Acidity

Excessive soil acidity means that there are too many hydrogen ions (H+) in the soil solution. An excess of hydrogen ions reduces soil pH and causes nutrient imbalance.

Excessively acidic soils generally have low available levels of some of the major nutrients, such as phosphorus, potassium, calcium, and magnesium. The availability of molybdenum is also reduced. Typically, aluminium and/or manganese may become toxic in excessively acidic soils.

**Indicators**

Things to look for that may indicate the constraint:
- poor crop performance
- visible symptoms of manganese toxicity or nutrient deficiencies.

**Measurement methods**

Measurements that may indicate the constraint:
- low field pH reading or pH result from standard nutrient soil test ($\text{pH}_{\text{water}}$ less than 5.5). See ‘Soil pH’ on p. 4 for a detailed description of pH.

**Management**

Excessively acidic soils require amendment with agricultural lime (calcium carbonate) or dolomite (magnesium carbonate) if soil magnesium is considered marginal. A ‘lime requirement’ soil test is available through ASPAC accredited soil testing laboratories and this test allows lime rate recommendations to be made for a target soil pH$_{\text{water}}$ of 5.5 or 6.0.

Salinity

Excessive levels of soluble salts in the soil, particularly sodium chloride, cause poor plant growth. A build-up of salts in the soil interferes with water and nutrient uptake by plants because of osmotic effects (i.e. high concentrations of salts in the soil make the soil water less available for plant uptake). Affected plants wilt or show salt burn symptoms on the older leaves. Crops vary in their tolerance to soil salinity and Table 9 provides soil salinity ratings based on field electrical conductivity (EC) measurements.

**Indicators**

Things to look for that may indicate the constraint:
- visible salt scalds on the soil surface
- crop wilting or salt burn on the leaves.

**Measurement methods**

Measurements that may indicate the constraint:
- high field EC reading
- high EC, chloride and sodium levels reported in a standard soil nutrient analysis.

**Management**

Ideally, the excess salts need to be leached out of the soil. This may take many years, and in severe cases requires some dramatic changes in farm layout to keep the salts below the root zone. Gypsum applied to manage a soil high in sodium will temporarily increase the salinity of the soil solution, which could adversely affect seed germination and plant growth. It may take several years and several applications of gypsum before soil salinity is noticeably lowered (also see ‘Sodicity’ on p. 18).
Table 9. Salt tolerance of crops grouped according to soil salinity criteria measured as EC$_{1:5}$ for different soil clay contents and field textures (Moody & Cong 2008)

<table>
<thead>
<tr>
<th>Soil salinity rating</th>
<th>EC$_{1:5}$ based on soil clay content (dS/m)</th>
<th>Plant salt-tolerance grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10–20% clay (loamy sand, sandy loam)</td>
<td></td>
</tr>
<tr>
<td>Very low</td>
<td>&lt; 0.07</td>
<td>Sensitive crops</td>
</tr>
<tr>
<td>Low</td>
<td>0.07–0.15</td>
<td>Moderately sensitive crops</td>
</tr>
<tr>
<td>Medium</td>
<td>0.15–0.34</td>
<td>Moderately tolerant corps</td>
</tr>
<tr>
<td>High</td>
<td>0.34–0.63</td>
<td>Tolerant crops</td>
</tr>
<tr>
<td>Very high</td>
<td>0.63–0.93</td>
<td>Very tolerant crops</td>
</tr>
<tr>
<td>Extreme</td>
<td>&gt; 0.93</td>
<td>Generally too saline for crops</td>
</tr>
</tbody>
</table>

|                      | 20–40% clay (loam, clay loam)               |                              |
| Very low            | < 0.09                                     | Sensitive crops              |
| Low                 | 0.09–0.19                                  | Moderately sensitive crops   |
| Medium              | 0.19–0.45                                  | Moderately tolerant corps    |
| High                | 0.45–0.76                                  | Tolerant crops               |
| Very high           | 0.76–1.21                                  | Very tolerant crops          |
| Extreme             | > 1.21                                     | Generally too saline for crops |

|                      | 40–60% clay (clay)                          |                              |
| Very low            | < 0.12                                     | Sensitive crops              |
| Low                 | 0.12–0.24                                  | Moderately sensitive crops   |
| Medium              | 0.24–0.56                                  | Moderately tolerant corps    |
| High                | 0.56–0.96                                  | Tolerant crops               |
| Very high           | 0.96–1.53                                  | Very tolerant crops          |
| Extreme             | > 1.53                                     | Generally too saline for crops |

|                      | 60–80% clay (heavy clay)                    |                              |
| Very low            | < 0.15                                     | Sensitive crops              |
| Low                 | 0.15–0.3                                  | Moderately sensitive crops   |
| Medium              | 0.3–0.7                                   | Moderately tolerant corps    |
| High                | 0.7–1.18                                   | Tolerant crops               |
| Very high           | 1.18–1.87                                  | Very tolerant crops          |
| Extreme             | > 1.87                                     | Generally too saline for crops |

