NUTRIENT MANAGEMENT FOR VEGETABLE CROPS IN NEW ZEALAND

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Fertiliser Association
Shaping profitable and sustainable farming

Plant & Food RESEARCH
RANGAHAU AHUMĀRA KAI

Vegetable RESEARCH+ INNOVATION Board

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ABBREVIATIONS AND SYMBOLS COMMONLY USED IN THIS BOOK

ASC	Anion storage capacity (% P retention)
Ca	Calcium
CEC	Cation exchange capacity
Cl	Chlorine
DAP	Di-ammonium phosphate
DM	Dry matter (of plants)
K	Potassium
Mg	Magnesium
MOP	Muriate of potash, KCl
N	Nitrogen
Na	Sodium
NH_3	Ammonia
NH_4^+	Ammonium
NMP	Nutrient management plan
NO_3^-	Nitrate
NZ	New Zealand
P	Phosphorus
QT	Quick test
S	Sulphur (Sulfur)
SOA	Sulphate of ammonia NH_4SO_4
SOP	Sulphate of potash, K_2SO_4
TBK	Tetraphenyl Boron K — also called Reserve K

CHAPTER 01

INTRODUCTION

This book is intended to be a resource of best-practice advice to manage the nutrition of vegetable crops in New Zealand (NZ). The emphasis is firmly on practices that are scientifically defensible.

In 1986, MAF published *Fertiliser Recommendations for Horticultural Crops*. The book summarised nutrient requirements for the major vegetable crops based on research results obtained up till then (Wood et al. 1986). In 2000, the Vegetable Growers Handbook (Wallace 2000) contained information for fertiliser use, but the scientific basis for many recommendations was unclear.

Since then, much has changed in the business, social and regulatory environment of horticulture. Crop location, varieties, management practices and yield expectations have changed, and growers are more aware of the impact of their practices on the environment. New scientific approaches have enabled researchers to quantify the influences of many of the key interactions between plants, soils, and management that influence productivity, profitability and risk.

This book builds on the 1986 recommendations with the results of a further thirty-odd years of research. In addition, there is information on environmental impacts and improving the efficiency of fertiliser use. The format is deliberately brief and direct.

These recommendations are intended to be a guide based on the best current experimental evidence; they are not prescriptive requirements. At times it may be beneficial to use the skills of a nutrient management adviser to interpret and if necessary modify them for specific circumstances.

Key point: Getting started

Read the generic material in Chapters 1 and 2 *before looking for recommendations for specific crops*. It is particularly important to read section 1.1 Crop needs for mineral nutrients. The terms defined there for yield may be new to some readers, and are used extensively throughout the book.

Further information

Further detail on the recommendations (including information sources) is in a companion document (Reid et al. 2019). See the References chapter at the end of this book.

1.1 CROP NEEDS FOR MINERAL NUTRIENTS

Plant tissue consists of carbon (C), hydrogen (H), oxygen (O), and about 14 other essential elements. The first three (C, H, O) are obtained from the air or water and make up most of the organic compounds in plants. The remainder are often called major and minor (or trace) mineral nutrients, depending on how much of them plants typically contain. They are:

Major elements — nitrogen (N), phosphorus (P), potassium (K), sulphur (S), magnesium (Mg), calcium (Ca), and sodium (Na);

Minor (trace) elements — boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn).

All these are taken up from the soil solution in the ionic form. When supply of any one nutrient is very low it will limit crop growth and yield, but the limitation becomes less and less as more of the nutrient is supplied. It may even reach the point where adding more will decrease growth and yield (see *Economic matters* below). If any single nutrient is limiting growth it will reduce the responsiveness of the crop to additions of the other nutrients.

Potential, field and marketable yields

Nutrient uptake and yield are mutually dependent. The amount of each nutrient that a crop needs to achieve its maximum yield and quality depends primarily on its potential yield.

Wherever possible for each crop we start by considering the potential yield. Other types of yield are referred to in this book: *field*, *harvested*, and *marketable yields* are all less than the potential yield. The meanings of these terms is explained by the sequence in Figure 1:1.

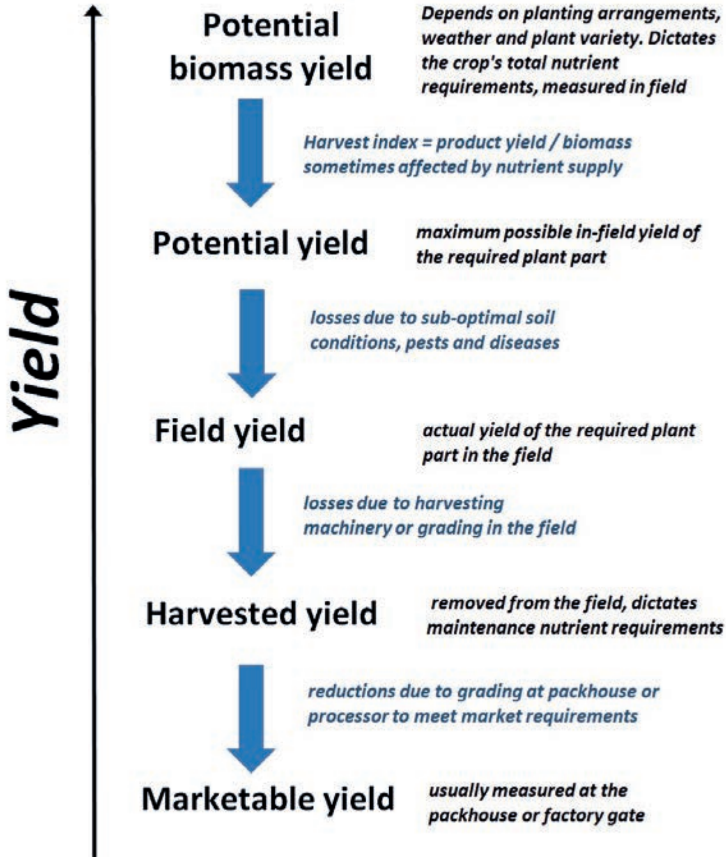


Figure 1-1. Relationships between potential, field and marketable yields in vegetable crops.

As noted above, potential yield sets the top limit for the crop's nutrient uptake requirements. But the field yield may be less because of stresses due to water availability, pests or diseases.

Usually these stresses reduce the amount of nutrients that the crop will need, *and you cannot compensate for these yield losses by applying more fertiliser.* The best example of this is water stress (Figure 1-2). Water stress during growth will reduce the yield and the nutrient requirements proportionally.

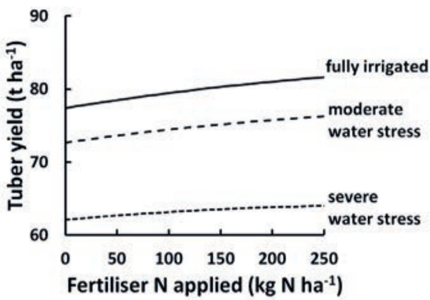


Figure 1-2 Effect of water stress (0, 2 and 4 weeks of missed irrigation) on the response of potatoes to N fertiliser under Canterbury conditions. The soil contained 100 kg/ha of Available N. There were no significant shortages of other nutrients.

Target yield

Sometimes growers will need to calculate nutrient requirements to achieve a target yield that they want from the crop. The value may be based on previous experience of the crop and land, or by marketing requirements, but it should never be set greater than the potential yields indicated in each chapter. Achieving a field yield close to the potential value requires more than optimum supply of nutrients — it also requires excellent soil physical conditions, control of pests and diseases, and a perfectly timed harvest.

Nutrient uptake vs nutrient supply

Crops take up most of their mineral nutrients from the soil. Only a fraction of the total amount of nutrients held in soil is rapidly available to plants. Vegetable crops typically have a short growing season and need to take up large quantities of nutrients quickly. Their root systems are quite sparse, and have little time to explore the soil and access nutrients in it.

So, compared with pasture species, arable crops and perennial horticultural crops, most vegetable crops require the soil to have quite high concentrations of mineral nutrients to maintain a high rate of nutrient uptake.

Having said that, it is easy to over-estimate the amount of nutrients that need to be added to a soil for optimum vegetable growth. Some vegetables can take up nutrients well beyond the amounts they actually need (this is called luxury uptake). Leafy vegetables and root crops are predisposed to *luxury uptake* (especially of N and K), and this may be associated with negative effects on crop quality. Furthermore, yield of some crops can be decreased by an over-supply of some nutrients (examples include N for tomatoes and P for lettuce).

1.2 NUTRIENT SUPPLY FROM THE SOIL

Vegetable growing soils in NZ

Soils of sedimentary origin

Many areas growing vegetable crops are based on young sedimentary soils formed by river systems. Usually these are Recent soils. Examples include the Mataura soils in Southland, Templeton soils in Canterbury, Twyford soils around Hastings and Matawai soils around Gisborne. Natural drainage is usually good, or artificial drainage has been installed. Soil organic matter concentrations are medium to high (3-5% organic-C) when cultivated from pasture but are often depleted under continual cropping. Most Recent soils have low anion storage capacity (10 – 20%), medium cation exchange capacity (15 – 20 meq/100 g) and medium to high reserves of potassium, magnesium and calcium.

Soils of volcanic origin

These are usually well drained. Examples include Granular soils (such as Patumahoe soils around Pukekohe, and Wairereka soils near Oamaru), Allophanic soils (such as Ohakune soils around Ohakune) and Allophanic Brown soils (such as Levin soils in Horowhenua). Soil organic matter concentrations are higher than in sedimentary soils and are slower to deplete with continual cropping. In contrast to sedimentary soils they have high anion storage capacity (70 – 90%) and cation exchange capacity (25 – 30 meq/100 g) but often have low reserves of potassium.

Soils of organic origin

For horticultural production these soils normally need artificial drainage installed. The ones used for vegetable cropping are mainly located in Waikato (e.g. Kaipaki soils) and Southland (e.g. Otautau soils). Soil organic-C concentrations are high (15 – 40%). Anion storage capacities can be moderately high (40 – 60%) if the mineral soil content is of volcanic origin, but lower if it is of sedimentary origin. Cation exchange capacity is high (>40 meq/100 g) which means that they can retain potassium, magnesium and calcium.

Assessing soil nutrient status

This is a crucial step in managing nutrients for vegetable crops, and for each crop soil testing should be carried out before deciding a fertiliser regime. For some crops, this can be complemented by plant analysis at specific growth stages.

There is a wide range of soil tests available from most commercial laboratories. The traditional analyses for readily available soil nutrients include:

- Olsen P — a measure of plant-available P;
- Quick test (QT) Ca, Mg, K and Na — measures of the plant-available amounts of these nutrients;
- Cation exchange capacity — a measure of the capacity of a soil to store positively charged nutrients such as Ca, Mg, and K;
- pH — a measure of soil acidity and an indication of both lime requirement and the likelihood of trace element deficiencies or toxicities.

The usual analyses now often include:

- Tetraphenyl Boron K (TBK) — a measure of the K reserve;
- Organic-C — a measure of the organic matter content of the soil;
- Anion storage capacity (previously called *phosphate retention*) — measures the capacity to store P and S

Soil analysis is often unreliable for measuring trace-element availability, because solubility of these nutrients varies greatly with changes in soil pH and aeration status. They are best measured by plant analysis.

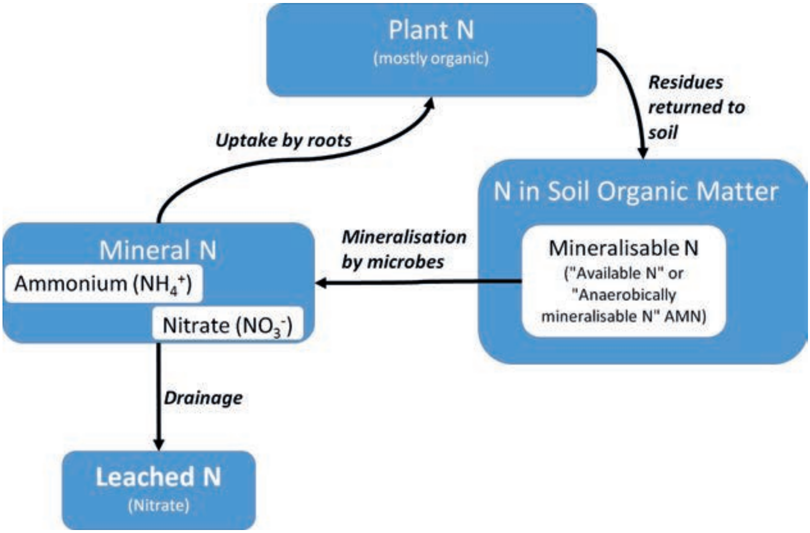
Key point: Soils that fix P

Growers sometimes expect the optimum soil test P to be greater on volcanic soils or other soils with a high anion storage capacity (ASC, or P retention %). There is no good evidence for this in vegetables — the standard soil test ranks P supply very well across a wide range of soil types.

But high ASC values do restrict the efficiency of P fertilisers — so band soluble P fertiliser as much as possible. This reduces the percentage that is fixed onto soil surfaces.

Soil nitrogen tests

Measuring soil N is now essential for economic and environmental reasons. This is a major change from the 1986 recommendations. However, the total amount of N and the amount of organic N in the soil are relatively poor indicators of what plants can access.



There are various soil tests available. It is important to understand what each tells you so you order the correct test. The recommendations in this book, and a number of crop calculators, use measures that are usually called *Mineral-N* and *Available N*.

Mineral-N

Also called Deep Soil Mineral N, this measures the nitrate and ammonium content of freshly collected soil. It represents the N *immediately* available to plants and does not account for what may be mineralised from soil organic matter over the coming weeks and months. Sampling depths often go from the surface to 60 cm. In each paddock, take about 8 – 12 randomly located samples, but keep away from headlands, gates, and stock camps.

The results are reported for ammonium-N and nitrate-N, in units of µg/mL, µg/g or mg/kg (the numbers are identical for all those units). To convert these to kg N/ha you multiply them by sampling depth and the soil bulk density.

kg N/ha = (ammonium-N + nitrate-N µg/g)

x depth of soil sample (cm)

x relevant bulk density (g/cm^3)

x 0.1

The 0.1 factor in this equation balances the units from µg/cm^2 to kg/ha. Typical values for the bulk density would be 1.1 g/cm^3 for the top 0 – 30 cm and 1.3 for the 30 – 60 cm depths. If the samples were taken from 0-60 cm in one core, use 1.2 g/cm^3. For example, if nitrate was 11.9 µg/g and ammonium was 6.0 µg/g, the total Mineral-N would be

(11.9 + 6.0 µg/g) x 60 cm x 1.2 g/cm^3 x 0.1 = 129 kg N/ha

In sedimentary soils the bulk density is usually greater in the subsoil than the topsoil. Subsoil values may be close to 1.5 g/cm^3 (rising to 1.6 –1.7 g/cm^3 if there is an appreciable compaction pan).

Key point: Keep the samples cool

For both Mineral-N and Available N measurements the soil samples must be chilled or frozen to prevent extra mineralisation occurring after sampling. Samples must arrive at the laboratory at less than 4°C.

Available N, also known as Anaerobic Mineralisable Nitrogen (AMN)

This is a measure of N mineralised under specific laboratory conditions (anaerobic incubation at 40°C for 7 days). It represents an estimate of nitrogen that will be potentially mineralised in the field through the season. It does not include the immediately plant-available component of soil nitrogen (Mineral-N). Usually, Available N is measured only in the top 15 cm of soil as this is where the organic matter is most concentrated. The results are reported as kg N/ha.

For more information see https://www.far.org.nz/assets/files/uploads/Extra_37.pdf

Soil sampling

This should be carried out well before planting. Take samples from 0 – 15 cm depth (deeper for soil mineral-N, see below). The best benefit is achieved by regular testing over a number of years.

Setting up a soil monitoring system on your farm

- Identify different soil types in each paddock.
- Sample each paddock before every crop. The cost of this is regained by savings on fertiliser and improved yield.

- Across or along each paddock, set up and mark a transect across each of the major soil types. The idea is that you will return to this transect to take soil samples before each crop. Or you could use 15 – 20 GPS waypoints and take cores from the same spots whenever the paddock is sampled.
- Along the transect take 15 – 20 cores at equal intervals, or take samples from each of your GPS waypoints.
- Combine and mix the samples from the major soil types in each paddock. Then conduct soil tests according to the recommendations for each crop (see specific chapters). Usually this involves soil pH, P, K, Mg, Ca, CEC, and Available N or Mineral-N. Every 4 – 5 years, analyse for organic-C.
- Where possible, take the samples in the same month of each year (when there is the most constant moisture status).

Using the monitoring results

- For the next crop, plan nutrient management according to the specific recommendations given in this book.
- Plot the trends in soil test values over time. Use these trends (over at least four sampling occasions) to assess whether fertiliser nutrient application has been sufficient or inadequate to maintain soil fertility.
- *If a soil test value has been climbing*, check why. In particular check if previous applications have been above recommended rates. Make appropriate corrections to your future fertiliser application rates.
- If a soil test value has been falling, check if that matters by comparing with the soil test ranges referred to in the crop chapters. Increasing the size of the maintenance applications may be needed. In some cases a reduction in soil test values may be desirable if the initial values are excessive.
- Plot trends in organic-C concentrations over time to assess what effect your management is having on soil nutrient reserves. Soil organic-C should be maintained or increased by including grazed pasture in the rotation. Cultivation practices may need to be reviewed if soil organic-C shows a downward trend.

1.3 NUTRIENT SUPPLY FROM FERTILISERS AND COMPOSTS

The chapters for each crop here emphasise the best amounts of nutrients to apply, the most appropriate placement of fertilisers, and the timing of applications so the crop has the best opportunity to take up the nutrient supplied.

The best outcomes may require multiple small applications rather than a single large application. The choice of which fertiliser product is down to the grower or adviser.

Key point: The 4 Rs

The principles of best practice with fertiliser applications are neatly summarised in the 4 Rs: Right product; Right rate; Right place; Right time (see also the section Code of Practice for Nutrient Management).

Forms of fertilisers

Solid fertilisers are used as either dry mixed blends of powders or granules.

Granular fertilisers are most frequently used for vegetable crops. The most common products in NZ are urea, DAP and SOA. They are made by finely grinding the ingredients and forming them into roughly spherical granules (4-5 mm diameter). These are dried and hardened. Granule size needs to be as even as possible so they flow freely through the fertiliser box on the drill when used as a starter fertiliser.

Compound fertilisers are made from combining different chemical compounds into granules. In some products, not all the granules contain all the ingredients. Examples where all ingredients are in each granule include Nitrophoska® and Yara Mila® Complex™ (these products contain ammonium nitrate, SOA, SOP or MOP, and a range of phosphate compounds).

Blended fertilisers are dry mixes of different solid fertilisers. There may be a large variation in granule size, and compared with compound fertilisers the blends may not be as stable during storage and handling.

In **controlled-release fertilisers and some slow-release fertiliser** the granules are coated with a polymer. Compound fertiliser examples include Osmocote® and Agroblen® and single-compound examples include urea in Smartfert®. The polymer slows the nutrient release into the soil, and there is a range of technologies used for this. Some slow-release fertilisers are not coated, but they dissolve slowly or are broken down slowly by microbial action. An example is urea-formaldehyde which is used in Grotabs®.

Controlled- and slow-release fertilisers have promise to reduce the risk of nitrate leaching from starter fertilisers in situations where N or P fertiliser is needed but the crop will take up very little of it in the first 4-6 weeks after planting. Some of the products have been available for many years, but cost issues have confined them mainly to amenity horticulture. Field testing of cheaper products such as Smartfert under NZ conditions is at a young stage. If indeed those products meet the manufacturers' claims to improve nutrient-use efficiency, some of the application rates recommended by the manufacturers in 2018 appear excessive.

Liquid fertilisers in NZ are made by dissolving solid fertilisers (e.g. urea) in water. **Fertigation** is the application of liquid fertilisers through an irrigation system at intervals during crop growth. It is used mainly for soluble nitrogen fertilisers. It can be very effective at matching the timing of nutrient supply to crop demands and reducing the risks of leaching. A potential disadvantage is if wet weather makes irrigation inadvisable, so N applications may fall behind schedule.

Suspension fertilisers are sometimes injected into the soil. They are a fluid, made by mixing finely-ground fertiliser with 40-60% water by weight. A saturated solution is formed, with the rest of the ingredients suspended as fine particles. A gelling agent or a clay such as bentonite may be added to slow the settling of the fertiliser particles, but usually agitation is still required just before application.

Foliar fertilisers come in a variety of products derived from other mineral fertilisers, seaweed extracts, fish waste, blood etc. They are usually applied in dilute form because concentrated nutrient solutions sprayed onto foliage can stress the plants. The actual amounts of nutrients applied can be very low, and foliar applications are mainly used to complement solid fertilisers. However, liquid fertilisers may have a place for the short-term requirements of a crop and where weather conditions make solid fertiliser applications inefficient. Trace element sprays can be effective for overcoming some specific deficiencies, especially those linked to soil conditions such as dry topsoils and high pH.

Composts and organic waste materials like blood and bone are also sometimes used to supply plant nutrients. They have an advantage over mineral fertilisers in that they also supply organic matter that will benefit soil quality. A disadvantage is usually they are not very concentrated in terms of mineral nutrients, so large applications are needed. They supply N, P and S over time as the composts are decomposed by soil microbes. This can be an advantage or a disadvantage depending on the urgency for plant uptake. Nutrient concentrations may vary greatly between batches of composts so it is important to obtain a laboratory measure of their composition.

Microbial-based fertilisers or soil amendments are sometimes sold with claims to improve the efficiency of nutrient use. Growers are urged to check for independent, scientifically credible, research into their effectiveness.

Plant establishment and starter fertilisers

Placing fertiliser too close to seeds or transplants can impair plant establishment. This is caused by ammonia release from N fertilisers or the osmotic (salt) effect of the fertiliser. Maximum damage occurs where there is sufficient soil moisture to commence fertiliser dissolution and seed swelling but insufficient to disperse and dilute the fertiliser through the soil. Ideally seed and fertiliser should be 2 – 5 cm apart.

Fertiliser rankings according to risk of germination damage are shown below.

Least risk	Serpentine, dicalcic superphosphate
	Superphosphate
	Nitrophoska and Mila range
	Monoammonium phosphate
	DAP, Cropmaster 15, Crop Zeal 15
	Cropmaster 20, Crop Zeal 20, SOA
Most risk	Urea, MOP, boron fertilisers

General recommendations

- Do not sow more than 20 kg N/ha as urea with the seed. For other N fertilisers sow no more than 30-50 kg N/ha with the seed, and always try to maintain separation between fertiliser and seed.
- With small-seed crops (e.g. brassicas) use reverted superphosphates (superphosphate products that have been combined with lime and water).
- Banded side-dressings of N fertiliser should be at least 10 cm from the plant.

Soil pH and liming

For optimal yield, the required soil pH varies between vegetable crops (refer to the specific chapter for each crop). Yield and quality can be reduced if pH is too low or too high — but for different reasons.

To raise soil pH, a silt loam on average requires 1 tonne of good quality lime (80% $CaCO_3$ equivalent), for each 0.1 unit increase. A higher rate will be required for clay soils or if the $CaCO_3$ content of the lime is less than 80%.

