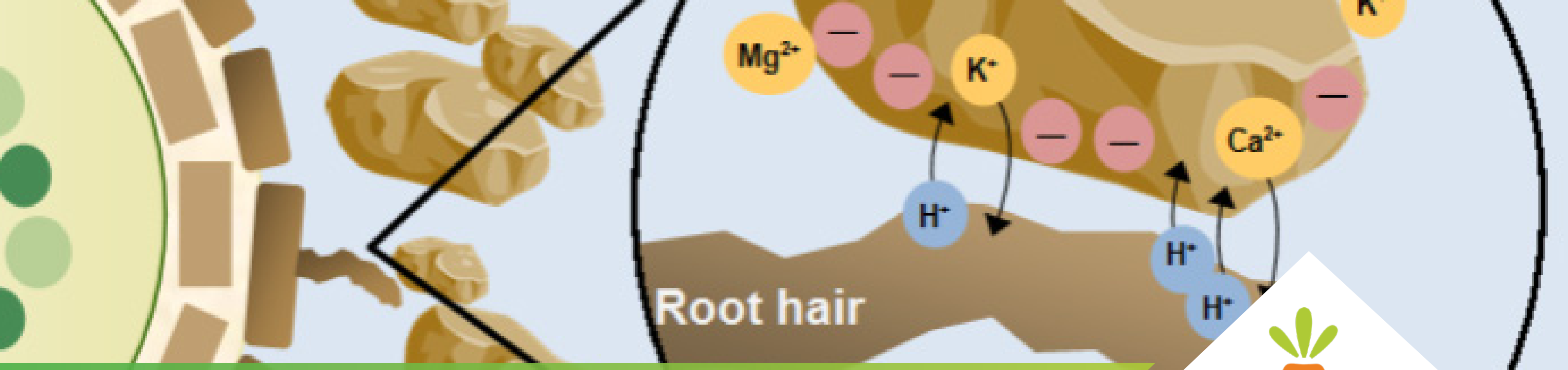



# Getting more value from fertiliser

## Factsheet - January 2023

National Vegetable Extension Network
TASMANIA

For applied fertiliser to be efficiently used by the plant, the pre-requisites are that:

- the plant has a healthy root system
- the soil structure is optimised to hold and deliver water and nutrients to the plant roots - nutrients are only taken up with water - **no water, no nutrients**
- applied nutrients are placed so plant roots can reach them when needed.

**Good soil structure is critical.** It dictates air, water and nutrient availability. These conditions also influence other soil life such as beneficial bacteria, fungi, mycorrhizae, earthworms, insects. These, in turn, contribute to plant root health.

### Healthy plant roots

Why are healthy plant roots so important?

1. Roots are the key organ responsible for nutrient uptake and transport to the aboveground plant parts.

   They are the fundamental 'delivery mechanism' of nutrients into the plant - they need to be working properly for the plant to function optimally and produce a good yield.

2. Root exudates attract and feed microbes that, in turn, help to make nutrients more available to the plant.

   While the soil can be teeming with microbial life, the 1 mm around the roots (rhizosphere) can have 1,000 times more microbes (McNear 2013).

   *Plant symbionts colonise plant root surfaces protecting the roots from several pathogens, as well as often enhancing root growth, nutrient uptake, abiotic stress tolerance, and overall productivity.*

   *adapted from Harman et. al 2004*

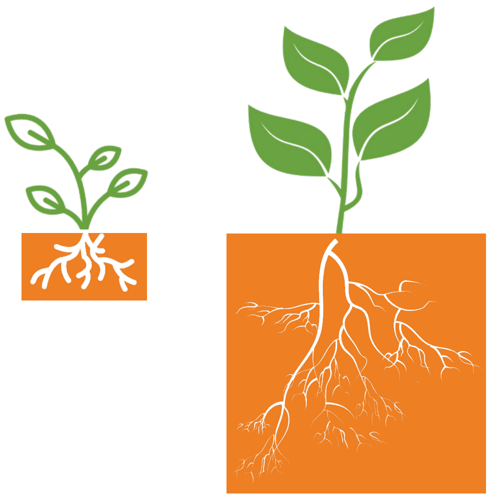
3. It's a maths thing (see diagram below).

