion crop was sown on 25 September 2021 using 3–4 mm seed, coated with Apron®, Fludioxonil and Captan to ensure no insect or disease loss during establishment. Seed were sown to achieve a plant population of 50 plants/m^2 as many of the commercial growers in Hawke's Bay aim for a larger bulb export market.
- Unlike the Canterbury-based rotations, which are sown in a single column of 200 m length and 50 m wide (a 1 hectare block), the Hawke's Bay rotations are grown in two columns 100 m long and 50 m wide. This is because of the field size and arrangement in the Hawke's Bay PFR farm allowing column lengths of 100 m. The column width of 50 m matches the width of the travelling irrigator boom.
- Soil P content was somewhat low and K was slightly moderate prior to planting (Table 2). Basal fertiliser was determined based on the Column 2 Olsen P values, and basal rates applied prior to planting were 86 kg P/ha and 113 kg K/ha using a mix of triple super and 50% potassic super.
- Soil mineral N content in the N3 plots (these are the plots for recommended optimum N rates) and the PMN soil test result are still to be completed. The final N rates are therefore to be determined, but an N rate at planting was recommended of 0, 15, 30 and 60 kg N/ha. Side dressing rates will be confirmed subject to the soil test results.

Table 2. Soil nutrient content of soil for the Hawke's Bay onion crop.

Cropping column	pH	Olsen P (mg/L)	Potassium (me/100g)	Calcium (me/100g)	Magnesium (me/100g)	Sodium (me/100g)	Sulphate-S (mg/kg)	Cation Exchange Capacity (me/100g)	Base saturation (%)
1	7.1	38	1.78	19.6	2.07	0.07	2	24	97
2	7.1	26	1.26	17.8	1.34	0.11	3	23	93

1.1.4 Hawke's Bay Vegetable rotation

- During this quarter, the Pak Choy was harvested and the lettuce crop was sown (Figure 13).

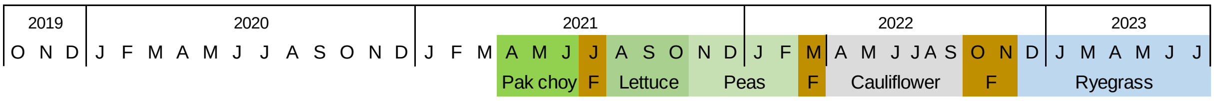

Figure 13. Hawke's Bay vegetable rotation. Fallows ('F') occur between some of the crops in the rotation.

Pak choy harvest

- The pak choy crop was harvested on 8 July 2021, with all plants from a 2 m length of bed collected. Plants were separated into marketable and unmarketable; marketable plants were free from blemish and >65 mm in diameter. Plant numbers were counted and fresh and dry weight recorded. Ground samples were sent for N analysis.
- Roots were sampled using corers, within and between rows to a depth of 30 cm depth, in order to obtain an indication of root biomass and N content. Root samples were washed out, dried, weighed and sent for N analysis.
- The remainder of the area was harvested by a contractor (Thornhill) from 20 to 22 July, and crop residue samples following this were also collected.
- N analysis of all plant material has not yet been completed because of COVID-19 restrictions; a N balance analysis will be completed for subsequent reporting.
- Marketable yield averaged 37.3 t/ha across all N treatments, ranging from 33.0 to 41.6 t/ha (Figure 14a). Marketable yield averaged 72% of the total fresh biomass produced. The amount of residue (blemished or poorly sized plants) averaged 23.7 t/ha, ranging from 23.8 to 24.3 t/ha across all N treatments (Figure 14b).