Using finer lime than AgLime and incorporating it will speed the process of raising soil pH, but the size of the increase in soil pH depends on the rate of lime applied.

Normally about 2.5 t/ha of lime is required every 3-5 years to maintain soil pH. The frequency increases with greater rainfall, irrigation and use of N fertiliser. Applications should be 3-6 months before the crop is sown — but see the recommendations for specific crops.

To lower soil pH is more difficult and can be expensive. Soil is acidified slowly by nitrifying soil bacteria. It can be acidified rapidly by addition of compounds such as ferrous sulphate or various alums, but this is expensive. Application of finely divided, elemental S will acidify soil more slowly as it is slowly oxidised to sulphuric acid by soil microbes. There are no general recommendations for rates and timing, though 1 – 1.5 t S/ha may be required to lower soil pH by one unit.

Nitrogen fertilisers that contain urea or ammonium can acidify soil.

		kg of lime to neutralise 100 kg of fertiliser
Least effect	**Calcium ammonium nitrate**	**30**
↘	**Diammonium phosphate**	**40**
	Urea	**50**
Most effect	**Ammonium sulphate**	**210**

Economic matters

Applying more fertiliser than required reduces the profit to be made from a crop and increases the risk of N and P loss to water bodies (Figure 1-3). Too little fertiliser reduces both yield and profitability. The fertiliser rate that gives the best financial return is unique for each situation. It depends on the price the grower will receive per tonne of yield, the cost of the fertiliser, and how responsive the crop is to the fertiliser. The responsiveness of the crop depends strongly on the soil test values.

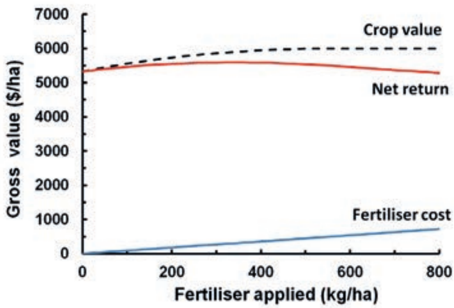


Figure 1-3 The economics of applying fertiliser. This example is for DAP fertiliser applied to sweet corn with a potential yield of 30 t/ha. The calculations assume crop value is $200/t, fertiliser costs $900/t, and without fertiliser soil N and P are limiting yield by 13%. Costs rise in simple proportion to the fertiliser rate, but the yield (and crop value) increases less and less. The best net return here occurs at a fertiliser rate of 320 kg/ha.

Usually, the financial gain is better if the fertiliser is applied to achieve slightly less than the potential yield. Even so, the rate of nutrients applied to crops should be determined by economic *and* environmental matters.

Environmental matters

Nitrate Leaching

Leaching of nitrate-N from the soil is important. It represents both an economic loss to the grower and a threat to the environment.

Nitrate leaching occurs when drainage follows rainfall or irrigation. It is greatest if nitrate-N has been released from the breakdown of soil organic matter, or added from fertiliser, faster than the crop can take it up. Usually the risk is greatest between late autumn and early spring, or if irrigation is excessive during crop growth.

How to minimise nitrate leaching

Cultivation

- Minimise the time between harvest and establishment of the next crop.
- Avoid winter fallow, particularly after pasture, clover seed or grazed forages.
- Minimise depth and intensity of cultivation to reduce breakdown of organic matter.

Fertiliser N application

- Use fertiliser N rates that minimise residual mineral N — nitrate and ammonium left in the soil at harvest.
- Apply as little N fertiliser as possible in autumn and winter, and no more than the crop can take up at that time.

- Split applications to match plant N requirements with N supply.
- Avoid excess irrigation soon after the application of N fertiliser.
- If soil temperature is low, apply lower rates of N.

For more information refer to
www.far.org.nz/assets/files/uploads/Nitrogen_leaching.pdf

Volatilisation of N fertilisers

Five to twenty percent of the N from N fertilisers may be lost as ammonia gas. These volatilisation losses are enhanced by windy conditions, high soil temperatures, lack of crop cover, and high rates of N fertiliser.

Ammonia losses from urea are about twice that from di-ammonium phosphate and ten times greater than from ammonium sulphate. Urea is readily converted to ammonium by the urease enzyme in soil. This raises the soil pH around the granule, which enhances volatilisation by converting ammonium ions to ammonia.

Volatilisation losses from urea applied to the soil surface can be minimised if there is 5 – 10 mm of rainfall or irrigation within 8 hours. Unfortunately this is not a practical solution on most farms. This requirement for water straight after urea application is especially important if the soil is moist since this small amount of moisture is sufficient to start the breakdown of urea to ammonium but insufficient to disperse it sufficiently by absorption into the soil.

In some urea fertilisers (e.g. SustaiN and N-Protect®) the granules are coated with urease inhibitors that slow down the rate of volatilisation. They can reduce the amount of N lost by 50%. The return on urease inhibitors for the extra cost is maximised in situations where high rates of N must be spread on the soil surface; they can reduce the risk of ammonia loss and increase flexibility in the timing of application.

For vegetable production ammonia volatilisation is best reduced by incorporating N fertilisers into the soil. For side-dressings this is best done by knifing them into the soil especially if there is deep placement and the soil groove is covered.

For more information refer to
https://www.far.org.nz/assets/files/uploads/Volatilisation.pdf

Cadmium

Cadmium (Cd) is a naturally occurring heavy metal that has gradually accumulated in our soils through the application of P fertilisers and can be detected in varying amounts in root and leafy vegetables. Plant uptake of Cd can be influenced by many factors. In general, uptake is reduced by using low accumulating plant species and/or varieties, improving soil organic matter, increasing soil pH to the high end of the optimum range, alleviating any zinc deficiency and maintaining recommended amounts, avoiding chloride in irrigation water, and minimising localised acidification effects. Growers should consider if there is a risk of excessive uptake with the crop varieties and land they use, and if so how to deal with it.

The Tiered Fertiliser Management System (TFMS) has been designed to manage the accumulation of soil Cd from P fertilisers. In addition, the TFMS recommends field management practices to minimise the uptake of Cd in horticultural crops.

Tier 0 indicates no limitation on choice or rate of P fertiliser. However, routine soil Cd assessment should occur every 5 years.

Tiers 1 and above apply if soil Cd concentrations are greater or equal to a trigger value of 0.6 mg Cd/kg soil.

The consequences range from Tier 1 where there is a slight restriction on rate and choice of P fertiliser products, through to the top tier where no further accumulation of Cd is acceptable (so there are strong restrictions on P fertiliser use). At or above the top tier there should be a detailed site-specific investigation to identify and risks and pathways for potential harm.

Management of plant uptake may be required at any Tier level, including Tier 0.

Key point: Are Cd tests needed?

Excessive plant uptake can occur at any soil cadmium content, depending on species/variety and soil factors. *Monitoring of harvested produce is advised.*

To understand and manage the risks associated with soil Cd, all farmers applying P fertiliser should undertake soil tests for Cd, and implement the tiered Fertiliser Management System

If the soil Cd concentration is <0.6 mg Cd/kg soil, Tier 0 applies and no restriction on P fertiliser use is required — but repeat the sampling in 5 years.

For the background and details of the TFMS — and sample collection procedures see the resources tab of the web site www.fertiliser.org.nz.

1.4 CODE OF PRACTICE FOR NUTRIENT MANAGEMENT

To assist growers with safe, responsible and efficient use of fertilisers, the Fertiliser Association of New Zealand and Horticulture New Zealand have each developed a *Code of Practice for Nutrient Management* (Anon 2014; FANZ 2013). These provide practical advice on effective nutrient management and Best Management Practices for the most efficient use of nutrients. The codes are complementary; the Horticulture New Zealand code includes some specific checklists for vegetable growers, whereas the FANZ code is more detailed, especially for nutrients other than nitrogen, fertiliser contaminants, nutrient management plans, and the handling and application of fertiliser.

These codes help growers achieve their production goals and meet their responsibilities under the Resource Management Act. Neither code contains prescriptive practices (or "rules" about use), and neither attempts to recommend nutrient requirements for specific crops. Both provide flexibility and allow for site-specific solutions.

The FANZ code is especially useful where it focuses on significant environmental considerations, including:

- Determining the land's requirements for nutrients;
- Nitrate leaching to groundwater;
- Surface water contamination from fertiliser runoff;
- Contamination of surface water from direct application;
- Potential effects on third parties.

Some examples of the FANZ code's recommendations for these are given below.

Determining the land's needs for nutrients

- Apply fertiliser to achieve an identified response or objective (not as a "routine" procedure).
- Prepare a *Nutrient Budget* and operate a Nutrient Management Plan in consultation with your farm or fertiliser nutrient management adviser.
- Test soil and plant tissue.
- Have a working understanding of the principles underlying fertiliser use.
- Use the *Code of Practice for Nutrient Management* and the Fact Sheets included.

Minimise nitrate leaching to groundwater

- Match nitrogen application to plant requirements and rate of uptake.
- Split fertiliser applications, applying smaller amounts more often.
- Avoid application if heavy rain is forecast or if the ground is saturated.

Minimise surface water contamination through run off

- Split fertiliser applications, applying smaller amounts more often.
- Avoid application if heavy rain is forecast or if the ground is saturated.
- Set realistic growth rate targets, and match application to requirements.
- Use a *Spreadmark*-certified spreader where appropriate.

Avoid contamination of surface water from direct application

- When windy (anything greater than 5 kmph), apply when it is blowing away from open water.
- Be fastidious about accurate and uniform application, and containing fertiliser to application zone.
- Use fertiliser with larger particle sizes (particles of less than 1 mm have poor ballistic properties).
- Establish a riparian strip or allow for a realistic buffer zone.

Minimise third party effects

- Consider noise implications, and choose appropriate time.
- Consider sensitive times and places (for example schools, or neighbour practicing organic farming) and choose appropriate time and application techniques.
- Winds above 5 kph can cause drift. So consider particle size and application method.
- Be fastidious about accurate application.
- Be neighbourly and tell others in advance, and of changes to plans.

For more detailed information on the Code and for the series of Fact Sheets relating to it (including *Spreadmark*) visit www.fertiliser.org.nz

1.5 NUTRIENT MANAGEMENT PLANS & NUTRIENT BUDGETS

A nutrient management plan (NMP) is a written plan that describes how the major plant nutrients will be managed annually on a particular area or property. Implementing the plan should optimise productivity, reduce nutrient losses and avoid, remedy or mitigate adverse effects on the environment. *It is recommended that advice is sought from an NMACP-accredited management adviser to develop nutrient management plans and nutrient budgets.* A good NMP should:

- Ensure that nutrient management meets all legal and industry requirements;
- Include a nutrient budget that compares all inputs and outputs;
- Achieve desired changes in nutrient contents and production (e.g. increasing soil fertility from a poor base to maintain or improve production capacity);
- Minimise the cost of supplying nutrients and avoid wasted spending on unnecessary or unused nutrients;
- Promote efficient and effective nutrient use;
- Minimise the risk of adverse environmental effects; and
- Consider the land manager's personal objectives.

A sample NMP template is available in the Code of Practice for Nutrient Management.

Nutrient budgets

Nutrient budgets summarise the nutrient inputs and outputs from land. They are important tools for sustainable management and can be devised at scales from the paddock up to whole landscapes. Increasingly, regional councils and accreditation schemes are using them.

It is prohibitively expensive to measure directly the flows of nutrients in a farm system. The only viable option is to use nutrient budget models that use unique input data for each property. Normally these budgets calculate offtakes and losses of nutrients on the basis of typical or expected yields, and inputs that the user chooses.

Key point: What's the use?

Nutrient budgets can provide a check on the sustainability and potential environmental impacts of nutrient management practices. They do not calculate yield or nutrient requirements of crops, nor do they indicate if using fertilisers will be profitable.

If nutrient inputs (e.g. from fertilisers) are known, and offtakes in harvested produce are estimated from yields and typical crop composition data, then simple nutrient budgets for vegetable crops can be constructed on paper or in a spreadsheet. However, these can seriously underestimate the potential for adverse environmental impacts unless proper account is made for processes like leaching, mineralisation and N-fixation by legumes. For some crops, nutrient budgets can be constructed using information gained from crop or nutrient management software although this can be challenging to extract and document.

Overseer®

Overseer® is a decision support system for calculating nutrient budgets using long-term weather data. It models the cycling and flow of nutrients to estimate the:

- Losses of key nutrients including N and P (which can have environmental impacts);
- Losses of agricultural greenhouse gases;
- Balance of inputs and outputs of essential plant nutrients to indicate sustainability of nutrient supply to plants;
- Effect of different crop rotations, nutrient inputs, residue management and fallow periods on availability or losses of nutrients.

The best method of interpreting Overseer's output is to use trends of the nutrient balances and losses over several years. Overseer can work well for pastoral agriculture and many cropping situations, but current (2018) versions lack sufficient capability for some vegetable-growing businesses. This is especially the case where the total length of a crop rotation lasts several years and involves several different crops, and where crops grown in the same year have disparate needs and impacts. There may be some work-arounds for this but they are most likely beyond the resources of most growers and advisors.

Some regulatory authorities have adopted Overseer to provide information on the sustainability of agricultural production, and for assessing and controlling the potential for nutrient losses to the wider environment. Overseer can offer useful insights into those matters, but as noted above the software has important limitations for some vegetable-growing businesses. Where use of Overseer is required of growers, often the best approach is via an accredited consultant, such as a Certified Nutrient Management Adviser, who has a good understanding of the programme and is trained to fully interpret its output.

For more information visit www.overseer.co.nz or www.fertiliser.org.nz/Site/faq.

CHAPTER 02

MAKING NUTRIENT RECOMMENDATIONS

The optimum plan for supplying nutrients can vary a great deal between situations. Even for a single type of crop there is no single best way for all growers.

The main factors that influence the likely outcomes from nutrient amendments are:

- Potential yield — this dictates the maximum amount of nutrients the crop needs, and is influenced mainly by weather, the plant population and quality considerations for marketing (e.g. plant size). It is defined in Chapter 1 Potential, field and marketable yields;
- Non-nutritional factors that lower potential yield to field yield (Chapter 1 Potential, field and marketable yields). Examples are water stress, poor soil structure, pests and diseases;
- Chemical fertility of the soil (quantified by soil testing);
- Nature of the amendments and how they are applied — are the nutrients quickly or slowly available, are they broadcast or banded, when are they applied relative to crop needs? (*Right product, Right rate, Right place, Right time*);
- Value of the crop compared with the costs of the amendment (see Economic matters in Chapter 1);
- Risks of nutrients being lost to the wider environment (see Environmental matters in Chapter 1).

There are two major components of a fertiliser nutrient recommendation:

1. How much nutrient is required to grow the crop?
2. How much nutrient is needed for maintenance — i.e. will be needed to replace that removed in the crop (offtake)?

It is important to remember that the nutrient supplied to a crop is the total of that from the soil and that from amendments such as fertilisers.

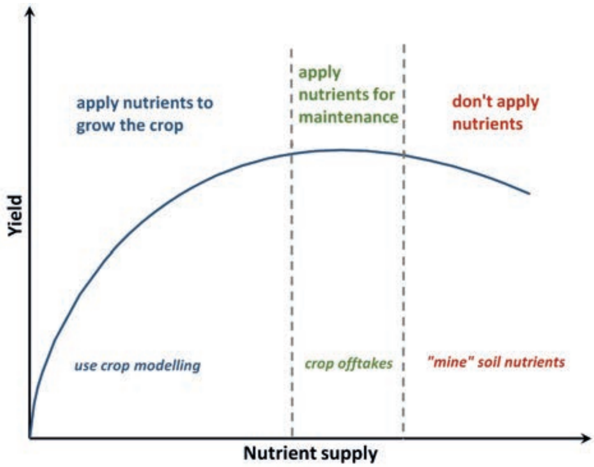


Figure 2-1 Typical response of crop yield to the total supply of a single nutrient (from the soil and from amendments). The upper limit of yield is set by crop characteristics and the weather — you cannot increase this by adding more and more nutrients.

Key point: too much nutrient supply?

If soil nutrient supply is small, additions are often needed to achieve potential yields and quality. At a certain rate of supply there will be little or no gain from extra nutrient. Then the best policy is to apply only enough to maintain the soil fertility. At a still higher rate, yield may decline, or the risk of environmental damage becomes unacceptable. Then it is best not to apply more nutrient. For some nutrients and crops this decline in yield can be very pronounced; for others it is gradual (Figure 2-1).

2.1 NUTRIENTS TO GROW THE CROP

First we need to know if nutrient additions like fertilisers are necessary to achieve the target crop yield and quality. This depends on the amounts of nutrients already in the soil, so:

Amount of extra nutrient required = amount of nutrient required for target yield
— the soil supply of the nutrient

Often the uptake of nutrients for each crop is not a reliable estimate of the amount of nutrient that should be applied to grow vegetables.

- Some vegetable crops have a strong capacity to take up nutrients in greater quantities than required for maximum yield ("luxury uptake").
- Others (like buttercup squash and onions) may have sparse root systems and a short time to take up the nutrients they need. To achieve a high rate of uptake by each mm of root these crops need high concentrations of nutrients in the soil. Then the optimum fertiliser applications may be greater than plant uptake. However, the disparity between uptake and the fertiliser rate for the best yield can be reduced by careful placement and timing of fertiliser applications.

In this book, computer models based on field research have mostly been used to estimate the amount of nutrient that needs to be added to "grow the crop". The results are summarised in tables that relate the nutrient application rate required to crop potential yield and the initial soil test nutrient concentration.

Recommendations from models

For a number of vegetable crops, NZ research has considered all or most of the factors that will influence the response to supply of the major nutrients. Developing general recommendations for those crops is still complex, but computer models can help greatly. That is the main approach used in this book. The models most used are adaptations of PARJIB (Reid 2002) and the Potato Calculator (Jamieson et al. 2006). These have been calibrated for each crop type individually using results from field experiments in NZ.

PARJIB relates crop yield to the supply of N, P, K and Mg from the soil and fertilisers. It takes into account potential yield and interactions between the effects of these nutrients and soil pH. It also accounts for differences between the efficiency of nutrients already in the soil compared with those in fertilisers.

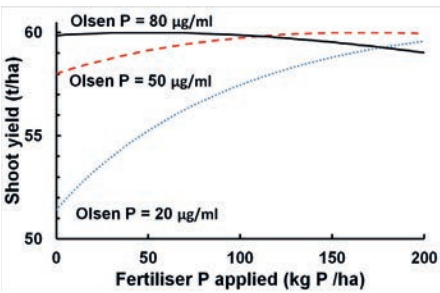


Figure 2-2 Lettuce response to fertiliser P at three different concentrations of soil Olsen P, simulated using the PARJIB model (Reid 2002). The potential yield was 60 t/ha of shoot biomass (30 t heads/ha), and there were no limitations from other nutrients, pH or soil water. The rate of applied P required to grow the crop decreases as Olsen P increases.

The models mimic the way that crop yields respond to nutrient supply, with yield response to fertilisers decreasing to nil as the soil test value increases — in some cases yield may decrease if nutrient is supplied beyond an optimum (Figure 2-2). That optimum depends on the crop's potential yield. For the recommendations here the models examined yield response to nutrient supply under different scenarios. These included different potential yields and situations where yield was also limited by factors such as water stress.

For each scenario, the models simulated the response curves individually for N, P, K and Mg when the other nutrients were optimally supplied. Recommended fertiliser rates were chosen for the crop to achieve 99% of the maximum yield. This avoided the very high fertiliser rates often necessary to achieve potential yields when the response curve is very gradual. It was not practical to identify economically optimum fertiliser rates; there are too many variations in fertiliser and crop prices to include in a book of this size.

Key point: nutrient uptake and yield response are not the same thing

When soil test values are low, crops may yield best at fertiliser rates that exceed their actual uptake of the same nutrients. This is probably because the crops have sparse root systems and a short growing season. However, the disparity between uptake and the fertiliser rate for the best yield should be reduced by careful placement and timing of fertiliser applications.

Using critical nutrient concentrations in the plant

This approach is being used increasingly overseas (e.g. in the UK and Germany).

Crop yield declines if the concentration of any nutrient in the plants is less than a critical value. So if you know that, you can calculate the amount of nutrient that it must take up to reach any particular potential or target field yield; you simply multiply the critical concentration by yield (making sure the units are compatible). This provides a clear indication of the amount of the nutrient that must be supplied from the soil and fertilisers together, assuming all the fertiliser is used efficiently.

For N you may subtract the soil test Available N figure from the calculated uptake to estimate the fertiliser N requirement. For nutrients like P and K, soil test laboratories do not report kg of available nutrient per hectare, and the calculations can be difficult.

Usually, the critical concentrations of nutrients like N, P and K must be measured *for the whole plant* (not just leaves) and these values generally change as the plants grow bigger. So you need to know the critical concentrations when the plants are at the same dry mass at which you want to harvest them. For a few crops these values are well documented, and nutrient requirements can be forecast using them.

In this book, the nutrient recommendations for beetroot, cabbage, broccoli, cauliflower, silverbeet and spinach have been calculated using published relationships between plant dry mass and critical N concentrations.

Key point: plant nutrient concentrations

For most of the major nutrients plant concentrations are greatest when the plants are young (Figure 2-3). As the plants grow larger, more and more of the plant mass is made up of structural material that contains very few mineral nutrients. The growth of this structural material "dilutes" the concentrations of nutrients like N, P and K in particular, which fall as the crop gets older and bigger.

The critical concentrations of N, P and K in plants also tend to fall markedly as plants grow bigger. For some crops, however, the change in critical nutrient concentrations is quite predictable and well documented.

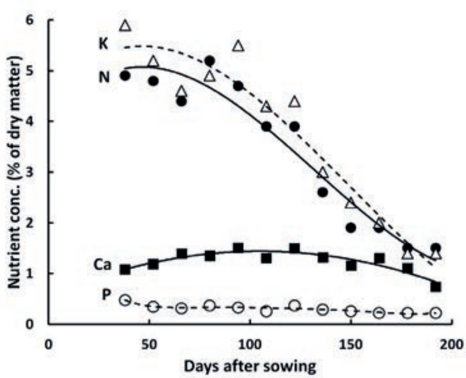


Figure 2-3 Nutrient concentrations in leaves and bulbs of an onion crop ('Pukekohe Long Keeper') grown at Pukekohe in 1993–94. Drawn from data kindly supplied by David Sher. Note that Ca concentrations did not follow the same pattern as the other nutrients. This crop appeared to be adequately supplied with nutrients.

Using target soil test values

There has not been enough research to calibrate models for all crops in NZ. For some crops, however, there are indications of soil test ranges that do not appear to limit crop yield, and nutrient recommendations can be made on that basis.

The approach assumes that yield varies in a simple way with the soil test values.

Target values for P and K were used extensively in earlier fertiliser recommendations for NZ.

Soil test targets can work well, but are often less reliable than use of a properly checked and calibrated model. One concern is that supporting evidence for the target ranges is surprisingly difficult to find. Be wary especially of targets based on overseas evidence — always check that they refer specifically to the same soil test method that is used in NZ. Olsen P tests are standard throughout much of the world, but not everywhere. The NZ methods for measuring and reporting pH, cations and N differ from those in most other countries.

