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FACT SHEET | MAY 2025

NITROGEN CYCLING AND ACCOUNTING FOR INCREASED NITROGEN USE EFFICIENCY

Why focus on nitrogen (N) use efficiency?

When part of a crop is removed (i.e. harvested), the nutrient in the harvested biomass is removed from the production system. Traditionally nitrogen, one of the major plant nutrients along with potassium, is added back to the production system by applying various nitrogen fertilisers.

Australia manufactures only a small proportion of the urea that it uses - for use on crops and producing fertilisers such as MAP and DAP - with the remainder being imported. Recent global events have resulted in volatility in the market and supply problems from China, Russia and Europe. Urea prices are closely linked to energy prices both in production and shipping. All of these factors have meant Australian farmers have been faced with rising nitrogen fertiliser costs for some years.

To alleviate this, growers are increasingly focusing on nutrient use efficiency (NUE) using organic rather than synthetic nutrient sources such as organic amendments or including N fixing crops such as legumes in their rotations. Focussing on NUE for nitrogen (N) and alternate N sources, growers have a greater range of options than sole reliance on products with

KEY MESSAGES

- Reduce nitrogen losses by determining the crop requirement based on initial soil tests and crop nitrogen removal rates.
- Maintain nutrient use efficiency by conducting in-field monitoring such as sap tests to understand nutrient uptake and adjust the nutrition program if needed.
- Consider the use of nitrogen fixing cover crops such as legumes to be planted between crop rotations to benefit from the nitrogen the crops fix.
- The rate of N released from crop residues and cover crops depends on the C:N ratio of the residues which should be below 24:1.
- Remember the “4Rs” rules – Right fertiliser, Right place, Right time, Right amount.
- Consider the use of slow-release mineral or organic nitrogen fertilisers
- Nitrogen input to crops.

Hort Innovation

This project has been funded by Hort Innovation using the vegetable and melon research and development levies and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