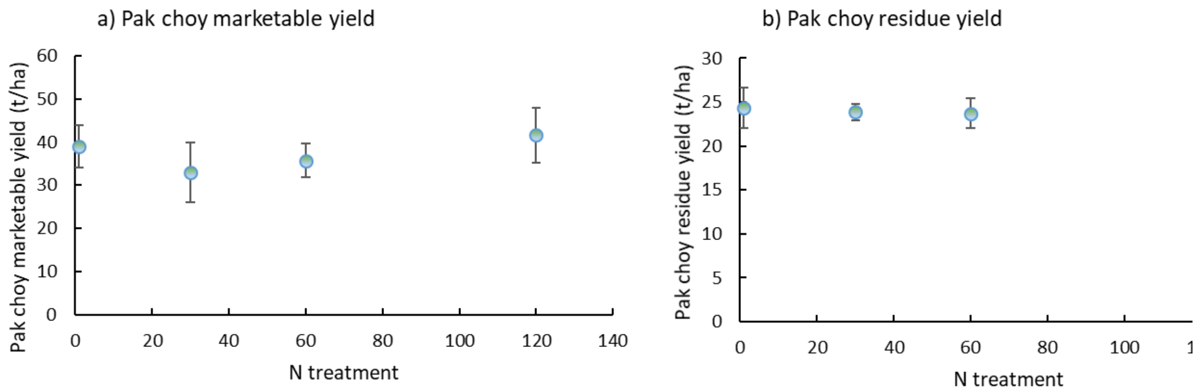

Figure 14. Pak choy a) marketable yield, and b) residue yield, for the different applied N fertiliser rates.

Lettuce planting

- Lettuce seedlings with an average of four leaves were transplanted on 9 September 2021 with a planting population target of 5 plants/m^2. Transplants were irrigated with 5 mm immediately after planting and again with 10 mm on the 13 September to ensure transplants were not stressed by lack of water.

- Soil Olsen P test results varied slightly between the two columns at 21 and 27 mg/L, respectively (Table 3). Consequently, fertiliser recommendations from supporting agronomists were based on the lower Olsen P value and suggested basal fertiliser P rates of 53 kg P/ha applied at planting as 10% potassic super. This provided a K rate of 33 kg/ha.

Table 3. Soil nutrient content of soil for the oat crop in the Canterbury vegetable rotation.

Cropping column	pH	Olsen P (mg/L)	Potassium (me/100g)	Calcium (me/100g)	Magnesium (me/100g)	Sodium (me/100g)	Sulphate-S (mg/kg)	Cation Exchange Capacity (me/100g)	Base saturation (%)
1	6.2	21	0.93	14.5	2.16	0.11	4	22	80
2	6.5	27	1.02	15.5	1.96	0.12	2	22	84

- Soil mineral N content in the N3 plots (these are the plots for recommended optimum N rates) and the PMN soil test result are still to be completed. The final N rates are therefore to be determined, but an N rate at planting was recommended of 0, 12, 25 and 50 kg N/ha. Side dressing rates will be confirmed subject to the soil test results.

1.1.5 Workstream 1 buried leachate cup installation

Experiments started out using leachate cups buried at 60 cm with tube access, which was above the soil for ease of access and obtaining a leachate sample. However, these then had to be removed at the end of every crop, and then re-installed.

This increased soil damage meant that leachate samples were not collected from the same location across the rotation, increasing variability. Hence, buried leachate cups were constructed and placed in all plots. Delayed delivery of material from overseas due to COVID-19 led to delays with construction and field installation of the leachate cups. However, this has since been completed, so all crops currently have buried leachate cups. All normal cultivation operations can occur without affecting the leachate cups and sampling points.

There have been three leachate cups placed at 60 cm depth and three at 120 cm depth in each plot, for a total of six in each plot. This means that every rotation has 192 leachate samples collected after a drainage event.

The set-up of the leachate sampling points is as follows (Figure 15):

- A trench was dug within each plot, as well as a trench from the plot to a sampling point outside of the plot.
- Location of suction cups within the trenches was identified, and holes drilled to the appropriate depth at a 15° angle from the trench.
- Suction cups were installed in an alternating pattern of 60 cm followed by 120 cm depth. Standard practices to ensure good suction cup connection with soil were implemented.
- Tubes from suction cups to sumps were linked for sampling to proceed. Suction cups and tubes were buried at a depth of at least 40 cm.

Figure 15. Suction cup installation. Clockwise from the top, shows the trenches set up to connect the suction cup via tubes to a sampling sump. During crop growth, the sump is located at soil surface level for access. During cultivation, the top portion of the sump is removed and the lower portion buried. Tubes from suction cups along trench floor, and views of suction cups in soil and tubes leading from them towards the sump and sampling point.

1.2 Workstream 2: Regional monitoring

Details of site activities:

- Minimal activity has occurred over this quarter, partly because of seasonal activity patterns and COVID-19 restrictions. We have continued to process plant samples; analysis has been slowed due to COVID-19 restrictions (Table 4).