For field vegetables, the approach seems to have been tested most thoroughly for Olsen P. For some crops, identifying a target Olsen P appears straightforward (e.g. Figure 2-4a). For others the evidence is much less convincing (e.g. Figure 2-4b) and it is hard to justify the targets used in earlier recommendations.

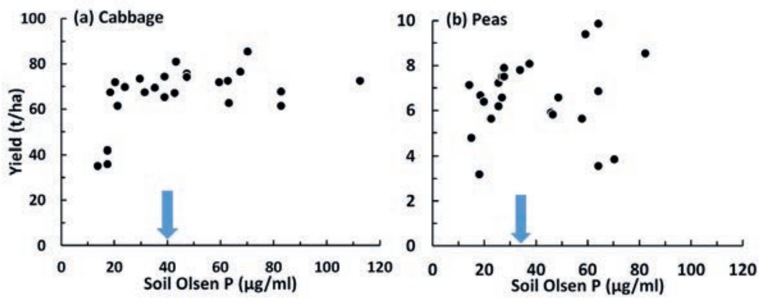


Figure 2-4 Relationship between yield and soil Olsen P for cabbage and peas grown at Levin (Prasad et al. 1988). The arrows indicate the target Olsen P identified by Prasad and colleagues.

For nutrients like K and Mg it is hard to find supporting evidence that comes close to the quality of that for the Olsen P targets. Very few field experiments with vegetables in NZ demonstrate response curves to either soil test values or fertiliser applications for these nutrients. Experiments at Pukekohe over 4 years failed to find a consistent relationship between QT K and potato yield. Previously recommended target ranges were perhaps estimated as the lowest soil test value at which no fertiliser response was measured. There is almost no experimental information available on target soil test values for N. So, for vegetable crops, nutrient recommendations based on target soil test values should be regarded with considerable caution.

In this book, the P and K recommendations for beetroot, cabbage, broccoli, cauliflower, silverbeet and spinach were calculated using target ranges.

Using target values to make a nutrient recommendation

Targets are often quoted as ranges.

If a soil test value is more than the target range, either:

- Withhold fertiliser and allow the value to drop into the target range; or
- Apply a maintenance nutrient rate.

In the case of P, there is an environmental cost to the second option because high soil test values incur a greater risk of P contamination of water bodies. Calculation of maintenance nutrient rates is explained later in this chapter.

If a soil test value is within the target range, apply a maintenance nutrient rate.

If a soil test value is below the target range, nutrients should be applied before planting to increase the soil test value into the target range. Use the following guidelines to calculate the amounts of nutrient to apply. They are all calculated to raise the soil test value in the top 15 cm of soil only.

To raise soil Olsen P

To raise Olsen P (from 0 – 150 mm depth) by one unit (µg/mL) requires:

25 kg P/ha (range 20 – 30 kg P/ha) on volcanic ash (Allophanic and Granular) soils

13 kg P/ha (range 10 – 16 kg P/ha) on peat (Organic) and sands (Recent) soils

10 kg P/ha (range 3 – 16 kg P/ha) on sedimentary (Recent and Brown) soils.

To raise soil QT K

On average to raise QTK (from 0 – 150 mm depth) by one unit requires 50 kg K/ha (range 30-70) for the volcanic ash and 33 kg K/ha for the Brown sedimentary soils. With Recent soils the exact clay types present may be very important and it is best to check local experience with each specific soil.

On some peat soils, for example those in Hawke's Bay, it is very difficult to increase QT K concentrations even with high capital rates of application of K fertiliser.

2.2 MAINTENANCE NUTRIENT APPLICATIONS

The offtake, or amount of nutrient removed in the harvestable portion of the crop, represents the loss of nutrients from the soil. This rate of nutrient is usually referred to as the maintenance application.

Key point: is it necessary?

Maintenance applications should be made only if no nutrients have been applied to grow the crop. Unless soil test values are high, nutrient applications to grow the crop are usually greater than maintenance rates.

Usually in vegetable cropping, maintenance nutrient applications are best made before or during the crop's growth. Strictly, maintenance rates are most accurately calculated (and applications made) after you know the yield and nutrient offtake of the crop — but often this is impractical, particularly because soil tests should be taken for the next crop:

- An extra round of fertiliser applications may complicate interpretation of those soil tests because of slow equilibration within the soil;
- The soil test results will reflect any depletion by the previous crop. Nutrient applications to grow that next crop will be calculated from those soil tests and will correct that depletion if it is likely to affect crop performance;
- The grower may want a decrease in soil test values for best performance of the next crop.

The first step to calculating maintenance applications is to estimate the amount of plant material that will be removed from the field. If you are forecasting a target yield, wherever possible use information for the same crop grown in the same general location.

The next step is to identify the most likely nutrient offtake per tonne of yield. There is no standard data source for this in NZ, but there are options.

Sometimes information on typical nutrient concentrations in the crop can be supplied by accredited chemical testing laboratories within NZ. If not, overseas data may have to be used. Useful sources of uptake and offtake (removal) data include USDA (2018) and IPNI (2018).

Key point: Check the units

If you are using data from overseas, be sure you use values quoted in kg of each element per tonne of yield. Overseas they often quote values in kg P_2O_5/t (multiply by 0.43 to get kg P/t) and kg K_2O/t (multiply by 0.83 to get kg K/t).

Also check if the values are quoted for dry or fresh yields.

For each nutrient multiply the target yield (t/ha) by the estimated nutrient concentration (kg nutrient/t) to get the recommended maintenance nutrient application rate.

Is maintenance always best?

Generally, the risks of nutrient losses to groundwater and run-off will be greatest from soils with high soil-test values. So if soil test values are already above the amounts that would limit crop growth it could be environmentally damaging and financially pointless to apply maintenance fertiliser. For some crops the figures available for K removals (here and in OVERSEER) reflect luxury uptake — forever replacing these removals would encourage further unnecessary uptake.

Maintenance applications of N by soluble fertilisers are not recommended. Except in organic production systems, N fertiliser is applied for crop needs, not to replace losses, because most soils do not retain N and it will be subject to leaching. To minimise leaching in the fallow period following harvest growers should aim for soil mineral N to be as low as possible when the crop is harvested. This restriction need not apply to applications of composts which slowly release mineral N.

2.3 NUTRIENT RECOMMENDATIONS FOR CROPS NOT IN THIS BOOK

Approaches that can be taken include:

- *Using target soil test values*. Target ranges may be quoted in earlier publications, but be cautious over their reliability.
- *Using estimated uptakes*. For some crops uptake can be calculated from critical nutrient concentrations (see above). Values for N in particular may be available from the scientific literature, but there is much less data for P and K, and the calculations can be tricky.

- *Using estimated offtakes*. For some crops, the only suitable information available may be the target yield and overseas data for nutrient content of harvested plant material (see above section on maintenance fertiliser applications). This approach may underestimate nutrient requirements when soil test values are low, and overestimate them when they are high.

2.4 FROM RECOMMENDATION TO APPLICATION RATES

The nutrient recommendations in this book are given as kg of the nutrient per hectare. For each nutrient there will be a number of ways of applying the recommended amount using the fertiliser products available locally. Products differ in their composition so it is important to follow a reliable way of calculating how much of each product is needed.

The N-P-K-S rating of a fertiliser indicates the percentage amount of plant nutrients in it. For example a 15-10-10 fertiliser contains 15% N, 10% P, and 10% K. To calculate the quantity of fertiliser needed to apply a given rate of nutrient, use the following formula:

Rate of fertiliser application = rate desired for nutrient (kg/ha) x 100

(kg/ha) nutrient in fertiliser (%)

Example: A nutrient recommendation is for 30 kg N/ha, 20 kg P/ha, and 30 kg K/ha. What rate of a 15-10-10 fertiliser should be applied?

$$\text{N: rate of fertiliser} = \frac{30 \times 100}{15} = 200 \text{ kg/ha}$$

$$\text{P: rate of fertiliser} = \frac{20 \times 100}{10} = 200 \text{ kg/ha}$$

$$\text{K: rate of fertiliser} = \frac{30 \times 100}{10} = 300 \text{ kg/ha}$$

So, you cannot apply the required N, P and K with this fertiliser. Applying 200 kg/ha of 15:10:10 meets the N and P recommendations but will deliver only 20 kg K/ha. The remaining 10 kg K/ha that is required could be met by adding say some muriate of potash (0-0-50). The amount required will be (10 x 100/50) = 20 kg/ha.

2.5 A FINAL NOTE

Irrespective of how a nutrient recommendation is arrived at, it must be consistent with the Code of Practice for Nutrient Management (FANZ 2013). In particular:

- Fertiliser application methods, placement, and timing must be arranged to minimise the risks of leaching, run-off or volatilisation. Generally this entails incorporating fertiliser whenever possible, and splitting N fertiliser applications.
- Recommended applications of P, K, and Mg should not be less than required for maintenance of soil nutrient reserves, except if soil test values are already excessive (see *Is maintenance always best?*).

CHAPTER 03
BEANS FOR PROCESSING

Beans grown for processing in NZ are usually *Phaseolus vulgaris* L. and are often referred to as process beans, dwarf beans, or French green beans. They are grown mainly in Canterbury and Hawke's Bay. Like peas, beans are legumes capable of fixing atmospheric nitrogen (N) for their own use, and are sometimes regarded as a useful crop in a rotation because of this. However, compared with peas, process beans are grown at about half the plant population density (usually <45 m-2) and have a shallower root system. So usually they have sparser root systems that have to support similar amounts of shoot growth. A consequence is that, unlike peas, beans have shown strong responses to soil nutrient concentrations and fertiliser applications.

3.1 POTENTIAL YIELDS

Potential yields depend greatly on air temperatures, interception of light by the canopy, and factory requirements that influence harvest times. Preliminary indications are that under NZ conditions potential yields may be as high as 30 t/ha of fresh beans in pod, equivalent to about 3.3 t/ha of dry matter. Many crops, in Canterbury at least fail to achieve field or marketable yields of 20 t/ha, and plant nutrition may be an important limitation.

These recommendations assume a potential yield of 30 t/ha of fresh beans in pod, and that 90% of the pods are removed from the field.

3.2 NUTRIENTS TO GROW THE CROP

Soil tests

Before the crop is planted carry out soil testing from 0–15 cm depth in each paddock. Choose the standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and soil volume weight) PLUS 'Available N' (anaerobically mineralisable N) in kg N/ha.

Nitrogen (N)

Although beans can fix much of their own N, some fertiliser N applied at sowing often increases yields.

- If soil Available N < 150 kg N/ha, apply up to 46 kg N/ha.
- If Available N > 150 kg N/ha, do not apply N.

If using soluble fertilisers, keep high salt-effect fertilisers from being too close to the seed (see Plant establishment and starter fertilisers in Chapter 1). If using fertilisers with a low to moderate risk of seedling damage (e.g. YaraMila and Nitrophoska ranges, Crop Zeal 15/Cropmaster 15), apply up to 46 kg N/ha down the spout. If using fertilisers with a high risk of seedling damage (e.g. Crop Zeal 20/Cropmaster 20, urea), ensure there is separation between fertiliser and the seed and take special care of this under dry conditions. Experiments have found broadcast fertiliser to be poorly effective for beans grown in Canterbury, so side-dressing is unlikely to be effective.

If using compost sources of N, incorporate these at least a month before planting so that there is time for the N to start becoming available to the plant.

Phosphorus (P)

Olsen P (µg/mL)	Recommended P application (kg P/ha) to grow the crop
<45	67
45 – 60	30
>60	nil

If using soluble fertilisers, keep high salt-effect fertilisers separate from the seed (see Plant establishment and starter fertilisers in Chapter 1). If using fertilisers with a low to moderate risk of seedling damage (e.g. superphosphate, Nitrophoska, YaraMila, Cropmaster 15/Crop Zeal 15) apply up to 30 kg P/ha down the spout (the rate might be limited by the capacity of the drill itself, but aim for fertiliser placement that separates seed from the fertiliser). If using fertilisers with a high risk of seedling damage (e.g. Cropmaster 20/Crop Zeal 20), ensure there is separation between fertiliser and the seed and take special care of this under dry conditions. Do not side-dress P fertilisers as the plants will take up very little of the P applied.

If using compost sources of P, incorporate these at least two weeks before planting.

Potassium (K)

Soil QT K	Recommended K application (kg K/ha) to grow the crop
3	260
4	210
5	150
6	80
>6	nil

If using soluble K fertilisers, apply up to 30 kg K/ha of the recommendation down the spout, but do not apply high salt-effect fertilisers like MOP this way (see Plant establishment and starter fertilisers in Chapter 1). If using fertilisers with moderate risk of seedling damage (e.g. YaraMila, Nitrophoska, Cropmaster 15), apply up to 30 kg K/ha of the total recommendation down the spout and apply the remainder of the recommendation 5 cm from the drill line. Fertilisers with a high risk of seedling damage (e.g. MOP) should be broadcast.

If using compost sources of K, incorporate these at least two weeks before planting.

Calcium (Ca) and lime

Yield or quality responses to fertiliser Ca are very unlikely in NZ because most soils contain large quantities of this nutrient, and much is applied in the form of lime to correct low soil pH.

There appears to be no definitive study of lime effects on process beans in NZ. Marked effects of low soil pH were noted in the modelling carried out for these recommendations; yield losses of 30 – 40% were indicated when soil pH fell below 5. Soil pH values in excess of 6.5 enhance the risk of trace element deficiencies.

- Apply lime only if pH is less than 5.5, targeting a pH of 6.0.
- Apply fine lime at least a month before planting.

Magnesium (Mg), sodium (Na), sulphur (S) and trace elements

There is no evidence that fertilisers for these nutrients are needed for process bean crops in NZ. However, the crop is reputedly vulnerable to Zn deficiency when grown on high pH soils. If Zn deficiency is suspected, the best treatment is probably foliar sprays applied at manufacturers' recommended rates. Foliar sprays are best applied in the early morning or evening to extend the drying time and the opportunity for the nutrient to enter the leaves.

3.3 MAINTENANCE NUTRIENT APPLICATIONS

Maintenance applications of any particular nutrient should be made only if none will be applied to grow the crop.

There appears to be no information available on nutrient uptake and offtake by process bean crops grown in NZ. Offtake values have to be calculated using overseas data.

Table 3-1 Estimated offtakes of N, P and K by a process bean crop where the yield removed from the field is 27 t/ha. The values are based on data from the USA (USDA 2018).

	N (kg N/ha)	P (kg P/ha)	K (kg K/ha)
kg nutrient/t[1] pods	**3.7**	**0.60**	**2.8**
offtake by a 27 t/ha crop	**100**	**16**	**76**

Estimate maintenance application rates from the kg of each element taken up or removed per tonne of harvested roots (see Table 3-1 above). For a crop where 27 t/ha pods are removed from the field, the maintenance P application should be 27 x 0.6 = 16 kg P/ha.

For N, maintenance applications should be considered only under organic production systems using composts.

If Olsen P>75, do not apply any maintenance P (allow Olsen P to decrease).

If QT K>10, do not apply any maintenance K.

For methods of application of nutrients, follow the guidelines for nutrients to grow the crop.

3.4 PLANT NUTRIENT ANALYSIS

Typical concentrations in the foliage or even whole plants are of little use. It is very difficult to establish critical concentrations of nutrient elements in beans grown in the field and, for N, P and K at least, these critical concentrations decrease markedly as the plants grow larger (Table 3-2).

Table 3-2 Critical concentrations for whole plants (above ground) of beans grown in the UK (Greenwood et al. 1980). Values are given on a dry mass basis.

Plant dry mass (g)	N	P	K
3	5.1	0.48	3.8
10	2.8	0.3	2.7
11	1.7	0.2	2.1

Most likely deficiency symptoms

Visual symptoms of nutrient deficiency are very unlikely in NZ bean crops. Damage from extreme weather, insects, diseases or sprays are much more likely to cause unusual appearance of the shoots. Helpful images are available from the Yara CheckIT app for mobile telephones (Yara 2017). On high pH soils Zn deficiency may appear early in crop growth; symptoms include pale green colours between the leaf veins and abortion of pods formed from terminal flowers.

CHAPTER 04
BUTTERCUP SQUASH

Buttercup squash (*Cucurbits maxima* Duch.) is grown mainly in the North Island and Canterbury under a wide range of soil and weather conditions. Good crops have a very fast growth rate per plant. The crop is grown at 15,000 – 22,000 plants/ha, producing about 11 t/ha of dry matter. An individual plant may achieve a dry mass of 500 – 730 g of dry matter about 110 days from planting. That is two to three times the growth achieved by individual plants in sweet corn crops over much the same time. Squash roots may grow very deep along the planting line, but the root system is sparse in the topsoil away from that line. To sustain fast shoot growth rates, the crop requires the soil to be of quite high fertility, at least in the regions close to the base of the vines.

4.1 POTENTIAL AND MARKETABLE YIELDS

Potential fruit yields in squash are dictated mainly by the weather. In particular, the crop needs warm soil temperatures (preferably >15°C) to germinate and emerge. After emergence, yield is strongly influenced by the amount of sunshine the crop can intercept, and rapid leaf growth is crucial (ready access to nutrients and water are important for this). Hot weather through the season can speed leaf growth but it will encourage faster maturation of the crop so that potential yield is not necessarily greater than in cooler but bright weather.

Potential yields can seem high — but it must be remembered these refer to the maximum possible in-field yield of all fruit. Field yields are generally less and marketable yields less again. Drought in particular may reduce field yields, and this will usually reduce the nutrient demands of the crop.

These recommendations consider two distinct scenarios:

Scenario 1: Potential yield of 40 t/ha. This is representative of mid-season crops with a duration of around 110 days, grown under favourable weather conditions. *These crops might achieve 24 – 32 t/ha of marketable fruit.*

Scenario 2: Potential yield 28 t/ha. This is representative of early or late-planted crops that achieve *marketable yields around 16 – 22 t/ha*.

For each scenario the recommendations consider an additional variation where the field yield is 80% of potential because of water stress. This is most appropriate for crops where irrigation is not available and water stress is likely because of low rainfall (e.g. on the East Coast of the North Island).

4.2 NUTRIENTS TO GROW THE CROP

Soil tests

Before the crop is planted carry out soil testing from 0–15 cm depth in each paddock. Choose the standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and soil volume weight) PLUS 'Available N' (anaerobically mineralisable N, in kg N/ha).

Nitrogen (N)

Buttercup squash can take up much N, but yield can be reduced by excessive N supply. Probably, this yield reduction occurs because excess N can encourage late-season leaf growth and further flowering at the expense of growing the fruit that should be approaching harvestable maturity.

If using soluble fertilisers (this includes solid, suspension or dissolved fertilisers), apply half the recommended N just before planting as a band 12 – 30 cm wide centred on the planting line. Incorporate the fertiliser but not deeper than 12 cm. Side-dress the rest of the recommended N within two weeks of crop emergence (around the 2 – 3 leaf stage and before runners start to form). These applications can be broadcast, but there may be an advantage in applying the N in another band just outside the original banded area or knifing it in about 15 – 20 cm from the plant line. All side-dressings should be readily available forms like urea to ensure adequate N is available to the crop as it rapidly accumulates biomass.

The N side-dressing at the 2 – 3 leaf stage can be replaced by **slow- or controlled-release N fertilisers applied at planting**. This may reduce the risk of leaching. Choose products where the majority of the N becomes plant-available 30-40 days after application. Apply them in a band up to 50 cm wide down the planting line.

If fertigation is available, split the recommended N fertiliser across several applications during crop growth. This can assist in matching N fertiliser supply with the demands of the crop, and lessen the risk of nitrate leaching, but wet weather may restrict the opportunities to apply the fertiliser.

If using compost sources of N, incorporate these at least 2 weeks before planting.

Available N (kg N/ha)	Recommended N application (kg N/ha) to grow the crop			
	Scenario 1: Potential yield of 40 t/ha		Scenario 2: Potential yield of 28 t/ha	
	No water stress	Water stressed	No water stress	Water stressed
60	180	150	70	20
70	150	110	40	20
80	120	80	20	20
90	90	50	nil	nil
110	30	nil		
120	nil			

These recommendations, based on the PARJIB model, are in accord with earlier industry recommendations that were based on experiments conducted in the 1980s. However, some growers achieve good results with N applications less than those in the above table.

Nitrogen and squash quality

Inadequate N supply may cause early leaf death, raising the risk of sunburnt fruit.

Phosphorus (P)

Earlier recommendations emphasized target soil Olsen P ranges that now seem excessive. Those recommendations were based on experiments where fertiliser P was largely broadcast on soils with high ability to fix P. More recent research has emphasized the better efficiency of P fertilisers that are banded or knifed in.

If using compost sources of P, broadcast and incorporate these at least 2 weeks before planting.

If using organic or mineral P fertilisers that are slowly soluble, these can be bulky. Broadcast most of the recommendation before planting, but retain a portion to apply at planting in a band about 25 cm wide centred on the drill line.

If using soluble P fertilisers, apply as much as possible of the recommended P in bands or by knifing it in.

- Knife the P fertiliser in to 5 – 10 cm depth 3 – 5 cm from the drill line at planting; or
- Apply it just before planting as a band 12 – 30 cm wide centred on the planting line, and incorporate the fertiliser to 10 – 15 cm depth.

Soil Olsen P (µg/mL)	Recommended P application (kg P/ha) to grow the crop			
	Scenario 1: Potential yield of 40 t/ha		Scenario 2: Potential yield of 28 t/ha	
	No water stress	Water stressed	No water stress	Water stressed
10	50	50	30	30
20	40	30	20	20
30	30	20	10	10
40	20	15	11	nil
50	16	nil	nil	
60	nil			

Phosphorus and buttercup squash quality

There is no clear evidence that P supply noticeably affects squash fruit quality in NZ.

Potassium (K)

If using composts, broadcast and incorporate these at least 2 weeks before planting.

If using soluble K fertilisers, apply as much as possible of the recommendation in bands. If K fertiliser is required, apply up to 10 kg K/ha as a starter down the spout or close to the drill line — but avoid scorching germinating seeds. Apply the remainder of the recommendation just before planting as a band centred on the planting line. Make the band 12 – 30 cm wide and incorporate the fertiliser to 10 – 15 cm.

QT K	Recommended K application (kg K/ha) to grow the crop			
	Scenario 1: Potential yield of 40 t/ha		Scenario 2: Potential yield of 28 t/ha	
	No water stress	Water stressed	No water stress	Water stressed
4	270	130	75	60
5	170	81	nil	nil
6	101	nil		
7	nil			

Potassium and buttercup squash quality

There is a suggestion that high K supply (from the soil and fertilisers) may decrease the incidence of fruit storage rots. This influence is complex and depends upon the weather and calcium concentrations in the fruit, so no recommendation can yet be made.

Calcium (Ca) and lime

Yield responses to fertiliser applications of Ca are very unlikely in NZ. Low Ca concentrations in the fruit may increase the incidence of storage rots. Soil applications of Ca are very unlikely to affect Ca concentrations in the fruit.

Overseas, there is evidence that foliar sprays of Ca compounds may improve shelf life of some cucurbits such as honeydew melon, but not others such as cantaloupes. There are no data indicating effects of foliar Ca applications for buttercup squash in NZ; however, any benefits may be rather small because Ca will not be translocated out of leaves into the fruit, and growers usually aim for good canopy cover to avoid sunburn of the fruit.

