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2020

Future Proofing Vegetable Production Milestone 8 Progress Report

Sustainable Farming Fund · Ballance agri-nutrients · horizons regional council · Gisborne District Council · Potatoes New Zealand

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LandWISE Inc

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Executive Summary

This report summarises progress made, and deliverables met for **Milestone 8** of Future Proofing Vegetable Production, completed on 30 June, 2020.

The focus of this milestone was wrapping up summer work, presenting findings to industry and supporting farmers make continual on-farm improvements. Through the COVID-19 lockdown we worked from home, wrapped up the summer trial work and continued planning for the next year. As we were not able to visit with growers on farm, we created more online and print resources that will last past the end of the project. Major outputs are an updated and improved nutrient budget template to support growers making science-based fertiliser decisions and nutrient plans and significant additions to the online fertiliser applicator calculator, FertSpread.

With support from the project team, the focus on edge-of-field mitigation was redirected to additional resource development. The FertSpread tool helps growers, contractors or advisors perform fertiliser spreader calibrations and generate standard reports. Originally built for broadcast fertiliser spreaders, it has been updated for calibrating both PTO and ground-drive placement fertiliser equipment commonly used by intensive vegetable growers.

We retain some mitigation activity through a planned trial of biochar filters in local drains in Levin. Currently, growers place sandbags in drains to slow the water and capture sediment after rain events. By using sacks of coarse biochar instead of inert sandbags, there is a chance of removing some nitrogen for minimal cost or time investment. We are designing a monitoring programme to assess the effectiveness of the drain filters, and organising installation. We also have activity in Gisborne supporting grower initiatives to treat nursery wastewater to remove phosphates and nitrates.

The annual LandWISE conference is a major networking event to share project results with the wider farming, research, and industry community. This year's conference was cancelled due to COVID-19 but we have created a virtual conference as a series of podcast interviews with many of the planned presenters and other scientists, farmers and on-farm influencers.

Since moving to level 2 for COVID-19, we have been able to travel again to the regions. We have harvested a potato fertiliser trial, set up a slow-release nitrogen fertiliser trial in a broccoli crop, started a liquid fertiliser trial with a beetroot grower and worked through nutrient budgeting with other growers. Some larger growers are still limiting external visitors to their sites which is delaying some planned trial work.

Much of our work over the last few months has been helping growers confidently complete nutrient budgets for their crops so they can make science informed fertiliser decisions. We appreciate the feedback growers and other users supplied about our first version Nutrient Budget Templates. It helped us revise the templates and we believe Version 2 is a much more informative and grower-friendly product.

Nutrient budgeting has highlighted a severe lack of published information about the Asian brassica crops such as Choy Sum or Shanghai Bok Choy grown in New Zealand. These crops are important for many intensive vegetable growers, and we are collaborating with them to collect typical yield data and taking plant samples to get default nutrient values.

1. Introduction

COVID-19 impacted our activities over the past three months. Our team shifted to working from home and continued resource development, a literature review of crop residue breakdown, phone conversations with growers, and further grower friendly tools being developed. Since NZ moved back to Level 2, we have been able to travel through the regions and have harvested one potato trial in Levin, as well as worked through nutrient budgets with growers, taken yield and residue measurements for Asian brassica crops as part of goal of creating a database for less normal crops, and set up a SmartFert fertiliser trial for a winter broccoli crop.

Over the first period of the lockdown, we took the opportunity to focus on creating tools to further support growers past the end of this project. The two areas we focused on were nutrient budgeting and gear calibration as growers all over New Zealand face the same issues:

1. How much fertiliser should I apply?
2. Am I putting fertiliser in the correct place?

We have re-created the original nutrient templates we made to make them more intuitive for growers and to improve the post-harvest assessment section which is where growers review their practices. Thanks to Agrilink, we now have a pdf version of the Nitrate Budget Template which automatically completes calculations and we have an online tool in development which will automate more of the process for users. One area with poor information for vegetable growing is the nitrogen mineralisation of the previous crop residues. We have put together a LandWISE Note for growers on budgeting nitrogen release from crop residues as part of the suite of tools around nitrogen budgeting.

Due to COVID-19, we had to cancel the annual LandWISE conference, but are taking the opportunity to engage with growers through a different medium. We have re-geared the original conference and in conjunction with Radio Kidnappers have a series of weekly podcasts. Each month has a different theme and at the end of the month the presenters join for a panel. The legacy is a series of discussions on various aspects of sustainable crop production, to which we can continue directing growers in the future.