Table 4. Activity in Workstream 2 regional sites.

Site	Region	Crop	Activities
1	Pukekawa	Ryegrass cover crop	*Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing. *Soil bulk density* samples received, reported to WS2 manager.
2	Pukekohe	Barley cover crop	*Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing. *Soil bulk density* samples received, reported to WS2 manager.
3	Tuakau	Mustard cover crop	*Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing. *Soil bulk density* samples received, analysis ongoing.
4	Matamata	Potato	*Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing. Visit has not been able to be organised. *Soil bulk density* samples received, reported to WS2 manager.
5	Manawatu	Potato	*Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing. *Soil bulk density* samples received, reported to WS2 manager.
6	Manawatu	Summer maize	*Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing. *Soil bulk density* samples received, reported to WS2 manager.
7	Hawke's Bay	Squash	*Discussions* reviewing sampling methodologies and protocols as crop matured. *Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing. *Soil bulk density* samples received, reported to WS2 manager.
8	Canterbury	Potatoes	*Discussions* reviewing sampling methodologies and protocols as crop matured. *Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing and mostly completed. *Soil bulk density* samples received, reported to WS2 manager
9	Canterbury	Pumpkin	*Discussions* reviewing sampling methodologies and protocols as crop matured. *Plant biomass* samples received, processed and submitted to lab for analysis. Plant N content analysis ongoing and mostly completed. *Soil bulk density* samples received, reported to WS2 manager.

1.3 Workstream 3: Modelling

Modelling design and development

- An SVS modelling workshop was held at Lincoln (28 July 2021) and attended by modellers working in science and industry. The aim was to understand the issues around modelling, identify connections and start to develop an approach to modelling for the programme. PFR modellers gave presentations on the science involved in the programme, as well as on the modelling of crop N uptake, organic matter mineralisation, crop residue contributions, drainage and leaching, and initial modelling results obtained. There were also presentations by industry-based modellers.
- Next key steps identified were:
    - Ensure ongoing interactive exchange with a document hub for the group, and interaction with the Community of Practice.
    - Involve social scientists learnings in next meeting.
    - Provide a glossary of common terms and definitions of soil N tests, and publish via Workstream 4.

Modelling delivery and implementation

- Earlier work with the data from the potato–wheat rotation (Searle et al. 2021) identified that, on average, soil mineral N was over-predicted across treatments, indicating the need to refine the components of N balance in the system. Work continues to refine soil parameters for accurate estimation of soil water dynamics as this influences the prediction of drainage and ultimately leaching losses.
- Simulations are being updated with data from new crops in rotation for which harvests have been completed and data summarised. This initial data exploration will show the predictive accuracy of the model and also help identify areas of improvement. Potential N mineralised during growth has been quantified for one crop at Lincoln, providing an opportunity to compare with modelled estimates.

1.4 Workstream 4: Technology transfer

1.4.1 Facilitating implementation

Understanding what is enabling and useful for growers in nutrient management is a key focus of the SVS project, and any developed tool needs to be fit for purpose. This requires strong grower input and understanding of issues faced.

As part of this process, a PFR social scientist had a work plan of focus groups and interviews; this fits into the larger stakeholder map that has been developed.

Focus groups

These have been delayed due to COVID-19 restrictions.

The aim of the focus groups was to explore who makes decisions and takes action on-farm for nutrient management, the drivers, values and attitudes, tools being used – the how and why of these tools.

Focus groups will be made up of a mix of growers from across the potato, onion, and leafy green vegetable sectors.

Key grower and consultant/agronomist interviews:

The aim was to have face-to-face interviews, but because of COVID-19 these have been conducted either by video call or phone call. In this quarter, 10 interviews were held with growers across the key regions of vegetable production.

A report from these interviews is being prepared and will be presented separately.

Grower survey (either e-survey or tele-survey)

The aim of the grower survey was to connect to a wider range of growers with questions that were arising in focus groups. This is on hold for now, given the COVID-19 situation.

Next steps

- Initial survey results will be shared with Workstream 3 modelling group, and others to help shape up further discussions regarding the development of the farmer – facing tool. As part of this, the need for further data acquisition via interviews will be determined.
- Focus groups will be initiated. These groups will provide input and feedback into issues growers face regarding nutrient management, as well as input into what a tool needs, how it would best work. These groups will be key to guiding discussion and design of a farmer − facing tool.
- Focus groups will initially be online while COVID restrictions on travel and meetings are in place.