Calcium is frequently added to the soil in lime applied to raise soil pH. Soil pH appears to have an important influence on buttercup squash yield.

- Apply lime if pH is less than 6.0, targeting a pH of 6.4 – 6.8.
- Apply fine lime at least a month before planting.

Magnesium (Mg)

Experiments on buttercup squash in NZ have failed so far to demonstrate any relationship between yield or quality and soil QT Mg, and experiments with Mg fertiliser have not been carried out. Many horticultural soils already contain much exchangeable Mg, and deficiency symptoms in squash are most likely to occur close to maturity when it is too late to correct by fertilisers or foliar sprays. So unless there is clear evidence of deficiency on previous or adjacent crops, Mg fertilisers appear unnecessary.

Sodium (Na), sulphur (S) and trace elements

Do not apply Na fertilisers to buttercup squash in NZ. Small amounts of Na present in some compound fertilisers are unlikely to be harmful.

Yield or quality responses to fertiliser applications of S have not been documented in NZ. Soils used for vegetables in NZ usually contain adequate quantities of S already; S is commonly applied as part of other fertiliser applications (such as superphosphate or potassium sulphate).

Starter applications of trace elements are unlikely to be economic, unless there is strong evidence of specific deficiencies in previous crops at that site. Maintenance applications are of the order of a few g/ha and availability of these nutrients is so dependent upon pH and changes in soil water content that trace elements applied to the soil can be ineffective. Where a specific deficiency is confirmed by foliar analysis the best option may be to apply a foliar fertiliser as soon as possible at manufacturers' recommended rates. These sprays are best applied in the early morning or evening to extend the drying time and the opportunity for the nutrient to enter the leaves.

4.3 MAINTENANCE NUTRIENT APPLICATIONS

Maintenance applications of any particular nutrient should be made only if none will be applied to grow the crop. For N, maintenance applications should be considered only under organic production systems using composts.

There is little information available on uptake and partitioning of nutrients within squash crops. There is a great deal of information on nutrients in the fruit flesh, but these may differ considerably from concentrations in the whole fruit.

Table 4-1 Typical amounts of N, P and K removed from the soil by buttercup squash crops. These assume that only the marketable fruit are removed from the field.

	N	P	K
kg/t fruit removed from the field	**3.7**	**0.56**	**3.62**
Offtakes **(kg nutrient/ha)**			
Scenario 1: Potential yield 40 t/ha,			
no water stress, marketable yield 28 t/ha	**103**	**16**	**101**
water stressed, marketable yield 22 t/ha	**82**	**13**	**81**
Scenario 2: Potential yield 28 t/ha,			
no water stress, marketable yield 20 t/ha	**72**	**11**	**71**
water stressed, marketable yield 16 t/ha	**58**	**9**	**57**

Calculate maintenance nutrient applications from the kg of each element *per tonne of fruit removed from the field* (Table 4-1).

A crop yielding 40 t/ha of fruit would have about 40 x 0.56 = 22.4 kg P/ha in the fruit, but not all of this is removed from the field. If 60% of the fruit are removed from the field, the maintenance application of P would be about 40 x 0.56 x 60/100 = 13.4 kg P/ha.

If Olsen P>70, do not apply any maintenance P (allow Olsen P to decrease).

If QT K>10, do not apply any maintenance K.

For methods of application of nutrients, follow the guidelines for nutrients to grow the crop.

4.4 PLANT ANALYSIS

Laboratories may quote typical nutrient concentrations in leaves of buttercup squash using results collated from crops in NZ. Comparisons with critical or optimum nutrient concentrations are a better guide to whether a crop is experiencing a nutrient deficiency. However, there is little information available for critical or optimum concentrations.

Sample the youngest mature leaves or, preferably, whole plants (above ground) about 2 weeks after emergence and compare nutrient concentrations in the dried samples with the values tabulated below. Be very cautious using leaves or plants sampled earlier or later because optimum and critical concentrations of N, P and K will decrease as the plants grow larger (Table 4-2).

Table 4-2 Critical nutrient concentrations (% dry matter) for buttercup squash 16 days after emergence. The values are calculated as the minimum required for the crop to maintain at least 90% of its maximum growth rate.

	Whole plants	Youngest mature leaf
Nitrogen (N)	5.4	7.3
Phosphorus (P)	0.6	0.9
Potassium (K)	5.6	4.4

Most likely deficiency symptoms

Nitrogen (N) deficiency may occur in warm periods following heavy rain or irrigation if N mineralisation from soil organic matter has not caught up with plant demand. It is seen mainly as premature yellowing of the older leaves.

Phosphorus (P) deficiency is often hard to detect. It is expressed mainly as slowed growth, but the young leaves may also have a dull emerald colour.

4.5 OTHER CUCURBITS

There are many other cucurbits grown, but their nutritional requirements have been studied little under NZ conditions. Until definitive field experiments are carried out on these other cucurbits in NZ the best information available suggests:

- For pumpkin (buttercup, butternut), calculate nutrient requirements as per buttercup squash
- For the other cucurbits, treat the P and K requirements to grow the crop as per the recommendations for buttercup squash, but assume total N requirements (from the soil and fertiliser combined) will be roughly half of those recommended for buttercup squash.

CHAPTER 05
CABBAGE, BROCCOLI AND CAULIFLOWER

These are all varieties of the one species *Brassica oleracea L.*, along with Brussels sprouts, kale, collard greens, Savoy cabbage, kohlrabi, and broccoflower. Despite their botanical similarities these crops have important differences in their shape, size, and culinary uses. Quality attributes, grading standards, and horticultural management practices can differ substantially between the crops.

Cabbage, broccoli and cauliflower share a crucial agronomic characteristic — often they leave behind a considerable amount of plant residues on the soil surface. They also share another characteristic — these residues are rich in nutrients.

Key point: Crop residues

If the plants are trimmed at the point of harvest, then the trimmings or residues left on the soil surface contain a great deal of P, K and organic N in particular. This is a resource that can save growers money. The residues are best cultivated back into the soil so the nutrients can be used by the following crop — and accounted for in the nutrient calculations for that next crop. If this is not done early, soil testing for the next crop may not detect the nutrients in the residues — and suggest far too much fertiliser for the following crop.

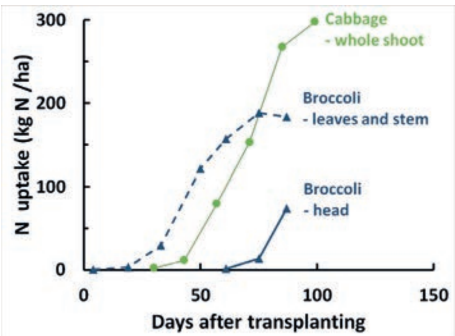


Figure 5-1 N uptake by cabbage and broccoli crops grown near Pukekohe. Note that very little N was taken up in the first month after transplanting. Note also that for broccoli 183 kg N/ha (or 71% of the total uptake) was in the leaves and stem — and left behind on the soil surface after harvest. For cabbage the trimmings (30 t/ha) would have left about 75 kg N/ha on the soil surface at harvest (25% of the total uptake).

5.1 POTENTIAL, FIELD, AND MARKETABLE YIELDS

Potential yield has been little studied in these crops. In terms of total dry matter production the crops are probably similar, but the percentage that goes into the harvestable portion of the plant differs considerably. It may be about 75, 18 and 37% for head cabbage, broccoli and cauliflower respectively; these figures can vary seasonally and with marketing requirements. A complication is that growers are usually paid on the basis of the number of marketable heads, and this depends on the number of plants as well as the required head size or weight. The percentage of plants that yield marketable heads will depend on grading standards that vary with marketing requirements.

Nutrient requirements to grow the crops have to be forecast on the basis of field yields (t/ha) before the crop is trimmed and graded.

Maintenance applications need to be based on offtakes — the nutrients removed from the field in the marketable product. Again these have to be calculated from measurements or estimates of yields in t/ha.

Recommendations are given for 6 scenarios, based on the top reported field yields in replicated experiments:

> **Key point: t/ha vs heads/ha**
>
> **If yield in t/ha is not measured then calculate it. This will require some measurement of the average mass of a marketable head (m measured in g), and the number of marketable heads per ha (n). Then**
>
> **yield in t/ha = m x n/1,000,000**
>
> **(1,000,000 is the number of grams in a tonne).**

1. Cabbage, winter planted, with a marketable yield of 68 t/ha fresh (90 t/ha fresh biomass in field, 25,000–33,000 marketable heads/ha);
2. Cabbage, summer planted, with a marketable yield of 45 t/ha (60 t/ha fresh biomass in field, 25,000–33,000 marketable heads/ha);
3. Broccoli, winter planted, with a marketable yield of 16 t/ha fresh (90 t/ha fresh biomass in field, approximately 33,000 marketable/ha);
4. Broccoli, summer planted, with a marketable yield of 11 t/ha (60 t/ha fresh biomass in field, approximately 33,000 marketable heads/ha);
5. Cauliflower, winter planted, with a marketable yield of 33 t/ha fresh (90 t/ha fresh biomass in field, approximately 28,000 marketable heads/ha);
6. Cauliflower, summer planted, with a marketable yield of 22 t/ha (60 t/ha fresh biomass in field, approximately 28,000 marketable heads/ha).

5.2 NUTRIENTS TO GROW THE CROP

There is no suitably calibrated model for these crops, so recommendations here are based on a combination of the best available information on critical nutrient concentrations in the crops and target soil test values.

A complication that may arise is if harvest must be advanced or delayed because of market requirements or the weather. No general recommendations can be made for managing nutrients to deal with such events, as the best actions will depend on the specific circumstances. However, it is worth remembering that unless the plants are clearly deficient in nutrients, applying extra nutrient will not make the crops grow faster — that growth rate will be set by the prevailing weather.

Soil tests

Before the crop is planted carry out soil testing for each paddock from 0–15 cm depth. Choose the standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and volume weight) PLUS 'Available N' (anaerobically mineralisable N, in kg N/ha).

Nitrogen (N)

Here, the N recommendations are based on critical plant N concentrations required for the target yields. The recommendations assume no leaching of nitrate below the root zone and the majority of the N available from the soil is in the top 15 cm depth, as estimated by the Available N (AMN) procedure. There are probable errors introduced by both assumptions, but they will tend to compensate for each other.

It is important to note that if the target yield is substantially different from those specified in the scenarios (Section 5.1), then the recommended fertiliser rates must be adjusted in simple proportion. For example in Table 5-1 the assumed target yield for summer-planted broccoli is 11 t/ha. If the target yield is 19 t/ha, for any soil-available N value the recommended N fertiliser rate will be (19/11) times the value in the table.

Total N requirements are often large, but these crops take up very little N in the first month after planting (Figure 5-1). This raises the risk of nitrate leaching from starter fertiliser. If wet weather is likely (e.g. for winter-planted crops), it is important that large applications of soluble N fertilisers are not made in that first month.

The total N fertiliser recommendations are given in Table 5-1.

At planting:

- **Soluble and controlled-release N fertilisers** are best incorporated or knifed in 2-5 cm from the plant row.
- **If using only soluble N fertilisers** like urea, ammonium sulphate, or CAN, apply no more than 20 kg N/ha, or up to 50 kg N/ha if this is a winter-planted crop and wet weather will greatly limit opportunities for side-dressing in the second and third months of growth.
- **If using controlled-release N fertilisers**, apply up to 100 kg N/ha of the controlled-release product and up to 20 kg N/ha of a soluble N fertiliser.

Split the remainder of the recommended N across at least two side-dressings after the plants have at least two true leaves (direct seeded crops) or have grown two extra leaves after transplanting. Avoid applying more than 50 kg N/ha at any one time. Side-dressings may be broadcast (if possible just before light rain or irrigation) but be careful to avoid fertiliser lodging amongst the leaves where it can cause cosmetic damage.

If applying N in the form of composts, incorporate these at least 2 weeks before planting.

Table 5-1 Recommended total N fertiliser rates (kg N/ha) for cabbage, broccoli and cauliflower. If the target yield is substantially different from that specified in the scenarios (Section 5.1), adjust the recommended fertiliser rates in simple proportion. For example if the target yield for summer-planted broccoli is 20 t/ha compared with the scenario yield of 11 t/ha, and the soil-available N is 50 kg N/ha, the recommended N fertiliser rate is 70 x 20/11 = 122 kg N/ha.

	1	2	3	4	5	6
Soil Available N (kg N/ha)	Cabbage, winter planted	Cabbage, summer planted	Broccoli, winter planted	Broccoli, summer planted	Cauliflower, winter planted	Cauliflower, summer planted
50	195	115	125	70	230	135
90	155	75	85	30	190	95
130	115	35	45	nil	150	55
170	75	nil	nil		110	15
210	35				70	nil
250	nil				30	
290					nil	

N and crop quality

Adequate N supply is important to maintain good leaf colour — but excessive N supply must be avoided. Applying more than the optimum N can decrease product quality by increasing the risk of head or spear rot in broccoli, lowering the dry matter percentage in cabbage, and causing yellow colours in cauliflower curds.

If harvest must be delayed, and experience indicates there is a risk of leaf yellowing because the crop is mature, then a light foliar application of N may help maintain leaf condition. The best rates have not been identified experimentally, and concentrated solutions risk leaf scorching, so it is probably best to limit individual applications to <5 kg N/ha. *If leaf yellowing has already begun, foliar N applications will not reverse it*, and may not slow it noticeably over periods of one or two weeks. For broccoli and cauliflower it is important to avoid applying too much N in this way because that may cause other quality issues (see above).

Phosphorus (P)

Here we must assume that broccoli responds to P supply similarly to cabbage and cauliflower.

If Olsen P <45 µg/mL, apply sufficient P fertiliser to raise the Olsen P to 45. The rate depends on the soil type and can be calculated using the rules in Chapter 2 (To raise soil Olsen P).

- Reserve up to 20 kg P/ha of this total to apply as a starter fertiliser. If direct seeding, apply the fertiliser down the spout if this enables some separation of seed and fertiliser; alternatively knife the starter P in as a narrow band 2-5 cm from the plants.
- The remainder of the recommendation should be applied as a capital or base dressing before planting. This fertiliser should be broadcast and incorporated to 15 cm depth.

P and crop quality

There have been few reports of P supply affecting the quality of these crops. There is a suggestion that sub-optimal P supply increases the incidence of stem rot in cabbage.

Potassium (K)

If QT K <12, apply sufficient K fertiliser to raise QT K to 12. The rate depends on the soil type and can be calculated using the rules in Chapter 2 (To raise soil QT K).

- Reserve a portion of the total to apply as a starter fertiliser. SOP will be safer to use for this than MOP. If direct seeding, apply up to 15 kg K/ha down the spout provided there is some separation of seed and fertiliser. Alternatively, knife in up to 30 kg K/ha as a narrow band 2-5 cm from the seed.
- The remainder of the recommendation should be applied as a capital or base dressing at least 4 weeks before planting. Broadcast and incorporate it to 15 cm depth. Use the cheapest form of K fertiliser you have available (usually MOP).
- Try to avoid surplus K supply to the crop because this can encourage clubroot infections.

Potassium and crop quality

There seem to be few issues associated with K supply and quality in these crops. Excessive supply of K may increase stem rot in cabbage, but sub-optimum supply has risks also. In cauliflower sub-optimal K supply may increase head defects (yellowing, bracted or loose curds).

Magnesium (Mg) and sodium (Na)

There is no evidence that in NZ yield of the cabbage, broccoli or cauliflower will respond to fertiliser applications of Mg, Na, or S. Taste of the leaves in particular might by affected by luxury uptake of these nutrients, but there have been no NZ studies that we are aware of. It will be a sensible precaution to apply a foliar spray of Mg at manufacturers recommended rates *if there have been clear visual symptoms of Mg deficiency in previous brassica crops at the same site*. The symptoms are mainly pale colours between the veins of the older leaves.

Sulphur (S)

There is no indication that deficiency of S affects yields of these crops in NZ and S supplements for crops cannot be recommended for improving yields. Much S is applied to crops indirectly in other fertilisers like superphosphate and potassium sulphate. Luxury uptake of S in particular may be quite large, and S is an important component of many of the chemical compounds associated with taste and health attributes of these brassica crops. So it is possible that with some local knowledge crop quality could be adjusted by varying S applications.

Calcium (Ca) and lime

Yield and quality responses to Ca applications are unlikely in NZ, as most horticultural soils contain an excess of this nutrient already.

Apply lime if pH is less than 6, targeting a pH of 6.5.

There is considerable uncertainty about this target pH. Clubroot disease can be devastating to yields and generally the incidence and severity of this disease is reduced at pH 7.2, but raising the soil pH to this value will not necessarily control the disease and may decrease yields. If clubroot is likely to be a problem, probably it is better to attempt control through an integrated use of resistant varieties, fungicides, and lime rather than rely on soil pH control alone. Maintaining pH values this high may induce trace element deficiencies in the crop (see below) and in subsequent crops of different species. There have been no definitive experiments measuring yield responses of vegetable brassicas to soil pH values in the absence of clubroot, but there are indications that the pH for maximum yield is less than that required to control clubroot.

Trace elements

Generally, trace element applications are unlikely to generate an economic return, unless there is strong evidence that specific deficiencies have occurred on previous crops at that site. Offtakes are of the order of a few g/ha and availability of these nutrients is so dependent upon changes in soil aeration (water content) and pH that usually fertiliser applications to the soil will be wasted.

Molybdenum (Mo) deficiency can be a problem for cauliflower on acid soils. Symptoms include restricted growth of the leaf lamina ('whiptail'). Following the recommendations above for lime should mean this problem does not occur. If soil pH has been raised above 6.5 to help control clubroot, deficiencies of Cu, Zn, Fe and Mn may occur.

If trace element deficiencies do occur, the best option may be a foliar spray at the manufacturers' recommended rates. Foliar sprays are best applied in the early morning or evening to extend the drying time and the opportunity for the nutrient to enter the leaves.

5.3 MAINTENANCE NUTRIENT APPLICATIONS

Representative concentrations of nutrients in these crops are given in Table 5-2.

Table 5-2 Concentrations (kg nutrient per tonne of yield) of N, P, K, S, Ca and Mg in cabbage, broccoli and cauliflower. Data for cabbage and broccoli are for NZ crops grown near Pukekohe; the cauliflower data are taken from the USA.

	N	P	K	S	Ca	Mg
Cabbage (whole shoot)	2.5	0.28	2.1	1.1	3.3	0.17
Broccoli (leaves and stems)	2.8	0.42	4.2	0.77	2.2	0.14
Broccoli (head)	4.1	0.62	3.3	0.77	0.28	0.13
Cauliflower (head)	4.0	0.61	2.9			

Maintenance nutrient applications can be calculated by multiplying the expected or measured yield (t/ha) by the kg nutrient per tonne of product removed from the field (see Table 5-2). Offtakes calculated in this way are given in Table 5-3.

Table 5-3 Calculated offtakes (kg/ha) of N, P, K, S, Ca and Mg from crops of cabbage, broccoli and cauliflower. Data are based on Table 5-2, assuming that only the marketable yield is removed from the paddock.

	Marketable yield (t/ha)	N	P	K	S	Ca	Mg
Cabbage, winter planted	68	169	19	142	71	223	11
Cabbage, summer planted	45	113	13	95	47	149	8
Broccoli, winter planted	16	67	10	53	13	5	2
Broccoli, summer planted	11	45	7	35	8	3	1
Cauliflower, winter planted	33	134	20	98	0	0	0
Cauliflower, summer planted	22	90	13	65	0	0	0

For methods of application of maintenance nutrients follow the guidelines for nutrients to grow the crop.

Maintenance applications of any particular nutrient should be made *only if none will be applied to grow the crop*. For N, maintenance applications should be considered only under organic production systems using composts.

If Olsen P>50, do not apply any maintenance P (allow Olsen P to decrease).

If QT K>15, do not apply any maintenance K.

5.4 PLANT ANALYSIS

Typical leaf or whole-plant nutrient concentrations are of little use here. It must be remembered that critical nutrient concentrations vary with plant mass. Suitable information on critical N, P and K concentrations is available from the UK for cabbage and cauliflower, but there appear to be no separate measures of critical P and K concentrations for broccoli.

Recommended values to use are in Table 5-4. These are useful benchmarks for diagnosis of N, P and K deficiencies. If plant analysis indicates values below the ranges given here, there is a substantial risk the crop is suffering from a nutrient deficiency.

Table 5-4 Critical concentrations of N, P, and K in whole plants of cabbage, broccoli and cauliflower. Values are given as % dry matter (DM). Plant fresh mass is estimated from dry mass, assuming dry matter percentages of 10.9, 7.8, 10.0, and 10.0 respectively for winter cabbage, summer cabbage, summer cauliflower and broccoli.

	Plant mass (g/plant)		Critical nutrient content (% DM)		
Crop	dry	fresh	N%	P%	K%
Winter cabbage	4.2	38	4.9	0.48	3.2
	10	92	4.7	0.49	3.0
	100	917	4.2	0.50	2.9
	164	1503	3.8	0.52	2.6
	125	1142	3.2	0.53	2.5
Summer cabbage	0.3	4	5.2	0.58	4.8
	7.2	92	5.1	0.55	4.3
	10	128	4.9	0.50	4.0
	100	1282	3.8	0.44	3.0
Summer cauliflower	0.2	2	5.9	0.58	3.8
	2.7	27	5.2	0.54	3.4
	10	100	5.0	0.51	3.3
	76	760	4.1	0.45	3.0
	100	1000	3.8	0.40	2.6
Broccoli	4	40	4.2		
Broccoli	10	100	2.4		
Broccoli	100	1000	1.9		
Broccoli	160	1600	1.9		

Most likely deficiency symptoms

Helpful images are available from the Yara CheckIT app for mobile telephones (Yara 2017).

N deficiency is usually seen as bronze, pink or purple colours in the foliage, with early yellowing and senescence of the older leaves. However, bronze, purple and pink colours may be caused by several other factors, and are sometimes cultivar characteristics. Excessive N supply can cause hollow stems (and branches of the head), and very small flower buds that give cauliflower and broccoli heads a fuzzy appearance.

P deficiency is hard to detect visually, it is usually expressed as muddy purple colours in old leaves, and sometimes red curd in cauliflowers. Again, these red colours can be caused by other things.

K deficiency is rarely seen in NZ soils; mild deficiency causes a general slowing of growth. In more extreme cases there is bronzing on the leaf edges, followed by death of tissue first around the leaf edges and then between the veins.

Mo deficiency is sometimes seen in cauliflowers. The leaves may be straplike and crinkled; in severe cases only the leaf ribs develop and head formation is stopped.

B deficiency causes the stems to become hollow, and cauliflower curds turn brown. Many NZ soils may be borderline in B-supplying ability, but B toxicity is easily induced by over-zealous application of B. *Hollow stems are also caused by excessive N supply.*

CHAPTER 06
CARROTS

Carrots for the fresh market are grown throughout New Zealand although carrots for processing are grown mostly in Canterbury, the Manawatu and Hawke's Bay. Carrot nutrient requirements depend greatly on potential yield — the total fresh yield of roots in the field if there is no water or nutrient stress.

6.1 POTENTIAL YIELDS

Potential yield of carrots typically varies from about 70 to 170 t/ha. Most crops do not reach their potential because of water or other stresses, and field yields vary from about 50 t/ha for table carrots to 120 t/ha for process carrots.