RMCG

ahr applied horticultural research

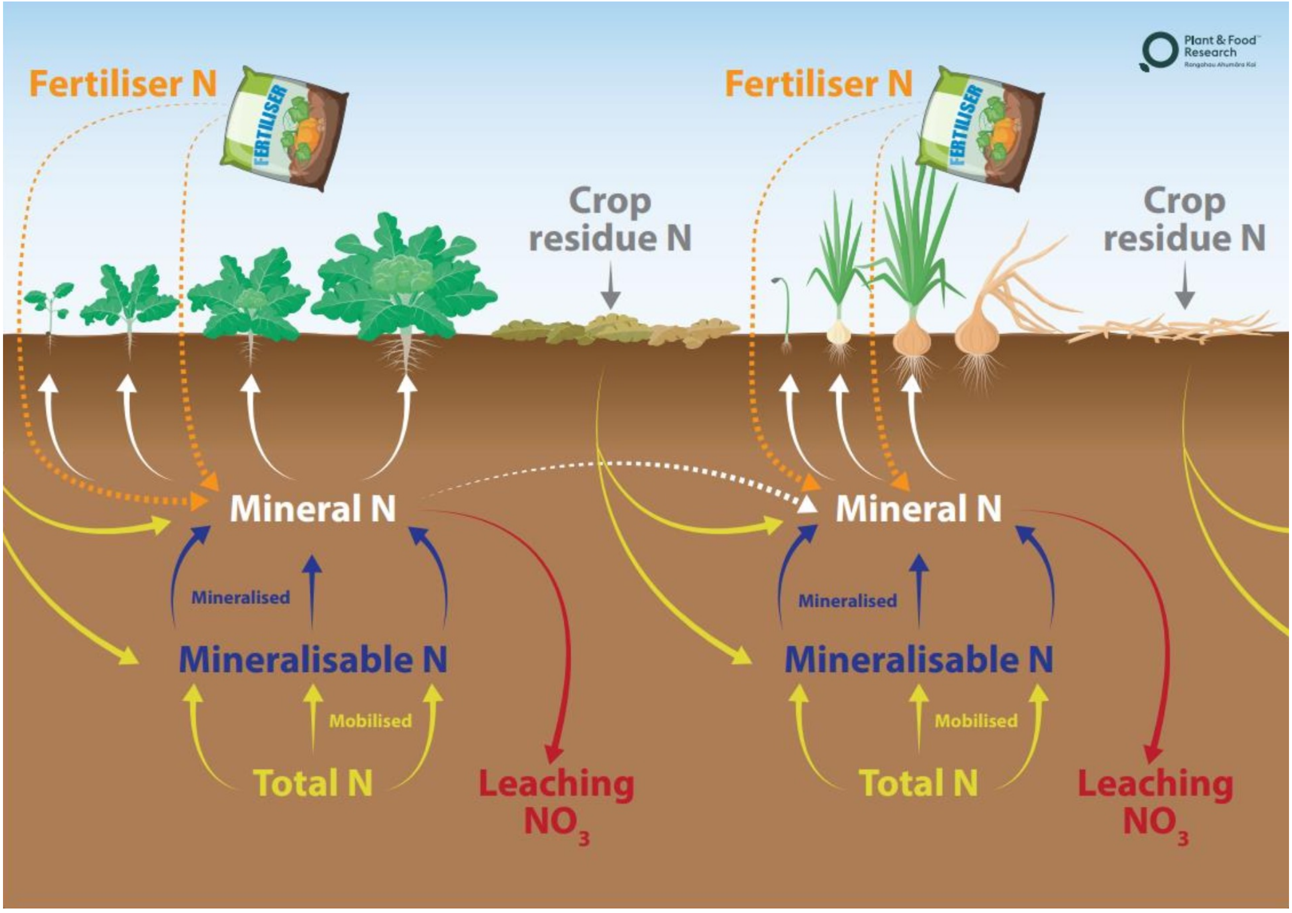


Figure 1: This figure shows nutrient uptake, cycling and recycling in a vegetable production system. Mineral fertilisers are taken up by the crop, nutrients are then recycled to the soil via crop residues and then cycled through the ecosystem by micro-organisms which mineralise nutrients or are leached out of the ecosystem. (image: Plant and Food Research, NZ)

at times unreliable availability and increasing pricing trend.

Nitrous oxide emissions from nitrogen manufacturing and N fertiliser use as well as volatilisation of urea and ammonium based fertilisers on farm is becoming another driver for monitoring and improving nitrogen use efficiency.

This factsheet provides a worked through example for calculating NUE and information on how alternative N sources can improve NUE%.

WHAT IS NITROGEN USE EFFICIENCY (NUE%)

- Nitrogen Use Efficiency (NUE) is a term used to indicate the ratio between the amounts of fertiliser nitrogen (N) applied to the crop and the amount of N removed from the paddock by the harvested crop materials. This includes the marketable yield, and everything brought into the packing shed and discarded when grading and packing.
- NUE% is an agronomic indicator.

Overview

1 Nitrogen (N) cycling

The nitrogen cycle is a repeating cycle of processes during which nitrogen moves through both living and non-living things: the atmosphere, soil, water, plants, animals and microorganisms.

For nitrogen to be cycled and utilised by crops, organic matter containing nitrogen needs to be broken down by invertebrates. Microorganisms (microbes) can then use the resulting fine matter as a food source. In the process, nitrogen is mineralised, i.e. complex organic molecules are broken down into plant available N forms of ammonium (NH_4^+) and nitrate (NO_3^-). This process cannot be achieved quickly without adequate incorporation of organic materials such as crop residues or cover crops into the soil (due to C:N ratios described below). The biological processes in the soil are influenced by soil pH, humidity, soil moisture, oxygen and temperature.

Nutrient cycling is disrupted when plants or organisms are removed from the system. In agriculture, this occurs via harvesting of crops or fodder or grazing. The removed nutrients including nitrogen can be supplemented by the incorporation of organic sources such as cover crops, particularly nitrogen fixing legumes and mineral sources which can replace the nutrients removed from the cropping system.

An important factor that affects nitrogen cycling and availability to plants is the carbon to nitrogen ratio (C:N) of the organic material available for microbes to use. Soil microorganisms that decompose organic matter have a specific C:N ratio within their cells of around 8:1. Table 1 gives an overview of the effect of the C:N ratio of organic matter (e.g. soil OM, crop residues, organic amendments) on soil microbiology and crops.

Table 1: Effect of C:N ratio of soil organic matter on soil microbiology and crops.

C:N ratio	Effect on soil microbiology	Effect on crops
Low (< 10:1 to about 20:1)	N is sufficient to cover the base requirements for microbial growth.	Mineralised ammonium (NH_4^+) and nitrate (NO3-) can be taken up by plants from the soil
	Microbes **mineralise** organic N into plant-available forms (ammonium (NH_4^+) and nitrate (NO_3^-).	
High (e.g., 25:1 or 35:1)	All available N is used to sustain microbes i.e. microbes **immobilise** N, also called N fixing.	No available N from organic material – microbes are competing for the resource
	N will cycle as microbes die – but will only be plant-available at lower C:N ratios.	