2. Nitrogen Mitigation Trials

We have now identified an opportunity to investigate in-drain nitrate capture. Currently, growers install sandbag baffles in drains to reduce the water speed and scouring of drain banks after heavy rain events. One grower had discussed the potential of using biochar bags instead of the sandbags.

After talking to growers and a biochar group, we have been offered biochar, and we are in the process of designing and installing a biochar filter within one of the more regularly flowing drains in the Horowhenua area.

The concept is that as the water is normally flowing through the drain, water will filter through the biochar, capturing nitrate in the biochar bags as the water flows through them. We plan to install bags in the base of the drain to allow high flows to pass readily through to drain. We are in the process of determining the best monitoring methods to capture the treatment effects.

2.1 Reallocation of Resources

As outlined in the team Project Review, we re-prioritised the majority of the budget for edge-of-field nitrogen mitigation methods. The reason for the change, as outlined in the project review, was that we had made limited progress identifying where nitrogen was moving through the catchment.

The resource reallocation has been directed to updating “FertSpread”, our online fertiliser spreader calibration tool. See below.

A block to changing on-farm practice we identified was that growers had limited information on equipment performance. Estimates were made with the level of accuracy varying depending on the grower. Also, the gear was often applying fertiliser unevenly, meaning that one row could be receiving up to 50% more fertiliser than others. We continue to complete calibrations with growers with good effect.

3. Supporting Groups and Growers

3.1 On-Farm Trials

We have planned a range of trials in autumn and winter vegetable crops. These trials had to be delayed due to delayed travel to the regions.

Winter on-farm trials that have either started or are planned include:

1. Using Nitrate Quick test strips to determine fertiliser rates for Baby lettuce. The grower currently applies considerably more nitrogen than is removed by the crop. This has been further delayed due to additional biosecurity measures adopted by the grower for visitors from out of the region.
2. Liquid fertiliser applied over the top of spinach and assessment of rates of liquid N that can be applied through the fertiliser nozzle system.
3. Using Nitrate Quick test strips in cauliflower and broccoli crops to determine side dressing rates over winter with 2-3 growers keen to replicate the trials on their farms. One trial with a broccoli crop has been started.
4. Using SmartFert* Generation 2 slow release nitrogen fertiliser in cauliflower and broccoli crops to see whether the grower can eliminate side-dressing in winter. We set up one trial in a broccoli block in mid-June with an expected harvest in early October.

*SmartFert is a 90-day slow-release urea based fertiliser that is sold through Ballance AgriNutrients and other fertiliser suppliers. The release of the nitrogen is based on the soil temperature and moisture levels in an attempt to follow plant demand. A limitation of the Generation 1 product is that it has a limited amount of nitrogen release over the winter period due to the cooler soil temperatures. Generation 2 is a revised product which will give a more constant nitrogen release over the cooler winter months.

3.2 Updated FertSpread Online tool

An important aspect of good farming practice is to apply the right rates of fertiliser in the correct place. Growers can now use the updated FertSpread tool to calibrate ground-drive and PTO driven placement fertiliser spreader gear as well as broadcast spreaders. The updated calculator is operative on www.fertspread.nz.

As growers start trying to target their fertiliser applications more closely to crop demands, poor fertiliser application performance will have a more significant effect on the crop performance as there is less tolerance before deficiencies reduce yield or quality.

The FertSpread system determines both the average rate of the fertiliser application over the whole application width and the consistency across each of the different outlets. Growers can quickly identify where maintenance or adjustment work is required. The accepted maximum variation for nitrogen-based fertiliser is CV = 15%. FertSpread shows growers if their fertiliser application equipment is performing as required. Ensuring the fertiliser is being applied where it is needed also allows growers to maximise the return on the fertiliser they apply.