   - The more roots, the greater the **volume** of soil (and nutrients) accessed by the plant - i.e. maximising the amount of nutrient available to each plant.
   - The greater the number of roots (especially the really important fine roots where most of the action happens), the greater the **surface area** available for nutrient absorption to occur - i.e. maximising the nutrient uptake by each plant.

Note: some varieties are known to have better root systems, e.g. Innovator potatoes vs Russet Burbank.

### Key messages

- **Healthy root systems produce healthy plants**
- **Choose varieties with proven ability to develop good root systems**
- **Increasing soil organic matter improves soils' ability to 'hold' nutrients**
- **Minimum/low tillage practices help maintain soil structure, organic matter and good soil life**
- **Nutrient budgets should be used that aim at providing a balanced nutrition and apply the 4Rs principles (refer pages 4 and 5)**



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RMCG

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## Improving soil structure

So, how do you improve soil structure?

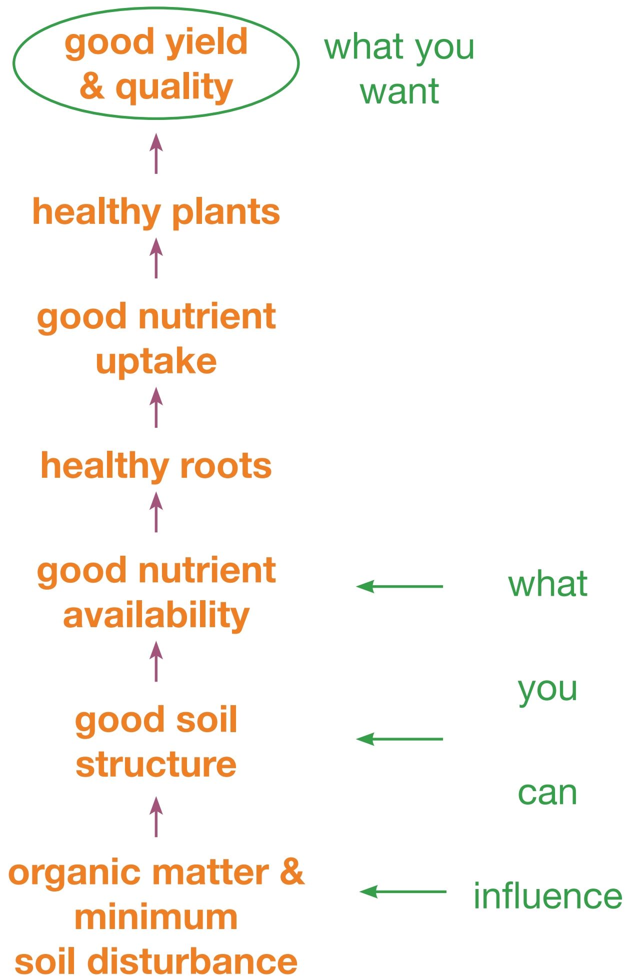
- Use minimum / 'soft' tillage or strip tillage where possible
  - it helps maintain soil pores already present - which is also important for even water infiltration and drainage
  - it helps maintain root system depth and lateral distribution
  - it maintains fungal hyphae networks, they're important in nutrient transfer through the soil
  - keep roots from cover crops in place where possible - maintains structure and increases organic matter
- Have good organic matter (OM) levels
  - maintain levels if good, grow (cover crops) or import OM if more is needed; try to maintain an OM level that is similar to that in non-cropped, non-disturbed soil of the same type.
  - OM supports soil structure stability and feeds soil life which also contributes to structural stability
- Make sure there is enough calcium (Ca) in the soil
  - Ca supports soil structure stability and plant health. Crops also require sufficient Ca in the nutrient solution - it's best applied via soluble fertilisers, while lime, dolomite or gypsum can be used to maintain or improve soil structure.

Timing is important - avoid soggy soil conditions when working soil or putting any weight on soil, including livestock.

**Good soil life for nutrient holding and turn-over/ availability**

All the beneficial lifeforms in soil contribute to healthy plants. They contribute to nutrient availability and soil structure.

