Appendices

vegetablesWA

Australian Government

swan catchment council

Natural Heritage Trust
Helping Communities Helping Australia

Government of Western Australia
Department of Agriculture and Food

Contents

Page

Appendix 1:
Recognising nutrient deficiencies in crops

	Nitrogen (N)*	Phosphorus (P)	Potassium (K)*	Calcium (Ca)*	Magnesium (Mg)*	Manganese (Mn)	Zinc (Zn)	Iron (Fe)**	Molybdenum (Mo)	Boron (B)	Copper (Cu)
Leaf colouring											
General yellowing	✓	–	–	–	–	–	–	–	✓	–	–
Red and purple tints	✓	–	–	–	–	–	–	–	✓	–	–
Purplish-blue appearance	–	–	✓	–	✓	–	–	–	–	–	–
Large yellow patches between veins	–	–	–	–	✓	✓	✓	✓	✓	–	–
Red tinge on leaf vein backs	–	✓	✓	–	–	–	✓	–	–	–	–
Leaf margins scorched	–	–	✓	✓	–	–	–	–	–	–	–
Leaf morphology/appearance											
Stunting and distortion	✓	✓	–	✓	–	–	✓	–	✓	✓	✓
Sparse growth	–	✓	–	–	–	–	–	–	–	–	–
Leaves roll or twist	–	–	–	–	–	–	✓	–	✓	✓	–
Multiple buds grow below dead leaves	–	–	–	–	–	–	–	–	–	–	✓
Plant morphology/appearance:											
Plants stunted	✓	✓	–	–	–	–	✓	–	–	–	✓
Growing point dies	–	–	–	✓	–	–	–	✓	–	–	–
Looks waterlogged or salt-damaged	–	–	✓	–	–	–	–	–	–	–	–
Symptoms confined to plant tops	–	–	–	–	–	–	–	✓	–	–	–
Black patch on blossom end of fruit	–	–	–	✓	–	–	–	–	–	–	–
Fruit distorted, with seed exposed	–	–	–	–	–	–	✓	–	–	–	–
Tip burn in celery, lettuce and brassicas	–	–	–	✓	–	–	–	–	–	–	–
Plant stems thick and brittle	–	–	–	–	–	–	–	–	–	✓	–
Reduced internode length	–	–	–	–	–	–	✓	–	–	✓	–
Deficiency more common on –											
Alkaline soils	–	–	–	–	–	✓	✓	✓	–	✓	✓
Acid soils	✓	✓	✓	✓	✓	–	–	–	✓	–	–

* *Ammonium ions, Ca, Mg and K all compete for uptake in the plant; therefore, excesses of one will decrease uptake of others, potentially leading to deficiencies.*

***More prevalent in autumn and winter crops.*

Appendix 2:
Determining soil texture

[Thiagalingam (1996); Hills & Miller (2000); Hutchison 2002; Phillips et al *(2001); Carey (2001); Hollier (2003)]*

The ribbon test

- Take a golf-ball-sized quantity of soil that is free of gravel stones.
- Work the soil up in your hand, adding drops of water until it is moist but not so that water can be squeezed from it.
- Work the soil out between your thumb and finger into a ribbon. The length of the ribbon that is formed and the feel of the soil determine its classification (Table 1).

Table 1. Determining soil texture from soil feel and soil ribbon length.

Texture	Description
Sand	Will not form a ribbon; cannot be moulded; feels gritty.
Loamy sand	Minimal ribbon, about 5 mm.
Clayey sand	Sand grains stick to and colour fingers; ribbon 5–15 mm .
Sandy loam	Can be moulded but feels gritty; ribbon 15–25 mm.
Loam	Spongy, smooth feel (not gritty or silky); ribbon about 25 mm.
Sandy clay loam	Gritty feel but plastic; ribbon 40–50 mm.
Clay loam	Smooth, plastic; ribbon 40–50 mm.
Clay loam, sandy	Plastic but some grittiness; ribbon 40–50 mm.
Light clay	Plastic; smooth; slight resistance to ribboning shear; ribbon about 75 mm.
Clay	Smooth; very plastic; moderate to firm ribboning shear; can be moulded into rods; ribbon 75 mm or more.

Looking at colour variations in the soil profile can often assist in identifying the different layers/horizons of soil within that profile. Soil colour can also indicate the amount of leaching, aeration and organic matter (Table 2).

Table 2. Soil colours and properties they may indicate.

Colour	Property*
Dark surface soil	The darker the colour, the higher the organic matter content.
Light-coloured (near-white) subsurface	Nutrient leaching.
Mottled subsoil (blotches of different colours or shades)	Soil has periods of waterlogging.
Strong colours	Good fertility.
Weak colours	Poor fertility and leaching.

