GROWERS' GUIDE TO NUTRIENT MANAGEMENT FOR NZ STRAWBERRIES

Overview

Strawberries can be grown in **many regions of the country** and on a **wide range of soil types**, however, **good soil drainage is essential**. Plants are typically grown in an autumn-planted annual system, where chill is acquired in situ through the winter.

Strawberries are increasingly being grown in **soilless systems** such as on raised tables in coir media, often covered to exclude rain.

Plant nutrient uptake can be estimated similarly for both systems, and there are common elements when **budgeting for nutrient efficiencies.**

Fertiliser application timing, placement and quantity could improve.
In the past, fruit growers have applied their entire nutrient application at bed formation, with the goal to front-load all the nutrients the crop will need for the whole fruiting season. Increasingly horticulture is under pressure to minimize nutrient loss to the environment, so recently there has been more emphasis on reducing over-fertilisation by understanding precisely what the plant needs, when nutrients are needed and how much is supplied by soil mineralization processes. Additionally, over-supply of nitrogen, can lead to excessive vegetation and fruit quality issues (eg soft berries that are more susceptible to botrytis). Nutrient balance is also an important influencer of flavour, particularly in soilless systems.

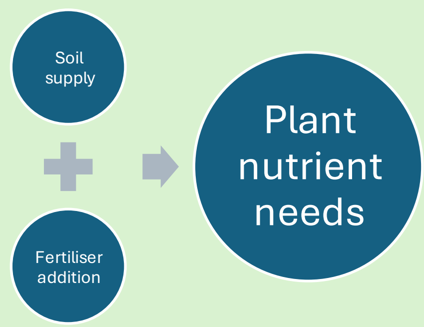
The following steps have to come before we can estimate how much fertiliser should be applied, and the timing of those applications.

1. Calculate how much nutrient is required to grow the crop.
2. Estimate how much nutrient the soil will supply (or at least what soil levels do not limit yields).

Objectives

⇒ **To show how growers can tailor publicly available information, to their individual growing systems, climates and varieties.**

⇒ **To support the nutrient budgeting required to minimise nitrogen and phosphorus losses, laying out the information and calculations required.**



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Estimating nutrient need based on potential yields

1.1 Plant density

Strawberry plant populations per hectare vary dramatically with the production system.

- In soil, plant populations are typically 60,000 plants/hectare, though this varies with the size of the plant (varietal genetics).
- In tabletops, population varies depending on whether the tabletop system is singles (70–90,000 plants/hectare), doubles, or triples (103,000 plants/hectare).

1.2 Yield per hectare

60,000 plants/ha yields (typical density in soil)	
Grams/plant	**Kg/hectare**
500	30,000
750	45,000
1000	60,000

90,000 plants/ha yields (typical density in tabletops)	
Grams/plant	**Kg/hectare**
500	45,000
750	68,000
1000	90,000
1250	112,500

Table 1. Strawberry yields per ha vary greatly depending on plant density and length of production season, as well as temperature.

1.3 Nutrient needs based on yield

We estimate that fruit contains 0.12% nitrogen, 0.02% phosphorus, and 0.16% potassium, on a fresh weight basis. This rough equation applies to fruit grown in any production system.

Further, using the proportion of the nutrient typically found in the fruit compared to the whole plant, the estimated amount of nutrient taken up in a strawberry crop at various yields can be calculated.

	Macronutrient **export** in fruit (kg/ha)					Macronutrient **uptake** in plant + fruit (kg/ha)				
Berry yield (kg/ha)	**N**	**P**	**K**	**Ca**	**Mg**	**N**	**P**	**K**	**Ca**	**Mg**
30,000	35	5	50	5	4	70	10	75	40	10
50,000	60	10	80	8	6	120	20	125	65	16
60,000	70	13	90	9	7	140	25	150	75	20
70,000	85	15	110	10	8	170	30	175	90	22
90,000	110	20	140	15	10	220	35	225	115	28

Table 2. Nutrients taken up by plant and fruit at various yields, on a fresh weight basis. Accumulation of Nutrients by Strawberry Plants and Fruit Grown in Annual Hill Culture, Albreghts and Howard, 1980 (numbers are rounded).

The focus here is on macronutrients, but of course plants require 'micronutrients' as well, just in smaller quantities. The most common micronutrient deficiencies seen are Boron and Iron, where limitations usually relate to soil pH, growing conditions and root health rather than to an actual nutrient deficiency in the soil.

Growing in soil

Plants acquire the nutrients they need largely from the soil by root uptake, from an exchangeable pool of nutrients already in the soil and from fertiliser applications. It is particularly important to quantify available nutrients in the soil and to quantify plant requirements for nitrogen and phosphorus, the nutrients where excess applications cause environmental problems.

2.1 Measure nutrients in the soil

Take a soil test prior to deciding on nutrient applications, and including "potentially mineralisable nitrogen". See "Measuring nitrogen in soil".

First, check the soil pH (a measure of soil acidity). The pH should be 5.5–6.5 for soil grown strawberries. If this is out of bounds the nutrient needs of the plants can't be fixed by simply adding fertiliser, as some plant nutrients become less plant available forms at extreme soil pHs.

Refer to 'Nutrient Management for Vegetable Crops in NZ' for guidance on increasing soil pH with lime, dolomite or other alkaline products.

How to take a soil test

Sample as deeply as you will be scraping to form the beds (typically 15 cm). Soil nutrients are naturally variable; use at least 20 soil cores per block to get a reasonable average.

Soil test levels of Phosphorus, Potassium, Magnesium, Calcium

Soil nutrient test results display the level of nutrient estimated to be available to crop roots at the time of sampling. 'Medium ranges' are shown for these nutrients, where Medium in this case means 'Sufficient'.

If a soil test number is considered 'low', 'medium' or 'high' depends on soil type and its soil bulk density.

If a soil nutrient result falls into this range:	Nutrient additions required:
Low	raise soil levels *plus* meet the crop uptake
Medium (sufficient)	meet crop uptake (see table 2)
High (excess)	no additions required to grow crop

Table 3. Explanation of low, medium and high soil test values.

If soil test levels are in the sufficient (medium) range, applications are required only to replace what the crop takes off (fruit removal).

If the soil test value is below the medium range, applications are calculated to bring the soil test level up to the "sufficient" range as well as replace what the crop removes.