- Improving soil structure contributes to improving soil life
  - soil structure is important to ensure air and water flow (drainage) – plant roots and other soil life must breathe
  - OM is important because it supports good soil structure and feeds soil life
  - OM has high cation exchange and anion exchange capacity (AEC) and typically cation exchange capacity (CEC) is greater than AEC (i.e. there are more positively charged particles on the surface [CEC] than negatively charged [AEC])
- Microorganisms in the rhizosphere
  - can convert nutrients into more plant-available forms
  - protect roots from pathogen attack
- Symbiotic fungi e.g. mycorrhiza
  - increase the volume of soil that roots can explore (see Figures 4, 5 and 6)
  - protect roots from pathogen attack
- Microorganisms release nutrients when their bodies break down - if there are healthy populations, they act as a pool of available nutrients.

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**Good soil fertility – nutrient availability**

Cation exchange capacity is important. It impacts the amount of nutrient available to a plant in any given soil. For more information see text box on page 6.

Soils with greater cation exchange capacity (CEC) can hold more nutrients - they have a greater number of ‘sticky’ sites for cations to hold onto (Figure 1).

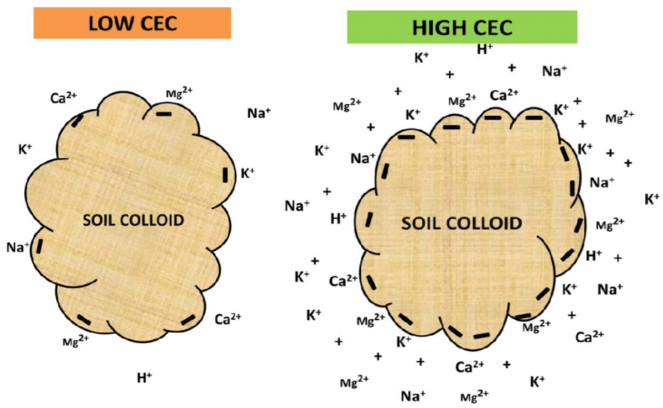


**Figure 1 Relative cation distribution around low and high cation exchange capacity (CEC) soil particles.**

CEC increases with increasing organic matter and is influenced by soil texture (see Table 1).

**Table 1 Relationship between soil texture and CEC**

| SOIL TEXTURE | CEC (cmol/kg OR meq/100 g)[a] |
|---|---|
| Sands (low OM) | 3–5 |
| Sands (high OM) | 10–20 |
| Loams | 10–15 |
| Silt loams | 15–25 |
| Clay and clay loams | 20–50 |
| Organic soils | 50–100 |

[a] meq/100 g soil - represents milliequivalents of CEC per 100 g soil.

From Havlin 2013.

In low CEC soils, the main way to improve CEC is by adding organic matter (refer to CEC for sands in Table 1).

Sometimes, clay is used on sandy soils to increase CEC.

pH influences CEC, which greatly influences nutrient availability; most adsorbed cations are plant nutrients, except for $Al^{3+}$ and $Na^+$.

- In acid soils (< 6.5) the major cations are $Al^{3+}$, $H^+$, $Ca^{2+}$, $Mg^{2+}$, and $K^+$.
- When soil pH is 6.5 or higher, the major exchangeable cations are $Ca^{2+}$, $Mg^{2+}$, $K^+$ and $Na^+$.
- Cations vary in how tightly they are held in place (adsorbed).

  From most tightly to most loosely held, they are:

  $Al^{3+} > H^+ > Ca^{2+} > Mg^{2+} > K^+ = NH^{4+} > Na^+$.

  Cations with greater charge are more strongly adsorbed. For cations with similar charge, adsorption strength is determined by the size of the hydrated cation.
- The more loosely cations are held, the more easily they are released (desorbed) and available for plant uptake.

• Soil texture influences CEC (amount of ‘sticky’ exchange sites) and thus nutrient availability.

• Figure 2 demonstrates two of the mechanisms of cation exchange between the soil and plants.