* *Note: soil colour is only an indication of possible soil properties. Further soil tests must be conducted to confirm or disprove these indications.*

Appendix 3:
Rates and practices to reduce leaching

[McPharlin & Hegney (1997); Hills & Miller (2000); Penny & Miller (2000b); McPharlin (2001); Summers (2001); Summers & Kingdon (2002); Summers & Rivers (2002); McConnell et al *(2003); Rose (2004); Teasdale* et al *(2001); McKay (unpublished)]*

Nitrogen

- **Rates should not exceed 70 kilos of nitrogen/ha (N/ha) in any single application**. Even smaller applications should be applied on sandy soil and to young crops that require less nitrogen than more advanced crops. Smaller, more frequent applications should be applied during autumn/ winter when rainfall is common and the risk of leaching is higher.
- **The concentration of nitrogen in irrigation water should be considered**, as significant quantities of nitrogen can be applied to the crop from irrigation water.
- **The cropping history of the site should also be considered. Residual nitrogen in the soil from preceding crops, as well as nitrogen mineralising from crop residues, can reduce nitrogen fertiliser requirements.** For example**,** carrots following cereals require more nitrogen than carrots following cauliflowers or lettuce.
- **Leafy green vegetables such as turnip, cabbage and spinach are heavy users of nitrogen**. Broccoli and sweetcorn also require more nitrogen than some other vegetables.
- **Peas and beans get nitrogen from the air and do not require heavy nitrogen fertilisation**. Over-fertilising of these vegetables with nitrogen causes excessive growth of leaves at the expense of the fruit.
- **A summer carrot crop** (16-18 week) requires less than a total of 300 kg N/ha.
- **A winter carrot crop** (24-26 week) requires less than a total of 350 kg N/ha.
- **Producing maximum crop yields may not be economically and environmentally justifiable**. To produce 95% of the maximum yield, the amount of nitrogen applied could be reduced by 20-50%, with the largest reduction in rate early in the life of the crop (Tables 1a & 1b). Note: too much nitrogen can result in excessive leafy growth and no, or only small, fruit.

Table 1a. Nitrogen rates, methods of application and irrigation rates for high yield with low leaching loss potential on sandy coastal soils, for lettuce *[adapted from Phillips* et al *2007 (unpublished)].*

	Days after transplanting	Nitrogen (kg/ha)	Products	Application method	Irrigation (% Epan)
Summer lettuce (iceberg and cos	0, 4, 7 and 11	12 each time	Tank mix of potassium nitrate 20 kg/ha and urea 20 kg/ha (low biuret)	Sprayed without wash-off in 1000 L/ha after last irrigation of the day	100% (no more than 3 mm in any single application)
	14	60 (in very hot weather split application over days 14 and 17)	Nitrophoska Blue Special® (NBS)	Banded between pairs of rows (banded)	140%
	21	60	NBS	Banded	140%
	28	60	NBS	Banded	140%
Spring and autumn lettuce (iceberg)	0, 4, 7, and 11	12 each time	Tank mix of potassium nitrate 20 kg/ha and urea 20 kg/ha (low biuret)	Sprayed without wash-off in 1000 L/ha after last irrigation of the day	100% (no more than 3 mm in any single application)
	14	60	NBS	Banded	140%
	21	60	NBS	Banded	140%
	28	60	NBS	Banded	140%
	35	60	NBS	Banded	140%
Spray alternative (replaces days 14 to 35 above) – lower N rates without yield loss	14	12	Tank mix of potassium nitrate 20 kg/ha and urea 20 kg/ha (low biuret)	Sprayed without wash-off in 1000 L/ha after last irrigation of the day	100% (no more than 3 mm in any single application)
	18	As above	As above	As above	As above
	21	As above	As above	As above	As above
	25	As above	As above	As above	As above
	28	60	NBS	Banded	140%
	35	As above	As above	As above	As above

Table 1b. Nitrogen and irrigation rates for maximum yield and 95% of maximum yield over the lifecycle of a cabbage crop *[adapted from Lantzke et al (unpublished)].*

		For maximum yield		For 95% of maximum yield	
	Days after planting	Nitrogen (kg/ha)	Irrigation (% Epan replacement)	Nitrogen (kg/ha)	Irrigation (% Epan replacement)
Summer cabbage crop	14	45	100	30	100
	21	50	110	35	105
	28	65	115	50	110
	35	85	125	70	120
	42	80	135	70	130
	56	80	135	75	130
	63	80	145	75	135

Phosphorus

Practices to minimise leaching

- **Do a pre-planting soil test** to determine how much phosphorus to apply.
- **Sandy soils require less phosphorus than clay soils**. This is because sandy soils have a very low capacity to compete with the plants for phosphorus (that is, they have a low PRI – see Appendix 4) compared to clay soils (high PRI).
- **Use rates suggested in Table 2 as a guide for phosphorus fertiliser rates on sand**. For alkaline sands of pH_{Ca} greater than 7, the phosphorus requirement can be doubled compared to the rate given in Table 2.
- **Ensure the pH is not low** (that is, less than pH_{Ca} 5.5) before applying phosphorus; otherwise, plants cannot grow well enough to use the phosphorus.
- To maintain phosphorus levels in soil, the quantity of phosphorus applied to vegetable crops can be calculated by determining the amount of phosphorus removed by a crop over its growing season. This depends on crop yield and the phosphorus content of the harvested part. Using a soil test, compare the quantity of phosphorus remaining in the soil after the crop is removed to the amount of phosphorus in the soil prior to planting, combined with the amount applied during the crop life.