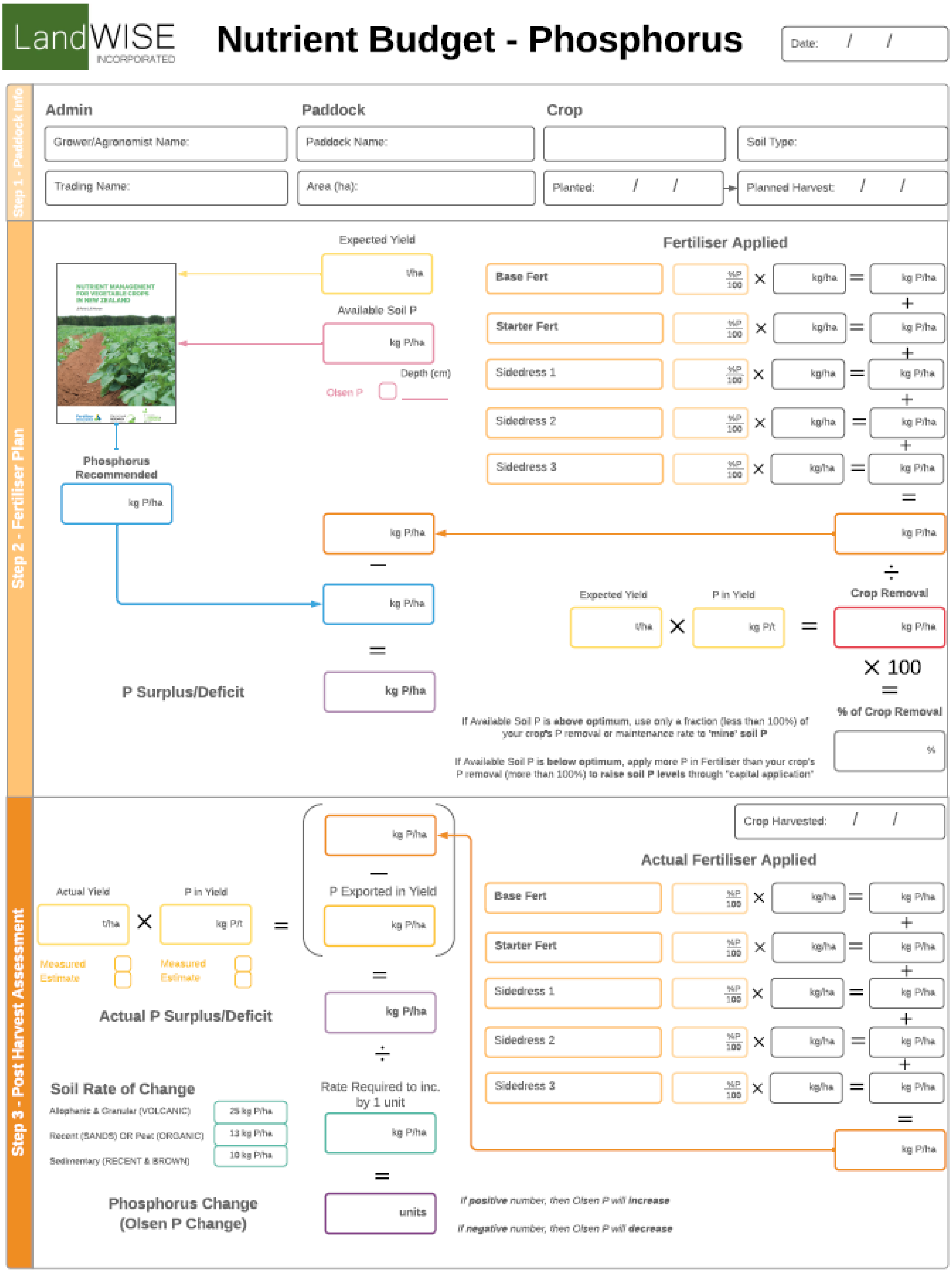
3.3 Revised Grower Nutrient Budgets

We have extensively revised our Nutrient Budget templates, created for growers to methodically determine and record appropriate fertiliser rates, and to review their practices at the end of the season. In June we used the new template for Nitrate with two growers, walking them through the process of the budgeting. Preliminary feedback has been positive. Growers are pleased to have some evidence to prove their fertiliser plans are at or below recommended rates (a requirement for NZ-GAP), and we have noted that it is encouraging them to review "Nutrient Management for Vegetable Crops in New Zealand" (Reid & Morton, 2019) in more detail.