Rule of thumb: for every tonne of carbon in soil organic matter or incorporated organic material of a C:N ratio of 10:1, there are about 100 kilograms (kg) of nitrogen, 15 kg of phosphorus and 15 kg of sulphur that become available.NUE% is an agronomic indicator.

2 Nitrogen Losses

Nitrogen losses are a financial loss to growers and pose an environmental risk.

Nitrogen losses to the production system can occur:

- directly from applied fertilisers,
- during a fallow period or
- from a cover crop which does not make use of residual nitrogen from a preceding crop.

Nitrogen losses occur in the following ways

- as gases to the atmosphere (volatilisation):
  - nitrogen oxide or dioxide gas (NO or N_2O, both are greenhouse gases) when soils are waterlogged, even for short periods - due to denitrification of nitrate
  - ammonia (NH^{4+}), this occurs with ammonium containing fertilisers, and particularly urea.
- via leaching / runoff (rain/irrigation) of soluble N (ammonium and nitrate)
- soil erosion that also takes organic matter (and soil microbes) from the growing system.
- waterlogged soils for short periods of time, leading to denitrification of nitrate (NO_3).

Reducing nitrogen losses

Generally, N losses can be mitigated by balancing inputs with crop requirements based on removal rates at key growth stages, accounting for N availability in the soil before planting, applying N inhibiting or slow-release fertilisers, using foliar applications strategically, timing of applications to avoid run-off and leaching risks, fertiliser placement to avoid non-cropped areas and the use of 'catch crops' such as N fixing crops or other cover crops between cash crops.

Cover crops 'mop up' available nutrients that have not been used by the cash crop and utilise nitrogen that mineralises during an otherwise fallow period. Legume cover crops can help replace nitrogen removed by the cash crop via symbiotic N-fixing bacteria (***Rhizobium***) in their roots. N-fixing by legumes can vary widely depending on the legume species, growing conditions and whether the legumes have been successfully inoculated. According to various literature sources N-fixing can range from very little to up to 300 kg/ha N.

Refer to the Skye Demo Site Case study which shows nutrient management in practice through the incorporation of various cover crops including legumes, buckwheat and sorghum (https://soilwealth.com.au/2023/09/nutrition-nous-key-to-productive-crops-in-skye-victoria/).

Monitoring for plant N levels can help to finetune the N nutrition program.

The following section provide more detail on some aspects of reducing N losses.

Rule of thumb: N-fixing cover crops such as legumes act as a nutrient 'catch crop', retaining nutrients for cycling to the next cash crop and they will also fix N from the atmosphere.

LEGUME CROPS CAN BE AN ALTERNATIVE N SOURCE TO FERTILISER

A well growing legume cover crop may add 100-200 kg/ha of nitrogen to the soil. This can be a substantial saving per hectare. In addition, for every tonne of shoot biomass (dry weight), about 20 kg of nitrogen will be added to the soil. The challenge of using legumes can be to manage the timing of N becoming available to the following crop and matching this with the vegetable crops N need.

Things to consider when choosing the right inoculum to get the best nitrogen out of your crop.

- Add the right Rhizobium inoculant – commercial inoculants are formulated and available in peat, clay or peat granules, liquids and as a freeze-dried powder.
- Know the right rate of rhizobium inoculant levels to apply to achieve good nodulation. High numbers of rhizobia result in rapid nodulation if lie in the desirable range of 100-1000 rhizobia per gram of soil (GRDC).
- Ensure that your inoculant meets the specification standards by checking for the Australian Inoculants Research Group (AIRG) Green Tick Logo.
- Select and grow a vigorous legume cover crop (the more biomass above and below ground, the more nitrogen added, if the crop is well nodulated).
- Inspect the crop after approximately 4 weeks plant growth to identify any nodulation on the plant roots.
- If possible, start with low to moderate soil nitrate levels – less than 50 kg/ha of soil nitrate will encourage your legumes to add the most nitrogen; if the cover crop will follow a cash crop that is expected to leave >50 kg/ha residual N in the soil and or mineralise high amounts of N, e.g. a high residue brassica crop, consider using a mixed cover crop that incudes legumes.
- If the soil conditions are favourable and satisfy desirable pH, texture and organic matter levels, rhizobia are able to survive in the soil for many years.
- Ask your local agricultural supplier to help with the selection of the right rhizobium inoculant.
- For more information about inoculants for legumes refer to the GRDC practical guide (listed in the additional resources section).