1.4.2 Facilitating communication

A series of articles has been planned for communication of concepts and developments within the programme. This includes information on soil N tests and meanings, N budgeting, modelling, as well as survey results.

This quarter, an article entitled “Understanding soil nitrogen” was written describing the soil N cycle and soil N testing terms. This article was sent for publication in NZ Grower; COVID-19 has delayed final publication. A copy is included in the Appendix.

2 Key highlights and achievements

Workstream 1

- Oats and broccoli harvest completed in the Lincoln rotations.
- Pak choy harvest completed in the Hawke's Bay rotations.
- Onions successfully sown in Lincoln and Hawke's Bay rotations. Lettuce successfully planted in Hawkes Bay rotation.
- N balance framework used to evaluate broccoli crop shows that where N above yield requirements is applied, the amount of residual soil mineral N increases and there is a greater loss from the system as evidenced by the 'unaccounted' pool of N.
- The N use across the rotation shows that the good management rate of N for the potato–wheat–broccoli rotation has good use of N from the system.
- Buried suction cups for leachate sampling successfully installed in all rotations, despite COVID-19 delays.

Workstream 2

- Samples that have been able to be collected have been processed. Some delays were due to COVID-19 in sample collection, particularly in Waikato and Pukekohe areas.
- Data for preparing N balances of crops are being collated; some delays in nutrient analysis due to COVID-19 restrictions in labs.

Workstream 3

- A meeting was held for PFR and industry modellers to discuss the approaches needed and issues to consider in developing a tool that is workable and usable. The key next step is to include social science findings from Workstream 4 in subsequent discussions.
- Modelling scenarios for all crops harvested so far are being developed and data collated.

Workstream 4

- COVID-19 restrictions meant that face-to-face focus groups did not proceed.
- Interviews were conducted via phone call or video conference due to COVID-19 restrictions. Initial data are being analysed and a report on findings will be presented next quarter.

3 Collaboration with other programmes

- Real time N-losses – Rural Professional Fund through Our Land and Water, looking at real time measurement of N losses under vegetable (onion) production in Hawkes Bay. PFR is providing data analysis support.
- Residue incubation – PFR-funded project looking to quantify the rate of decomposition of different vegetable residues and the rate of N release from the residues into the soil. Some residues will be obtained from crops in Workstream 1.
- Process Vegetable Coefficients – looking to quantify some of the coefficients needed for N uptake and use by processing crops within Overseer.
- Mineralisable N to improve management – a SFFF project looking to improve the measurement and prediction of the amount of biologically mineralised N in a field. This pool of N is a key component for understanding crop N requirements, together with measurements of mineral N (nitrate and ammonium).
- OLW Asparagus N budgeting – looking to quantify N budgets for asparagus crops. This project is using many of the same measurements of soil N and crop N uptake, and a similar outcome is being produced.

4 Upcoming

- Lettuce harvest will be completed in Workstream 1. Data from the onion crops sown will continue to be collected, and the potato crop sown.
- N balance discussions will be ongoing, and data from Workstreams 1 and 2 further evaluated for N balance development.
- Modelling workshop to be held. Scenario testing of data ongoing.
- Ongoing interviews and approaches to focus groups developed. Articles for communication of concepts and developments continue.

5 Acknowledgements

We would like to thank all the agronomists who have supported decision making in Workstream 1 . Thanks to Steve McArthur of Vigour Seeds for supplying onion seeds for sowing in Lincoln and Hawke's Bay. Also many thanks to the PFR Lincoln Soils Lab for all the analysis being done and to Dr Mike Beare (PFR) for calculating the mineralisation from PMN tests.

6 References

Searle B, Michel A, Brown H, Khaembah E, Fraser P, White T, Jenkins H 2021. Sustainable Vegetable Systems - Annual Report 2021. A Plant & Food Research report. SPTS No. 20835.

Appendix – Programme Progress

Recommendations/decision points

- With COVID-19 affecting opportunities for contact, an alternative approach to sharing information with growers (other than focus groups and field days) needs to be developed. A plan to use videos, podcasts and other communications is being investigated and developed.