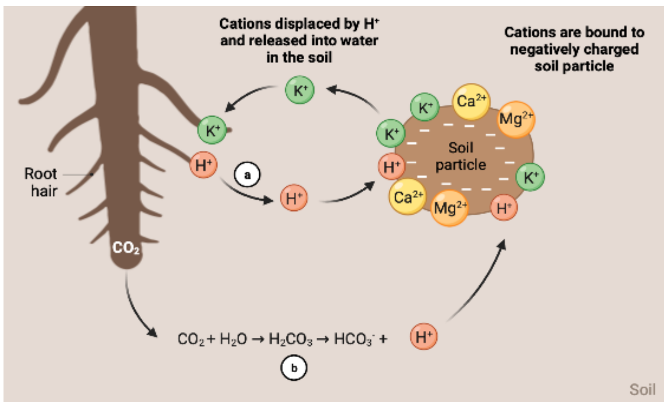


**Figure 2 Cation exchange between plants, soil solution and soil particles. Plants release $H^+$ by a) pumping it from the plant, and/or b) releasing $CO_2$ into the soil and $H^+$ is a byproduct of a reaction with water.**

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## Good fertiliser practices - 4Rs (see Figure 3)

**The first R is Right Source**

In order to determine the right source, the following should be taken into account:

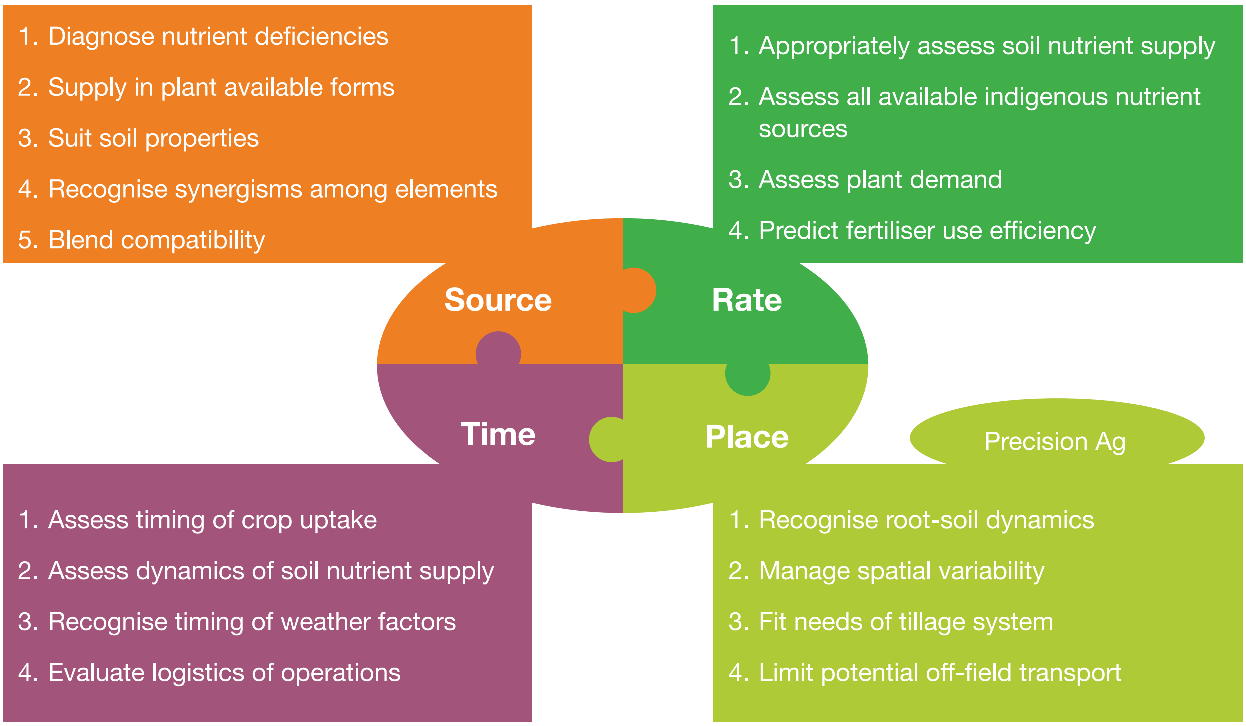
- What nutrients are already available in the soil?
- Are the fertiliser nutrients used (commercial or organic) available for immediate or delayed crop uptake?
- Is there a combination of fertilisers that can be utilised best?