1 Soil microbial activity for cycling N via mineralisation or immobilisation

As mentioned previously (in 'Nitrogen (N) cycling' and Table 1), soil biology is a major factor influencing the immobilisation "tie up" and mineralisation "release" of nitrogen, therefore the impact in a farming system depends on when these processors occur in relation to crop growth (Gupta et al. 2011). The processes of mineralisation ("release") and immobilisation ("tie up") depends on the composition and 'dryness or woodyness' of the residue as well as biological, chemical and physical properties of such as soil life other than microbes, soil pH, salinity and nutrient levels, soil structure (for available air) and environmental/production conditions such as temperature and rainfall/irrigation (soil moisture).

A key is to keep the C:N below 20-24:1 when incorporating organic matter from crop residues or external sources. If the carbon proportion of the organic material is too high compared to nitrogen, N fertiliser can be added to shift the balance. If the soil is dry, increasing soil moisture could be considered to hasten breakdown of the organic material.

Rule of thumb: the dryer and more straw-like or wood-like organic materials are, the higher will be their carbon proportions. Woody materials commonly contain high levels of the C source lignin while straw-like materials contain high levels of the C source cellulose. Both C sources are structural plant building blocks in cell walls. Cellulose is more readily broken down by microbes and generally decomposes faster than lignin.

2 Crop residues for recycling N

Crop residues contribute to soil inorganic N i.e. plant available nitrate and ammonium in the soil through biological degradation by invertebrates (life forms without a backbone) followed by microorganisms.

Many vegetable and herb crops have a short growing period, especially those grown in market gardens. Depending on the climate, this allows for multiple rotations per year in a cropping system. In a high crop rotation system, a large amount of vegetable biomass in the crop residues typically has a high nitrogen content (N) and low C:N ratios. Decomposition of these residues may contribute a significant amount of N to the subsequent crop. This amount of mineralised N from the plant residues must be accounted for in the nutrient budget calculations for the following crop to avoid excess N inputs which can diminish harvestable quality of the following crop.

N levels in crop residues vary between crop classes. N concentration is greatest in vegetable crop residues (on average 2.7%). Brassicas crop residues can contain more than 200 kg N/ha in residues left in the paddock at harvest. Legume crops which are used as cover crops to help fix atmospheric N and 'mop up' soil N residues from the previous cash crop can have N concentrations of around 2% and fix as a rule of thumb around 100 – 200 and up to 300 kg/ha N.

Rule of thumb: Vegetable crops that leave large amounts of residue after harvest, and cover crops, especially legumes, are a slow-release N resource, providing N to the subsequent crop in a rotation.

The table below shows the average C:N ratios in residues of different cover crops as a guide to show how crop biomass is an important factor contributing to the breakdown and release of plant available N.

Table 2: The average above and below ground estimates of C:N ratios in residues for different crops

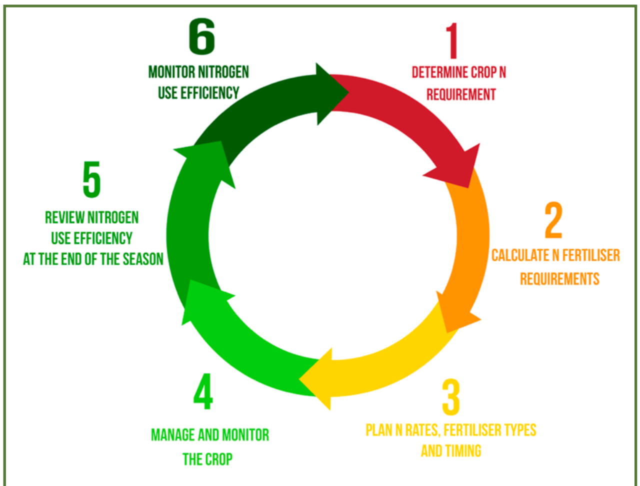
	Aboveground	Belowground
Cereals (dry)	75:1	50:1
Legumes	25:1	25:1
Oil Crops	50:1	20:1
Vegetables	20:1	25:1

The data in this table has been extracted from research conducted by Plant and Food Research Limited, NZ.