Unlike most other crops, potential yield of carrots depends mainly on the plant population and the target root size (dictated by the intended end-use). Baby carrots are planted for population densities up to 1500 plants/m^2. Processing carrots have populations typically around 50 plants/m^2. Between these extremes, table carrots typically have populations of 70 plants/m^2.

Usually the crop is left to grow until the target root size is achieved or the market or processor is ready for the crop. Unless frosts, pests or diseases affect plants, water and nutrient stresses will mainly have the effect of slowing crop growth. The main benefit of good nutrient supply is that the crop will grow quickly, reducing the risk of autumn frosts stopping growth before the target root size is reached. Partly because of this, and partly because they have a deep fine root system (Figure 6-1), carrots have a reputation of being unresponsive to fertiliser. Nevertheless they take up large amounts of nutrients and fertilisers can be beneficial when potential yields are high.

Nutrient recommendations are given for two contrasting scenarios.

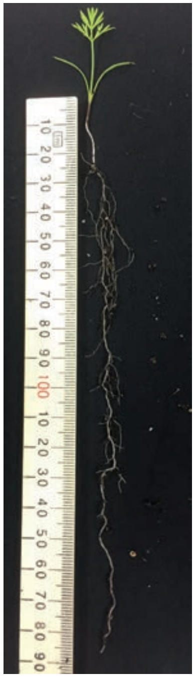


Figure 6-1: Root system of a carrot plant 17 days after planting. The depth scale is 0–190 mm. Photograph by Jeff Reid 2018.

Scenario 1: Potential yield of 100 t/ha. This is appropriate for many crops of fresh market carrots where marketable yields may be 70-90 t/ha. It is towards the top end for well-managed baby carrots.

Scenario 2: Potential yield of field 170 t/ha. This is realistic for process carrot crops if weather conditions are good and the crop is well managed — marketable yields may be up to 150 t/ha.

Despite their deep root system carrots are very sensitive to water stress which will suppress the crops responsiveness to nutrient applications.

6.2 NUTRIENTS TO GROW THE CROP

Soil tests

Before the crop is planted in each paddock carry out soil testing at TWO depths:

1. **0–15 cm depth** — standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and soil volume weight) PLUS 'Available N' (anaerobically mineralisable N, in kg N/ha) PLUS Anion Storage Capacity (ASC or P retention%). ASC needs to be tested only once — not before every crop.
2. **0-60 cm depth** — mineral N test (nitrate plus ammonium, in kg N/ha).

Root yield and crop nutrient requirements will be decreased substantially by water deficits >40% of the soil's available water capacity. The recommendations below have assumed no water stress.

Nitrogen (N)

Yield response to N fertiliser is slight unless the supply of N from the soil is very small. Fertiliser applications >150 kg N/ha are rarely economic because the crop is very effective at scavenging N mineralised from organic matter in the soil.

If using composts or slow-release fertilisers, broadcast and incorporate these at least 2 weeks before planting.

If using soluble N fertilisers, split recommendations >50 kg N/ha into at least two broadcast applications. Apply one at sowing or just after the crop has established, and the rest when the plants have at least 6 true leaves.

If fertigation is available, split the recommended N fertiliser amount across several smaller applications from emergence to about a month before harvest.

N recommendations are based on the sum of Available N from 0–15 cm and mineral N from 0–60 cm depth.

Sum of Available N and mineral N (kg N/ha)	Recommended N application (kg N/ha) to grow the crop	
	Scenario 1: Potential yield 100 t/ha	Scenario 2: Potential yield 170 t/ha
50	100	210
100	50	150
120	20	130
150	nil	100
190		50
210		up to 20
>240		nil

Phosphorus (P)

Base or maintenance dressings can be broadcast. However, any P fertiliser applications required to increase yield are best split with up to 20 kg P/ha applied as a starter (either down the spout or banded 2 – 5 cm from the drill line). The rest can be broadcast on soils with ASC less than about 30%, and banded close to the drill lines on soils with higher ASC. Only side-dress growing crops with P if it is early in the life of the crop so that the roots have time to access the P.

Soil Olsen P (µg/mL)	Recommended P application (kg P/ha) to grow the crop	
	Scenario 1: Potential yield 100 t/ha	Scenario 2: Potential yield 170 t/ha
10	30	70
15	30	60
20	25	50
30	nil	40
40	nil	nil

Potassium (K)

Yields are sometimes poor where soil QT K is small, but it has proven hard to detect carrot yield responses to K fertiliser even when QT K is as low as 4. It is worth noting that soil types with low QT K tend to be sandy and drought-prone.

- It is recommended that you do not apply K fertiliser to grow the crop.
- However, maintenance applications are suggested (see below).

Magnesium (Mg)

Additions of Mg from fertilisers or composts are unlikely to benefit carrots in NZ. In experiments in Canterbury, Hawke's Bay, and Ohakune, soil Mg QT values from 13 to 43 had no relationship to yield.

Sodium (Na)

Carrots are unusual in that they may respond to Na fertilisers (usually salt, NaCl) when K supply is poor. Carrot crops can remove quite large amounts of Na (see above) but if K supply is adequate, Na fertilisers can be omitted.

Sodium fertilisers can have undesirable effects on soil structure, but applications of <50 kg Na/ha incorporated before planting are unlikely to be detrimental in NZ.

Calcium (Ca) and Sulphur (S)

Direct responses to applications of Ca or S are very unlikely. Such responses have not been observed in NZ because the soils mainly used for carrots usually contain large amounts of Ca and S already. Both elements are commonly applied in other fertilisers (e.g. lime and superphosphate).

Lime requirements

Soil pH values as low as 5.2 do not appear to affect yield in NZ, but values above 6.5 may cause trace element deficiencies. Cavity spot disease of carrot roots is often reduced by raising soil pH through lime applications, but the optimal soil pH for cavity spot control is not known. If cavity spot has been a problem before, it may be most practical to plant your crop elsewhere.

Apply fine lime at least a month before planting and only if pH is less than 5.3, targeting a pH of 5.8 – 6.0.

Trace elements

Applications of trace elements to NZ carrot crops are very unlikely to generate an economic return, unless you have strong evidence from previous crops that specific deficiencies have occurred. Maintenance applications are tiny and availability of these nutrients is so dependent upon soil pH and water content that trace element applications to the soil will usually be wasted. Potential exceptions could be B following a wet winter and spring, and Cu on organic soils. If B or Cu deficiency have been observed in previous carrot crops at the site, the best option may be a foliar fertiliser at the manufacturers' recommended rates. These are best applied in the early morning or evening to extend the drying time and the opportunity for the nutrient to enter the leaves.

6.3 MAINTENANCE NUTRIENT APPLICATIONS

Carrots have a large capacity for luxury uptake. The surpluses are stored in the roots. Table 6-1 shows the approximate amounts of major nutrients that can be taken up. Nutrients in the storage roots are removed from the paddock, the rest are recycled.

Table 6-1 Typical amounts of major nutrients taken up by a 100 t/ha carrot crop.

	N	P	K	S	Ca	Mg	Na
Shoots (kg/ha)	67	6	80	17	89	11	49
Storage roots (kg/ha)	174	31	288	16	33	12	64
Total uptake (kg/ha)	241	37	368	33	123	23	113

For the trace elements, total uptake by a 100 t/ha crop appears to range from 0.2 kg/ha (for copper) to about 5 kg/ha (for iron).

Maintenance applications of any particular nutrient should be made only if none will be applied to grow the crop. For N, maintenance applications should be considered only under organic production systems using composts.

Maintenance applications should be calculated from the kg of each element taken up per tonne of roots *removed from the field* (Table 6-2). This is not necessarily the marketable yield reported to a grower by the processor. If 100 t/ha of roots are removed from the field, the maintenance P application is about 100 x 0.31 = 31 kg P/ha in the roots. Remember the values in Table 6-1 and Table 6-2 are typical — nutrient concentrations can vary between crops. The data may reflect a considerable amount of luxury uptake of some nutrients —especially K.

Table 6-2 Offtakes of the major nutrients calculated for scenarios 1 and 2. These values assume that 80% of the potential yield is removed from the field. That percentage will vary between crops. Maintenance applications of N are not recommended except under organic production systems.

	N	P	K	S	Ca	Mg	Na
kg/t roots	**1.74**	**0.31**	**2.88**	**0.16**	**0.33**	**0.12**	**0.64**
Offtakes (kg/ha)							
Scenario 1, pot. yield 100 t/ha	**139**	**25**	**230**	**13**	**26**	**10**	**51**
Scenario 2: pot. yield 170 t/ha	**237**	**42**	**392**	**22**	**45**	**17**	**87**

For methods of application of P follow the guidelines for nutrients to grow the crop. If Olsen P>55, do not apply any maintenance P (allow Olsen P to decrease).

Solid K fertiliser should be broadcast and incorporated before planting. Use the cheapest source available. Large rates of MOP left on the soil surface may reduce plant populations, affecting yield and quality. Recommended rates of either MOP or SOP incorporated pre-sowing are unlikely to affect crop yield or quality.

Maintenance K applications are not always necessary. There is little chance of these being profitable, and sedimentary soils in NZ already contain much K - serious depletion of these reserves by the occasional carrot crop is unlikely. Also the figures available for K removals probably reflect luxury uptake — forever replacing these removals would encourage further unnecessary uptake.

The maintenance recommendations here follow the strategy (a) If QT K<15, apply half the calculated amount for the potential yield; (b) Check the soil QT K at least a month before the following crop, (c) Apply further K fertiliser if the new QT value appears limiting for the next crop.

If QT K>15, do not apply any maintenance K.

If QT Mg >19, do not apply any maintenance Mg.

6.4 PLANT ANALYSIS

Laboratories may quote typical nutrient concentrations in leaves and roots — but carrots have a strong tendency for luxury uptake of mineral nutrients. A better measure is the critical nutrient concentration below which growth is adversely affected (Table 6-3). For young crops, sample the whole shoot. If the crop is close to harvest, sample separately the youngest mature leaves and the storage roots. By that time it is too late to affect the nutrition of that crop, but the results may be useful for managing future crops.

Table 6-3 Critical concentrations of N, P, and K in carrots. Values are given on a dry mass basis. The assumed dry matter (DM) % for shoots and roots was 10%.

	Dry mass (g/plant)	Fresh mass (g/plant)	Critical nutrient content (% DM)		
			N%	P%	K%
Storage root	0.2	2	2.4	0.31	2.5
Storage root	6.1	61	2.2	0.34	2.3
Storage root	24.0	240	2.0	0.33	2.1
Shoot	0.4	4	3.2	0.35	3.9
Shoot	2.4	24	2.6	0.39	2.9
Shoot	8.0	80	2.0	0.34	1.9

Most likely deficiency symptoms

Visual symptoms of nutrient deficiencies are rare in carrots grown in NZ.

N deficiency is sometimes seen as uniformly pale green/yellow with fine leaflets. For P deficiency there is no yellowing but the older leaves start to turn purple. Be careful diagnosing P deficiency from visual symptoms. Some high-carotene varieties may have purpling without P deficiency. Attack by carrot fly has similar symptoms, but it also has gnawing damage to the storage roots. Carrot 'motley dwarf' virus also reddens older leaves but younger leaves are yellow.

CHAPTER 07
LETTUCE

Lettuce (*Lactuca sativa* L.) for the local market is grown throughout New Zealand under a wide range of conditions. In Pukekohe, Poverty Bay and the Horowhenua especially it is grown intensively, sometimes with multiple crops per year on the same ground.

Lettuce yields need to be thought of in terms of the shoot biomass (total above-ground growth), the marketable mass of the crop, and the number of marketable heads. The key measure of yield when forecasting nutrient requirements is the potential biomass yield.

7.1 POTENTIAL AND FIELD YIELDS

The potential biomass yield is dictated mainly by plant population (plants/ha), plant variety and type of lettuce (e.g. head, leafy, frilly), and target plant or head size.

Weather conditions affect the growth rate, and usually harvest must wait until the heads reach the target size. If the nutrient supply is not optimal, the crop may take longer to reach that stage, which might affect quality but not field yield. If the nutrient supply is more than optimal the crop cannot grow faster than the weather conditions allow.

Some crops cannot reach their potential yield even if nutrients are optimally supplied. Pests and diseases can reduce growth rates and packout. Yields can be greatly reduced by excessive soil wetness or water deficits, and crop nutrient demands are reduced accordingly. A further complication is that lettuce yields may be sharply reduced by over-supply of some nutrients.

Key point: Marketable yields

The marketable mass is often about 50% of the shoot biomass — but this can vary greatly according to marketing requirements and the condition of the crop. Grading standards for fresh-packed heads can be very strict and marketable yields can vary from zero to almost 100% of the potential yield.

These recommendations consider two distinct scenarios (for transplanted crops):

Scenario 1: Potential yield of 30 t/ha (of heads). This is representative of crops growing for 40-60 days in spring, summer or early autumn, producing 60 t/ha of shoot biomass (about 4 t/ha dry matter), planted at 40,000 – 55,000 plants/ha.

Scenario 2: Potential yield of 18 t/ha (of heads). This is typical of winter crops grown for up to 120 days, producing 36 t/ha of shoot biomass (about 2.4 t/ha dry), at a plant population of 40,000 – 55,000 plants/ha. Packout on these winter crops may be quite low unless grading standards vary seasonally.

For each scenario the recommendations consider an additional variation where the field yield is 90% of potential. A 10% yield reduction can be expected if the soil is wetter than field capacity for a total of more than 10 days (for a summer crop) or 25 days (for a winter crop).

7.2 NUTRIENTS TO GROW THE CROP

Lettuce can take up considerable amounts of N, and rather less P (Figure 7-1). However, marketable yield responses to N fertiliser can be difficult to detect because N fertiliser may encourage growth of outer leaves more than the head. Furthermore lettuce may take up luxury amounts of N, much of which may be left behind in residues if the crop is trimmed at point of harvest. This N will be rapidly mineralised, and should reduce N fertiliser requirements for crops planted soon after.

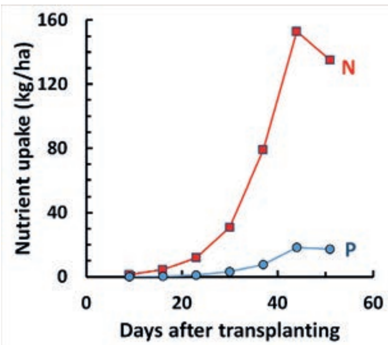


Figure 7-1 N and P uptake by autumn-planted lettuce grown near Pukekohe. The crop yielded 56 t/ha fresh and was planted at 66,000 plants/ha (which is high compared with current practice).

Soil tests

Before the crop is planted carry out a soil test from 0–15 cm depth in each paddock. If possible sample only the bed areas where lettuce will be grown. Choose the standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and soil volume weight) plus ‘Available N’ (anaerobically mineralisable N, in kg N/ha).

Nitrogen (N)

Here, the N recommendations are based on critical plant N concentrations required for the target yields. The recommendations assume no leaching of nitrate below the root zone and the majority of the N available from the soil is in the top 15 cm depth, as estimated by the Available N (AMN) procedure. There are probable errors introduced by both assumptions, but they will tend to compensate for each other.

Little of the N uptake will occur in the three weeks or so after transplanting (see Figure 7-1). This heightens the risk of nitrate leaching from starter fertiliser. If wet weather is likely (e.g. for winter-planted crops), large applications of soluble N fertilisers should be avoided in that first three weeks. In those circumstances a controlled release N fertiliser at planting may be the best option.

The total N fertiliser recommendations are given in the table below.

Soil Available N (kg N/ha)	Recommended N application (kg N/ha) to grow the crop			
	Scenario 1: Potential yield of 30 t/ha		Scenario 2: Potential yield of 18 t/ha	
	Field yield same as potential	Field yield 90% of potential	Field yield same as potential	Field yield 90% of potential
20	120	120	65	65
40	100	100	45	45
60	80	80	25	25
80	60	60	5	5
100	40	40	nil	nil
120	20	20		
140	nil	nil		

At planting:

- **Soluble and controlled-release N fertilisers** are best incorporated or knifed in 2-5 cm from the plant row. They may be spread as a band on the soil surface provided that irrigation or rainfall is imminent.
- **If using only soluble N fertilisers** like urea, ammonium sulphate, or CAN, apply no more than 20 kg N/ha, or up to 50 kg N/ha if this is a winter-planted crop and wet weather will greatly limit opportunities for side-dressing in the second and third months of growth.
- **If using controlled-release N fertilisers**, apply up to 100 kg N/ha of N recommendation as controlled-release product and up to 20 kg N/ha of it as a

soluble N fertiliser. Ensure the controlled-release formulation will release its N within the expected duration of the crop.

Apply the remainder of the recommended N in one or more side-dressings after the first month of growth. Avoid applying more than 50 kg N/ha at any one time. Side-dressings may be spread on the soil surface just before light rain or irrigation, or lightly incorporated; use readily available forms of N like urea. Be careful to avoid fertiliser lodging amongst the leaves where it can cause cosmetic damage.

If applying N in the form of composts, incorporate these at least two weeks before planting.

If fertigation is available, split the recommended N fertiliser across several applications during growth. This can greatly assist in matching N fertiliser supply with the demands of the crop, but wet weather may restrict the opportunities to fertigate. Yields may be reduced more by excessive soil wetness than by missing one or two small applications of N.

Nitrogen and lettuce quality

Excessive use of N fertilisers may encourage growth of the wrapper leaves, slowing plant trimming at harvest. It may also increase the risk of tip-burn (localised Ca deficiency in the heart leaves) but there is no strong experimental evidence for this under NZ conditions.

Phosphorus (P)

Stresses due to excessive soil pH or waterlogging greatly reduce the responsiveness of the crop to P fertiliser.

There is evidence that lettuce growth rates and yields can be reduced by excessive P.

If using composts or slowly soluble P fertilisers, broadcast and incorporate these before planting.

If using soluble P fertilisers, apply as much as possible of the recommendation in bands. If P fertiliser is required, apply up to 5 kg P/ha

Key point: Soil Olsen P

If initial soil Olsen P is low, for the best yields large applications of P fertiliser might be necessary for the first lettuce crop in a sequence. However, lettuce removes only small amounts of P from the soil, and large dressings for the first crop will greatly reduce the fertiliser requirements of the following crops. Have new soil tests carried out before each crop.

as a starter close to the transplant line. If possible, apply about 50 kg P/ha of the remaining recommendation as a band 5 – 10 cm from the transplant line. The remainder (if any) of the recommendation can be applied pre-planting as a base dressing. *Do not side-dress growing crops with P fertiliser* — it will be poorly utilised and may damage the crop.

Soil Olsen P (µg/mL)	Recommended P application (kg P/ha) to grow the crop			
	Scenario 1: Potential yield of 30 t/ha		Scenario 2: Potential yield of 18 t/ha	
	Field yield same as potential	Field yield 90% of potential	Field yield same as potential	Field yield 90% of potential
10	175	130	120	65
20	160	95	80	30
30	140	60	45	nil
40	110	20	5	
50	70	nil	nil	
60	30			
70	nil			

Phosphorus and lettuce quality

There is no evidence that P supply noticeably limits lettuce head quality in NZ.

Potassium (K)

Do not apply K fertiliser to grow the crop.

Experiments in NZ have failed to detect lettuce yield or quality responses to K supply. It appears that most soils used for lettuce growing have adequate K available. Maintenance applications can be required (see below)

Magnesium (Mg)

Experiments on lettuce in NZ have failed to detect any response in yield or quality to Mg fertilisers or soil QT Mg. Maintenance requirements are small (Table 7-1) and it seems most horticultural soils already contain an excess of Mg. It will be a sensible precaution to apply a foliar spray of Mg at manufacturers' recommended rates *if there have been clear visual symptoms of Mg deficiency in previous lettuce crops at* *the same site*. The symptoms are mainly that the older leaves turn yellow beginning at the edges, but the veins often remain green. Some marbling may be seen.

Calcium (Ca) and lime

Localised Ca deficiency is associated with tip-burn in lettuce. Soil applications of Ca fertilisers are very unlikely to affect this because the soil already contains a large amount of Ca, and tip-burn is usually caused by competition between wrapper and heart leaves for water (which transports Ca with it). Foliar Ca sprays (at manufacturers' recommended rates) may be of some benefit if they penetrate to tip-burn-susceptible regions, but this will vary between lettuce head types and varieties.

Large amounts of Ca are often applied in the form of lime to correct acid soil conditions. Previous recommendations were to keep soil pH in the range 6.0 – 7.0. However, it is difficult to find an experimental basis for this. Reanalysis of more recent experiments suggests that the optimum pH range is rather lower; at pH 7.0 yields may be depressed by about 20%. On the basis of the experimental evidence available:

- Apply lime only if pH is less than 5.5, targeting a pH of 6.0.
- Use fine lime and apply at least a month before planting.

Sodium (Na)

Do not apply Na fertilisers to lettuce in NZ.

Sulphur (S)

Yield or quality responses to fertiliser applications of S have not been documented in NZ. Soils used for lettuce in NZ usually contain adequate quantities of S already because S is commonly applied as part of other fertiliser applications (such as superphosphate or SOP).

Trace elements

Applications of trace elements to NZ lettuce crops are unlikely to provide economic returns, unless there is strong evidence that specific deficiencies have occurred on previous crops at that site. An exception might be if foliar testing confirms a trace element deficiency. In that case a foliar spray (at manufacturers' recommended rates) is probably best. Maintenance applications are of the order of a few g/ha and availability of these nutrients is so dependent upon pH and changes in soil water content that trace elements applied to the soil can be ineffective.

7.3 MAINTENANCE NUTRIENT APPLICATIONS

Maintenance applications of any particular nutrient should be made only if none will be applied to grow the crop. For N, maintenance applications should be considered only under organic production systems using composts.

Maintenance requirements should be calculated from the kg of each element per tonne of heads removed from the field. Often reject heads and trimmings are returned to the field at harvest, so the nutrients in those are recycled. If 30 t/ha of heads are removed from the field, the maintenance P applications need to be 30 x 0.31 = 9.3 kg P/ha.

Table 7-1 Typical amounts of major nutrients removed from the soil by lettuce crops. These values assume the crop is trimmed in the field.

	N	P	K	S	Ca	Mg
kg/t shoot removed from field	**2.4**	**0.31**	**2.4**	**0.17**	**0.81**	**0.18**
Offtakes (kg nutrient/ha)						
Marketable yield 30 t/ha	**73**	**9**	**73**	**5**	**24**	**5**
Marketable yield 18 t/ha	**44**	**6**	**44**	**3**	**15**	**3**

Nutrient concentrations can vary between crops and the figures above may reflect luxury uptake of some nutrients, so applying the amounts calculated from those figures may unnecessarily inflate soil test values. It is a good idea to keep track of trends in soil test values over several years to ensure they do not become excessive.

For methods of application of P follow the guidelines for nutrients to grow the crop.

If Olsen P>70, do not apply any maintenance P (allow Olsen P to decrease).

If QT K>10, do not apply maintenance K.

If maintenance applications of K are being made, broadcast and incorporate these at least 2 weeks before planting. Either MOP or SOP is a suitable choice if applied in this way.