EC$_{1:5} =$ electrical conductivity of a one part soil to five parts water solution

< = less than

> = greater than

Salt tolerance of vegetable crops can be found at: www.dpi.nsw.gov.au (click on ‘Agriculture’ › ‘Natural resources and climate’ › ‘Soil health and fertility’ › ‘Salinity’)

**Sodicity**

Sodicity refers to excessive levels of sodium ions (Na$^+$) in the soil. Sodicity causes physical problems in soil (such as dispersion) and also restricts rooting depth and plant growth.

Sodium tends to displace exchangeable cations, such as calcium, from the sites where they are attached to soil particles. Exchangeable calcium helps to keep soil particles bound together in aggregates, but in soils with excess sodium, the sodium causes clay particles to break away from soil aggregates and disperse. This has the effect of reducing pore spaces and reducing the movement of water through the soil profile. In sodic topsoils, a hard crust may form when the soil surface dries out.

**Indicators**

Things to look for that may indicate the constraint:

- surface crusting
- clay ‘skins’ on the soil surface.

**Measurement methods**

Measurements that may indicate the constraint:

- exchangeable sodium percentage (ESP) greater than 5% (from standard soil test)
- high field pH reading (pH greater than 9)
- dispersion using the Emerson dispersion test (see p. 6)
- low aggregate stability using the aggregate stability test (see p. 32).

**Management**

Applying gypsum (calcium sulphate) can improve the structure of these soils and make them less prone to waterlogging by replacing the sodium in the soil with calcium.

Apply 5–10 t of gypsum per hectare, preferably before the start of the wet season and well before planting. This will help leach the sodium beyond the root zone before planting. Gypsum will temporarily increase the salinity of the soil solution, which could adversely affect seed germination and plant growth. It may take several years and several applications of gypsum before there is a noticeable improvement in soil structure and drainage.
Alkalinity

Excessive soil alkalinity means that there are too many hydroxyl ions (OH−) in the soil solution. An excess of OH− increases the soil pH. Excessively high soil pH causes deficiencies for iron, manganese, copper and zinc and, depending on parent material, may also cause boron toxicity.

Indicators

Things to look for that may indicate the constraint:
- poor crop performance
- visible symptoms of trace element deficiencies.

Measurement methods

Measurements that may indicate the constraint:
- high field pH or standard soil analysis test pH reading (pH greater than 8.5).

Management

The availability of several trace elements is reduced in highly alkaline soils. The most effective method for managing this constraint is foliar applications of the nutrients.

High phosphorus fixation

Soils that are high in iron, aluminium or calcium react strongly with soluble phosphorus (P) fertilisers. Calcium forms insoluble compounds that make the phosphorus unavailable to plants, whereas soil iron and aluminium oxides adsorb the added phosphorus and ‘fix’ it. This fixation reaction is most evident in ferrosol soils because they have a high content of iron oxides.

The phosphorus buffer index (PBI) measures the amount of phosphorus ‘bound’ to the soil and unavailable to plants. A high PBI (>280) means the soil is able to fix phosphorus, making it unavailable to plants. A low PBI means phosphorus is not strongly bound to the soil and is more available to plants. At extremely low PBI (<15) such as occurs in sandy soils, phosphorus leaching is probable because the soil is unable to retain phosphorus.

Indicators

Things to look for that may indicate the constraint:
- phosphorus deficiency in crops
- red soils.

Measurement methods

Measurements that may indicate the constraint:
- PBI greater than 840. For more information see ‘Extractable phosphorus and phosphorus buffer index (PBI)’ on p. 27.