Rule of thumb: for every tonne of carbon in soil organic matter or incorporated organic material of a C:N ratio of 10:1, there are about 100 kilograms (kg) of nitrogen, 15 kg of phosphorus and 15 kg of sulphur that become available.NUE% is an agronomic indicator.

Step-by-step guide to manage nitrogen inputs

The approach to manage nutrient input at the Skye demonstration site (mentioned on page 4) follows the principles shown in Figure 2, which are explained further below using nitrogen as the nutrient.



1. Determine crop nitrogen requirement
2. Calculate nitrogen fertilier requirements based on nitrogen available from soil reserves
3. Plan nitrogen rates, fertiliser types, application system and timing
4. Manage and monitor the crop via plant testing

Figure 2: The four principles for managing nutrient inputs

1 Determine crop nitrogen requirement

Check nitrogen removal (and other nutrient) rates for the specified crop (see Additional resources for Soil Testing and Interpretation for Vegetable Crops: A Guide and Fertcare Soil Sampling Guide). Take a baseline soil test to adjust soil deficiencies and imbalances pre-plant. Determine total nutrient requirements based on yield potential (t/ha) and crop removal rates (kg/t).

2 Calculate nitrogen fertiliser requirements

Conduct a soil N-Check® test or deep soil nitrogen test to 30cm or rootzone depth to provide information on the amount of mineralised available plant nitrogen. This gives an indication of a soil's short to medium term nitrogen supplying capacity. Approximately 5% of total nitrogen (TN) is mineralised per year which fluctuates depending on soil type, soil health and climatic conditions.

If you want to get a better estimate of the mineralisation potential from total nitrogen, there are two options:

- **Use the Soil Wealth ICP Organic Nitrogen Rules of Thumb poster and calculator** to estimate nitrogen availability from total nitrogen in the soil (https://soilwealth.com.au/2024/11/organic-nitrogen-rules-of-thumb/)
- **Use the NZ N tool.** This is currently calibrated for NZ soils and climates. However, the Soil Wealth ICP team can help you to use it until it is calibrated for Australian vegetable soils.

3 Plan nitrogen rates, fertiliser types and timing

It is important to apply nitrogen and other nutrients at the right crop growth stage within the growing cycle to ensure enhanced nutrient use efficiency and make sure that nutrients are not lost. Soil test information and nutrient removal rates are a good tool for determining the amount of nitrogen and other nutrients to be used.

4 Manage and monitor the crop

Conduct plant sap tests as a quick tool for in-crop management of crop nutritional needs. The results will show nutrient uptake and balance at the time of sampling. A dry tissue test can show nutrient accumulation up to the time of sampling. (See Additional resources for plant sampling guides.)

5 Calculate cover crop nutrient uptake and recycling to the soil

Use a plant dry tissue test from typical samples of the cover crop biomass, representative of the proportion of all plant parts. Estimate the total biomass of the cover crop as dry weight (kg/ha). Given the root biomass is difficult to measure, only aboveground biomass is commonly used.

Biomass can be estimated by harvesting several 1m2 plots of aboveground material and weighing it, then drying a representative portion of the biomass to calculate total aboveground dry matter weight (kg/ha). The nutrient uptake is calculated using the below formula where nitrogen is used as an example.

$$\frac{\text{Total (aboveground) biomass as dry weight (kg/ha) x N\% in the biomass from the dry tissue analysis}}{100\%}$$

$$\frac{\text{10,000 (kg/ha) dry biomass x 2.4\% N in dry tissue}}{100\%} = \text{240 (kg/ha) N removed}$$

The crop removal calculation can be done for all nutrients.

Note: If any of the cover crop biomass was removed (e.g. for fodder), only the proportion remaining in the field can be used for a calculation of the amount of nutrients from the cover crop recycled to the soil.

6 Calculate crop nutrient removal via cash crops

Use a plant dry tissue test from representative samples of the cash crop biomass that is harvested. The harvested biomass comprises everything taken from the field for sale and weighed before grading and trimming (i.e. the total yield, not just the marketable yield). A sample of the biomass has to be dried and weighed to determine the nutrient removal with the harvested dry weight (kg/ha). The nutrient removal is calculated using the below formula where nitrogen is used as an example.

$$\frac{\text{Total removed biomass (kg)} \quad \text{x} \quad \text{N\% in the biomass from the dry tissue analysis}}{100\%}$$

$$\frac{\text{1,000 (kg/ha) dry biomass harvested} \quad \text{x} \quad \text{2.2\% N in dry tissue}}{100\%}$$

= 22 kg N removed

The crop removal calculation can be done for all nutrients.