If the soil test levels are in the "high" range, the soil will likely supply more than the crop needs throughout the season without any fertiliser additions. There is "money in the bank," so to speak.

Soil values near the thresholds of the ranges: Soil sampling is an attempt to characterize a naturally variable soil by one number, fairly. Although the lab reports soil levels with decimals, in actual fact the true average soil level for a block varies above and below the lab reported value, mostly due to the naturally variable soil medium. If a test level is very near the edge of the "sufficiency range," the resulting recommendation will be guided by the grower's attitude to risk.

Phosphorus in soil

The ‘Olsen P’ test estimates the *plant-available* Phosphorus. The soil itself contains much more total phosphorus than root plants can access; the fraction represented by the Olsen P test is the bit that roots can actually take up and that is most relevant to fertiliser planning.

Fields where strawberries have been grown for many years tend to be extremely high in Phosphorus because of past applications, and the fact that strawberry fruit exports remarkably little phosphorus.

A 50 tonne/ha crop only exports 10 kg of P in the berries. The plant body required to grow those berries would take up another 10 kg of P, which is returned to the soil at the end of the season when the plant is tilled in. See table 2.

Phosphorus is usually not lost unless topsoil itself is eroded, so historic applications that were above crop needs accumulate to extremely high Olsen P levels. With the price of fertiliser P, agricultural advisors have been known to joke that old vegetable and berry blocks could be profitably turned into Phosphorus mines.

If Olsen P is above 30, it is unlikely that putting more P on will translate into better crop growth or yields, and extra fertiliser P is not required. At an Olsen P of 30, only the phosphorus that will leave the field in harvested fruit should be replaced. At lower soil test levels, growers may want to raise the soil levels of P, but the feasibility of doing this varies with soil type, namely on how fast the minerals in the soil bind up the phosphorus making it unavailable to plants. Volcanic (allophanic) soils bind up P quickly so require more P to raise soil test levels compared to sedimentary soils. For these soils, smaller, more frequent applications of P, are more practical.

Growers are often in the habit of applying more phosphorus than necessary. The following chart can help put the soil supply of phosphorus into perspective.

Soil test level (Olsen P)	Plant available P in top 15 cm of soil*	P removed by 50 tonne strawberry fruit	Years of P supply on hand
30	45 kg	10 kg	4 years
60	90 kg	10 kg	9 years

*calculation assumes soil bulk density of 1.0 g/ml

Table 4. Soil supply of phosphorus in relation to strawberry crop removal and soil test levels.

Potassium in soil

Strawberries take up more potassium than nitrogen, particularly in the fruit (See table 2). Potassium is not an environmental pollution risk like N and P. The main reason to avoid overapplication of K is to avoid reducing Mg and Ca availability, which can induce a Ca or Mg deficiency.

Straw which is used to mulch between rows contains significant K, and if strawberries are grown in the same plot of ground year after year, this residue K is added to the soil each year.

2.2 Raising nutrient levels

Charts that estimate how many kg of P and K are required to raise soil test levels by soil type do exist (see Nutrient Management for Vegetable Crops in NZ). The challenge is that within the soil types the ranges of nutrient required to raise a soil test level are quite wide, and the ranges between soil types overlap.

Because of the considerations above, we consider that the "guess and check" method is a more practical approach to raising soil nutrient levels.

Many soils require approximately 70 kgK/ha to raise the soil test K by one MAF unit. When the goal is to raise soil test levels quite a bit, it is wise to split applications when the requirement is high.

To raise LOW soil test levels:

Nutrient	**Additions to raise soil test levels**
Phosphorus	Preferably apply no more than 45 –50kg of P (e.g. 500–600kg of superphosphate) at a time, followed up with no more than 20–25kg of P later that same season.
Potassium	Preferably apply no more than 70–80 kg of K at a time (e.g. 180–200 kg of potassium sulphate), followed up with no more than 50 kg of K later that same season. Do not use KCl, as strawberries are susceptible to chloride toxicity.

Table 5. Strategy for K and P applications when indicated by soil testing.

Retesting the soil a year following a fertiliser application is recommended to confirm the change in soil, and inform the next application requirements if nutrient levels are still low.

Notes on K applications:

- *Sometimes advisors experienced with soil responses in local regions can predict how much P or K will be required to shift soil levels up with greater accuracy.*
- *Generally speaking, sandy soils with low CEC require small applications of K applied often, to fulfil plant requirements, because they lose K in leaching. For some peat soils, it is very difficult to increase the soil K levels, even with high rates of K. In these soils, it makes more sense to apply some base K and then focus on providing further K through fertigation at the rate the plant requires than to try and bring up the plant-available soil K levels.*
- *Nutrient Guidelines for Vegetable Crops in NZ has a good discussion about the pros and cons of different sources of elemental nutrients.*

Putting it into context: Relating soil test levels to kg/ha nutrient availability

This chart relates soil test levels and nutrient sufficiency ranges to kg of that nutrient available in the top 15 cm of a soil (with an assumed density of 1 g/ml). Comparing the available nutrient per hectare to the amount taken up by the strawberry plant (including fruit) over the season can give growers more confidence in the sufficiency levels. See table 2 for crop uptakes.

	Kg/ha nutrient available to sample depth (usually 15 cm)		
Soil test level (MAF unit)	K	Ca	Mg
5	68	426	17
10	136	852	34
15	204	1278	51
20	272		68
25	340		85
Plant uptake in 60 tonne crop	**150**	**87**	**19**

Table 6. Relating soil test levels to kg/ha nutrient availability.

Soils tend to have large reserves of Ca and Mg. When deficiencies are seen in plants, they usually relate to uptake problems – soil pH, root health or occasionally, excess of one cation (K, Ca, Mg, Na) competing for uptake with others.

Measuring Nitrogen in soil

Nitrogen in the soil cycles rapidly between the plants and soil microorganisms. The speed of cycling depends on temperature and moisture, while the total amount of N cycling is strongly related to the soil's organic matter content.

There are two main ways to measure N in the soil.