Progress against workplan

Key: Project Status

Completed	Blue
On Track: no change to outcome(s) or milestone date; <10% variance to budget	Green
Slight Variation/Delay: adverse change to expected outcome(s); >3 month delay to milestone; 10–25% variance to budget	Amber
Attention Required: outcome(s) not expected to be achieved; >6 month delay to milestone; >25% variance to budget	Red

This Quarter

Workstream	Financial	Timing	Outcome	Progress against Work Plan Comments
1.	Green	Green	Green	1.1 Robust data from controlled experiments • Onions successfully sown in Lincoln Potato–Onion rotation. • Potatoes for fresh market will be sown in October. • Onions successfully sown in Hawke's Bay Onion rotation. • Lettuce successfully planted in Hawke's Bay Vegetable rotation. 1.2 Data analysis underway • Contribution to N budget development and modelling.
2.	Green	Amber	Amber	2.1 Data collection, analysis and contribution to reporting • Any changes to protocols with changing crops have been discussed as needed. • Data analysed and collation is ongoing; COVID-19 delay in N data. • N balance framework has been developed, but needs to be implemented with Workstream 2 data.
3.	Green	Green	Green	3.1 Model design and development • Modelling workshop held to discuss and determine structure and requirements of farmer-facing tool determined and detail required for baseline predictions, design options considered. • Update IP plan. 3.2 Model delivery and implementation • Model calibration continues; provides information on system leaching and information for development of farmer-facing tool.
4.	Green	Green	Green	4.1 Understanding the current landscape • Focus groups initiated. • Individual grower interviews conducted. • Surveys conducted as required. 4.2 Extension activities. • Data from focus groups and interviews analysed and used to inform developing extension plan. • N budget development with WS2 participants to co-develop a useable approach. • Communication plan implemented, articles submitted for publishing. • Development of feedback loops from Workstream 4 to Workstream 2 and 3.

Next Quarter

Workstream	Financial	Timing	Outcome	Activity in the next Quarter Comments
1.				1.1 Robust data from controlled experiments • Potatoes for fresh market sown in Lincoln vegetable rotation. • Ongoing data collection across all crops. 1.2 Data analysis underway • Contribution to N balance development and modelling.
2.				2.1 Data collection, analysis and contribution to reporting • Any changes to protocols with changing crops identified and discussed. • Data analysed and passed to Workstream 3. • N balance developed and discussed.
3.				3.1 Model design and development • Modelling workshop held to discuss and determine structure and requirements of farmer-facing tool determined and detail required for baseline predictions, design options considered. Modelling workshop. 3.2 Model delivery and implementation • Model calibration continues; provides information on system leaching and information for development of farmer-facing tool.
4.				4.1 Understanding the current landscape • Individual grower interviews data summarised and reported on. Any missing gaps identified and needed interviews conducted. • Focus groups initiated online due to COVID restrictions. Information to feed into modelling discussions, and used to identify gaps and shape further any surveys/questions needed. • Information from surveys contribute to model meeting and modelling discussions. • Surveys conducted as required. 4.2 Extension activities • Extension plan to be developed taking into account risks from COVID-19. Data from focus groups and interviews analysed and used to inform developing extension plan. • N balance development with Workstream 2 participants to co-develop a useable approach. • Next articles in the list of communication plant to be published. This includes baseline survey information, understanding N in the soil-crop system, and N balances. • Development of feedback loops from Workstream 4 to Workstreams 2 and 3.

Progress towards outcomes

These have been taken from The Programme – Schedule 5 and KPIs in the contract. There is a bit of repetition. Guidance on what is useful.

Outcome	Target	Actual	Status	Comment
WS1 Literature review	30 September			
WS1 Trial sites established at PFR Hawke's Bay and Lincoln	30 November			
WS2 Development of a Technical Working Group	30 Sept			
WS2 Regional on farm monitoring sites established	30 Sept			
WS3 Development of a community of practice made up of current Overseer users	30 Nov			
WS4 Development of extension activity plan	30 Oct			
KPIs				
1.1 & 2.3 Methodology is developed and approved by Technical Panel	31 Oct			
2.1 Attain and maintain participation of 9 monitor paddocks for workstream 2 across 5 regions	30 Sept			
2.2 Technical Panel is established and met	30 Sept			
3.1 Agreement on monitoring data requirements and links to WS2	31 Oct			
3.2 Agreement with Overseer on model access and working relationship	30 Nov			
4.1 Development of extension activity plan	30 Oct			

Key: Outcome Status

Completed: The outcome has been delivered	
On Track: The outcome is on-track to be delivered	
Variation/Delay: There is a delay expected or a change to the outcome	
Attention Required: It is likely that the outcome won't be achieved or the benefits associated with it will be significantly reduced if changes aren't made	

Programme issues or risks

COVID-19 limitations could pose a risk for technology transfer, grower engagement, and importantly for development of a 'farmer-facing' tool. A plan to deal with this risk is being developed.