Calculate the agronomic nitrogen use efficiency (NUE%) at the end of the season and check for residual soil nitrogen

1 Agronomic nitrogen use efficiency NUE%

Nitrogen use efficiency (or that of other nutrients) can be calculated by using nitrogen removal in the plant total biomass removed with harvest (e.g. 240 (kg/ha) divided by N inputs (kg/ha)). Nitrogen inputs are calculated by adding up all nitrogen added to the crop as fertiliser and via soil amendments (kg/ha) (e.g. 300 (kg/ha)).

Example:

240 (kg/ha) N removed / 300 kg/ha) N applied
= 0.8 x 100
= 80% nitrogen use efficiency,

which is quite good.

Factors affecting NUE%

- Current soil N status i.e. what N is available in the soil at the start of the crop and can be used by the crop
- Soil temperature and moisture both influence mineralisation and also volatilisation rates; mineralisation of organic matter contributes to the N pool for the crop, volatilisation and denitrification reduce the N pool available to the crop
- Seasonal weather e.g. prolonged or multiple heavy rainfall events can result in N leaching from the rootzone or surface runoff or loos via erosion
- Irrigation management i.e. if irrigation is not matched to crop requirements and too much is applied, water flows through the rootzone or runs of the soil surface, taking nitrogen with it as it is very soluble and moves easily in the soil
- Residues from previous crops or cover crops; these can contribute to the N pool.

Split applications of top–dressed N can be very efficient in reducing losses when they match plant needs at the crop's growth stage.

Interpreting NUE% results:

NUE = 100 indicates that the amount of nitrogen removed in harvested biomass equals the amount applied. This suggests efficient nitrogen utilisation.

NUE < 100:

Means more nitrogen is being applied than is being removed. This suggests potential for nitrogen loss to the environment (e.g., through runoff, leaching emission)

NUE > 100:

This is generally considered unrealistic, as it would imply more nitrogen output (removal with harvest) than input with fertilisers. However, it could be a result of nitrogen fixing by soil microorganisms (e.g. free living, N-fixing bacteria) or other N sources not included in the initial input calculation.

An NUE between 75% and 90% is considered a realistic aim.

Relationship between NUE and productivity

NUE is often calculated relative to total crop yields (N output). A high NUE coupled with high yields, especially marketable yields is desirable, indicating both efficient nitrogen use and high productivity.

2 Check the soil for residual soil nitrogen after a crop is harvested

Another option of checking whether nitrogen has been used well is to monitor residual available nitrogen (nitrate and ammonium) left in the soil immediately after harvest. This measures how much nitrogen has not been used by the crop. This N would be used by a following crop or cover crop if it is planted very soon afterwards. If the soil is left fallow, residual available nitrogen in the soil will be easily lost through leaching or denitrification from wet soils. Nitrogen from crop residues maybe lost as well during a fallow period.

Example: For instance, the demonstration trial at Butler Market Gardens experienced 40 mm of rainfall on bare soil after the soil nitrogen (N-check) test. This would have allowed for some nitrogen to be leached or lost to the atmosphere. In addition, some nitrogen might have been mineralised from organic matter and crop residues during the fallow periods and lost. Therefore, a test ahead of the next crop could have been useful to determine losses and how much nitrogen is left.

Additional resources

- Soil Testing and Interpretation for Vegetable Crops Guide, Doris Blaesing, RMCG https://soilwealth.com.au/2017/05/soil-testing-and-interpretation-for-vegetable-crops-a-guide/
- Fertcare Soil Sampling Guide https://fertilizer.org.au/Portals/0/Documents/Fertcare/Fertcare%20Soil%20Sampling%20Guide.pdf?ver=2019-06-17-095413-863
- The SVS NZ nitrogen calculator http://www.svstool.co.nz/
- Crop removal calculator http://www.ipni.net/article/IPNI-3346%20or%20http://www.fertilizer.org
- Butler Market Gardens demonstration site trial information https://soilwealth.com.au/2023/09/nutrition-nous-key-to-productive-crops-in-skye-victoria/
- GRDC Practical Guide for inoculating legumes: https://pir.sa.gov.au/__data/assets/pdf_file/0008/238409/SARDI-Inoculating_Legumes-A_Practical_Guide.pdf