**The next R is Right Rate**

- Match the amount of fertiliser applied to the crop nutrient uptake (over time)
- What is the crop nutrient demand – what are the yield goals and removal rates?
- Perform a soil analysis (organic amendment analysis as well if using, grid or NDVI based sampling) to appropriately match the amount of fertiliser needed to crops / pastures based on individual field fertility
- Make sure equipment being used to spread the fertiliser or organic amendment is calibrated properly for appropriate distribution
- Consider the law of diminishing returns: the unit of nutrient applied vs crop yield increase generated.

**The third R is Right Time**

- Plan for fertiliser nutrients to be available during crop demand – many times this is close to planting
- Consider the weather and seasonal conditions:
  - Potentially more nutrient runoff occurs during the winter but also during heavy rainfall at other times especially with soil erosion from bare soil and leaching
  - Saturated fields are unable to retain nutrients effectively, N is easily lost
  - Application of fertiliser immediately before a large rainfall could contribute to nutrient runoff.




Adapted from - International Plant Nutrition Institute / Nutrient Stewardship 4R Pocket Guide. https://nutrientstewardship.org/4r-pocket-guide/

**Figure 3 Diagram of the 4Rs of fertilisers - right source, rate, time and place**

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**Lastly, determine the Right Place**

- Place fertiliser in the root zone, where crops can successfully access the nutrients
- Consider the management practices for each field based on the following:
  - Crop/pasture being grown, rooting depth, timing of fast growth
  - Soil type/texture
  - Slope
  - Distance to surface waters and ground water (N leaching risks)
  - Soil characteristics (do they differ throughout the field) like nutrient supply capacity and the vulnerability to nutrient loss
- Use variable rate fertiliser, lime and seeding as required.

See Figure 3 for diagram of the interrelationship between the 4Rs.

## Monitor to manage

Adjust fertilisers topdressing rates based on plant testing or in season soil testing (e.g. soil N checks).

Plant analysis can detect deficiencies before they are visible. Once visible, the crop/pasture has been set back and the lack of certain elements is difficult to correct.

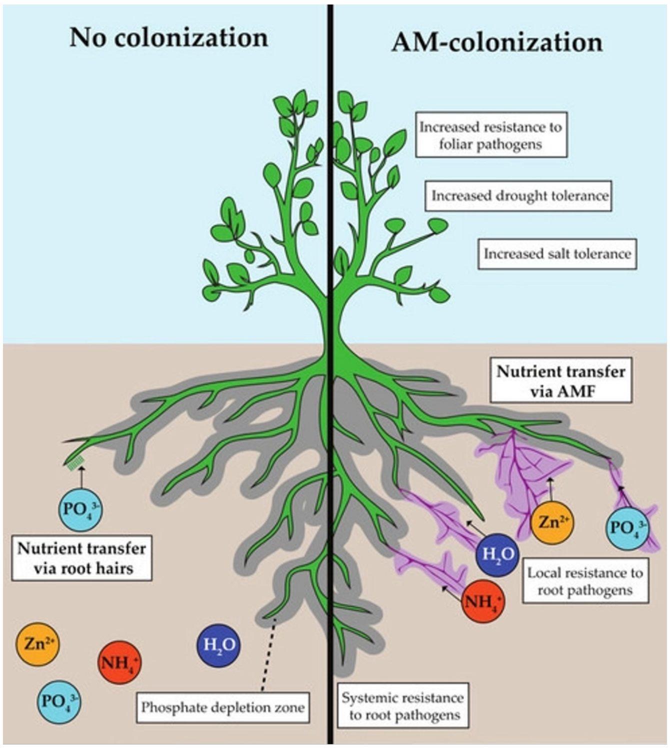


**Figure 4 Positive effects of arbuscular mycorrhizal (AM) colonisation. Benefits include tolerances to many abiotic and biotic stresses. The hyphal network of arbuscular mycorrhizal (AM) fungi extends beyond the plant roots, accessing a greater area of soil. Other nutrients have enhanced assimilation in AM-roots including N (as $NH_4$) and Zn. (adapted from Jacott et al. 2017)**