Communications and engagement

- A plan for monthly articles on the project with timely topics has been developed. This includes updates from the modelling workshop that will be held, N budget approaches, and soil testing terms.
- Within Workstream 2, individual discussion with participating growers of N budgets will help inform work in Workstreams 3 and 4.
- The SVS project was presented by Dr Bruce Searle at the HortNZ conference (August 2021).

Health and safety

Health and Safety protocols have been implemented when visiting fields and conducting experimentation.

Understanding soil nitrogen

Patricia Fraser, Bruce Searle and Mike Beare

Article for NZ Grower

Soils in New Zealand typically contain between 5000 and 9000 kg of total nitrogen (N) per hectare in the top 30 cm. Most (97-99 %) of the total soil N exists as a component of soil organic matter called the ***organic nitrogen fraction*** (included as part of ***Total N*** in Figure 1), which includes humus and soil organisms. This organic portion of soil N is not immediately available for plants to take up via their roots - it is described as being '*immobilised*'.

The other <1-3% of total soil N is in a soluble form present either as ammonium (NH_4) and/or nitrate (NO_3), depending upon the soil and environmental conditions. This portion of soil N is known as ***mineral nitrogen*** (Figure 1) and is the soil N that is immediately available for plants to use. The NO_3 component of ***mineral N*** is the primary source of N that is at risk of being lost if excess water (rainfall or irrigation) drains through (leaches) or runs off the soil. It is also the main source of N that contributes to nitrous oxide (N_2O, a greenhouse gas) emissions to the atmosphere.

There are three primary sources of N that contribute to accumulation of ***mineral N*** in soil: soil organic matter, crop residues and nitrogenous fertiliser. The breakdown of soil organic matter by soil microbes can release between 40 and 300 kg N/ha/yr through a process known as ***mineralisation***. The rate of mineral N release is dictated by soil temperature and moisture, being faster when soils are warm and moist (but not saturated). The ***mineralisable N*** fraction makes up about 1-4% of the total organic N in most soils, but varies depending on soil type and land use history. In annual cropping systems, the plant residues that remain after crop harvest also contribute to the release of mineral N through a process known as decomposition. In addition to ***mineral N*** release, crop residue breakdown also contributes to replenishing the pool of organic N held in soil organic matter.

Although there are well established methods for soil ***mineral N*** testing and recent advances in testing for ***mineralisable N*** (see the PMN test below), there are no well-established methods for predicting the supply of N from crop residues. Though often overlooked, crop residues (including all unharvested plant tops and roots) can be a key source of N to feed the next crop. The amount of this N in residues will vary, though, depending upon the crop grown. For some crops that are known for luxury uptake of N, it also depends on the amount of N the crop had available to it during the growing season, so it pays to understand not only how much N is in the soil, but also how much N might be contained in crop residues. The timing of when this N becomes available and how much is released to the next crop therefore varies depending on crop type that was grown, as well as, of course, the environmental conditions.

To accurately work out whether addition of ***nitrogen fertiliser*** is needed to match the N demand of the next crop, it is important to know how much ***mineral N*** is in the soil, how much N will be supplied by the previous crop residues (***crop residue N***) and how much N will be supplied via ***mineralisation*** of soil organic matter. The rate of ***mineral N*** released from fertiliser will depend on the type, amount and placement (on soil surface or buried) of the fertiliser applied.

Soil test results can be used to help understand how much soil N is available to plants and to work out how much fertiliser N might need to be added to supplement N that is already in the soil.

Total N – this measures the total amount of *organic and mineral N* in the soil. Because there is so much stable N in the soil, it is not possible to measure a change in total N from one year to the next, so it is not a very useful test for growers.