7.4 PLANT ANALYSIS

Laboratories may quote typical nutrient concentrations using results collated from crops in NZ. Comparisons with critical or optimum nutrient concentrations is a better guide to whether a crop is experiencing a nutrient deficiency, but even so it is of limited use for lettuce management decisions in-season.

However, plant nutrient analysis can be helpful in planning fertiliser regimes for the following crops at the same site. Sample whole plants (above ground) at harvest and compare nutrient concentrations with the values tabulated below. It is also useful to measure the fresh and dry masses of the plants after drying at 70°C, and compare these with the values in the table, because the optimum and critical concentrations of N, K, and maybe P, decrease as the plants grow larger (Table 7-2).

Table 7-2 Critical concentrations of N, P, and K in lettuce. Values are given on a dry mass basis for the whole shoot, assuming the dry matter (DM) % is 6.7%.

Dry mass (g/plant)	Fresh mass (g/plant)	Critical nutrient content (% DM)		
		N%	P%	K%
0.3	4	6.1	0.73	6.0
4.4	66	5.0	0.66	5.2
23	334	3.4	0.49	4.2

Most likely deficiency symptoms

Nitrogen (N) deficiency may occur in warm periods following heavy rain or irrigation if N mineralisation from soil organic matter has not caught up with plant demand. It is seen mainly as premature yellowing of the outer leaves.

Phosphorus (P) deficiency is often hard to detect. It is expressed mainly as slowed growth and failure of the crop to heart.

Helpful images are available from the Yara CheckIT app for mobile telephones (Yara 2017), although the accompanying descriptions are sometimes at odds with NZ experience of where such deficiencies may occur.

CHAPTER 08
ONIONS

Bulb onions are mostly grown around Pukekohe, Northern Waikato, Hawke's Bay and Canterbury. Nutrient supply must be managed carefully because the crop has an unusual root system.

The root system is shallow. This makes it poor at extracting N from below about 25 cm soil depth — heavy rainfall or irrigation may leach fertiliser N beyond reach of the roots. Mineral N released from soil organic matter will be leached also, but it is subsequently replaced by microbial action in the topsoil. To lessen the risks of nitrate pollution, for onions give preference to sites that have a high potential to mineralise N from soil organic matter, so that they need less N fertiliser. Planting a deep rooting crop after onions also reduces potential nitrate leaching.

The root system is poorly branched with few or no root hairs. This makes it poor at extracting phosphate (P) from soil. This has led to a history of large P fertiliser applications for onions. Repeated growing of onions runs the risk of raising soil P concentration to the point where it is an environmental risk. This can be avoided by soil testing before each crop, and smarter placement of whatever P fertiliser the crop actually needs.

8.1 POTENTIAL, FIELD, AND MARKETABLE YIELDS

Potential yield is influenced by sowing date and weather, variety, and plant population density. *We must consider potential yields of the basis of the dry mass of bulbs, because varieties may differ greatly in bulb dry matter %.*

Here we outline nutrient recommendations for two broad situations:

Scenario 1: Potential yield is 10.0 t/ha of bulb dry matter. This is typical of long-keeper crops grown for storage and export where fresh marketable yields are about 60 – 80 t/ha at 10 – 13% bulb dry matter.

Scenario 2: Potential yield is 6.0 t/ha of bulb dry matter. This is typical for sweet, red, and white onions and early crops not grown for storage. These crops have potential yields of about 100 t/ha fresh and marketable yields are often 50 – 80 t/ha, but their bulb dry mattercontents are about 6%. This scenario can be representative also of late-planted long-keeper varieties with lower fresh yields but higher dry matter %.

Potential yields of long-keeper varieties grown around Pukekohe are often close to those of scenario 1, but field yields may be less (6 – 10 t/ha of bulb dry matter) because of pressures from plant diseases. In those cases, maintenance nutrient applications should be adjusted to reflect the smaller amounts of material removed from the field.

The recommendations assume no water stress.

8.2 NUTRIENTS TO GROW THE CROP

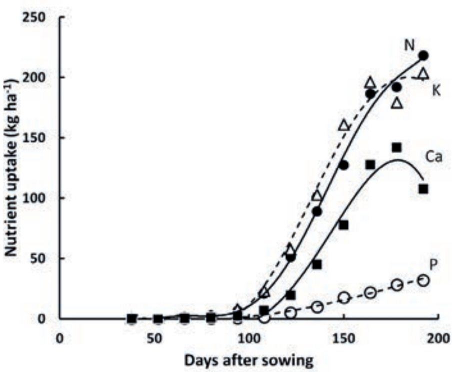


Figure 8-1 Nutrient uptake by an onion crop grown at Pukekohe. The crop yielded 7.5 t/ha of bulb dry matter (59 t/ha fresh).

> **Key point: Little uptake until bulbing**
>
> Onions have very modest nutrient needs until after bulbing when rapid growth starts (often about 80 days after sowing) (Figure 8-1).

Soil tests

Before the crop is planted carry out soil testing from 0–15 cm depth in each paddock. Choose the standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and soil volume weight) PLUS 'Available N' (anaerobically mineralisable N, in kg N/ha) PLUS Anion Storage Capacity (ASC or P retention%). ASC needs to be tested only once — not before every crop.

Nitrogen (N)

Nitrogen requirements for onions were calculated using the PARJIB model and then cross-checked against values calculated using critical plant N concentrations.

If fertigation is available, use this to split recommended N applications through the season.

Key point: Split N applications

In wet areas, or if irrigation is frequent, split applications of soluble N. Aim for two or more small applications spread through the season.

If using solid fertilisers, apply up to 20 kg N/ha of soluble or 40 kg N/ha of controlled-release fertiliser as a starter down the spout or banded close to the plants. Broadcast the remainder of the recommended N in at least two side-dressings of soluble N fertiliser once the rapid growth phase starts. Exceptions are composts that are best incorporated at least 2 weeks before sowing.

Available N (kg N/ha)	Recommended N application (kg N/ha) to grow the crop	
	Scenario 1: Potential yield 10 t/ha bulb dry matter	Scenario 2: Potential yield 6 t/ha bulb dry matter
20	140	80
40	120	60
60	100	40
80	80	20
100	60	nil
120	40	
140	20	
160	nil	

Nitrogen and onion quality

Overseas experience suggests that inadequate nitrogen supply may increase bolting, and N fertilisation may reduce storage life. Excessive N supply may increase the incidence of thick necks in bulb onions, and bolting in bunching onions (although firm evidence for this in bulbing onions is hard to find). NZ experience so far suggests little effect of N fertilisation on storage properties of 'Pukekohe Longkeeper', but pungency may be increased.

Phosphorus (P)

High ASC values lower the efficiency of P fertilisers — so band soluble P fertiliser as much as possible. This reduces the percentage that is fixed onto soil surfaces. *There is no evidence that high ASC values increase the optimum or target Olsen P for vegetables.*

If using slowly soluble organic or mineral P fertilisers, these can be bulky and pose some risks if concentrated close to the seeds. Broadcast most of the recommendation before planting, but retain a portion to band 5 – 10 cm from the drill line at planting.

If using soluble P fertilisers, apply as much as possible of the recommendation in bands, especially if soil Olsen P is low. If P fertiliser is required, apply up to 10 kg P/ha as a starter down the spout or banded close to the drill line — but avoid scorching germinating seeds. If possible, apply about 50 kg P/ha of the remaining recommendation as a band 5 – 10 cm from the drill line. The remainder (if any) of the recommendation can be broadcast pre-planting. Side-dressed P is very unlikely to be taken up by the crop.

If using composts, broadcast and incorporate these before planting.

Soil Olsen P (µg/mL)	Recommended P application (kg P/ha) to grow the crop	
	Scenario 1: Potential yield 10 t/ha bulb dry matter	Scenario 2: Potential yield 6 t/ha bulb dry matter
10	up to 270	up to 140
20	200	70
25	170	40
30	140	15
35	100	nil
40	70	
45	30	
50	20	
>55	nil	

A note on target Olsen P values

The 1986 Fertiliser Recommendations gave target Olsen P values that now seem too high. Figure 8-2 shows the response curve used here (from our analysis of crops in

Hawke's Bay and Canterbury on soils with ASC<30%). It also plots the original data used for the 1986 recommendations (from crops at Levin on a soil with ASC of 76%). The original data agree well with the model used here.

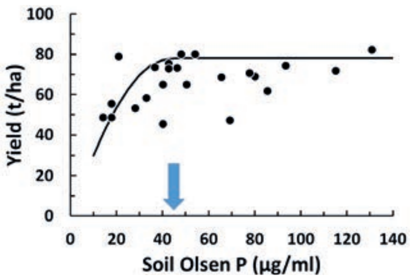


Figure 8-2: Onion yield response to Olsen P as measured by Prasad et al. (1988). The arrow indicates the target Olsen P proposed by Prasad and colleagues. The 1986 recommendations used the same data but proposed a target of about 75 µg/mL for the same soil. The solid black line is the predicted response from the model used here, with a potential yield of 8.4 t/ha of bulb dry matter.

Potassium (K)

Do not apply K fertiliser to grow the crop, but a maintenance application may be required (see below).

Early experiments at Pukekohe with QT K values as low as 8 failed to find yield responses to K fertiliser. Modelling analysis of the available data suggest positive yield responses may occur when potential yield is large and QT K is <4 (a rare set of circumstances). Even so, the predicted yield response is very gradual, indicating K fertiliser application will rarely be profitable. Furthermore, the same analysis suggests K fertiliser may *decrease* yield if potential yield is small and QT K is >10.

Magnesium (Mg)

It appears there are no verified cases of Mg deficiency or yield response to Mg fertiliser in NZ onion crops. It seems most horticultural soils in NZ already contain an excess of Mg. It will be a sensible precaution to apply a foliar spray of Mg at manufacturers' recommended rates *if there have been clear visual symptoms of Mg deficiency in previous onion crops at the same site*. The symptoms are mainly that the older leaves turn yellow along their entire length without dying back.

Calcium (Ca) and sodium (Na)

Soils used for vegetables in NZ usually contain large quantities of Ca already. It is very unlikely that you will achieve a yield response to applications of Ca, although crop quality may alter. There has been a suggestion that Ca applications may improve bulb skin quality, but firm evidence of this remains elusive.

Do not apply Na to onion crops in NZ.

Lime requirements

The optimum pH appears to be 6.1 and yield appears to fall away sharply between there and pH 5.5. The available evidence suggests dry matter yields decrease by about 30% between pH 6 and pH 5.5. Experiments at lower pH values have not been reported. Soil pH values above 6.5 may cause trace element deficiencies and should be avoided.

- Apply lime only if pH is less than 5.9, targeting a pH of 6.2.
- If applying close to sowing, use fine lime. Generally apply lime as early as possible before planting.

Sulphur (S)

Soils used for vegetables in NZ usually contain adequate amounts of S, because S is often applied in other fertilisers such as superphosphate. In NZ, yield response to S applications have not been measured and are unlikely in NZ. However, onions may take up much more than they need for maximum yield ("luxury uptake"). Luxury concentrations of S in the bulbs increase onion pungency and may increase storage life. Growers need to decide whether to restrict S on the basis of the quality characteristics required for future crops. Depleting soil S may be advisable if you wish to grow sweet onions.

Trace elements

Applications of trace elements to NZ onion crops are very unlikely to be economic, unless there is strong evidence from previous crops that specific deficiencies have occurred. Maintenance applications are very small and availability of these nutrients is so dependent upon pH and soil water content that trace element applications to the soil will usually be wasted. Potential exceptions could be B on sedimentary soils following a wet winter and spring, and Cu on organic soils. In those cases the best option may be foliar sprays at the manufacturers' recommended rates. These are best applied in the early morning or evening to extend the drying time and opportunity for the nutrient to enter the leaves.

8.3 MAINTENANCE NUTRIENT APPLICATIONS

Table 8-1 shows the typical amounts of nutrients that can be taken up by bulb onion crops. For some nutrients (especially Ca and S) the values probably include luxury uptake — the uptake required to achieve potential yields is likely to be rather less.

Table 8-1 Typical offtakes of major nutrients removed from the soil by bulb onion crops. These should be calculated on the basis of the dry mass of bulbs removed from the field — the dry matter % can vary greatly, and the nutrient contents per tonne of fresh mass here are given only for a long-keeper crop.

	N	P	K	S	Ca	Mg
kg/t bulbs dry	**15.0**	**2.2**	**14.0**	**3.7**	**7.4**	**0.9**
Offtakes (kg/ha)						
Removed yield 8 t/ha dry	**120**	**18**	**112**	**30**	**59**	**7**
Removed yield 5 t/ha dry	**75**	**11**	**70**	**18**	**37**	**4**

Maintenance applications of any particular nutrient should be made *only if none will be applied to grow the crop*. For N, maintenance applications should be considered only under organic production systems using composts. Depleting soil S (by not applying S containing fertilisers) may be advisable if future crops will include sweet onions.

Maintenance applications are best calculated on the basis of dry matter yields removed from the paddock and nutrient contents. Multiply the target dry bulb yield in t/ha by the kg of each element taken up or removed per tonne of dry bulbs removed from the field (see Table 8-1). For a crop where 8 t/ha of dry bulbs are removed from the field, the offtake of P would be about 8 x 2.2 = 18 kg P/ha.

Generally, fertiliser K for maintenance purposes should be *broadcast and incorporated either before planting or after harvest*. Potassium sulphate (SOP) is normally used. Management aims may include reducing soil S concentrations for long-term control of onion pungency. In that case use MOP for all or part of the K maintenance application, but apply it after harvest, to reduce the risks of negative effects of Cl on the crop.

8.4 PLANT ANALYSIS

Laboratories may quote typical or adequate nutrient concentrations in leaves from crops in NZ. Comparisons with these values do not indicate if a crop is deficient in any nutrient and might respond to fertiliser. A more useful comparison is with the *critical nutrient concentration* below which plant growth is adversely affected. Overseas, critical nutrient concentrations have been established for N, P and K (Table 8-2).

Sampling of whole shoots or whole bulbs when they are about 2 cm diameter can be useful for determining if further N fertiliser could improve yield, but it is too late for adjusting P and K supply. For strategic decisions affecting nutrient supply to future crops, sample whole bulbs at final harvest

Table 8-2 Critical nutrient concentrations (dry mass basis) for onions.

Nutrient	Whole plant about 20 g fresh mass	Whole plant about 90 g fresh mass	Mid-growth, 2-cm bulb	Around harvest, whole bulb
N %	2.5	1.6	2.75	
P %	0.65	0.23	0.3 – 0.4	0.3
K %	3.3	1.8		1.5

Most likely deficiency symptoms

In NZ few onion crops show visual symptoms of nutrient deficiency. *Nitrogen deficiency* is seen occasionally, as stunted and thin growth. The leaves are pale — older leaves turn yellow and die back from the tip. *Phosphorus deficiency* is much rarer. If it occurs, it shows as poor growth, with dull green leaves, and the older leaves may die back from the tip. These are also symptoms of a number of other problems, so be cautious in diagnosing P deficiency from visual symptoms. The same is true of *potassium deficiency*, where the older leaves die back from the tip without first becoming yellow.

CHAPTER 09
PEAS FOR PROCESSING

Peas for processing ("vining" or "garden" peas) are now grown mainly in Canterbury, Marlborough, Hawke's Bay and Poverty Bay; they have also been produced in the Manawatu region. Frozen peas are an important export from NZ.

Pea yields in NZ are extraordinarily variable between and within paddocks and growing seasons, which perhaps raises anxieties among growers about whether their crops receive enough mineral nutrients. The reasons for the yield variability are still uncertain, but it seems very unlikely that insufficient nutrient supply is an important factor.

From 1970 onwards at least 25 separate field experiments were conducted to measure pea responses to fertiliser in NZ, but none provided convincing evidence of positive responses to N, P, K, Mo fertilisers or lime. Growers sometimes believe they have seen benefits from starter fertilisers applied to peas. However, crop appearance can be deceptive; fertilisers can cause "darker, leafier, more bulky crops" but this rarely results in increased pea yields.

9.1 POTENTIAL YIELDS

Potential yields are influenced strongly by the choice of variety, weather conditions (and hence planting date), and the required maturity at harvest. Crops producing a large biomass do not necessarily yield the greatest pea yields. The variable harvest index makes it hard to specify what future potential yields might be if growers and scientists can conquer the variability within and between crops. Nutrient recommendations here assume a potential yield of 15 t/ha of peas for processing — certainly some crops do achieve that.

9.2 NUTRIENT RECOMMENDATIONS

The lack of yield responses to fertilisers in NZ experiments meant that it was impossible to calibrate and use the models used for other crops in this book. Earlier fertiliser recommendations were based on target soil test values that lack scientific evidence. *Here recommendations are based on offtake or maintenance requirements.*

Table 9-1 Estimated offtakes of N, P and K by a process pea crop with yield of 15 t/ha of pods. These values are based on data from the USA.

	N (kg N/ha)	P (kg P/ha)	K (kg K/ha)
kg nutrient/t pods	2.9	0.30	1.8
offtake by a 15 t/ha crop	44	5	27

Estimate maintenance requirements from the kg of each element per tonne of peas *removed from the field* (Table 9-1). A crop yielding 10 t/ha of peas would remove about 10 x 0.30 = 3 kg P/ha in the peas. Nutrient concentrations can vary between crops, and the values in Table 9-1 may reflect luxury uptake of P and K in particular.

Soil tests

Before the crop is planted, carry out soil testing for each paddock from 0–15 cm depth. Choose the standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and volume weight).

Nitrogen (N)

Do not apply N fertiliser to process peas — they are legumes that can fix N and are effective also at taking up mineral N already in the soil.

Phosphorus (P)

A maintenance P application for a crop yielding 15 t/ha would be about 5 kg P/ha (Table 9-1). Unless soil Olsen P is <10 µg/mL, pea yield responses to this fertiliser are unlikely. Use the most rapidly available form of P that is available and suitable for your growing system. Apply this down the spout at planting. Side-dressing P to growing crops is very unlikely to benefit their yield.

Do not apply maintenance P if soil Olsen P>50.

Potassium (K)

A maintenance K application for a crop yielding 15 t/ha would be about 27 kg P/ha (Table 9-1). Use the cheapest source of readily available K that you have available. Apply K fertilisers by broadcasting and incorporating before planting.

Do not apply maintenance K if QT K>10.

Calcium (Ca) and lime

There is no indication that natural amounts of Ca in vegetable-growing soils limit pea yield or quality in NZ. Lime requirements depend on the soil type and its pH. Experimental evidence for lime responses is weak, but there appears to be no response to lime if pH is as low as 5.4.

Apply lime if pH is less than 5.4, targeting a pH of 6.0; values appreciably above 6.5 may cause trace element deficiencies.

Magnesium (Mg), Sulphur (S), and trace elements

Yield or quality responses to applications of these elements are unlikely in NZ, and maintenance requirements are small. In the cases of Mg and S, it is better to apply these nutrients to crops for other crops in the rotation where and when soil tests indicate a response is likely. There is no scientific evidence of pea crops responding to applications of trace elements in NZ.

9.3 PLANT NUTRIENT ANALYSIS

Typical concentrations in the foliage or even whole plants are of little use. It is very difficult to establish critical concentrations of nutrient elements in peas grown in the field, and for N, P and K at least these critical concentrations decrease markedly as the plants grow larger (Table 9-2).

Table 9-2 Critical concentrations for whole plants (above ground) of peas grown in the UK (Greenwood et al. 1980). Values are given on a dry mass basis.

Plant dry mass (g)	N	P	K
0.56	5.6	0.47	3.4
23	3.4	0.40	2.2
31	2.6	0.33	1.6

Most likely deficiency symptoms

Visual symptoms of nutrient deficiency are rare in NZ pea crops. Damage from extreme weather, insects, diseases or sprays is much more likely to cause unusual appearance of the shoots.

CHAPTER 010
POTATOES

Potatoes (*Solanum tuberosum* L.) are grown throughout NZ for the fresh market. Potatoes for processing are grown mainly in Canterbury, Manawatu, Hawke's Bay, Waikato and South Auckland. Potato crops yield poorly if there are nutrient deficiencies, and plant nutrition often seems to affect tuber quality. They have a relatively shallow root system (maximum depth is about 75 cm under good conditions), a large demand for N, and a need for frequent irrigation in many regions. All these can lead to a substantial risk of nutrient leaching if excessive fertiliser is applied.

10.1 POTENTIAL, FIELD, AND MARKETABLE YIELDS

These can greatly influence the crop's requirements for mineral nutrients. Potential yields may be as small as 50 t/ha for winter-planted crops. The majority of potatoes are grown through spring and summer, and their potential yields vary from about 80 t/ha for early-harvest crops through to 100 t/ha for main-crop plantings. In Canterbury at least, field yields are often rather less than potential, perhaps because of a combination of inappropriate irrigation and disease; the reasons are still under investigation.

Four representative scenarios are presented here:

Scenario 1: Potential yield of 100 t/ha (23 t/ha dry matter). This would be typical for many varieties where a long season is possible, for example the variety 'Agria' grown in the Waikato region, Hawke's Bay, or Canterbury. The marketable yield in this scenario could be as high as 80 t/ha depending on grading standards and harvest conditions.

Scenario 2: Potential yield of 87 t/ha (20 t/ha dry matter). This is typical for the variety 'Russet Burbank' grown in Canterbury. The marketable yield here could be as high as 70 t/ha but will be less if irrigation restricts tuber size.

Scenario 3: Potential yield of 76 t/ha (14 t/ha dry matter). This is representative of table varieties like 'Nadine' grown for early harvest (small to medium size tubers) in locations like Matamata in the Waikato region. The marketable yield in this scenario could be as high as 65 t/ha depending on grading standards and harvest conditions.

Scenario 4: Potential yield of 50 t/ha (9 t/ha dry matter). This is representative of winter-planted crops of table varieties in areas like Pukekohe. The marketable yield could be as high as 46 t/ha depending on grading standards and harvest conditions.

Nutrient requirements will be reduced if the crop suffers water stress; here, recommendations assume no water stress.

Nutrient requirements to grow the crop are based on the potential yields for each scenario, but maintenance nutrient requirements have to be based on offtakes, which depend on the mass of tubers that are removed from the field. This depends in turn on harvesting machinery and grading standards. *The offtake calculations here assume 80% of the tuber yield is removed from the field.*

10.2 NUTRIENTS TO GROW THE CROP

Soil tests

Before each crop is planted, start the process of nutrient management with soil testing from the paddock at TWO depth ranges:

1. 0–15 cm depth — standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and volume weight) PLUS Reserve K (TBK, in meq/100g) PLUS Anion Storage Capacity (ASC or P retention%). TBK and ASC need to be tested only once for each paddock — not before every crop.
2. 0-60 cm depth — mineral N test (nitrate plus ammonium, in kg N/ha).

Nitrogen (N)

It is important for potatoes to establish ground cover rapidly, and keep green leaves as long as possible. N supply is crucial for this. Recommendations for the total amount of N to be applied are in the following tables.

At planting:

- Soluble and controlled-release N fertilisers are best incorporated or applied down the spout — but make sure they are not in contact with the seed piece. Controlled-release N fertilisers may significantly reduce the risk of nitrate leaching and improve yields in wet weather.