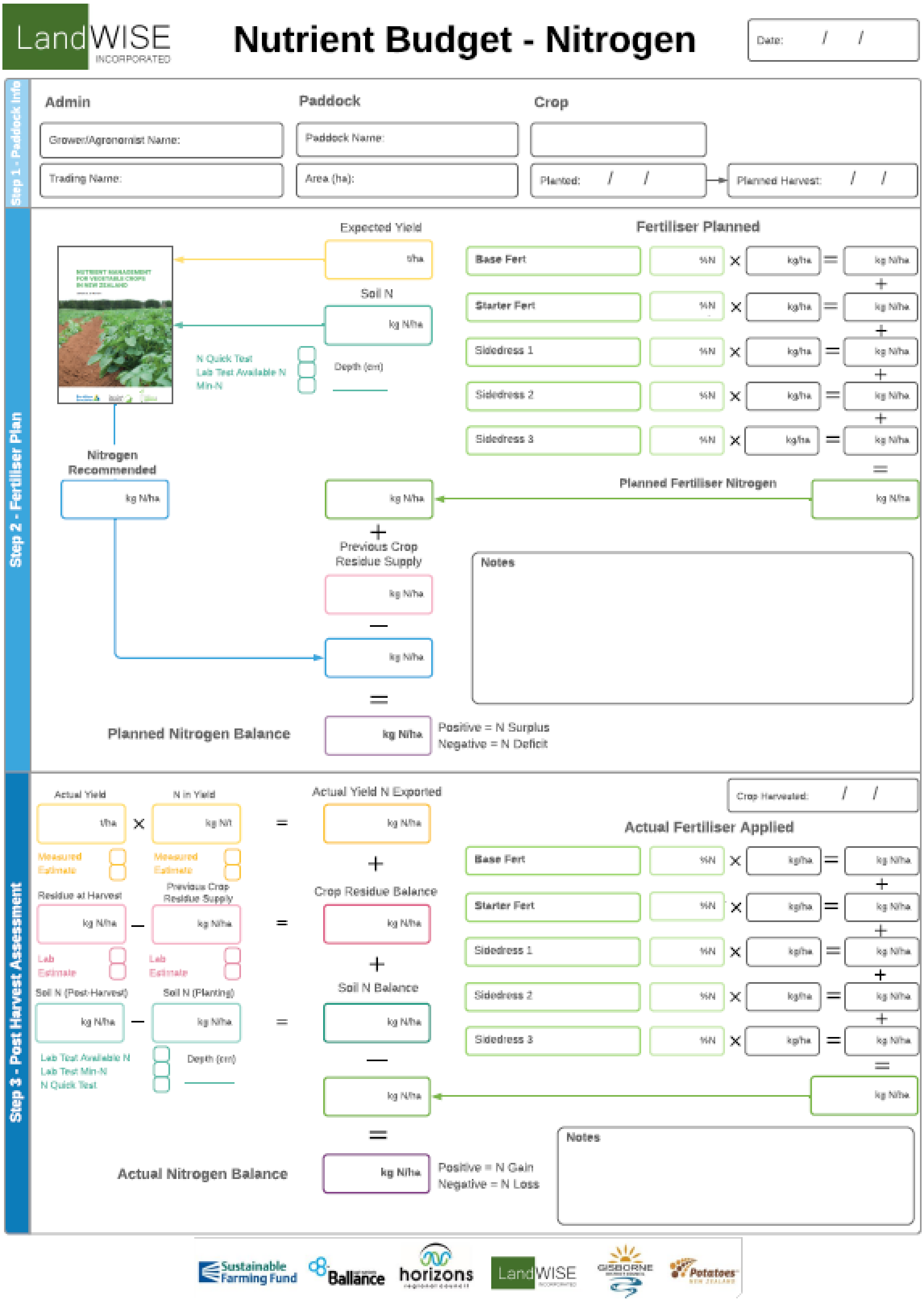
The last step in the revised templates encourages growers to collect real data from crops at harvest. Added data inputs include the weight of yield in tonnes per hectare, soil nitrogen levels post-harvest, and nitrogen supply from crop residues. This series of post-harvest assessments is not typical for many vegetable growers but encourages them to collect data to understand nutrient flows within their farm system on a deeper level.

We are in completing revision of Nutrient Budget User Guides. These take growers through the step-by-step process for nutrient budgeting.