Mineral N – this measures the *combined amount of ammonium and nitrate* in a soil sample. It is the only form of N that is taken up by plants as well as the main form of N lost via leaching and gaseous emissions, and the test result tells you how much N is immediately available to plants. It needs to be measured as soon as possible after sampling. Either refrigerate or freeze samples if they cannot be delivered to the laboratory immediately. The amount of ***mineral N*** in the soil changes during the year mainly due to plant uptake, gaseous losses or leaching.

Mineralisable N – this is the small portion of (1-4%) of the total organic N that is broken down each year by a process called *mineralisation* to mineral N by the action of soil microbes. ***Mineralisation*** occurs most rapidly when the soil is moist and warm. The new *Potentially Mineralisable N* (PMN) test provides the best measure of the ***mineralisable N*** pool in soil. Information on how to convert PMN to the kg N/ha that can be released over a crop growing season is available from most of the commercial testing laboratories in New Zealand.

Crop Residue N – there are currently no reliable methods to predict the release of mineral N from crop residues. This is an important of focus for future research.

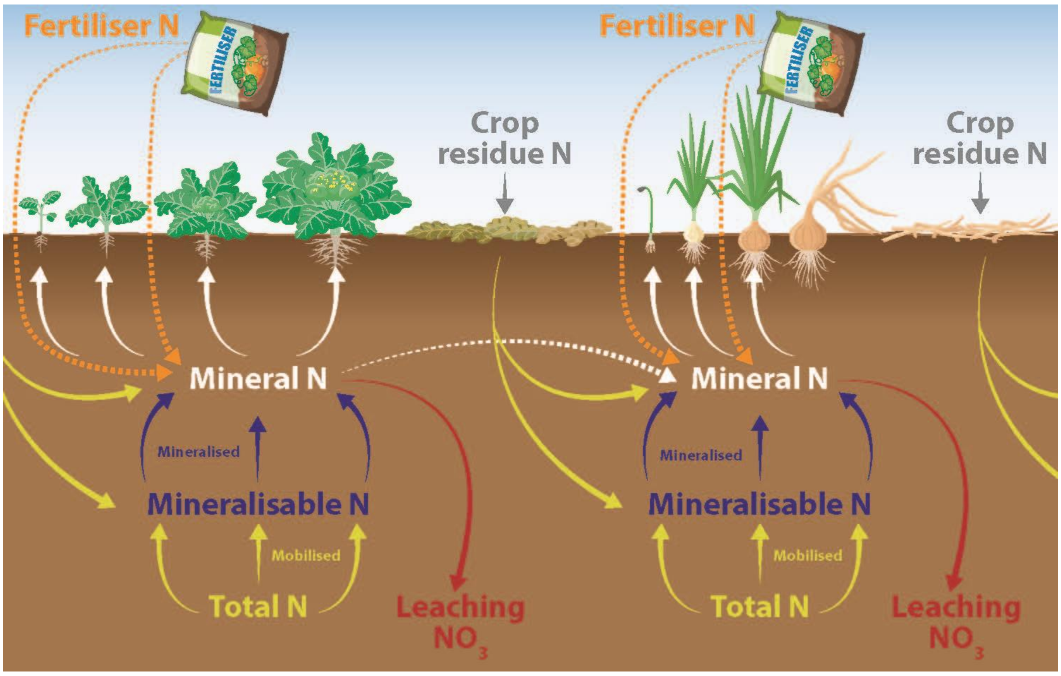

Figure A1: A schematic diagram showing the movement of nitrogen in soil (gaseous losses not shown) during growth of a broccoli crop, followed by an onion crop, within a cropping rotation.
Illustration by Donna Gibson, © Plant & Food Research.

Confidential report for:

Potatoes New Zealand Incorporated

PUBLICATION DATA

Searle B, Michel A, Fraser T, Brown H, Sharp J, Maley S, Dellow S, George M, Arnold NA, van der Weyden J, Sorensen I, Tan Y, Khaembah E, Gillespie R, Tregurtha C, Thomas S, Cichota R, Liu J, Paul W. November 2021. Sustainable vegetable systems – Quarterly report for July–September 2021. A Plant & Food Research report prepared for: Potatoes New Zealand Incorporated. Milestone No. 89135. Contract No. 38729. Job code: P/444006/01. PFR SPTS No. 21743.

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