- **If using controlled-release N fertilisers**, apply up to 100 kg N/ha of recommendation as the controlled-release product and up to 20 kg N/ha of a soluble N fertiliser.
- **If using only soluble N fertilisers** like urea, ammonium sulphate, or CAN, apply less than half the total recommended N fertiliser (up to 100 kg N/ha if soil N supply is low).
- **Compost sources of N** incorporated at planting may reduce the risk of nitrate leaching, but can be expensive.

Split the remainder of the recommended N across at least one or more side-dressings shortly after canopy closure (or earlier if the crop is struggling to achieve canopy closure). Side-dressings should be readily available forms like urea or CAN.

If fertigation is available, split the recommended N fertiliser across several applications during the season. This can greatly assist in matching N fertiliser supply with the demands of the crop, lessening the risk of nitrate leaching.

Soil mineral N to 60 cm depth (kg N/ha)	Recommended N application (kg N/ha) to grow the crop	
	Scenario 1: Potential yield 100 t/ha (main crop, table variety)	Scenario 2: Potential yield 87 t/ha (main crop, processing variety)
50	225	225
100	200	175
150	150	125
200	125	100
250	75	50
300	50	nil
350	25	
400	nil	

Soil mineral N to 60 cm depth (kg N/ha)	Recommended N application (kg N/ha) to grow the crop	
	Scenario3: Potential yield 76 t/ha (early harvest, table variety)	Scenario 4: Potential yield 50 t/ha (winter planted crop, table variety)
50	260	230
100	200	195
150	150	188
200	100	182
250	50	175
300	25	140
350	nil	130

*See Key point “Winter rainfall”

Key point: Winter rainfall

Under Scenario 4 there is considerable potential for nitrate leaching due to the winter rainfall in the Pukekohe area. If controlled-release sources of N are used rather than readily soluble N, then the amounts of N recommended are considerably smaller; ranging from 130 kg N/ha (when the soil mineral N is 50 kg N/ha) down to 90 kg N/ha (when the soil mineral N concentration is 350 kg N/ha).

Excessive N concentrations in the tubers may decrease tuber DM% and specific gravity. Provided N applications are kept within the above recommendations, detrimental effects on tuber quality are unlikely.

Phosphorus (P)

Potatoes often respond strongly to P fertiliser when soil Olsen P is low — but the response curve flattens out quickly, and yield may be suppressed if P supply is beyond the optimum. If P fertiliser is required, apply up to 15 kg P/ha as a starter down the spout (keeping some separation from the seed piece) or knifed in close to the planting line. If possible, apply up to 50 kg P/ha of the remaining recommendation as a band 5 – 10 cm from the planting line. The remainder (if any) of the recommendation can be broadcast and incorporated pre-planting. *Side-dressings of P are unlikely to be taken up by the crop.* Do not leave P fertilisers on the soil surface, where they will not be effective.

Soil Olsen P (µg/mL)	Recommended P application (kg P/ha) to grow the crop	
	Scenario 1: Potential yield 100 t/ha (main crop, table variety)	Scenario 2: Potential yield 87 t/ha (main crop, processing variety)
10	up to 340	up to 310
20	280	220
30	180	130
35	140	90
40	90	56
45	50	nil
50	nil	nil

Soil Olsen P (µg/mL)	Recommended P application (kg P/ha) to grow the crop	
	Scenario3: Potential yield 76 t/ha (early harvest, table variety)	Scenario 4: Potential yield 50 t/ha (winter planted crop, table variety)
10	up to 200	up to 110
20	110	20
25	60	20
30	30	nil
35	nil	nil

Phosphorus and tuber quality

A small supply of P may limit the number of tubers set and so decrease the number of small tubers harvested — but that risks overall yield losses. There is insufficient evidence yet to recommend fertilisers for manipulation of tuber numbers and sizes.

Potassium (K)

Potatoes can take up large amounts of K, but the yield response to K fertiliser depends strongly on the mineralogy of the soil. An effective way of dealing with this is to include the Reserve K or TBK value in soil tests.

Recommendations are given for TBK values, of 1, 2, and 3 meq/100 g which covers a wide range of soils used for potatoes in NZ.

Key point: Applying K fertiliser

K fertiliser is best applied as a base-dressing especially if QT K values are low. For maintenance applications use the cheapest source of K available (usually MOP) — but it must be broadcast and incorporated at least 2 weeks before planting so that it has chance to equilibrate with the soil. Side-dressing will be much less effective.

Scenario 1: Potential yield 100 t/ha (main crop, table variety)

Soil QT K	Recommended K application (kg K/ha) to grow the crop		
	TBK = 1 meq/100 g	TBK = 2 meq/100 g	TBK = 3 meq/100 g
4	340	290	210
5	320	270	150
6	310	240	nil
7	290	200	
8	270	140	
9	240	nil	
10	190		
11	130		
12	nil		

Scenario 2: Potential yield 87 t/ha (main crop, processing variety)

Soil QT K	Recommended K application (kg K/ha) to grow the crop		
	TBK = 1 meq/100 g	TBK = 2 meq/100 g	TBK = 3 meq/100 g
3	330	250	nil
4	320	210	
5	300	150	
6	270	nil	
7	240		
8	190		
9	130		
10	nil		

Scenario 3: Potential yield 76 t/ha (early harvest, table variety)

Soil QT K	Recommended K application (kg K/ha) to grow the crop		
	TBK = 1 meq/100 g	TBK = 2 meq/100 g	TBK = 3 meq/100 g
3	320	200	160
4	300	160	nil
5	250	nil	
6	190		
7	160		
8	nil		

Scenario 4: Potential yield 50 t/ha (winter planted crop, table variety)

Soil QT K	Recommended K application (kg K/ha) to grow the crop		
	TBK = 1 meq/100 g	TBK = 2 meq/100 g	TBK = 3 meq/100 g
3	100	100	100
4	nil	nil	nil

Potassium fertilisers and tuber quality

Many have suggested that use of MOP rather than SOP will reduce tuber quality, especially dry matter % or specific gravity. That is very unlikely provided that the K fertiliser is applied as a base dressing and does not exceed the recommendations for yield given above.

Magnesium (Mg)

There appears to be no verified case of Mg deficiency or yield response to Mg fertiliser in NZ potato crops. There is anecdotal evidence that low Mg concentrations are sometimes obtained in petiole testing. The calibration of potato petiole test results against fertiliser response in NZ is poorly documented. It seems most horticultural soils in NZ already contain an excess of Mg, and increasing Mg uptake by the roots in some crops may be limited by competitive effects of other nutrients like Ca and K. It will be a sensible precaution to apply at least one foliar spray of Mg, at manufacturers' recommended rates, *if there have been clear visual symptoms of Mg deficiency in previous potato crops at the same site*. The symptoms are mainly that the older leaves turn yellow between the veins and eventually die back.

Calcium (Ca), sodium (Na) and Sulphur (S)

Yield or quality responses to fertiliser applications of Ca and S have not been observed in NZ. Soils used for vegetables in NZ usually contain large quantities of Ca and S already. Both elements are commonly applied in other fertilisers. For instance, superphosphate contains appreciable amounts of Ca and S.

Do not apply Na fertilisers to potatoes in NZ - there is no evidence that these will benefit yield or quality.

Lime requirements

The available evidence suggests soil pH should be in the range 5.2 – 6.0. Do not apply lime during crop growth or even in the 1-2 years preceding the crop. This is especially important if potatoes have been grown in the field previously and the pathogen common scab (*Streptomyces scabies*) is present. If there is a need to increase soil pH for other crops in the rotation, apply lime after the potato crop is harvested.

Trace elements

Applications of trace elements to NZ potato crops are unlikely to generate an economic return, unless there is strong evidence that specific deficiencies have occurred on previous crops at that site. Offtakes are usually a few g/ha and availability of these nutrients is so dependent upon pH and changes in soil aeration (water content) that trace elements applied to the soil will usually be wasted. Potential exceptions could be B on sedimentary soils following a wet winter and spring, and Cu on organic soils. In those cases the best option may be a foliar spray applied in the early morning or evening at the manufacturers' recommended rates.

10.3 MAINTENANCE NUTRIENT APPLICATIONS

Total uptake of N and K can be very large (Table 10-1). Nutrient amounts in the shoots are considerable, and these are returned to the soil in crop residues, but the amounts potentially removed from the paddock in tubers remain large.

Table 10-1 Amounts of major nutrients removed from the soil by a 77 t/ha potato crop. Nutrients in the tubers are removed from the field, the rest are recycled. These values may reflect some luxury uptake — especially of N and K.

	N	P	K	S	Ca	Mg
Roots (kg/ha)	6.4	0.65	7.9	1.6	3.6	1.7
Shoots (kg/ha)	106	6.5	310	7.8	43	29
Tubers (kg/ha)	341	47	511	32	10	21
Total uptake (kg/ha)	454	54	828	42	57	51

Table 10-2 Offtakes of major nutrients for potato crops. These assume 80% of the tuber yield is removed from the paddock. Maintenance applications of N are not recommended except under organic production systems.

	N	P	K	S	Ca	Mg
kg/t tubers	3.4	0.47	5.1	0.32	0.10	0.21
Offtakes (kg nutrient/ha)						
Scenario 1: pot. yield 100 t/ha	273	37	409	26	8.3	16.6
Scenario 2: pot. yield 87 t/ha	237	32	355	23	7.2	14.4
Scenario 3: pot. yield 76 t/ha	208	29	312	20	6.3	12.7
Scenario 4: pot. yield 50 t/ha	135	18	202	13	4.1	8.2

Maintenance nutrient applications must be estimated from the kg of each element per tonne of tubers removed from the paddock (Table 10-2). If a crop yields 100 t/ha in the field and 80% of the tubers are removed then the offtake of P would be about 100 x 80/100 x 0.47 = 37 kg P/ha in the tubers.

Maintenance applications of any particular nutrient should be made only if none will be applied to grow the crop. For N, maintenance applications should be considered only under organic production systems using composts.

The calculated maintenance applications for P and K are large, possibly because the concentrations in Table 10-1 reflect some luxury uptake. Applying such large amounts of K is expensive and may pose risks for crop establishment and tuber quality. The maintenance recommendations here follow the strategy (a) If QT K>12, do not apply any maintenance K; (b) If QT K<=12, apply half the calculated amount for the potential yield. If half-maintenance rates are being applied, be sure to check the soil QT K at least a month before the next crop, and apply further K if the new QT value appears limiting for the next crop.

If Olsen P>70, do not apply any maintenance P (allow Olsen P to decrease).

For methods of application of nutrients follow the guidelines for nutrients to grow the crop.

10.4 PLANT ANALYSIS

Petiole or sap nutrient tests are likely to be helpful only for growers with several years of experience gathering and interpreting such data for the same variety and growing locations. Some processing companies have that experience but it is rarely made available to other than their own growers.

Laboratories often quote “typical” or “adequate” nutrient concentrations in leaves, petioles, or sap. These are difficult to interpret in terms of whether a specific crop will respond to more fertiliser. However, there is information for the optimum nutrient contents of tubers at maturity (Table 10-3). This can be useful as part of a post-mortem on why a crop may not have yielded to potential, so practices can be adjusted for future crops.

Table 10-3 Optimum nutrient concentrations for potato tubers at harvest. Values are given on a dry mass (DM) basis.

Nutrient	Concentration (% DM)
N	1.6
P	0.23
K	1.7

Most likely deficiency symptoms

Nitrogen deficiency causes weak growth, while older leaves yellow and die early.

Phosphorus deficiency also manifests as weak or stunted growth, but the leaves are darker than normal. Older leaves develop necrotic spots. Some varieties may show unusual purpling of the stem, petiole and undersides of leaves — but there are other possible causes of such symptoms.

Potassium deficiency is rarer. The older leaves may be bluish green, become bronzed and then curl or crinkle. Areas between veins may develop spots and the leaf margins may scorch.

Helpful images are available from the Yara CheckIT app for mobile telephones (Yara 2017), although the accompanying descriptions are sometimes at odds with NZ experience of where such deficiencies may occur.

CHAPTER 011

SPINACH, SILVERBEET AND BEETROOT

Spinach (*Spinacia oleracea* L.), silverbeet (or Swiss chard, *Beta vulgaris* L.), and beetroot (red beet, *Beta vulgaris* L.) are grown throughout NZ for the domestic market. Silverbeet, beetroot, fodder beet and sugar beet are varieties of the same species, although silverbeet varieties have been developed for harvesting of the leaf and stem rather than the swollen stems ("roots" or "bulbs") of the others. Beetroot is occasionally grown so the leaves can be used in salads; there may be multiple harvests. Beetroot is grown for processing of the roots in Hawke's Bay.

These crops are members of the *Chenopodiacea* family of plants that has a strong ability for luxury uptake of nutrients — given the chance, they will accumulate more mineral nutrients than they need for maximum yield or quality. This can make it difficult to forecast nutrient budgets accurately.

11.1 POTENTIAL, FIELD, AND MARKETABLE YIELDS

There are no available models for potential yields of these crops. Nutrient recommendations are best based on target yields that should be limited to the best field yields attained in each region for the same planting month. Even there it can be difficult to obtain consistent information. The recommendations here are based on the following field yields that growers may use as targets:

- *For spinach*, 15, 20, and 25 t/ha (up to 200,000 plants/ha). For baby spinach populations may be much higher, but yields will often be 15-20 t/ha;
- *For silverbeet*, 10, 20, and 30 t/ha (up to 120,000 plants/ha). Variations in market requirements complicate the choice of target yield. A yield of 20 t/ha corresponds roughly to 100,000 heads/ha at an average size of 250 g each after trimming;
- *For beetroot leaves*, 20, 30 and 50 t/ha (up to 600,000 plants/ha);
- *For beetroot roots*, 40, 60 and 80 t/ha (plants/ha varies from about 400,000 through to 1,400,000 depending on the target market, and whether it is a main crop or baby beetroot crop).

Marketable yields will often be less than the above targets. For calculation of maintenance nutrient requirements here we have assumed 90% of the yield fits market requirements.

Until potential yield and nutrient response models for these crops are available, nutrient recommendations need to be based on a combination of likely uptakes, offtakes and target soil test values.

11.2 NUTRIENTS TO GROW THE CROP

Soil tests

Before planting or applying any fertiliser, soil test each paddock from 0–15 cm depth. Choose the standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and volume weight) PLUS 'Available N' (anaerobically mineralisable N, in kg N/ha).

Nitrogen (N)

High N application rates at planting are very inefficient and can lead to depressed yields, unacceptable concentrations of nitrate in the edible plant parts, and large amounts of nitrate leaching; it is much better to apply smaller N rates and split them over several applications to better match the demands of the crop.

Recommendations here are given on the basis of published critical N concentrations in spinach and beetroot. They assume no leaching of nitrate below the root zone and that the majority of the N available from the soil is in the top 15 cm depth, as estimated by the Available N procedure. There are probable errors introduced by both assumptions, but they will tend to compensate for each other.

Recommendations for the total amounts of N to apply are given in Table 11-1. The total amounts recommended should normally be split into 3 or more applications.

At planting:

- **Soluble and controlled-release N fertilisers** are best incorporated or (if planting arrangements permit) knifed in 2-5 cm from the plant row.
- **If using controlled-release N fertilisers**, apply up to 100 kg N/ha of the controlled-release product and up to 20 kg N/ha of a soluble N fertiliser.

- **If using only soluble N fertilisers** like urea, ammonium sulphate, or CAN, apply no more than 20 kg N/ha, or up to 50 kg N/ha if this is a winter-planted crop and wet weather will greatly limit opportunities for side-dressing in the second and third months of growth.

Split the remainder of the recommended N across at least two side-dressings after the plants have at least two true leaves (direct-seeded crops). Avoid applying more than 50 kg N/ha at any one time. Side-dressings may be broadcast (if possible just before light rain or irrigation), but be careful to avoid fertiliser lodging amongst the leaves where it can cause cosmetic damage.

If applying N in the form of composts, incorporate these at least 2 weeks before planting.

Table 11-1 Recommended N fertiliser rates for spinach, silverbeet, and beetroot. The values are calculated from the critical concentrations of N needed in the crops for maximum yield.

	Spinach			Silverbeet			Beetroot leaves			Beetroot roots		
Target yield (t/ha)	**15**	**20**	**25**	**10**	**20**	**30**	**20**	**30**	**50**	**40**	**60**	**80**
Available N (kg N/ha)												
30	**40**	**65**	**90**	**10**	**40**	**75**	**60**	**105**	**195**	**130**	**185**	**240**
60	**10**	**35**	**60**	**nil**	**10**	**45**	**30**	**75**	**165**	**100**	**155**	**210**
90	**nil**	**5**	**30**		**nil**	**15**	**nil**	**45**	**135**	**70**	**125**	**180**
120		**nil**	**nil**			**nil**		**15**	**105**	**40**	**95**	**150**
150								**nil**	**75**	**10**	**65**	**120**
180									**45**	**nil**	**35**	**90**
210									**15**		**10**	**60**
240									**nil**		**nil**	**30**
270												**nil**

Phosphorus (P)

Silverbeet and beetroot are the same species, and we must assume they respond similarly to P supply. For spinach, silverbeet, and beetroot the recommended strategy is to use a two-step combination of broadcast and carefully banded starter P fertilisers:

If Olsen P <35 µg/mL, apply sufficient P fertiliser to raise the Olsen P to 35. The rate depends on the soil type and can be calculated using the rules in Chapter 2 (*To raise soil Olsen P*).

Reserve up to 20 kg P/ha of this total to apply as a starter fertiliser. If direct seeding, apply the fertiliser down the spout, providing this enables some separation of seed and fertiliser. Alternatively, if planting arrangements allow, knife the starter P in 2-5 cm from the plants. For baby spinach or baby beetroot crops P fertiliser may have to be broadcast and incorporated ahead of planting. If soil ASC (P retention) is >40% then the efficiency of broadcast starter P fertiliser will be low; try to find ways of applying it in bands or incorporating it shallowly (say to only 5 cm).

The remainder (if any) of the recommendation should be applied as a capital or base dressing before planting. This fertiliser should be broadcast and incorporated to 15 cm depth.

Potassium (K)

The recommendations here are a combination of broadcast and banded fertilisers. For spinach, silverbeet and beetroot the recommended strategy is to use a two-step combination of broadcast and carefully banded starter K fertilisers. We must assume silverbeet and beetroot respond similarly to K supply.

If QT K <10, apply sufficient K fertiliser to raise QT K to 10. The rate depends on the soil type and can be calculated using the rules in Chapter 2 (To raise soil QT K).

- Reserve a portion of the total to apply as a starter fertiliser. SOP will be safer to use for this than MOP. If direct seeding, apply up to 15 kg K/ha down the spout, provided there is some separation of seed and fertiliser. Alternatively, knife in up to 30 kg K/ha as a narrow band 2-5 cm from the seed.
- The remainder of the recommendation should be applied as a capital or base dressing at least 4 weeks before planting. Broadcast and incorporate it to 15 cm depth. Use the cheapest form of K fertiliser you have available (usually MOP).

Magnesium (Mg), sodium (Na), sulphur (S) and trace elements

There is no evidence that in NZ yield of the spinach, silverbeet or beetroot will respond to fertiliser applications of Mg, Na, or S, although the plants have a strong capacity for luxury uptake of these nutrients. Taste of the leaves in particular might by affected by such luxury uptake, but little has been published.

Applications of trace elements to these crops are unlikely to generate an economic return, unless there is strong evidence that specific deficiencies have occurred on previous crops at that site. Offtakes are of the order of a few g/ha and availability of these nutrients is so dependent upon changes in soil aeration (water content) and pH that fertiliser applications to the soil will usually be wasted. Potential exceptions could be B for beetroot grown on sedimentary soils following a wet winter and spring, and Zn for spinach grown on soils with pH values >6.5. In those cases the best option may be a foliar spray applied in the early morning or evening at the manufacturers' recommended rates.

Calcium (Ca) and lime

Yield and quality responses to Ca applications are unlikely in NZ, as most horticultural soils contain an excess of this nutrient already.

Spinach: Apply lime if pH is less than 5.6, targeting a pH of 6.2.

Silverbeet and beetroot: Apply lime if pH is less than 6, targeting a pH of 6.5

Apply fine lime at least a month before planting.

11.3 MAINTENANCE NUTRIENT APPLICATIONS

Typical concentrations in spinach and beetroot are given in Table 11-2.

Table 11-2 Estimated concentrations of N, P and K in spinach and beetroot at harvest. The data are taken from the USDA and are given as kg nutrient per tonne of yield.

Plant part	N	P	K
Spinach (whole shoot)	4.9	0.5	5.3
Silverbeet leaves	2.9	0.5	2.4
Beetroot leaves	4.4	0.5	7.5
Beetroot roots	2.7	0.4	3.1

Maintenance requirements are estimated by multiplying the target or expected yield by the concentrations in kg nutrient per tonne of yield in Table 11-2. Representative offtakes calculated in this way are given in Table 11-3.

- Maintenance applications of any particular nutrient should be made only if none will be applied to grow the crop.

- For N, maintenance applications should be considered only under organic production systems using composts.
- Maintenance P should be broadcast and incorporated in advance of planting. Do not apply maintenance P if soil Olsen P>50.
- K maintenance applications should be applied as a capital or base dressing. Broadcast and incorporate it to 15 cm depth at least 4 weeks before planting, using the cheapest form of K fertiliser you have available (usually MOP). If the applications are made closer to planting, use SOP.

The calculated maintenance applications of K are large, especially for beetroot. Applying such large amounts before or at planting is expensive and may pose risks for crop establishment. Furthermore, provided QT K is >6, most NZ soils contain large reserves of K. The recommendations for K maintenance applications follow the strategy: (a) Apply half the calculated amount for the expected yield; (b) Check the Soil QT K at least a month before the following crop; (c) Apply further K fertiliser if the new QT value appears limiting for the next crop.

If QT K>12, do not apply any maintenance K.

Table 11-3- Calculated offtakes of N, P and K by spinach, silverbeet, and beetroot crops using USDA data for crop composition. These values assume 90% of the field yield is marketable.

	Field yield fresh (t/ha)	N	P	K
Spinach	15	66	7	72
Spinach	20	88	9	95
Spinach	25	110	11	119
Silverbeet	10	26	5	22
Silverbeet	20	52	9	43
Silverbeet	30	78	14	65
Beetroot, leaves	20	79	9	135
Beetroot, leaves	30	119	14	203
Beetroot, leaves	50	198	23	338
Beetroot, roots	40	97	14	112
Beetroot, roots	60	146	22	167
Beetroot, roots	80	194	29	223

Table 11-4 Critical concentrations of N, P, and K in spinach and beetroot. The critical concentrations are given as % DM.

Plant part	Dry mass (g/plant)	Fresh mass (g/plant)	N	P	K
Spinach (whole shoot)	0.52	5.2	5.1	1.4	8
Spinach (whole shoot)	8.0	80	4.4	0.45	5.1
Beetroot (whole shoot)	1.3	13	3.9	0.51	6.8
Beetroot (whole shoot)	14	140	2.4	0.49	1.6
Beetroot (root)	1.4	14	2.5	0.47	3.7
Beetroot (root)	10	77	2.1	0.45	3.1
Beetroot (root)	39	300	1.4	0.43	2.4

11.4 PLANT ANALYSIS

Published concentrations of nutrients in NZ crops are few and scattered. The values held in the databases of the commercial laboratories are difficult to interpret because of the risk of luxury uptake. Critical nutrient concentrations have been carefully measured for spinach and beetroot crops in the UK; for present purposes, assume that concentrations for silverbeet are the same as those for beetroot. The critical concentrations decrease as the plants grow bigger (Table 11-4).