1. **Estimating the season-long N release:** The Hot Water Extractable Nitrogen (HWEN) test uses a lab assay where soil is incubated at ideal conditions for microbes to break down organic matter and release nitrogen. It has superseded the older Anaerobically Mineralizable Nitrogen Test in terms of reproducibility and speed of analysis. The HWEN test can give users a sense of whether the soil will supply "a lot" or "a little" N over the season, so can inform how much fertiliser N a grower will need to make up the shortfall over the season.

2. **Estimating nitrogen availability on the day:** The "Pre-sidedress Nitrogen test" measures nitrate (the dominant form of N) in the soil. The measure is a "snapshot" in time, used for short term decision making around when N fertiliser is required. Soil nitrate concentrations can change rapidly, with more N being released from soil organic matter and losses due to plant uptake or leaching. This test can let growers know whether it's time to start giving N through fertigation or if the N levels are excessive and extra fertilization would be unhelpful.

Below is an example of a Hot-water extractable soil N results:

HWEN lab result (mg N/kg soil)	Conservative estimate of in-season nitrogen supply (kg N/ha)	Interpretation
25–50	15–25	Typical long term strawberry block (low N supply)
200	100	Typical first year after perennial pasture (high N supply)

Table 7. The full calculations that relate NWEN to kg of N available during the growing season require an estimate of soil bulk density, a factor for the relevant soil depth, and a correction for the fact that field conditions are not always ideal for N mineralization. Given the number of unknown variables, the figures above are given for frame of reference only.

In practice, the HWEN is useful background to understand the magnitude of N supply from the soil in comparison to the total N required to grow a strawberry plant. The in-season N measures such as soil nitrate testing and leaf testing are more useful for making fertiliser adjustments during the growing season.

How to do a pre-sidedness Nitrogen Test

*The level of **nitrate** in the plant root zone can be checked frequently (fortnightly or more often) in season, to steer liquid fertiliser applications.*

Sample Collection: Sample the block systematically, in a pattern representative of the whole block (X, W, etc). It's critical to take 20+ soil cores from the block, to a standard depth (15 or 30 cm), and at a standard distance from the drip tape.

***Lab Test Option**: A soil sample can be sent to the lab to test a snapshot of available nitrate, but these samples must be kept cool and delivered to the lab on ice, making it difficult to obtain reliable results.*

***On Farm Soil Nitrate Quick Test Kit Option**: Mix the soil cores for the block well. Fill the test tube with 30 ml of $CaCl_2$ solution, then add enough of the mixed soil to bring the liquid level up to 40 ml. Shake well, then let settle until the liquid on top is clear; this can be a couple hours with fine textured soils. Dip the test strip into the clear solution. Read against the colour scale after 60 seconds. Record the estimated soil nitrate level, making sure to read the NO_3^- scale (top scale that goes 1, 10, 25, 50, 100 etc).*

The simplest way to interpret the Quick N test results is to take the **California approach**, where the general guideline is that if the soil nitrate test shows less than 50 ppm NO3 (<11ppm NO3–N), plants will respond to nitrogen fertigation.

To translate the concentration of nitrate in the solution to the amount of elemental nitrogen currently available for crop uptake, use the following equation:

$$\frac{\text{NO3 (mg/L)}}{\text{Soil moisture correction}} \times \frac{\text{Soil depth (cm)}}{10} \times \text{Bulk Density (g/cm3)} = \text{N (kg/ha)}$$

Soil Correction Table

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

Table from FAR's Nitrate Quick Test Mass Balance Tool

Table 8. FAR's nitrate quick test mass balance tool.

Below is an example where the Quick N soil test showed 25mgNO3/L, in a moist sandy loam soil:

$$\frac{25\ \text{mg}\ NO_3/L \times 15\text{cm} \times 1\ g/cm^3}{1.8 \times 10} = 20.8\ \text{kg N/ha}$$

In this example, on the day the test was performed, about 20 kg of N per hectare in nitrate form was available for root uptake in the top 15 cm of soil.

The question of whether this 20kg/ha of nitrogen depends on the speed of plant growth (see figure 1). It is probably sufficient for winter when light levels and temperatures limit plant growth. However, if this was summer, plants would soon be running short when plant uptake reaches 1 kg/ha per day.

2.3 Estimate fertiliser need

Once you estimate your crop uptake, both in fruit and plant body (see table 2), and you have estimated the levels of N, P and K that your soil has with a soil test, you can work out how much fertiliser is required to make up any shortfalls.

First, optimistically estimate your yield so you can choose appropriate nutrient uptake requirements from table 2. Here an example is supplied at a 60 tonne/ha yield (1000g/plant for an in-soil planting, and 700g/plant in tabletop). See tables 2 and 6.

Example 1: Minimum nutrient requirements for growing a strawberry crop after considering soil supplies

Soil test results		Crop uptake (kg/ha)	– Soil supply calculated from soil test	= Need
NWEN = 50 mg/kg	**N (kg/ha)**	140	25	115 kg N
30 (Olsen P)	**P (kg/ha)**	25	45	0 kg P
5 (MAF units)	**K (kg/ha)**	150	68	82 kg K

Table 9. Starting with soil test levels of N, P and K, then moving on to expected crop uptake, the table above calculates the fertiliser additions that would theoretically be necessary to grow a 60 tonne strawberry crop. pH is assumed to be in the fine range.

In Example 1, no phosphorous is needed. Soil levels are high due to historical P applications exceeding crop needs. Choosing a fertiliser without P but which supplies K and N is appropriate.

For many growers, this level of N input will look very small. Our farming systems aren't fully described by these simple equations, as we aren't operating in a closed system – nutrient losses do happen. Our job is to understand what the plants actually need and when they need it, so we can make better decisions to minimize the losses.

Table 9 gives a starting point for fertiliser planning. The next steps involve optimizing fertiliser placement and timing, and strategies for adjusting the fertiliser in response to growing conditions in-season when necessary.

For frame of reference, table 10 shows the nutrients contained in 'Mila Complex,' a commonly used fertilizer in strawberry production. Notice the high levels of P compared to plant removal (table 2). This is why our strawberry soils have such high Olsen P readings.

Nutrients delivered with various rates of Mila Complex.

kg/ha Mila Complex	N	P	K	Mg	S
100	12	5	15	1.6	8
500	60	25	75	8	40
1500	180	75	300	24	120

Table 10. Nutrients delivered at various per hectare rates of Mila Complex, fertiliser commonly used in horticulture. Micronutrients are also supplied.