3.3.1 Phosphorus Budget Template



3.3.2 Nitrogen Budget Template



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Nutrient Budget - Nitrogen

Date: / /

Step 1 - Paddock Info

Admin	Paddock	Crop
Grower/Agronomist Name:	Paddock Name:	
Trading Name:	Area (ha):	Planted: / / → Planned Harvest: / /

Step 2 - Fertiliser Plan

Expected Yield: t/ha

Soil N: kg N/ha

N Quick Test / Lab Test Available N / Min-N

Depth (cm)

Nitrogen Recommended: kg N/ha

Fertiliser Planned

Base Fert	%N	×	kg/ha	=	kg N/ha
Starter Fert	%N	×	kg/ha	=	kg N/ha
Sidedress 1	%N	×	kg/ha	=	kg N/ha
Sidedress 2	%N	×	kg/ha	=	kg N/ha
Sidedress 3	%N	×	kg/ha	=	kg N/ha

Planned Fertiliser Nitrogen: kg N/ha

kg N/ha + Previous Crop Residue Supply kg N/ha − kg N/ha =

Notes

Planned Nitrogen Balance: kg N/ha

Positive = N Surplus
Negative = N Deficit

Step 3 - Post Harvest Assessment

Crop Harvested: / /

Actual Yield t/ha × N in Yield kg N/t = Actual Yield N Exported kg N/ha

Measured / Estimate

\+

Residue at Harvest kg N/ha − Previous Crop Residue Supply kg N/ha = Crop Residue Balance kg N/ha

Lab / Estimate

\+

Soil N (Post-Harvest) kg N/ha − Soil N (Planting) kg N/ha = Soil N Balance kg N/ha

Lab Test Available N / Lab Test Min-N / N Quick Test

Depth (cm)

− kg N/ha

Actual Fertiliser Applied

Base Fert	%N	×	kg/ha	=	kg N/ha
Starter Fert	%N	×	kg/ha	=	kg N/ha
Sidedress 1	%N	×	kg/ha	=	kg N/ha
Sidedress 2	%N	×	kg/ha	=	kg N/ha
Sidedress 3	%N	×	kg/ha	=	kg N/ha

= kg N/ha

Actual Nitrogen Balance: kg N/ha

Positive = N Gain
Negative = N Loss

Notes

3.4 MQuant StripScan Reference Card

The Nitrate Quick Test strips are an easy, rough tool to estimate how many kg N/ha are currently available in the soil. Combined with soil sampling to the crop's rooting depth at key crop growth stages they are an important part of actively managing soil nitrogen inputs.

Estimating the soil Nitrate level from the colour chart is subjective and some growers have difficulty. MQuant has created a reference card and the MQuant StripScan app to simply measure and record the soil nitrate levels. We have tested the card and app, and found them easy to use.

Figure 1. MQuant StripScan Card

The StripScan cards can be bought online through: [www.labsupply.co.nz/stripscan-reference-card-for-the-measurement-of-mquant-nitrate-test-cat-no110020.](www.labsupply.co.nz/stripscan-reference-card-for-the-measurement-of-mquant-nitrate-test-cat-no110020) We will organise a group order if there is sufficient grower demand.

3.5 Asian Brassicas

Many Levin growers produce a range of fresh vegetables including Asian brassicas such as Wong Bok (Chinese Cabbage), Bok Choy (either Shanghai or regular), Choy Sum and others. Currently, there is very little published information on these crops in NZ, and neither the "Nutrient Management for Vegetable Crops in New Zealand" guidelines book or compliance tools such as Overseer have information on these crops.

We have started to collect typical values for these crops to assess if these crops are similar or substantially different to any of the other crops that have New Zealand published information.

We are collecting information on typical yield information, root depths and residues and sending plant samples for analysis to get a better understanding of the nutrient uptake. Preliminary information is shown in Table 1.

Table 1 Concentrations (kg nutrient per tonne fresh weight) for N & P, along with typical fresh yield values and predicted mineralisation rates. Data for crops is from locally grown crops near Levin, New Zealand (2020).

	Typical Yield (fresh weight) tonne/ha	N	P	Mineralisation over 4 weeks (% total N)*	Mineralisation over 10 weeks (% total N)*	Dry Matter (DM) %
Bok Choy *Shanghai* (Head)	***45***	1.9	0.32	55	57	3.9
Bok Choy *Shanghai* (Residue)	***26***	1.9	0.29	51	55	4.3
Choy Sum (Head)	***24***	2.8	0.42	65	65	4.9
Choy Sum (Residue)	***18***	2.3	0.23	67	67	3.9

*Mineralisation estimates are based on the Oregon State University Cover Crop formula (Sullivan et al., 2019).