These values are useful benchmarks for diagnosis of N, P and K deficiencies. If plant analysis indicates values below the ranges given here, there is a substantial risk the crop is suffering from a nutrient deficiency.

Most likely deficiency symptoms

N deficiency is usually seen as yellowing of the lower leaves. Under some conditions there may be some purpling of leaves in beetroot but there may be other causes of this.

P deficiency is hard to detect visually; it is usually expressed as a general reduction in growth.

K deficiency is rarely seen in NZ soils. Mild deficiency causes a general slowing of growth. In more extreme cases old leaves loose turgor and die back from tip (silverbeet and beetroot), or there are papery dead patches and flaccid tips of leaves (spinach).

CHAPTER 012
SWEETCORN

In NZ, sweet corn for processing is grown mainly in Gisborne, Hawke's Bay, Marlborough and Canterbury, but for the fresh market crops are grown in most regions. Sweet corn has a less vigorous root system than its cousin maize — which makes it less capable of extracting nutrients from the soil. On the other hand, it is harvested well before maize and so requires less nutrient uptake.

Surveys of commercial crops in Hawke's Bay and Gisborne in 1998 – 99 and 1999 – 2000 indicated that 70% lost yield because of insufficient or poorly timed irrigation, and 84% lost yield because of inadequate nutrition. The nutrients most usually in short supply were nitrogen (N) and phosphorus (P). However, extra fertiliser will not compensate for poor crop establishment, water stress, or waterlogging due to heavy rain, excessive irrigation or poor drainage. However, excess fertiliser can lead to significant nutrient losses to the environment.

12.1 POTENTIAL YIELDS

These vary substantially with the weather, hybrid or variety, planting date and the plant population. Here we primarily consider situations where yield is measured in the mass of marketable ears. Nutrient recommendations are given for two scenarios:

Scenario 1: Potential yield of 20 t/ha of fresh ears. This is typical for short-duration hybrids, and for late- or medium-duration hybrids planted in especially warm regions north of the Bay of Plenty. For nutrient maintenance calculations, 80% of the field yield is assumed to be removed from the field (16 t/ha).

Scenario 2: Potential yield of 30 t/ha of fresh ears. This is typical for early-planted crops of medium- to long-duration hybrids in Gisborne, Hawke's Bay, Marlborough and Canterbury. For nutrient maintenance calculations, 80% of the field yield is assumed to be removed from the field (24 t/ha).

Where it is more appropriate to consider yield in numbers rather than mass of ears, the above yields will have to be divided by the target average mass of a marketable ear as defined by the intended market. Similarly, kernel yields for some processing uses have to be calculated from the above ear yields multiplied by a kernel recovery factor supplied by the processor.

12.2 NUTRIENTS TO GROW THE CROP

Soil tests

Before the crop is planted carry out soil testing for each paddock from 0–15 cm depth. Choose the standard soil testing suite (pH, Olsen P, QT Ca, K, Mg and Na, cation exchange capacity and volume weight) PLUS 'Available N' (anaerobically mineralisable N, in kg N/ha).

Nitrogen

When available N is low, yield responds strongly to N fertiliser, but it is a "diminishing returns" style of response.

If fertigation is available, spread the N applications between crop emergence and the start of stem elongation.

If using a slow release form of N fertiliser or composts, broadcast and incorporate these before or at sowing.

> **Key point: Previous land use**
>
> **If the soil has been under pasture continuously for the previous 2 years, apply no N fertiliser. Ensure the pasture residues are cultivated into the soil and kept moist for at least a month before planting.**

If using soluble, solid, N fertilisers (like urea), remember that generally N applied before planting is at risk of leaching. Around Gisborne that risk is slight and N can be broadcast and incorporated just before or after planting. In other regions avoid applying N before planting *and split the recommended N fertiliser into two applications*, one at planting and the majority applied as a side-dressing 4–6 weeks later (preferably just as stem elongation begins).

For side-dressing knife the fertiliser in no closer than 10 cm from the plants. Side-dressings simply placed on the soil surface risk significant volatilisation losses.

Soil Available N (kg N/ha)	Recommended N application (kg N/ha) to grow the crop	
	Scenario 1: Potential yield about 20 t/ha fresh ears	Scenario 2: Potential yield about 30 t/ha fresh ears
50	180	250*
80	100	240
100	40	180
110	20	160
120	nil	130
150		40
160		20
170		nil

* responses to more N may occur but be uneconomic.

Phosphorus

Use the most rapidly available form of P that is available and suitable for your growing system. Base or capital dressings can be broadcast before planting, but make sure that up to 10 kg P/ha of the recommended application is placed down the spout at planting. Larger amounts can be knifed in 50- 100 mm from the drill line, again at or very soon after planting. *Do not side-dress growing crops with P because this will be poorly taken up by the crop.*

Soil Olsen P (µg/mL)	Recommended P application (kg P/ha) to grow the crop	
	Scenario 1: Potential yield about 20 t/ha fresh ears	Scenario 2: Potential yield about 30 t/ha fresh ears
10	80	up to 140
20	20	80
25	nil	60
30		40
35	nil	nil

Potassium

Generally, K fertiliser applications are not economic for short-duration sweet corn crops, unless the soil is severely depleted in K. Use the cheapest source of readily available K that you have available. Apply K fertilisers by broadcasting and incorporating before planting.

QT K	Recommended K application (kg K/ha) to grow the crop	
	Scenario 1: Potential yield about 20 t/ha fresh ears	Scenario 2: Potential yield about 30 t/ha fresh ears
3	60	180
4	nil	120
5		40
6		nil

Magnesium (Mg)

Yield or quality responses to Mg applications are unlikely in NZ. Fertiliser Mg applications Mg have been tested at sites with Mg QT values down to 13 but no crop responses were observed. Maintenance applications are not recommended unless the Mg QT value falls below about 13.

Calcium (Ca), sodium (Na), and sulphur (S)

Do not apply Na to sweet corn crops. It is very unlikely the crop will respond directly to applications of Ca or S. Soils used for vegetables in NZ usually contain large quantities of Ca and S already. Both elements are commonly applied as part of other fertiliser applications. For instance, superphosphate contains appreciable amounts of Ca and S. Lime also contains a large amount of Ca.

Lime

Apply lime if pH is less than 5.5, targeting a pH of 6.0. Soil pH values as low as 5.5 do not appear to affect yield, but values appreciably above 6.5 may cause trace element deficiencies.

Trace elements

Trace element deficiencies are occasionally identified in sweet corn or maize crops. The deficiencies are most likely to be caused by an unsuitable soil pH affecting trace element solubility rather than there being inadequate amounts actually in the soil.

Sweet corn has relatively high demand for Zinc (Zn) compared with other trace elements. Deficiency of Zn may occur in alkaline soils (pH > 7.0) and sandy soils. The risks in such situations are increased if the soil Olsen P is greater than about

30 µg/mL because that may discourage the plants to form mycorrhizal symbioses that greatly help Zn uptake. Zn deficiency can lead to iron deficiency which also causes similar symptoms. Lowering soil pH can increase Zn availability to the point of toxicity — but there is no evidence of this in NZ.

Sweet corn may perform badly in poorly drained soils because of trace element toxicities. Poor soil aeration increases the solubility of many trace elements, and excessive uptake of copper (Cu), manganese (Mn), iron (Fe) and Zn is probably more common than deficiencies of these nutrients. Occasionally plants show Fe deficiency even when they have taken up plenty of the element. Excessive uptake of other trace elements (like Cu) because of wet soil conditions may impair the crop's Fe metabolism.

12.3 MAINTENANCE NUTRIENT APPLICATIONS

The nutrients taken up in the largest quantities by sweet corn crops are N, P and K. Up to 60% of the crops total N is taken up in the period from two weeks before tasselling to two weeks after. Table 12-1 below shows the approximate amounts of these elements that can be removed from the soil by a sweet corn crop.

Table 12-1 Typical amounts of N, P, and K removed from the soil by a sweet corn crop yielding 16 t/ha of ears. Nutrients in the ears are removed from the paddock, the rest are recycled.

		N	P	K
Plant (stems, leaves)	**kg/ha**	**112**	**13**	**84**
Ears	**kg/ha**	**62**	**9**	**34**
Total	**kg/ha**	**174**	**22**	**118**

Maintenance requirements are estimated by multiplying tonnes of ears removed from the paddock by the concentrations in kg nutrient per tonne of yield in Table 12-2. The maintenance K application for crop where 24 t/ha of ears were removed from the paddock would be 24 x 2.1 = 50 kg K/ha. Representative offtakes calculated this way are given in Table 12-2.

Table 12-2 Typical nutrient offtakes by sweet corn crops. Uptake and removal figures for Mg and S are not available for NZ crops, but they will be less than the values given for P.

	N	P	K
kg/t ear yield	3.9	0.56	2.1
Offtakes (kg/ha)			
Scenario 1: removed yield 16 t/ha	62	9	34
Scenario 2: removed yield 24 t/ha	93	14	51

- Maintenance applications of any particular nutrient should be made *only if none will be applied to grow the crop.*
- For N maintenance applications should be considered only under organic production systems using composts.
- Maintenance P should be broadcast and incorporated in advance of planting. Do not apply maintenance P if soil Olsen P>40.
- K maintenance applications should be applied as a capital or base dressing. Broadcast and incorporate it to 15 cm depth at least 4 weeks before planting, using the cheapest form of K fertiliser you have available (usually MOP). If the applications are made closer to planting, use SOP.
- Do not apply maintenance K if QT K>10.

12.4 PLANT ANALYSIS

Conduct leaf analysis only if deficiencies are suspected. Take samples of the whole leaf around the primary ear at the tasselling to initial silking stage. By then it is often too late to affect the nutrition of that crop, but the results may be useful for managing future crops. Compare the analysis results to the *critical nutrient concentration* below which plant growth is slowed (Table 12-3).

Table 12-3 Critical leaf nutrient concentrations for sweet corn. These are given on a dry weight bases for the ear leaf at silking. Values are not available for sulphur (S) or sodium (Na).

Nutrient		Critical concentration
Nitrogen (N)	%	3.0
Phosphorus (P)	%	0.25
Potassium (K)	%	1.9
Calcium (Ca)	%	0.4
Magnesium(Mg)	%	0.25
Copper (Cu)	µg/mL	5
Zinc (Zn)	µg/mL	20
Iron (Fe)	µg/mL	50
Boron (B)	µg/mL	5

Most likely deficiency symptoms

N deficiency is usually seen as pale green leaves (especially the lower leaves).

P deficiency is uncommon in NZ. It is expressed as small plants with uniform purpling of leaves; however, cold weather can cause similar discolouration and will not be avoided by applying P fertiliser. Some varieties have occasional plants with purpling on leaves that is not stress related

CHAPTER 013
TOMATOES

Process tomatoes (*Lycopersicon esculentum* Mill.) are grown mainly in Hawke's Bay and Poverty Bay. Often the soils used contain large amounts of calcium and magnesium. This can greatly reduce the availability of potassium (K) for tomatoes, limiting yields and quality.

Usually, tomatoes are irrigated in Hawke's Bay but not in Poverty Bay. The yields are sensitive to water deficit, but there may be little effect until late in the season on heavier soils that have shallow water tables in spring. On slow-draining soils yield is sharply reduced by water excesses following excess irrigation or rainfall. If yield is reduced by water deficits, nutrient requirements will be reduced too, but yield losses due to water excess rarely reduce the crop's needs for nutrients because typically they occur after much of the crop's nutrient uptake.

13.1 POTENTIAL AND FIELD YIELDS

Potential yield is often around 150 t/ha (total fruit yield in the field, before deductions). Field yields are rarely this high, mainly because of the effects of deficits or surpluses of water, sometimes because soil structure is poor, and there may be necessary compromises associated with the date of harvest. Further contributing factors may include nutrient stresses limiting growth. Excessive or inadequate nutrient supply may contribute to further losses because of increased disease pressure in dense canopies and mixed fruit maturity.

Recommendations are made here for two scenarios:

Scenario 1: Potential and field yield both 150 t/ha. This is typical for most of the tomatoes grown in Hawke's Bay provided that irrigation is scheduled and applied carefully. After allowing for fruit left in the field and factory grading, *marketable yields might be up to 120 t/ha*.

Scenario 2: Field yield 120 t/ha due to water stress. Here water deficits are sufficient to reduce yield by 20% from a potential value of 150 t/ha. This is representative of most tomato crops in Poverty Bay and some in Hawke's Bay. *Marketable yields might be up to 85 t/ha.*

For both scenarios, maintenance nutrient rates have been calculated assuming 80% of the crop is removed from the field.

13.1 NUTRIENTS TO GROW THE CROP

Soil tests

Before each crop is planted soil test each paddock from 0–15 cm depth. Choose the standard soil testing suite (pH, QT P, Ca, K, Mg and Na, cation exchange capacity and soil volume weight) PLUS 'Available N' (anaerobically mineralisable N, in kg N/ha).

Nitrogen (N)

Unless soil structure is poor, tomato roots may grow beyond 70 cm depth. This makes them very effective at taking up N within the soil profile. Process tomato crops can take up large amounts of N, but the available evidence suggests this is not always best for yield.

If using solid fertiliser and the Available N value is <50 kg N/ha, apply half the recommended fertiliser N at or soon after planting, banding it near the plants (but not closer than 5 cm). Side-dress the rest before flowering; knife in the N, no closer than 10 cm from the plants. Calcium ammonium nitrate is often used, but there is no strong evidence that this is better for tomatoes than cheaper products like urea.

If applying N in the form of composts, incorporate these at least 2 weeks before to planting, preferably during bed-formation.

If fertigation is available, split the recommended N fertiliser applications from establishment through to flowering.

Key point: Ration N for tomatoes

An ample supply of N encourages leaf growth. That is important to support fruit growth. ***But too much N decreases fruit yield.*** Late in the season surplus N encourages leaf growth and prolongs flowering and setting of more young fruit. All this happens when growers want the crop to be maturing the larger, early-set fruit — but instead these may rot or fall off before the whole canopy is ready for harvest.

Available N (kg N/ha)	Recommended N application (kg N/ha) to grow the crop	
	Scenario 1: Field yield 150 t/ha	Scenario 2: Field yield 120 t/ha
30	90	70
40	70	50
50	50	20
60	30	20
70	20	nil
80	20	
100	nil	

Nitrogen and fruit quality

Excessive N fertiliser can reduce tomato paste viscosity and increase the percentage of green fruit at harvest.

Phosphorus (P)

If P fertiliser is required, apply up to 10 kg P/ha as a starter under the transplant or banded or knifed in no closer than 5 cm to the planting line. The remainder (if any) of the recommendation can be broadcast and incorporated pre-planting. For tomatoes, banding of P fertiliser is slightly more effective than broadcasting, but the total P application may be too large for banding using superphosphate or compound fertilisers with a similarly small %P.

Side-dressings of P are unlikely to be effective unless applied early in crop growth and if soil Olsen P is low (say <30 µg/mL).

	Recommended P application (kg P/ha) to grow the crop	
Soil Olsen P (µg/mL)	Scenario 1: Field yield 150 t/ha	Scenario 2: Field yield 120 t/ha
20	280	190
30	180	90
35	130	20
40	70	nil
45	20	
50	nil	

Phosphorus and fruit quality

There is little conclusive evidence linking P supply with processing tomato quality.

Potassium (K)

Tomatoes take up large amounts of K. There is good evidence that tomato yield will often respond strongly to K fertiliser.

In Hawke's Bay and Poverty Bay, QT K is often very high (>20) by national standards. Nevertheless, tomatoes will often still respond to additional K applied, as long *as it is incorporated well in advance of planting*.

Key point: Applying K fertiliser

K fertiliser is best applied as a base-dressing before raising beds. Side-dressed K will not be effective.

For applications a month or more ahead of planting, use the cheapest source of K available (usually MOP). *If applications must be made closer to planting, use SOP*.

K applications should be broadcast and incorporated to minimise the risk of plant osmotic stresses.

	Recommended K application (kg K/ha) to grow the crop	
Soil QT K	Scenario 1: Field yield 150 t/ha	Scenario 2: Field yield 120 t/ha
10	380	350
12	370	260
15	300	nil
16	250	
17	nil	

Generally these recommendations are for K rates that are much larger than usually applied overseas. This is because soils in Hawke's Bay and Poverty Bay have high concentrations of Ca and Mg, which suppress K availability for tomatoes. The above recommendations are calculated for a QT Ca of 18. If QT Ca<10, there will be almost no yield response to K applied at QT K values greater than 13 (scenario 1) or 11 (scenario 2).

Potassium and fruit quality

High QT K values K may improve fruit quality, reducing the percentage of reject fruit at harvest. However, this effect is lessened if QT Ca is high, and K fertiliser applications in the same season have little benefit in this way.

Calcium (Ca), magnesium (Mg), lime and soil pH

Soil pH values as low as 5.0 do not appear to adversely affect yields in Hawke's Bay. Even if soil pH values are close to 5, the available evidence indicates *lime should not be applied in the same growing season as tomatoes are grown.*

Applications of Ca and Mg to the soil are likely to decrease tomato yield and quality by suppressing K supply to the crop. Excessive Ca supply to the crop may reduce tomato paste viscosity.

Blossom-end rot of fruit is associated with localised Ca deficiency, but it is induced mainly by water stress rather than insufficient soil Ca. Some varieties are susceptible to internal blackening, a milder form of blossom end-rot. Foliar sprays of Ca compounds (at manufacturers' recommended rates) may help reduce the incidence of blossom-end rot while not affecting yield. The effectiveness of such sprays appears to vary between crops and seasons.

Key point: Ca, lime, and K supply

An experiment in 1998-99 examined the effect of liming on a silt loam in Hawke's Bay. One treatment was limed 30 days before planting and other was not. Both received the same N, P and K fertilisers. At planting the limed treatment had a higher pH (5.7 compared with 5.2), and slightly higher soil test values for available N, P and K. The final yield in the limed treatment was less, at 90 t/ha, than the 107 t/ha in the non-limed treatment.

Sodium (Na)

Sodium treatments are sometimes used to increase fruit dry matter percentages in glasshouse tomatoes, but this can be risky for field crops. There is no evidence that NZ soils contain insufficient Na for excellent yields of process tomatoes. Historically, growers have not applied Na except where it is a minor part of a compound fertiliser or trace element application, and for the present there is no recommendation to apply Na.

Sulphur (S)

Yield or quality responses to fertiliser S have not been observed in NZ. Soils used for process tomatoes in NZ usually contain large quantities of S already, and it is commonly applied in other fertilisers (e.g. superphosphate, SOP).

Trace elements

Experiments in Hawke's Bay found no benefits from applications of iron, boron, copper, manganese and zinc applied as solid fertilisers. Maintenance applications are tiny, and availability of these nutrients is so dependent upon pH and changes in soil water content (because of its effect on aeration) that trace element applications to the soil will usually be ineffective.

A potential exception is that during water stress boron (B) supply from the soil may be inadequate for complete pollination, and may be involved with blossom-end rot. Soil applications are unlikely to be effective. Some success has been achieved with foliar sprays of B plus Ca at manufacturers' recommended rates; however, it has proven difficult to achieve consistent control using those sprays.

Foliar nutrient sprays are best applied in the early morning or evening to extend the drying time and the opportunity for the nutrient to enter the leaves.

13.3 MAINTENANCE NUTRIENT REQUIREMENTS

Table 13-1 indicates the amounts of nutrients that may be taken up by tomatoes in NZ. Some of these values might reflect luxury uptake of some nutrients, especially K and Mg. Note the values quoted are typical — nutrient concentrations can vary between crops. Nutrients in the shoots are returned to the soil in crop residues.

Table 13-1 Typical amounts of major nutrients removed from the soil by an 83 t/ha tomato crop grown near Gisborne. Nutrients in the fruit are removed from the paddock, the rest are recycled.

	N	P	K	S	Ca	Mg
Shoots ex. fruit (kg/ha)	51	5	34	24	161	34
Fruit (kg/ha)	138	18	198	10	17	12
Total uptake (kg/ha)	189	23	232	34	178	46

Estimate maintenance requirements from the offtake in kg of each element per tonne of fruit removed from the field (Table 13-2). Except under organic growing systems, *do not apply N fertiliser for maintenance* — see Chapter 2. For a crop yielding 120 t/ha in the field, and with 80% of the fruit sent to the factory, the maintenance P application would be about 0.22 x 120 x 80/100= 26 kg P/ha.

- Maintenance applications of any particular nutrient are recommended *only if none is recommended to grow the crop.*
- For N, maintenance applications should be considered only under organic production systems using composts.
- Methods for applying maintenance P and K should follow the guidelines for nutrients to grow the crop.
- Do not apply maintenance P if soil Olsen >55.
- Do not apply maintenance C if QT K>20.

Table 13-2 Typical maintenance nutrient requirements of process tomato crops. The offtake values assume that 80% of the fruit are removed from the field.

	N	P	K	S	Ca	Mg
kg/t fruit yield	1.7	0.22	2.4	0.1	0.2	0.1
Offtakes (kg/ha)						
Scenario 1: Field yield 150 t/ha	200	26	287	15	25	17
Scenario 1: Field yield 120 t/ha	160	21	230	12	20	14

Table 13-3 Deficient and adequate nutrient concentrations for whole shoots of tomatoes. Values are given on a dry mass basis for plants with 13 leaves.

Nutrient		Deficient	Adequate
N	%	<3.0	4.0 – 6.0
P	%	<0.4	0.65 – 1.2
K	%	<3.0	4.0 – 6.0
Ca	%	<1.0	1.5 – 2.5
Mg	%	<0.3	0.4 – 0.4
B	μg/mL		40 – 100
Mn	μg/mL	<25	50 – 500
Zn	μg/mL	<20	30 – 200

13.4 PLANT ANALYSIS

Typical plant nutrient concentrations are of little use. Deficient and adequate concentration ranges for whole shoots are more useful (Table 13-3). To compare with these values, sample whole plants from 1 cm above ground when the plants have about 13 leaves. By then it may be too late to affect the nutrition of that crop, but the results may be useful for managing future crops.

Most likely deficiency symptoms

Helpful images are available from the Yara CheckIT app for mobile telephones (Yara 2017), although the accompanying descriptions are sometimes at odds with NZ experience of where such deficiencies may occur.

Nitrogen (N) and Phosphorus (P) deficiencies are rarely seen in NZ. The symptoms of N deficiency are premature yellowing and death of the lower leaves. P deficiency symptoms include stunted growth and very dark green leaves. In extreme cases there may be red colours on the leaves. It is risky to diagnose P deficiency visually because some tomato varieties have darker foliage than others, and cold stress can cause similar red colours. Applying P fertiliser is very unlikely to relieve cold stress.

Potassium (K) deficiency is hard to spot in the field. Severe symptoms include chlorotic (whitened) areas on older leaves that eventually include small dry spots with brown margins. The leaf margins may become scorched and curls (resembling drought stress). The fruit ripen unevenly and may have a blotchy appearance.

Calcium (Ca) deficiency in the whole plant is unknown in NZ, but localised deficiency in fruit is associated with blossom-end rot (blackening and withering of the fruit).

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