2.4 Timing of nutrient application

The goal of a grower fertilization program is to provide all the nutrients a crop needs to perform optimally, while losing as little as possible to the environment.

Phosphorus

Where P addition is required to grow the crop (Olsen P <30), broadcast apply and incorporate the P before bed formation. P at these soil levels is not a leaching hazard, and what is incorporated will still be there for plant uptake. Granular P is cheaper than liquid P used in fertigation. At low P levels always supply some P in a starter fertiliser.

An exception to this generalization is the "allophanic" soils, often derived from volcanic ash, with a mineral structure rapidly binds up P. In these cases, it would make more sense to put only a small amount of P on before bed formation, and meet ongoing plant demand through fertigation, starting with the rapid growth period in spring.

Potassium

Potassium can leach in light soils, but it isn't an environmental concern like nitrogen or phosphorus. In most cases, where soil tests indicate a need, it is cheapest to apply potassium in granular form before bed formation. Exceptions are very sandy soils where K can be easily lost by leaching and some peat soils where it is very difficult to increase the soil test values of available K despite high rates of application. In these cases, it makes more sense to supply some K to meet ongoing plant demand through fertigation.

Do not use potassium chloride, as strawberries are sensitive to the chlorine component of potassium chloride. Potassium sulphate or potassium nitrate are the preferred sources of potassium.

Nitrogen

Nitrogen is the principal concern for leaching below the plant root zone, where it will eventually reach ground water. Nitrogen leaching loss occurs when there is extra nitrate ($-NO_3$) dissolved in the soil solution, then excess water to cause drainage movement below the root zone.

Strawberries take up very little nitrogen after planting and through the winter months when plant growth is very slow. Estimates from California in similar production systems show that nitrogen uptake is only around 22kg/ha from planting in April, until September. When active growth starts in the spring, strawberries will take up 6–7 kg of nitrogen/week (figure 1).

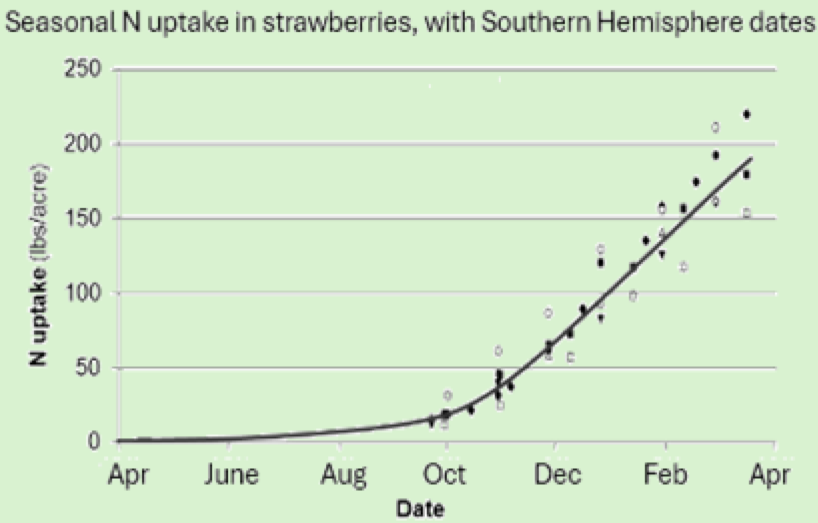

Figure 1. Extract from California Crop Fertilisation Strawberry Nitrogen Uptake and Partitioning.

Best practice for soil application is to only apply Nitrogen at a rate which meets the plant needs for establishment over the winter. Winter carries risk of nitrate leaching due to more saturated soils, lower evapotranspiration and frequent rain, though the plastic mulch somewhat protects nutrients from leaching during rain.

Fertigation though drip tape installed under the plastic mulch can then deliver the rest of the nitrogen as the plant requires it, starting in spring, and this can be adjusted based on **soil nitrate testing** and **leaf testing**. Care must be taken as over-irrigation can move nutrients out of reach below the root zone.

Fertigation: Once spring begins and plants start to grow rapidly, both N and K will be needed to match increased uptake. See table 2 for an estimate of nutrient uptake based on season-long expected yields, and adjust based on expected soil supply (table 5).

Some growers choose to meet crop need with a soluble "complete" fertiliser containing both NPK and micronutrients in the required N:K ratio such as the 'Kristalon' series from Yara. These "one bag brews" do not contain Ca, so are often fed alternatively with calcium nitrate. Other growers use a mixture of Calcium nitrate and Potassium nitrate. Liquid feed formulas are discussed in "Growing in media", and nutrient ratios used by strawberries are pictured in figure 5.

As a general guideline, a "trigger point" for fertiliser application is a soil nitrate test showing less than 50 ppm NO_3^- (< 11 ppm elemental Nitrogen in nitrate form) in the root zone (*California Crop Fertilization Guidelines, Strawberry Nitrogen Uptake and Partitioning*).

3. Checking nutrients with leaf test

Leaf tissue tests are the best way to check that the plant has all the nutrient it needs. Remember to review leaf test levels in relation to plant health – if roots are suffering from drought, or conversely are excessively wet, leading to issues such as *Phytophthora*, then leaf testing may report low nutrient levels even though nutrients in the soil are adequate.

Leaf testing is also a way to check plant nitrogen status, though results can be tricky to interpret because sometimes a rapidly growing plant has low leaf nitrogen levels (expressed as percent of dry matter). This is because during quick growth the leaf N can become diluted, though not limited by lack of N. Always interpret with the recent growth pattern and root health in mind, with the soil test also in hand, and through the lens of how the plants in the block look.

The sufficiency levels for leaf nutrients vary a little between sources, but not greatly. As in soil tests, the "medium" levels are the target, rather than "high."

As with the soil testing, a fair sampling procedure is essential, and Hill Lab's leaf test instructions are below. The term "youngest mature leaf" means the youngest leaf that has fully opened.

Blade	
Sampling Time:	During fruiting, preferably at first harvest.
Plant Part	Leaf blades (excluding petioles).
Collect From:	Youngest mature leaves.
Quantity per Sample:	30-50.
Recommended Tests:	Basic Plant (BP), Molybdenum (Mo), Chloride (Cl)

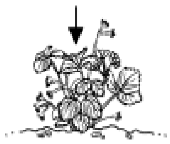

Figure 2. Leaf sampling instructions from Hill Labs.