Table 2. Pre-planting phosphorus requirements for vegetables grown on yellow Karrakatta sands according to soil test results *[McPharlin & Hegney (1997)].*

Soil test (ppm P Colwell extraction)	Phosphorus requirement (kg P/ha) on yellow sands (Karrakatta and Bassendean)							
	Carrots	Cauliflower		Winter lettuce	Spring lettuce	Onions	Potatoes	Broccoli
		Yellow sands	Soils containing clay in the south-west					
Below 11	180	170	300	420	372	408	162	175
11–20	160	150	220	410	365	400	147	150
21–30	130	115	220	370	330	349	111	115
31–40	110	80	220	330	295	315	75	80
41–50	80	50	170	290	261	280	40	40
51–60	40	40	170	250	226	226	27	25
61–70	30	30	170	213	191	188	25	25
71–80	30	30	170	170	157	146	25	25
81–90	30	30	150	130	123	100	25	25
91–100	30	30	150	90	87	44	25	25
Over 100	30	30	150	50	52	30	25	25

Note*: rates are based on fertiliser being broadcast and incorporated before planting.*

Cadmium, a contaminant of phosphatic fertilisers, accumulates in plant tissues

To minimise plant uptake of cadmium, growers can:

- ensure that fertilisers are as low in cadmium as possible;
- maintain soil pH (CaC_{l2}) above 5.5, as cadmium becomes more available at a lower pH;
- grow crops that do not preferentially accumulate cadmium in the consumed tissues;
- maintain zinc fertility of soils, as low zinc status increases cadmium uptake, and
- use less saline water or move production to less saline soils, as high salt increases cadmium availability.

Potassium

- **Potassium should be applied in small quantities**, as it leaches easily from sandy soils.
- Be careful, as an excess of potassium can also affect the uptake of magnesium, ammonium, calcium and sodium.

Note*: an application rate of 30 kg/ha/week for lettuce on coastal sands did not limit yield (Teasdale* et al *(2001)). By contrast, three applications of potassium to a total of 210 kg/ha, ceasing at 14 days after planting, was not enough for broccoli grown on virgin sandy soil, but it still produced a marketable crop* [Phillips (unpublished)]*.*

Magnesium

Care must be taken when using magnesium on sodic soils or where the exchangeable calcium-to-magnesium ratio is about 1:1. The addition of magnesium in these situations can cause loss of soil structure.

Lime

- **Lime should be applied at no more than** 10 tonnes per hectare (t/ha) for sandy soils, while maximum rates for loam and clay soils can be higher in a single application. Usually, for vegetables, higher rates of lime than the published levels for pastures and other crops are required, because cultivation for vegetables is usually deeper, resulting in a greater dilution factor for the lime and a pH change for the greater depth of soil.
- **The solubility of lime in soil is low**, so, to be more effective against soil acidity, lime particles need to be less than 2 mm in diameter. Ideally, 90% of lime particles would pass through a 0.6 mm sieve, as the smaller the particle size the faster the lime will dissolve in the soil solution.
- The percentage neutralisng value (NV) affects the level of expected pH rise in a soil. It is important to consider both NV and costs when choosing between lime sources. There are four main types of lime available in Western Australia:
    - limestone (50-85% NV);
    - limesand (50-95% NV);
    - dolomite (40-110% NV), and
    - industrial limes such as quick lime or cement kiln dust (70–110% NV).
- To compare the lime sources of different NVs and different prices, the following formula can be used.

Lime cost at pit ($/t) + **transport cost to the paddock ($/t)** + **spreading cost ($/t)** ÷ **NV** (divide the NV% by 100) = **cost of pure lime equivalent ($/t)**

- **All ammonium-based fertilisers** (such as di-ammonium phosphate (DAP) and sulphate of ammonia) **cause soil acidification**, whether leached or not (Table 3). Non-ammonium based fertilisers such as urea cause soil acidification only if the nitrate they are converted to is leached from the root zone (Table 3). Calcium nitrate and calcium ammonium nitrate are less acidifying fertilisers but cost needs to be considered. When deciding on a nitrogen fertiliser product, it should be fully costed – including the cost of lime to neutralise the acidifying effect of the nitrogen source. This should indicate whether a less acidifying product would be more cost-effective.
- **in areas with alkaline irrigation water, acidifying fertilisers may have to be used to maintain the soil pH below 6.5.**

Table 3. Acidifying levels of different fertilisers and amount of lime required to neutralise the effect *[Hills & Miller (80/2000)].*