Management

Phosphorus fertiliser management for high phosphorus-fixing soils depends on reducing contact between the soil and water-soluble phosphorus sources, such as fertilisers. This can be achieved by placing the fertiliser in concentrated bands below and to the side of crop seeds (band placement), so that emerging roots contact the fertiliser early in crop development. Placing the fertiliser in concentrated bands rather than dispersing the applied phosphorus through the soil reduces the chance of phosphorus fixation by minerals in the soil.

Freshly incorporated organic matter in the soil releases plant-available phosphorus as it decays. Also, phosphorus that is bound to soil particles can be accessed by some soil fungi such as mycorrhizae, passing the phosphorus onto the plant. These fungi form special relationships with the plant root; however, their populations decline if too much phosphorus is added to the soil. Phosphorus uptake by plants can also be reduced by soil compaction, plough pans and waterlogging due to the restricted growth of the root system.

A soil with an extremely low PBI means the soil cannot retain much phosphorus in an adsorbed form, meaning phosphorus may be lost by leaching or water run-off. On these soils, phosphorus application needs to be carefully managed to limit losses. Phosphorus losses potentially cause environmental problems off-site.
Soil health for vegetable production in Australia — Part 3: Managing common soil constraints

Low organic matter content

Soil organic carbon (SOC) is critical for maintaining the chemical, physical and biological health of soil. In general, as SOC increases, so does the amount of organic nitrogen that can be converted into plant-available mineral forms (ammonium and nitrate) by soil microbes.

In sandy soils and soils high in iron oxides, SOC makes an important contribution to CEC (the ability of the soil to hold the nutrient cations of calcium, magnesium and potassium).

Soil microbes require a carbon source for energy. Thus, increasing SOC is generally associated with increasing microbial activity in the soil. This in turn increases the rate that nutrients are released from the soil organic matter. SOC also helps to bind soil particles into aggregates, which helps maintain soil porosity, water infiltration and soil aeration. Stable aggregates also resist compaction caused by tillage and machinery. Soils with optimum SOC may be less prone to soil-borne plant diseases.

Indicators

Things to look for that may indicate the constraint:

- light-coloured soil with a sandy texture.

Measurement tools

Measurements that may indicate the constraint:

- low SOC (measured by standard soil nutrient analysis)
- low level of labile (or active) carbon.

Management

Because SOC has a role in many important soil properties, attempt to maintain or increase SOC whenever possible. This can be achieved by:

- mulching and incorporating green manure crops (e.g. legumes or forage grasses) into the topsoil
- retaining all crop residues in the field where the crop has grown
- not burning crop residues—burning causes the loss of carbon as carbon dioxide gas and exposes the soil surface to erosion
- controlling erosion—erosion is particularly detrimental to SOC because of the off-site movement of topsoil, which is richer in SOC than subsoil
- using minimum or zero-tillage farming systems to reduce the loss of SOC from cultivation
- applying organic materials (e.g. animal manure, composted municipal waste, and locally available industrial organic wastes) obtained from off-site. Always check your customer’s food safety requirements before using these materials.

For detailed descriptions of organic matter, soil carbon and labile carbon see Part 4.

Figure 7. Adding organic matter to the soil benefits the soil in many ways. It protects the soil surface, increases nutrient recycling, provides food for soil organisms, stabilises soil aggregates, increases air and water movement into the soil and helps retain water and nutrients in the root zone.
Case study 3: Dealing with soils low in organic carbon

Maintaining adequate soil carbon levels is a problem for vegetable growers in dry tropical climates. The higher soil temperatures mean that soil microbes tend to be very active, especially in irrigated crops where water is rarely limiting. When soil microbes find carbon in the soil, they consume it and release it as carbon dioxide (CO₂) into the atmosphere. Tillage speeds up this process.

Over the past eight years, Paul LeFeuvre has developed a minimum tillage and mulch system for growing zucchinis on his farm south of Townsville. Forage sorghum is grown on permanent beds over the summer fallow period, slashed regularly and then killed with a herbicide in autumn. This produces a thick mat of mulch that suppresses weeds and protects the soil against rain drop impact and erosion. Zucchinis are planted through the mulch. The permanent beds help minimise interruptions to farm operations through wet weather.

Beds are renovated every 4–5 years when soil is tilled, new subsurface trickle tape is laid and beds are reformed. This lowers bulk density, improves soil porosity and counteracts compaction caused by many feet during the almost daily manual harvesting of zucchinis. This strategic tillage seems to have had little negative impact on organic carbon or aggregate stability as there was little difference between the five-year-old and newly renovated beds.