An example of a leaf nutrient test result is below:

Sample Name: Leaf Sample **Lab Number:** 2773821.
Sample Type: BLADE Strawberry (P41)

Analysis		Level Found	Medium Range
Nitrogen	%	2.9	2.6 - 3.5
Phosphorus	%	0.33	0.25 - 0.35
Potassium	%	2.0	1.0 - 2.0
Sulphur	%	0.19	0.15 - 0.35
Calcium	%	1.09	0.70 - 1.50
Magnesium	%	0.29	0.25 - 0.40
Sodium	%	0.006	0.020 - 0.100
Iron	mg/kg	90	100 - 200
Manganese	mg/kg	210	200 - 500
Zinc	mg/kg	41	30 - 80
Copper	mg/kg	6	5 - 12
Boron	mg/kg	128	30 - 100

Figure 3. Example of a leaf nutrient test result from Hill Labs.

This test result shows the main nutrients to be in the sufficient range. Iron is a little low, which may indicate that the soil or media pH is too high. It is important to interrupt the leaf test in relation to the soil or media test.

It is important to not overreact to micronutrient levels that are slightly out of the medium range, when plant growth is still good. Micronutrients are required in very small quantities, and are often soil type specific, unless soil pH is restricting *availability* or root health is restricting uptake It's easy to overdo micronutrient applications; so proceed with caution.

"Sufficiency levels" have been determined by measuring leaf levels in high yielding blocks. The ranges are wide, and in many cases it is unclear whether lower than "medium" levels restrict yield. For visual deficiency (or toxicity) symptoms to occur, nutrient levels have to be in the deficient or toxic range.

Target levels of nutrients can change as the crop goes from vegetative to fruiting. California's strawberry leaf nutrient guidelines reflect this:

Sampling stage	Nutrient concentration (%)		
	N	P	K
Pre-harvest	3.1-3.8	0.5-0.9	1.8-2.2
Main harvest	2.4-3.0	0.3-0.4	1.3-1.8

Figure 4. Leaf nutrient sufficiency levels from California Crop Fertilization Guidelines, Strawberry

4. Growing in media

Growing strawberries in media is different in many important ways from growing in field soil. This manual does not aim to repeat the excellent primer information given in other sources, but builds on how growers can adjust the basic practices to optimize their own individual growing systems.

The main functions of the media are to have high water holding capacity as well as good drainage to maintain air spaces to ensure oxygen is available in the root zone.

More attention is paid to micronutrients with media-grown plants than when growing plants in field soil, because unlike field soil, none are supplied by the media and their availability can change rapidly with pH changes.

Fertigation
For strawberries grown in media, the aim is to provide nutrients via liquid feeding at the same rate that the plant uses nutrients and water from the media. The challenge is to maintain an appropriate media electroconductivity (EC) and keep the pH in bounds, while providing "just in time" nutrition to the plants at various growth stages. It is very much a moving target.

A typical nutrient feed recipe for strawberry can be found in multiple manuals, such as "Principles of Strawberry Nutrition in Soilless Substrates, or "Nutrient Solutions for Greenhouse Crops." These manuals offer good primers on media growing, including media quality, water quality testing and adjustments. Don't underestimate the importance of these considerations. These subjects are outside of the scope of this document, but are important for media strawberry growers to understand.

Water and mineral nutrients are linked
When growing in media, the watering regime and the nutrient delivery are inextricably linked, and must be managed together.

The skill is in the constant adjustment
Plants vary in growth rates and therefore nutrient demand according to plant size, light energy available for photosynthesis, and temperature. This means that nutrient inputs must be varied constantly according to changing plant growth stage, season, and daily weather. A major skill in growing is to read the plant and use the available tools to make these constant adjustments.

Nutrients supplied by media

Coir media, which we often use for strawberry production, is assumed to be relatively inert and not a source of N, P or K. Peat is considered similarly inert, but some sources provide small amounts of N and P.

Coir is often purchased "rinsed and buffered" which means potential sodium contamination has been rinsed out and replaced with other plant-nutrient elements such as potassium. When wetting coir media, growers will often add a dilute solution of their fertigation mix to the water, so upon planting there are some plant nutrients in the root zone (the amounts proportional to the ElectroConductivity, or EC). However, the media is not considered to be a reservoir of plant nutrients other than what is measured in the irrigation solution EC.

If using peat or composted bark (often 'CAN fines') in the media, some nutrient could be supplied. A pour-through EC test can indicate whether the media contains available nutrients or not, but a lab test will be needed to determine which nutrients are currently available. Most of the time the nutrients contributed by the media are small.

4.1 Water management

The main goal of careful water management is to grow a strong root system. Growers should look at the plant roots, frequently. The goal is that white active roots fill the whole soil volume.

Media made from coir and/or peat have a high water holding capacity per unit of media volume. At the same time, the media texture allows for good drainage, which enables oxygen to reach the root zone. Still, plant roots benefit from allowing the media to dry somewhat between waterings, which stimulates root growth as the plant searches for water. As the greenhouse mantra goes, "Fish grow in Water, ROOTS grow in Air." Active roots grow where plants are taking up water and nutrients, and oxygen is present.

Figure 5. Check roots to make sure they are active (white with lots of root hairs) and to assess if watering is even. Here there is a dry spot on the left.

The challenge is that "dry" and "wet" are subjective terms, and hard to communicate in a reproduceable strategy to growers and staff. We therefore try to use measures of these subjective terms.

Wetness of media is often measured as "volumetric water content (VWC)," or the volume of water held in the total volume of media. VWC is expressed as a percentage, with water content as the numerator and total container volume (filled with media, air and water) as the denominator.

When a media has been watered heavily and allowed to drain until the drips have stopped, the water content is referred to as "container capacity."