Fertiliser	Lime required to neutralise fertiliser addition (kg calcium carbonate**/kg nitrogen) when amount of nutrient leached is:		
	0%	**50%**	**100%**
Nitrogen fertilisers			
Ammonium sulphate	3.6	5.0	7.1
Ammonium nitrate	–	1.8	3.6
Anhydrous ammonia	–	1.8	3.6
Urea	–	1.8	3.6
DAP	1.8	3.1	5.4
Sodium nitrate	-3.6*		0
Sulphur fertilisers			
Elemental fertilisers	3.1	–	–
Gypsum	–	–	–
Potassium sulphate	–	–	–
Phosphorus fertilisers			
Single superphosphate	–	–	–
Muriate of potash	–	–	–

** Negative values indicate an alkaline effect on soils. **Calcium carbonate ($CaCO_3$) = pure lime.*

Appendix 4: *Understanding soil analysis*

Total nitrogen (N)

- This is a measure of the total amount of nitrogen in the soil, not what is available to plants.
- Less than 0.10% is regarded as low, while over 0.25% is high. Sandy soils on the Swan Coastal Plain can contain as little as 0.025% N.

Nitrate-nitrogen

- This is an indication of the soil nitrogen readily available for plant growth.
- In heavy soils, 50 ppm nitrate-nitrogen (dry basis), or in sands 10-20 ppm (roughly equivalent to 22.5 to 45 kg N/ha in the top 150 mm of soil) is considered high *(Note: 1 ppm = 1 mg/kg)*.

Available phosphorus (P)

- Colwell (most common), Bray or Olsen tests can be used – for consistency, conduct the same test each time.
- 300 ppm (Colwell test) is considered high on most soils and this may cause toxicity, reducing the yield of some crops.
- 200 ppm or greater (Colwell test), while high for sandy soils, may be just adequate on some loamy and clay soils – reduce P application rates on light soils to a level that replaces crop removal.

PRI (Phosphorus Retention Index)

- This is a measure of the soil's capacity to retain phosphorous.
- Low PRI – soil has a low capacity to hold onto phosphorous, which increases leaching. In general, light-coloured sands have a low reactive iron content and low clay content, which means they will have a low PRI. White and grey sands have the lowest PRIs.
- High PRI – soil has a high capacity to hold onto phosphorous, which reduces leaching. In general, loamy or gravely soils have a moderate to high iron content, which ensures that most of the soil phosphorous is bound to soil particles; therefore, phosphorous is retained in the topsoil and not easily leached.
- **If soil 'PRI-100' values are less than 2.0 to 3.0**, then phosphorous is best applied by either:
  - broadcasting in three applications, or
  - a light application pre-planting, with more than 75% of the phosphorous applied by top-dressing during crop growth.
- **If soil 'PRI-100' values exceed 15.0 to 20.0** – if available phosphorous soil test results are low, total phosphorous application can be banded or broadcast at planting, depending on the crop.
- The PRI of a soil can be increased through the use of soil amendments that alter the properties of the soil.

Organic carbon

- This is a measure of soil organic matter – organic matter improves soil structure (it helps bind sand and silt together), conserves soil moisture and releases nutrients as it decomposes. The carbon content of organic matter is about 62%.
- Less than 1% organic carbon in soil is low, while over 4% is high. Sandy soils on the Swan Coastal Plain normally contain less than 0.5% carbon.

Soil pH

- A pH of less than 7.0 is considered acid (the lower the number the higher the acidity), whereas a pH of greater than 7.0 is alkaline (the higher the number the greater the alkalinity).
- The optimum pH range for the growth of most plants is a pH_{Ca} of 5.0 to 6.5.
- Test pH in the topsoil (0–10 cm) and in the subsurface (10–20 cm). If soil pH is lower in the subsurface soil compared to the topsoil, a liming program must commence immediately as it can take 5 or more years before there is any noticeable pH increase in the subsurface after a topsoil application.

EC (electrical conductivity)

- EC measures the amount of soluble salts in the soil.
- Soil salt can affect plants in two ways – through a direct toxic effect and/or by reducing soil moisture availability.
- Soil salinity mainly results from natural processes of landscape evolution; however, salts can also be introduced to the soil through irrigation water and fertilisers. While sodium chloride (table salt) is generally the predominant salt, salinity can also be made up of many other salts (such as calcium, magnesium and potassium salts).
- It is advisable that a laboratory salinity test be sought if farm monitoring reveals the possibility that salinity levels may affect crop growth.

The international unit of EC is dS/m (deciSiemen per metre).
dS/m = milliSiemen per centimetre (mS/cm)

The units based on the direct measurement of total dissolved salts (TDS) are:
ppm (of TDS) = mg/L (of TDS)
dS/m x 640 = mg/L or ppm
dS/m = mS/m x 0.01.

A guide to the soil salt tolerance of some vegetable crops is shown in Table 1.