**Figure 5 Diagram of (purple) mycorrhizal hyphae around a (yellow) tuber (from UFZ 2014a)**

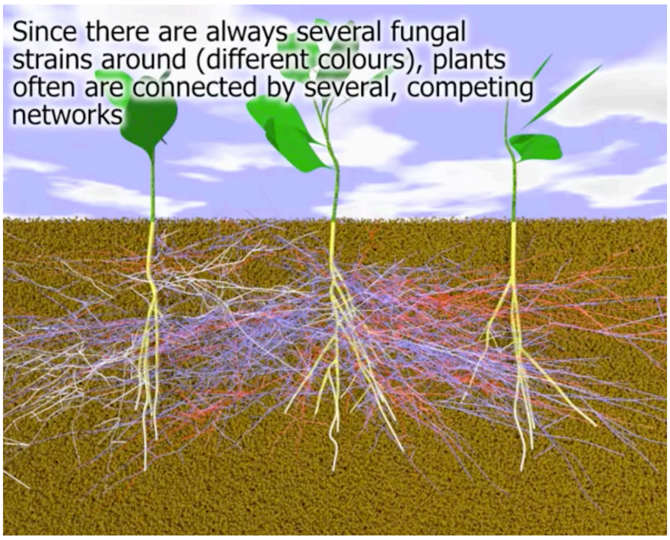


**Figure 6 Diagram of multiple mycorrhizal-plant interactions (from UFZ 2014b)**

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## Cation exchange capacity (CEC) and nutrients

The CEC of a soil can have a significant impact on the efficiency of fertilisers.

In soils with a high CEC, fertilisers are more likely to be held onto by the soil and made available to the plants over a longer period of time. As a result, fertilisers may be more efficient in these soils and may require fewer applications to meet the nutrient needs of plants.

On the other hand, in soils with a low CEC, fertilisers are more likely to be leached out of the soil, leading to reduced fertiliser use efficiency. In these soils, it may be necessary to apply fertilisers more frequently or to use slow-release fertilisers, including organic sources, which release their nutrients over a longer period of time, to ensure that the plants have an adequate supply of nutrients.

Soil tests provide information on the CEC of a soil and thus guide fertiliser choice, timing, frequency and application rate decisions.

Apart from soil texture and the addition of organic matter, the CEC of a soil can be influenced by pH.

At a neutral pH (around 7), the CEC of a soil is generally highest because the soil particles are most effective at holding onto cations. As the soil pH becomes more acidic (below 7) or more alkaline (above 7), the CEC of the soil tends to decrease because the soil particles are less effective at holding onto cations. The effect of pH on CEC can vary depending on the specific soil type and other factors.

## References and Resources


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Magdoff, F. and Van Es, H. (2021). Building Soils for Better Crops. Sustainable Soil Management, IV Ed, Sustainable Agriculture Research and Education (SARE) Program, National Institute of Food and Agriculture, (USDA).

Over 300 pages, including chapters on cover crops, minimising tillage, nutrient management and integrating crops and livestock. Available here: https://www.sare.org/wp-content/uploads/Building-Soils-for-Better-Crops.pdf

SWICP (2016). Factsheet - Nutrient element functions in vegetable crops.

Also includes which nutrients are taken up by mass flow, diffusion, root interception - https://www.soilwealth.com.au/imagesDB/news/NutrientElement_July2016.pdf

SWICP comprehensive lists of resources

Phase 2 - December 2017 to July 2020. Available here: https://www.soilwealth.com.au/imagesDB/news/Phase2resourcesfactsheet20200812.pdf

Phase 1 - 2014-2017. Available here: https://www.soilwealth.com.au/imagesDB/news/SW-ICP_Summaryofresources_Nov2017_v4.pdf

UFZ (2014a and b). Mycorrhiza (I) Mycorrhiza and the environment, and Mycrorrhiza (II) What is it and how does it work. Screenshots from videos available here: (I) https://www.youtube.com/watch?v=IZVniNFTWh4; (II) https://www.youtube.com/watch?v=QYmrOrTM-FA


Cover image: from Louisiana State University Agricultural Center