3.6 LandWISE Note: Crop Residue Nitrogen Release Calculator

Growers lacked information on crop residue nutrient levels and release rates. From a comprehensive review of recent trial work done in the USA and the EU for organic cropping farms, where crop residues are the primary source of nutrients to the subsequent crop, we have prepared a LandWISE Note on Nitrogen Release from Crop Residues (refer to the Appendix). An up-to-date comprehensive nutrient table from recent work out of the Leibniz Institute of Vegetable and Ornamental Crops (IGZ) in Germany was used to estimate the nitrogen content and dry matter percentages for the majority of crops of interest.

The Oregon crop residue decomposition research suggests the majority of the mineralisation happens within the first four weeks after incorporation if soil is warm. Using default crop values, the percentage of nitrogen release from the total nitrogen content of the crop residues is estimated for the first four and ten weeks. The work done suggested that after ten weeks, the crop residues are well decomposed and the rate of further release of nitrogen will be slowed.

3.7 Other LandWISE Notes

We continue to find there may be information on what is best practice, but little guidance on how growers are actually supposed to implement it on-farm. We are adding to our series, “LandWISE Notes”; resources growers can continue to access after the project has finished. Modelled after the old MAF Advisory “AgLinks”, these are typically 1-2 page reference guides to help inform grower decisions.

The first series of LandWISE notes focus on nutrient budgeting. Three further LandWISE Notes in preparation are:

1. Soil Sampling for Bed Vegetable Crops
   Where fertiliser is typically applied in bands

2. Target Soil Nitrogen Test Values and Rooting Depth/Soil Testing Depths
   For different crop growth stages across a range of common vegetable crops. Research work in Europe has identified target levels for various crops, which we are in the process of consolidating into a simple document for growers.

3. Soil Test or Estimated Value?
   In many vegetable cropping systems, there is a high likelihood of gaining economically beneficial information from soil nitrogen testing prior to side-dressing.

4. LandWISE Online Conference

The LandWISE Online conference began in June with four podcast interviews released so far. The "Reducing Nitrogen Losses from Vegetable Production" live panel discussion is on Tuesday June 30th. Engagement so far has been good with over 80 listens in our first month of podcasting. The podcasts are also being aired on a local station, Radio Kidnappers, at 5:00pm on Fridays.

The podcast interviews have been aimed at farmers and introduce a variety of topics, updates and insights from lead growers, researchers and industry. We are planning webcast presentations for topics of a more technical nature or which need visuals.

- Podcast Page: http://www.landwise.org.nz/landwise-online-podcast/
- Radio Kidnappers: https://www.radiokidnappers.org.nz/Programmes/Details.aspx?PID=ecc3affb-c438-4025-8d8c-e1f5ef7b83dd

JUNE PODCASTS: Reducing Nitrogen Losses from Intensive Vegetable Cropping	Released
Growers Making Changes (Jay Clarke – Woodhaven Gardens)	5th June
On-Farm Trials with Growers (Luke Posthuma – LandWISE)	12th June
"Back of an Envelope" Nutrient Budgeting (Georgia O'Brien – LandWISE)	12th June
Cover Cropping for Vegetable Systems (Charles Merfield – BHU Organics Trust)	19th June
PANEL DISCUSSION: 1 hour at the end of the month	30th June

JULY PODCASTS: Managing Herbicide Resistance	Released
Identifying Instances of Resistance (Kerry Harrington & Hossein Ghanizadeh – Massey University)	3rd July
Herbicide Resistance Survey (Chris Buddenhagen – AgResearch)	10th July
Herbicide Use and its Drivers (Martin Espig & Robyn Dynes – AgResearch)	17th July
Non-Herbicide Weed Control (Dan Bloomer – LandWISE / Trevor James & Katherine Tozer - AgResearch)	24th July
PANEL DISCUSSION: 1 hour at the end of the month	TBD

JULY WEBINARS: Managing Herbicide Resistance	Released
Big Data & Modelling (Philip Hulme – Bioprotection Research Centre)	TBC
Using Genetic Markers to Identify Herbicide Resistance (Andrew Griffiths – AgResearch)	TBC

The themes for August, September, and October have been decided but we are yet to confirm the speakers and topic outlines. They are as follows:

- August: Strip-Till and Cover Crops
- September: Harnessing the Power of Microbes
- October: Edge of Field Treatments

5. Project Team Meeting & Status Report

We were not able to hold a face-to-face Project Team meeting. After discussion with our SFF Advisor, the LandWISE Board and project farmers we distributed project updates and a recommendation document to the Project Team members. The main recommendation was to divert resources from Edge of Field Mitigation (bioreactors etc.) to updating the FertSpread on-line tool. Specific phone conversations were held with the Team Chair, Jay Clarke and Finance Person, John Evans and the recommendations agreed. We did not receive any alternative views from other team members.