By converting to a minimum till–mulch system, Paul has achieved SOC levels well above 1%, which is considered very high for this region and soil type. He has established a production system that saves on inputs, provides better management flexibility and improves soil health. This has helped Paul overcome the constraints associated with low organic carbon in the soil.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Five-year-old beds</th>
<th>Newly renovated beds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Texture</td>
<td>Clay loam</td>
<td>Clay loam</td>
</tr>
<tr>
<td>Bulk density (g/cm³)</td>
<td>1.23</td>
<td>1.18</td>
</tr>
<tr>
<td>Aggregate stability (%)</td>
<td>55</td>
<td>46</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>(Walkley–Black method)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labile carbon (mg/kg)</td>
<td>691</td>
<td>692</td>
</tr>
<tr>
<td>CEC (meq/100 g)</td>
<td>17</td>
<td>24</td>
</tr>
<tr>
<td>Colwell-P (mg/kg)</td>
<td>257</td>
<td>247</td>
</tr>
</tbody>
</table>

Biological constraints

Soil-borne diseases

Soil-borne diseases are caused by pathogenic soil microbes such as bacteria, fungi and plant-parasitic nematodes, and can be a severe constraint in some vegetable production systems.

Most soil microbes are saprophytic (i.e. grow only on dead organic matter) and help decompose organic material and recycle nutrients. The free-living nematodes in the soil feed on fungi, bacteria and other nematodes, helping to release nutrients and making them available to plants.

Physical and chemical soil constraints such as waterlogging, poor soil structure, compaction and acidity can all interfere with root growth, stunting the plant and reducing the uptake of water and nutrients.

These soil constraints cause plant stress and favour conditions that lead to soil-borne diseases.

Some soil-borne diseases such as the plant-parasitic root-knot nematode (Meloidogyne spp.) are associated with certain soil types. For example, the root-knot nematode causes greater yield losses in sandy soils than in heavier textured soils.

Bacterial infections can cause quick decline of plants because of their ability to reproduce rapidly. Bacterial pathogens cause the plant to wilt and lead to the formation of ooze, often with a bad odour.

Soil fungi that cause disease produce symptoms such as stunting, yellowing of leaves, wilting and plant death. The incidence of fungal diseases may be increased by leaving crop residue on the soil, not using crop rotations, and poor soil conditions.
Plant-parasitic nematodes reduce plant growth by feeding on plant roots. This reduces the plant’s ability to take up water and nutrients and may produce nutrient deficiency symptoms, stunting and yellowing of the leaves. Plant roots affected by nematodes may appear stunted, or have dead areas or galls (depending on which nematode is causing the problem).

**Management**

Crop rotation and good farm hygiene practices are fundamental for limiting plant disease problems. Improving soil conditions and overcoming other soil constraints will reduce plant stress and increase a plant’s resilience and ability to withstand soil-borne diseases.

Incorporating organic matter into the soil and reducing nitrogen inputs can help to suppress plant-pathogenic nematodes by increasing soil organisms that parasitise and prey on these nematodes. Other management strategies are to use resistant varieties and healthy seedling transplants or seed of high vigour.

**Soil insect pests**

Insects affecting vegetable crops may use the soil as a temporary residence to complete their life cycle or they may live permanently in the soil. Since insects and other arthropods are mobile, they can cause damage to above ground and below ground parts of plants, sometimes very quickly (e.g. cutworm damage to newly planted seedlings).

Either the developing larvae of the insect or the adult can cause damage, and sometimes both life stages are damaging (e.g. false wireworm and crickets). Root feeding by insects can also create entry sites for soil-borne diseases, thus making plants more susceptible to root and stem rots.

**Management**

Reducing soil constraints can help maintain a healthy root system, allowing the plant to tolerate damage caused by soil insects. It may also help to increase the number of beneficial organisms, such as fungi and nematodes, which can parasitise insects. Conversely, high levels of freshly incorporated organic matter can provide the right soil conditions for some insect pests.

An integrated approach based on regular monitoring of pests can reduce reliance on pesticides for insect control, thus reducing the detrimental effect of pesticides on soil biological diversity. Some practices can help reduce insect problems; for example, cultivating at particular times to expose soil insect larvae and pupae to bird predators, and allowing sufficient time for organic matter (from weedy or grassy paddocks) to decompose.