Table 1. A guide to the soil salt tolerance of some vegetable crops using EC_e measurements *[from Jarwal et al (2006)].*

Common name of vegetable	Scientific name of vegetable	Soil salinity (EC_e) threshold (dS/m) [a]	Yield reduction % per dS/m above threshold [b]	Salinity rating [c]
Artichoke	*Cynara scolymus*	6.1	11.5	MT
Asparagus	*Asparagus officinalis*	4.1	2.0	T
Bean	*Phaseolus vulgaris*	1.0	18.9	S
Beetroot	*Beta vulgaris*	4.0	9.0	MT
Broccoli	*Brassica oleracea*	2.8	9.1	MS
Cabbage	*Brassica oleracea* var. *capitata*	1.8	9.7	MS
Carrot	*Daucus carota*	1.0	14.1	S
Cauliflower	*Brassica oleracea* var. *botrytis*	2.5	Not available	MS
Celery	*Apium graveolens*	1.8	6.2	MS
Cucumber	*Cucumis sativus*	2.5	13.0	MS
Eggplant	*Solanum melongena*	1.1	6.9	MS
Garlic	*Allium sativum*	3.9	14.3	MS
Lettuce	*Latuca sativa*	1.3	13.0	MS
Onion	*Allium cepa*	1.2	16.1	MS
Pea	*Pisum sativum*	3.4	10.6	MS
Pepper	*Capsicum annum*	1.5	14.1	MS
Potato	*Solanum tuberosum*	1.7	12.0	MS
Pumpkin	*Curcurbita pepo pepo*	3.2	16.0	MS
Radish	*Raphanus sativus*	1.2	13.0	MS
Rockmelon	*Cucumis melo*	1.0	8.4	MS
Spinach	*Spinacia oleracea*	2.0	7.6	MS
Sweetcorn	*Zea mays*	1.7	12.0	MS
Sweet potato	*Ipomoea batatas*	1.5	11.0	MS
Tomato	*Lycopersicon esculentum*	2.3	18.9	MS
Turnip	*Brassica rapa*	0.9	9.0	MS
Zucchini	*Cucubita pepo melopepo*	4.7	9.4	MT

a *Level of soil salinity above which there is reduction in crop yield. (Note: all data is in EC_e – see Appendix 6.)*
b *Yield reduction (%) for every 1 dS/m above threshold.*
c *Salinity rating as given by relevant researchers (generally based on the level of yield reduction for every 1 dS/m of soil salinity above threshold): S = sensitive; MS = moderately sensitive; MT = moderately tolerant, and T = tolerant.*

Appendix 5: *Soil sampling technique*

[Thiagalingam (1996); McFarlin & Hegney (1997); Summers (2001); Summers & Rivers (2002); Hutchison (2002)]

Materials

- Soil auger or soil sampling tube (2 cm in diameter).
- Bucket to mix soil.
- Plastic bags (approximately 12 cm x 15 cm – needs to hold 500 grams of soil).
- Marker pens for writing grower name, bay number of soil being tested and date on bags.
- Soil record sheet to record information about the site.

Method

- **Locate sample site** – sample areas representative of the soil that the crop will grow in. If individual beds have different fertiliser histories, cropping sequences and/or soil types, take separate samples for each bed.
- **Scrape away surface litter**.
- **Take soil sample to 15 cm** (that is, the depth of the root zone of most vegetable crops) **using the soil auger or sampling tube**.
- **Take at least 20 to 30 soil samples in a zigzag pattern** (Figure 1) – avoid unrepresentative areas such as sprinkler lines, fence lines and sheds that may have had higher rates of fertilisers through spillage, traffic, etc. than the main area of the paddock.
- **Bulk core samples together** – thoroughly mix soil in the bucket and remove a sub-sample of approximately 500 grams into the labelled plastic bag.
- **Clean soil sampling tools and buckets** with water between sampling from different paddocks, to avoid cross-contamination of samples.
- **Have soil tested at an accredited laboratory** such as CSBP, the Chemistry Centre – if using other labs, be aware that they may use different chemical analysis techniques that will produce readings that vary from those of the standard tests used in Western Australia.

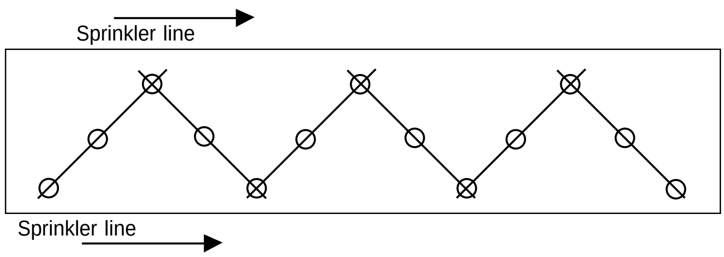

Figure 1. *Random sampling points arranged in a zigzag pattern.*

Appendix 6: *Measuring soil pH and EC*

Soil pH

[Hills & Miller (2000); Miller & Hills (2000)]

Soil pH can be measured in water (pH_w) or calcium chloride (pH_{Ca}). The latter is the most reliable method. A 1:5 mixture of soil to calcium chloride ($CaCl_2$) (0.01 molar (M)*), is used to estimate the pH. However, if a 0.01 M* solution of $CaCl_2$ is not available, a 1:5 mixture of soil to water (10 grams of soil with 50 mL water) can be used for measurement with the pH meter after shaking the mixture for 2 to 3 minutes and allowing it to settle for about 1 minute. A rough guide on how to convert pH_w to pH_{Ca} is to subtract 0.8 from the pH_w (although the real difference in pH at the extremes may be from 0.6 to 1.2).