6. References

Reid, J. B & Morton, J. D. (2019). "*Nutrient Management for Vegetable Crops in New Zealand*". Horticulture New Zealand on behalf of Vegetables Research and Innovation Board and Fertiliser Association of New Zealand, Wellington.

Sullivan, D. M., Ameloot, N., Sullivan, C., & Brewer, L. J. (2019). *OSU Organic Fertilizer & Cover Crop Calculator: Predicting Plant-available Nitrogen Why use the OSU calculator? Oregon State University Extension Service*. *May*, 1–19. www.oregon.gov/oda/programs/pesticides/

7. Appendix

Crop Residue Nitrogen Release Calculator

Predicting Plant-available Nitrogen Release from green plant material

#Mineralisation, #Nitrogen release, #Cover Crop, #Crop Residues

Introduction

Crop residues are plant materials left in the paddock after a crop has been harvested. These residues include stalks, stubble, leaves, and diseased product. When the crop residues are incorporated into the soil, they quickly decompose and release a flush of plant-available nitrogen (PAN) into the soil profile. The Crop Residue calculator is based on the Oregon State University Cover Crop Calculator – it is a tool to assist with nitrogen budgeting. It can be used to estimate the amount of PAN that will be become available from a cover crop or crop residues for the next crop.

Calculator Data input

To estimate the plant-available Nitrogen (PAN) release from a crop residue (either vegetable harvest residue or cover crop), you need to measure:

- Total Residue on field (t/ha)
- Moisture content (%)
- Nitrogen concentration (N% of DM)

Crop residues in the field can be estimated by taking 2-4 yield measurements from a measured area in the field. If the moisture and N% values are unknown, send a representative sample to an agricultural lab, and ask for total N and dry matter percentage. Refer to the back page for typical values of a wide range of vegetable crops.

Calculator Assumptions

- Sufficient moisture or irrigation is present to support the mineralisation process in the soil. Where crop residues are left on the surface, the regular drying/wetting slows the decomposition process.
- Soil temperatures are 22°C. See the comments on temperature to estimate PAN release over the winter period.
- After mineralisation, PAN is retained as nitrate-N in the soil. Excess rain or irrigation will cause leaching as would occur with soluble fertiliser N.
- In crop residues with low N concentrations (<1% N in DM), the PAN is negative indicating that surplus PAN is consumed by microbes in the soil creating soil organic matter (SOM) This can result in less PAN nitrogen for your next crop.
- Only a portion of the nitrogen in the crop residues will be released as PAN. The remaining portion will predominantly be added to the soil organic matter which will break down slowly over time.
- The equations run for just 10 weeks. Data collected to build the OSU calculator suggested that most of the PAN release occurs within the first 4 weeks. After 10 weeks, the extra release is minimal and is less useful when trying to make a fertiliser decision.

Temperature Effects on PAN

All the experiments and calculations are done based on a soil temperature of 22°C. As a generalisation, the biological activity in the soil doubles with every 10°C increase. This is true for the decomposition process which influences the rapid breakdown of green plant material and PAN release.

Although temperature does affect the speed of the release of PAN, after 4 weeks even at lower soil temperatures, a substantial portion of the total decomposition and PAN release has occurred. The rapid release of PAN will still occur even at low soil temperatures (<10°C). The quality and N concentration of the crop residue has a larger impact on the nitrogen release than the soil temperature.

PAN from Crop Residues

PAN is predicted by segmented equations, as shown in Figure 1. The “change point” between the two linear equations is approximately 2.3% Total N at both 4 and 10 weeks after incorporation.