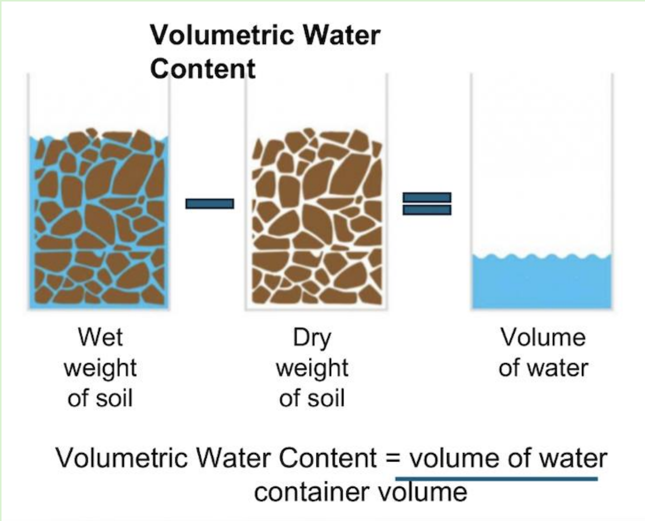

Figure 6. Concept of how volumetric soil water content is determined.

There are several methods to measure water content of crops grown in media.

Volume of water held in the media

1. **Weight:** Weight of media can be related to "volumetric water content," because as media dries it becomes lighter. Conveniently, 1 litre of water weights 1 kg. This can be measured initially by measuring the change in weight of the plant production container from pre-wetting (such as dry compressed coir slab) to fully wetted to container capacity. During the growing season, container weight correlates well with media moisture.

2. **Soil probes:** Moisture meters (di-electric types) estimate volumetric water content based on increased ability of the soil to hold a charge when it's wet. Readings are often expressed as VWC (a percentage). The number is only relative; the grower must determine what reading indicates "container capacity" and at what point to water.

3. **Volume of irrigation required to reach field capacity:** The volume of irrigation required to reach container capacity is the amount of water that can be added before water starts to drain from the bottom of the container. Measuring the water input before drain occurs can inform growers of how dry the media became prior to watering, provided that the media absorbs water evenly. It is a retrospective measure, but simple and helpful in adjusting watering strategies going forward.

All these methods still require a calibration step where the grower establishes *how dry* is desirable.

The upper limit is full media water capacity, where the media has been watered thoroughly and excess water has been allowed to drain by gravity. This weight or measurement represents the maximum water the media can hold. The maximum changes slightly over the growing season, as the media texture changes (settles, roots take up space, hard-to-wet pores get saturated or vice versa, etc).

A mild stress point is when the media dries out enough that the plant has to work to take up water. Mild stress is beneficial because it induces the plant to grow more roots in search of water, and to grow a thicker cuticle and stronger leaves, which in turn makes it more resilient to future stress. It takes great skill as a grower to obtain the benefits of mild stress while avoiding the damage of more severe moisture stress.

The lower limit is the "permanent wilting point," which represents the place where roots can no longer extract water from the media to meet transpiration needs, even during the night when the transpiration rate decreases. There is still moisture in the media, but it is held too tightly to soil particles to be accessible to plant roots.

A commonly accepted metric (also used in field crops) is to keep media moisture fluctuating between full capacity and **half way** to the wilting point, whether that is being measured by container weight or a reading from a moisture meter. This is known as the dry down target.

The dry down target is less dry for newly planted crops/seeds, and also varies according to crop growth stage and how "generatively" or "vegetatively" the grower wants to drive the plant growth. Wetter media encourages increased runner production, while allowing roots to dry favours flower initiation.

Figure 7. Left: free water between figures: no irrigation needed. Right: upon squeezing, no free water appears between fingers. An irrigation decision depends on the circumstances (time of day, upcoming weather).

When using soil probes, calibration is required to determine the weight or meter reading at full capacity, and at the wilting point, and the point at which to irrigate (figure 8).

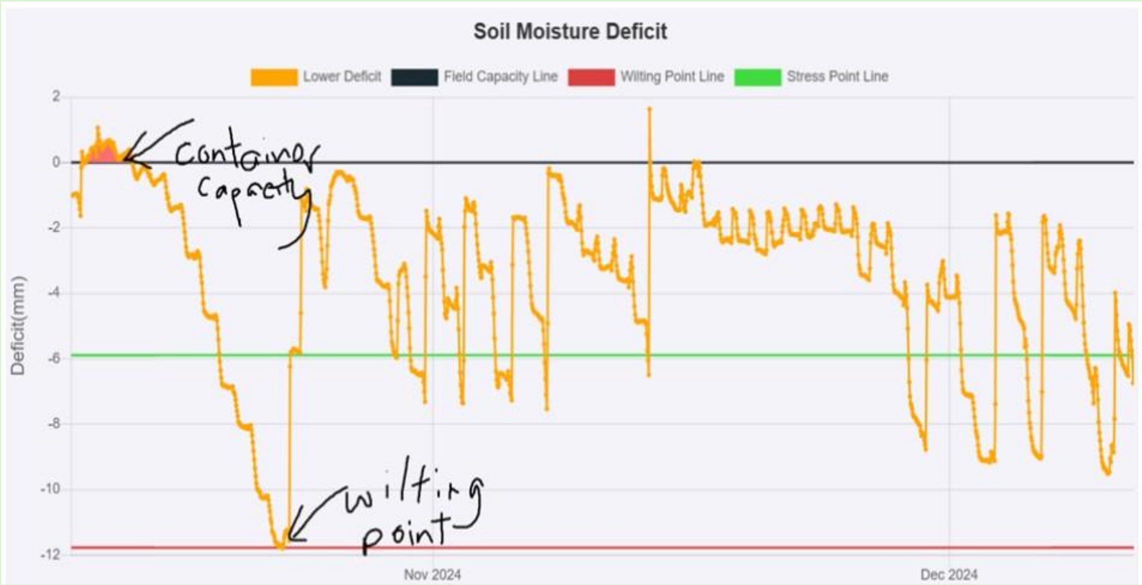

Figure 8. The graph above shows fluctuating soil moisture in a strawberry tabletop system, where the green line represents the dry down target at half way between container capacity (black line) and wilting point (red line).

4.2 Nutrient balance

There are certain ratios between the major nutrients that are desirable for growing strawberries. These ratios change slightly from vegetative growth to the fruiting time period (see figure 4).

A typical strawberry feed recipe from "Nutrient Solutions for Greenhouse Crops" is provided as an example in figure 11. Note that some elements are not required as plant nutrients, but as they can be contaminants in media and nutrient brews, their levels are listed as maximum allowed.