A field pH kit can be bought from rural suppliers. Using it involves taking a small sample of soil, adding an indicator solution, coating this with barium sulphate powder and comparing the colour that develops with the calibrated colours provided.

The 1:5 mixture of soil to water can also be used for testing EC. However, EC must be tested **before** pH because the pH electrode contains potassium chloride, which may cause an over-estimation of the EC.

** To make a 0.01 M solution of $CaCl_2$, add:*

- *1.11 grams of anhydrous $CaCl_2$ to 1 litre of water,* ***or***
- *1.47 grams of dihydrate $CaCl_2$ to 1 litre of water.*

Soil EC

[Anderson & Cummings (1999)]

EC_e, which represents the EC of a saturated paste extract from soil, is more representative of field conditions than $EC_{1:5}$ (which estimates the salt content of soils using a 1:5 soil-to-water suspension), as it takes into account soil texture (the relative proportions of sand, silt and clay). However, this method is tedious, so to monitor EC_e in the field, $EC_{1:5}$ can be converted as outlined below.

To convert (approximately) the $EC_{1:5}$ to EC_e to take into account soil texture, the $EC_{1:5}$ value (in mS/m) can be multiplied by the following factors (approximate only), depending on soil texture.

- Sand 15
- Sandy loam 12
- Loam 10
- Clay loam 9
- Light/medium clay 8
- Heavy clay 6

Appendix 7: *Plant sampling*

Plant sampling technique is often the most limiting factor in a successful plant analysis program. Plant sap/tissue analysis should be conducted at an accredited laboratory (such as CSBP or the Chemistry Centre).

A number of steps can be taken to ensure good sampling technique.

- **The optimum time to sample is between 8.00 am and 3.00 pm and each sampling should take place at around the same time**. This is because nitrate-nitrogen can vary with time of day and prevailing conditions. Sampling immediately after rain or during damp conditions should be avoided because, although it is acceptable, extra care is required to prevent plant tissue from decomposing during storage. Heat or cold stresses should be noted when sampling, along with fertiliser and irrigation times and application rates if possible.
- **It is important that the correct leaf be sampled**. A large variation in nutrient concentrations exists among different parts on the same plant. When no specific sampling instructions are given (Table 1), the rule of thumb is to sample the most recently matured leaves (first fully expanded leaf), collected with petioles (leaf stalks) intact, from at least 20 plants. This will cover both plant and sap analysis. Young emerging leaves, older mature leaves and seeds are not considered suitable plant tissues for analysis since they do not ordinarily reflect the current nutrient element status of the whole plant. The recommended time to sample many plants is usually just prior to the beginning of the reproductive stage. Table 1 lists sampling instructions for vegetable crops.

Table 1. Specific sampling instructions for vegetable crops.

Crop type	Instructions for sampling
Asparagus	Sample from fern section or stems from top 20 cm of plant.
Cabbage	Sample recently matured leaf at centre of whorl.
Carrots	Sample youngest mature leaf at mid-growth period.
Cauliflower	Sample recently matured leaf at centre of whorl.
Lettuce	Sample recently matured leaf – take wrapper leaf.
Onion	Sample 20 whole plants – remove leaf tips and roots.
Pea	Sample leaves from third node from top.
Potato	Sample third to sixth leaf from growing tip – take whole leaf and not just leaflets.
Sweet potato	Sample third to sixth leaf from growing tip – take whole leaf and not just leaflets.
Sweetcorn	At tasselling, sample the ear leaves – for sampling before plants reach this height, send 30 whole plants.

- **A representative area in the field should be selected for monitoring and collecting samples randomly**. When monitoring the status of healthy plants, samples must be taken from a uniform area. If the entire field is uniform, one sample can represent a number of acres. If there are variations in crop growth stage, crop varieties, soil type, topography or crop history, multiple samples should be taken so that each unique area is represented by its own sample. Sampling from diseased or dead plants, or those that have insect or mechanical damage, should be avoided.
- **When problem-solving, separate samples should be taken from areas showing symptoms of deficiency/toxicity and an adjacent area in the field containing normal plants**. Sampling normal plants will provide a reference that helps with interpretation of the chemical analysis of the deficient plant sample.
- **A minimum of 20 plants should be sampled**. Usually, a minimum sample of 100 grams of fresh weight is required for plant tissue analysis and 3 mL of sap for sap analysis.
- **When the tissue sample is gathered in the field, a clean container should be used**. A plastic container or a paper bag works best. A metal container should never be used because it may contaminate the sample.
- **If the plant samples have soil, fertiliser, dust or spray residues on them they will need to be cleaned**. A dry brush works best, but for stubborn residues the samples should be wiped with a damp cloth or washed with distilled or de-ionised water. However, washing should not be prolonged because it can leach nutrients out of the plant tissue.
- **Samples should be air-dried in the shade**.
- **To prevent contamination, samples should then be placed into clean paper bags or envelopes**. Fresh plant tissue samples should never be placed in plastic bags for mailing, as such bags will not allow the samples to dry and they may decompose as a result.
- **For sound interpretation of the plant tissue analysis, it is important to provide crop information** – details such as crop type, variety, stage of growth (for example, flowering), age, irrigation (type and efficiency and water quality), symptoms (if any), soil type (if known) and history (such as previous crop problems, length of fallow, fertiliser application) should be included.
- **Samples should be kept cool and dry during transportation and not over-packed**, as compression will lead to deterioration of the sample.
- **Monitoring should continue** – for monitoring of plant nutrient status to be most effective, samples should be taken during the recommended growth stages for a specific crop. Samples should be taken weekly or biweekly during critical periods, depending on management intensity and crop value. However, to identify a specific plant growth problem, samples should be taken whenever a problem is suspected. Taking a soil sample in the same vicinity as the plant sample is recommended, as the soil test may help to interpret the plant tissue/sap analysis readings.