At 4 weeks after incorporation

When total N is less than 2.34%:

PAN = -31 + [(total N – 1.03) x 43.3]

Where total N is greater than 2.34%:

PAN = 25.8 + [(total N – 2.34) x 11.7]

At 10 weeks after incorporation

When total N is less than 2.26%:

PAN = -11 + [(total N – 1.03) x 37.9]

Where total N is greater than 2.26%:

PAN = 35.6 + [(total N – 2.26) x 8.5]

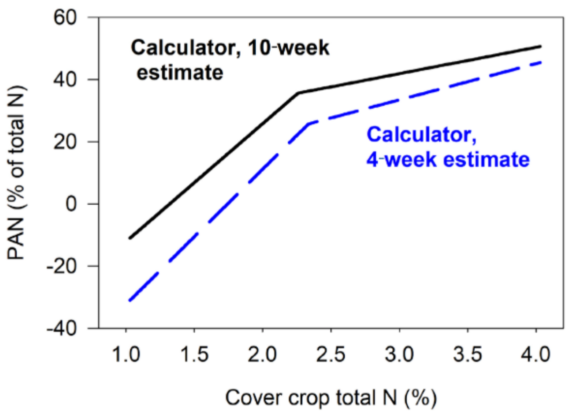

Figure 2. Relationship between the total N analysis of crop residues and predicted PAN produced at 4 and 10 weeks after incorporation (Source: Sullivan et al. (2019). OSU calculator)

Crop PAN Typical Values

Table 2. PAN estimate for typical crop values (Crop data adapted from Feller, C. (2013): Leibniz Institute for Vegetable and Ornamental Plant Cultivation).

Crop Type	Crop N	PAN @ 4 weeks	PAN @ 10 weeks	PAN @ 4 weeks	PAN @ 10 weeks
	% of DM	% of total N		kg N/ha	
Broccoli	3.5%	39	46	76	89
Brussel Sprouts	1.0%	-32	-12	-29	-11
Cabbage (White)	2.7%	30	40	45	59
Cabbage (Red)	1.3%	-20	-1	-18	-1
Cabbage (Savoy)	2.7%	30	39	41	55
Cauliflower	3.8%	43	49	65	74
Kale	2.0%	9	26	19	54
Bok Choy (Shanghai)*	4.5%	51	55	26	28
Choy Sum*	6.0%	67	67	28	28
Wong Bok	3.0%	34	42	30	38
Beetroot (Retail)	2.5%	28	38	28	38
Carrots	2.2%	17	33	32	63
Radish, bunch	2.4%	27	37	5	6
Green Beans	2.2%	18	34	16	30
Process Peas	2.0%	9	26	12	33
Sweetcorn	1.7%	-5	13	-6	16
Bulbous fennel	3.0%	34	42	25	31
Celery	2.3%	19	35	3	5
Lettuce (Baby Leaf)	5.0%	57	59	2	2
Lettuce (Ice-berg)	4.0%	45	50	23	25
Lettuce (Fancy leaf)	3.6%	41	47	7	8
Lettuce (Romana)	4.4%	50	54	17	19
Spinach	4.0%	45	50	9	10
Spinach (Baby Leaf)	4.5%	51	55	11	12
Onion	1.0%	-32	-12	-19	-7
Spring Onion	2.0%	9	26	4	10
Leek	2.5%	28	38	28	38

Note: The above data is from international literature, this should be checked with local plant samples.

*NZ Nitrogen data from crop samples tested (2020).

Reference

Feller, C., Fink, M., Rather, M., Laber, H., Strohmeyer, K., and Ziegler, J. (2013). *Düngung im Freilandgemüsebau. In: Fink, M. (Hrsg.).* Schriftenreihe des Leibniz-Instituts für Gemüse- und Zierpflanzenbau (IGZ), Heft 4, 4. Auflage. Großbeeren. ISBN 1437-3394: Retrieved from: http://www.igzev.de/publikationen/IGZ_Duengung_im_Freilandgemuesebau.pdf

Magid, J., Henriksen, O., Thorup-Kristensen, K., & Mueller, T. (2001). Disproportionately high N-mineralisation rates from green manures at low temperatures–implications for modeling and management in cool temperate agro-ecosystems. *Plant and Soil*, *228*(1), 73-82.

Sullivan, D. M., Ameloot, N., Sullivan, C., & Brewer, L. J. (2019). *OSU Organic Fertilizer & Cover Crop Calculator: Predicting Plant-available Nitrogen Why use the OSU calculator? OREGON STATE UNIVERSIT Y EXTENSION SERVICE*. *May*, 1–19. www.oregon.gov/oda/programs/pesticides/