Nutrient ratios can be achieved using a one-bag-blend (such as the "Kristalon" series from Yara, which typically does not contain calcium), or a custom blend of individual nutrients. Some understanding of chemistry and a bit of maths is required to construct your own blend. This is described in detail in the manual "Nutrient Solutions for Greenhouse Crops."

Fruit flavour and quality can be impacted dramatically by nutrient balance (particularly K and Ca levels).

Nutrient recipes are a starting point only. They need to varied according to the minerals already in the nutrient solution, the needs of the varieties being grown, and the seasonal conditions. Adjustments to the base recipe can be made using leaf tests to assess deficiencies (and some excesses). See "Checking plant nutrients with a leaf test."

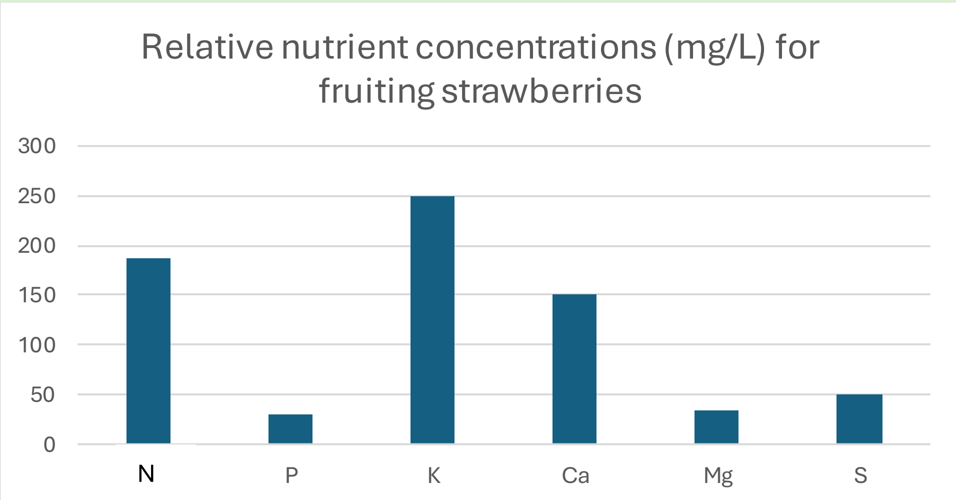

Figure 9. The chart above shows the relative concentrations of macronutrients required to support fruiting strawberries (Nutrient Solutions for Greenhouse Crops).

Drain Testing

Another method to check that the nutrient supply is meeting the plant demand is to look at what is coming through in the drain water. If individual nutrients are present at higher proportion in the drain than the feed, it indicates that the plants did not take them up. Provided that the plants have a healthy root system, excess of a certain nutrient in the drain indicates that it was supplied in excess of what the plant needed.

Example liquid nutrient recipe for fruiting strawberries

Broad parameters		
pH	5.3 (in feed)	5.8 measured in media
EC	1.6 (mS/cm)	
Plant nutrients		
	Feed solution (mg/L)	***Adjustments at fruiting***
N as NH_4	10 (mg/L)	Reduce to 3
N as NO_3	165 (mg/L)	Increase to 185
P	30 (mg/L)	
K	175 (mg/L)	Increase to 250
Ca	150 (mg/L)	
Mg	35 (mg/L)	
S	50 (mg/L)	
Micronutrients (mg/1000L)		
Fe	1680	
Mn	550	
Zn	450	
B	110	
Cu	50	
Mo	50	
Non-nutrient ions		
Na	<45 (mg/L)	
Cl	<70 (mg/L)	
HCO_3	<120(mg/L)	(alkalinity)

Table 11. Nutrient solution recipe for strawberries, from "Nutrient Solutions for Greenhouse Crops".

4.3 Concentration of nutrient

In soilless culture, EC measures the total nutrient concentration or total salts in the solution. EC is a gross measure of total concentration of ions, but does not indicate which specific ions are present and in what proportion. However, with a known nutrient recipe, it's a useful shorthand to assess liquid feed strength and drain nutrient concentration, to indicate whether plants are using more or less total nutrient than is being supplied in the feed.

In practice, growers often use drain water nutrient testing to extrapolate what is present in the strawberry root zone. The drain EC is similar in concept to the "pour-through" EC test used in container plant production.

During the winter, plants are growing very slowly and fertigation is infrequent, so media EC and pH change slowly. During the active growing season there can be rapid changes up and down from optimal levels (optimal ranges are EC 1.0–1.8 and pH 5.5–5.8) in the media. Frequent monitoring is required.

Three measurements are important:

1. The EC being delivered to the plants from the fertigation system (to check the fertigation solution is delivering your target EC).
2. The EC of the media, typically accomplished with a meter installed in the bag, or a media "squeeze test."
3. The EC/pH draining from the root zone.

The *trends* up or down are significant.

Figure 10. Checking fertiliser concentration supplied by the dripper (left), and drain water being collected for measurement at row end.

Adjust fertigation in hot weather. Plants use water for cooling (like sweating in humans), but unlike humans their transpiration removes just water and no salts. The consequence is that when weather is hot, sunny and windy, plants need more water for transpirational cooling, since fertigation to meet high crop water needs, delivers nutrients as well. Extra salts tend to accumulate in the media and cause root damage. Unlike some crops such as tomatoes, strawberries are intolerant of high salts in the root zone. Growers can counter this by reducing the EC of feeds during the hot parts of the day, or interspersing clear water with the fertigation.

Monitor the drain EC to adjust the EC being delivered. **If plants are being fed EC 1.6**:

Drain EC	Action required
1.5	Increase EC input slightly (by 0.2) and recheck
1.8	It's normal for drain to be 0.2 EC units above the input
2.0	Reduce EC in by 0.2 and recheck
2.5	Give some clear water and recheck

Table 12. Managing EC levels in uncovered systems.

It can be particularly challenging to manage the EC in uncovered systems that are receiving rain. Growers may choose to run a higher EC and a lower water content before a rain event, anticipating the dilution effect that will be coming.

4.4 Nutrients contained in the drain water

In a season-long nutrient budget, the total nutrient input is easily calculated from the weight and analysis of the fertilisers that were used. The plant nutrient uptake can be estimated by the same yield calculation method as in field soils (table 2). This allows the grower to anticipate how much N and P will be in the season-long drain, and plan appropriately for that collection and management. Table 13 shows an example of a tabletop nutrient budget where the drain contains significant N and P.