Appendix 8:
Optimum nutrient concentrations
at certain stages of the crop cycle for different crops grown on coastal sands

[Adapted from Phillips (1990); Sutherland & Waverley (1995); Burt & McKay (1999); McPharlin (2003c); Teasdale et al *(2001)]*

Nutrient	Unit	Optimum leaf concentration					
		Broccoli [C] Heads just visible	**Carrot** [C] (cv* Western Red) Summer sown: after 8 weeks' growth	**Cauliflower** [C] Heads just visible	**Onion** [A,C] Mid-growth stage	**Potatoes** [D] Largest tuber 10 mm in diameter	**Lettuce** [D] Throughout lifecycle
Nitrogen [B]	%	3.2–5.5	2.9–3.2	5.0–7.0	2.5–3.5	4.5–5.5	
Nitrate-nitrogen	mg/L or ppm						390–600
Phosphorus	% mg/L or ppm	0.3–0.7	0.4	0.5–0.7	0.25–0.40	0.8–1.1	 300–400
Potassium	%	2.0–4.0	3.0	3.0–3.7	2.50–5.00	10–16	
	mg/L or ppm						2000–3700
Calcium	%	1.2–4.0	1.4–3.0	1.0–3.0	1.50–3.50	0.5–1.5	
Magnesium	%	0.23–0.40	0.35	0.15–0.30	0.30–0.50	0.30–0.75	
Iron	mg/kg or ppm	50–200	50–350		230		
Manganese	mg/kg or ppm	25–200	40–100		20–100	20–100	
Molybdenum	mg/kg or ppm	0.4–3.0	0.5–1.5		0.1–1.5	0.1–1.5	
Boron	mg/kg or ppm	30–100	30–60	30–45	20–40	20–40	
Zinc	mg/kg or ppm	20–100	18–50	20–55	30–110	30–110	

* *cv = cultivar.*

A *Values are for onions grown on Victorian soils.*

B *Some plants (such as onions) accumulate very little nitrate in the leaves, so it is necessary to use total nitrogen rather than nitrate-nitrogen to evaluate the status of this nutrient.*

C *Tissue analysis of leaves (levels are a proportion of the dry weight of plant tissue).*

D *Petiole sap analysis.*

Appendix 9:
Collecting a water sample for nutrient analysis

[Anderson & Cummings (1999); de Hayr & Gordon (2003); Herbert (2004)]

Procedure

- Operate the irrigation system for 5 minutes.
- Rinse a clean plastic bottle (500 mL volume) or jar and its lid with the irrigation water. Soft-drink or chemical containers are not acceptable because residues are likely to remain in them, even if they have been washed out.
- After emptying the rinse water, collect a 200 mL water sample from the sprinklers and place the lid tightly on the container.
- Do not completely fill the container, as it may need to be frozen before analysis.
- The water sample should be forwarded promptly to a laboratory for analysis. Accredited testing laboratories can be found at the National Association of Testing Authorities, Australia (NATA) website at www.nata.asn.au. *Note: before sampling, the testing laboratory should be contacted to check whether any special procedures are necessary – examples of such procedures are given in Table 1.*

Table 1. Examples of specific sampling instructions for nutrient analysis of water.

Nutrient	Specific sampling instructions
Nitrogen *[Lantzke (1995)]*	Take a sample of at least 100 mL of water. Keep the sample cool and deliver it to the laboratory within a few hours. Frozen samples will last up to 4 weeks (fill the bottle to two-thirds of its volume only, to allow for expansion during freezing).
Sulphate	Collect and store as described for nitrogen.
Iron, manganese and other metals	For most metals, 5 mL of concentrated nitric acid is added per L of the sample, to act as a preservative.

pH

Although laboratory analysis will give an accurate reading of pH, it is simple for growers to monitor the pH of irrigation water themselves. Unlike the procedure for soil, no procedures for preparation of the sample are necessary and the water can be measured directly using a pH meter.

EC (electrical conductivity)

A laboratory analysis will accurately measure EC and provide the relative proportions of salts present in the water (such as sodium, calcium, magnesium and potassium salts). However, growers can monitor the total EC of their water with an EC meter.