The ultimate goal of a soilless system is to capture and recycle all nutrients contained in the drain water. The drain water can carry with it pathogen spores, so this typically involves filtering and/or sterilizing the water before it cycles back to the crop. The capital costs of installing effective filtering or sanitising systems for reusing liquid feed drain water may be justified larger scale operations, but may not be affordable for small operators. For these growers, capturing the nutrient water and using on another crop (even pasture) can often be more practical.

If spreading nutrient water to pasture, the approach is similar to effluent capture and storage systems. Storage is a must, to avoid spreading to land when the soils are saturated or plant growth is too slow to take up the nutrient. Estimating the nutrient quantity is also a must, so that application can be matched to plant needs, even in the pastural system.

Example of a tabletop nutrient budget

	Plant	Fruit	Total uptake	Fertiliser input	Drain contents
N kg/ha	130	130	260	485	225
P kg/ha	20	20	40	75	35

Table 13. Estimated nutrient budget for tabletop strawberry production on a per hectare basis, with 6500m of tabletops and yield of 100 tonne/ha.

Drain water is not produced at a constant rate during the year. Table 14 shows an example of one farm's estimate of drain water produced each month, and the nutrients it contains.

Making assumptions about the percentage of irrigation that goes to drain is not accurate enough to predict nutrients in the season-long drain water. Measurement is required. Plan on measuring the drain volume and EC, and periodically, the total nutrient breakdown (lab test) for a season, to come up with your own numbers. A simple system with a container with volume markings and a lid (to prevent evaporation) can be used at a single row end to make drain measurements.

Example of a drain schedule showing nutrient content and volume per month			
month	drain (L)	N (kg)	P (kg)
May	5500	1	0
Jun	5500	1	0
Jul	5000	1	0
Aug	29000	6	0
Sep	70000	14	1
Oct	75000	15	1
Nov	13000	24	2
Dec	14000	30	4
Jan	14000	28	4
Feb	14000	50	7
Mar	75000	29	4
Total	**320000**	**200**	**23**

Table 14. Drain figures for 1ha of tabletops under cover in Auckland region. For this farm, the vast majority of the drain is created in the summer months, when fertigation rates are highest.

Nutrient water can only be applied to land (such as pasture) when soils are not saturated and crops are growing and can take up nutrients. Figure 11 shows when soils are likely to be saturated in Auckland, based on average rainfalls and evapotranspiration. Refer to Greenhouse Nutrient Solution Discharge.

Roughly speaking, nutrient water can be applied during the spring and summer months when pastures would require irrigation, but should be stored during the winter months when soils are saturated.

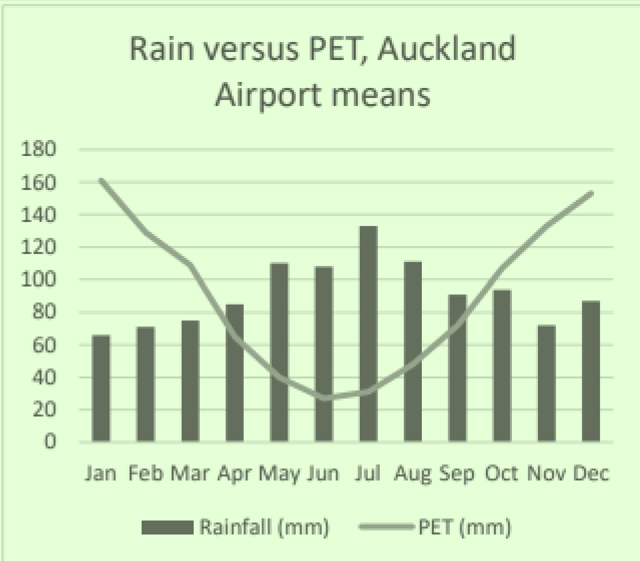

Figure 11. When rainfall exceeds evapotranspiration, nutrient water cannot be spread to pasture and must be stored. According to this graph, from October to April irrigation run-off would need to be stored.

NIWA's regional climate summaries contain average rainfall and evapotranspiration figures that growers can use to create their own graph showing when the soils are likely too wet to spread liquid nutrients. Such generalized climate summaries can help to plan the likely storage requirement, noting which months have historically higher rainfall than evapotranspiration. However, this clearly varies year-to-year and the moisture status of the soils receiving the stored drain water still needs to be checked in real time.

Only apply the amount of nitrogen and phosphorus that the receiving crop will take up. This requires matching up of drain nutrients with receiving field sizes. In the table 13 example, approximately 1 hectare of pasture will be required to take up 200kg N and 23 kg P, provided that the soil Olsen P values are not already excessive. For more details, see "A Growers' Guide to The Management of Greenhouse Nutrient Discharges."

Summary of growing in media

growing strawberries in media requires constant measurement of the current media pH and EC, constant assessment of plant water and nutrient status, and constant adjustments to match plant demand, as the seasonal and daily weather changes. Growers need the right tools (pH and EC meters), good plant observation skills, a method to track media moisture, and good record keeping habits, in order to make the constant adjustments required to optimise plant performance.

References

1. Nutrient Management for Vegetable Crops in NZ, 2020 (Hort NZ) https://www.hortnz.co.nz/assets/Compliance/Nutrient-Management-for-Vegetable-Crops-in-NZ-Manual-Feb-2020.pdf
2. California Crop Fertilization Guidelines https://www.cdfa.ca.gov/is/ffldrs/frep/FertilizationGuidelines/Strawberry.html
3. Nutrient Solutions for Greenhouse Crops, 2020 (European fertilizer suppliers) https://www.nouryon.com/globalassets/inriver/resources/article-micronutrients-nutrient-solutions-for-greenhouse-crops-global-en.pdf
4. Principles of Strawberry Nutrition in Soilless Substrates, 2007(AHDB, UK) https://horticulture.ahdb.org.uk/knowledge-library/principles-of-strawberry-nutrition-in-soilless-substrates
5. A Growers' Guide to Management of Greenhouse Nutrient Solution Discharges, 2007 (Hort NZ) https://www.hortnz.co.nz/assets/Compliance/Grower-Guide-Managing-GH-Nutrient-Discharges-1.pdf

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