Steps to monitor EC

- Ensure that the EC meter has been calibrated.
- Insert the probe in the water sample and move it up and down to remove bubbles from around the electrodes.
- Allow the probe to reach the temperature of the water before taking a reading.
- If the meter has automatic temperature compensation, wait about 30 seconds before taking a reading if the water and probe are about the same temperature (if the water is much colder than the probe, allow a longer period, approximately 2 minutes, before taking a reading) – make sure that the reading has stabilised.
- If the meter has no temperature compensation, take the temperature of the sample and use a correction table (usually provided with the meter) to get the right value.
- Read the display and record the result (see below).
- Rinse the probe with tank water and drain off any excess water between each sample and at the end of sampling for the day, to prevent salt build-up. (For optimum meter performance, clean the stainless steel electrodes periodically by rinsing in a pure alcohol such as methylated spirits for between 10 and 15 minutes.)

Collecting a water sample for biological analysis

Bacteriological content

A sample for bacteriological analysis should be collected in a sterile container supplied by the analytical laboratory. A minimum volume of 200 mL is required. The sample should be placed in cold storage immediately. Ideally, such samples should be analysed within 6 hours but certainly no longer than 24 hours after collection.

Algae

A 1-litre sample, preferably taken in an opaque bottle, is necessary for algae identification and cell count. The bottle, with about 25 mm air space left at the top, should be sealed and the sample should not contain thick ‘scum’ algae, as this makes the count inaccurate. If the sample can be delivered to a laboratory within 24 hours, it need only be kept in the dark and in cool storage (as in an Esky); otherwise, it must be refrigerated (preferably on ice but not frozen).

Appendix 10:
Comparison of nutrients in major fertilisers

Fertiliser	Cost ($/t): Perth 2005/2006 [a]	Nutrient component [b] (% by weight of nutrient)					
		N	P	K	S	Ca	Mg
Single superphosphate	200–245	–	8–9	–	11	20	–
Double superphosphate	410	–	17.5	–	3.5	16	–
Triple superphosphate	380–460	–	20	–	0–1.5	15	–
Phosphate rock	–	11–16	30–37	–	–	–	–
North Carolina rock	–	13.5	36	–	–	–	–
Wet process phosphoric acid	–	13	–	–	–	–	–
DAP (di-ammonium phosphate)	430–530	17.5	20	–	1–3	–	–
MAP (monoammonium-phosphate)	430–540	11.2	22.5	–	1.9	–	–
MAP (technical grade that is soluble)	940–1200	12	22.6	–	1–2	1–2	–
Ammonium nitrate ('Agran')	566	34	–	–	–	–	–
Ammonium sulphate/sulphate of ammonia	220–330	21	–	–	24	–	–
Calcium ammonium nitrate	470	21–27	–	–	–	8–14	–
Calcium nitrate	770	15.5	–	–	–	19	–

Potassium nitrate	1220	13.4	–	39	0.2	–	–
Muriate of potash (potassium chloride)	380–495	–	–	49.8	–	–	–
Sulphate of potash (standard crystal or fine grade is better than granular grade)	540–730	–	–	41.5	16	–	–
Magnesium sulphate (Epsom salts)	550	–	–	–	13	–	9.6
Magnesium nitrate	1440	10	–	–	–	–	9.3
Urea	360–495	46	–	–	–	–	–
Gypsum ($CaSO_4.2H_2O$)	–	–	22	–	–	0.4	17
Nitrophoska Perfekt	–	15	2.2	16.6	8.0	2.0	1.2
Entec Nitrophoska Blue Special	–	5.2	4.3	14.1	–	1.2	6
Elemental sulphur	–	–	–	–	90–100	–	–
Potato-E™	320	4	7	7	11	15	–
Summit-Spud™	–	6.9	10.2	10.2	8.0	1.8	0.9
Agras No. 1™	370	17.5	7.6	–	17	–	17
K-Mag™	825	–	–	18.6	22.5	0.1	11.5
Histart Granular™	845	11	12	7	10	–	4.3
Polyfeed™ High K	1980	12	2.6	32.3	–	–	–
Polyfeed™ standard	1880	19	8.4	15.8	–	–	–

a *These prices are a guide only;* b *Intended as a guide only – components may differ between products/manufacturers.*

Appendix 11: *Comparison of major fertilisers*

[Adapted from Burt (2001).]

Fertiliser	Main advantages	Main disadvantages
Ammonium nitrate	■ Quick-acting ■ Very high solubility (191 kg/100 L)	■ Needs special transport and storage arrangements ■ Higher salinity hazard than urea or sulphate of ammonia
Sulphate of ammonia	■ Decreases pH; therefore, suitable on alkaline soils ■ High solubility (71 kg/100 L)	■ Increases acidity of soils ■ If applied to recently limed soils, nitrogen loss is high ■ May increase tip burn and blossom end rot
Urea	■ 39% cheaper than ammonium nitrate, per unit of N ■ High solubility (105 kg/100 L) ■ Cheaper than ammonium nitrate ■ Not subject to the same storage and transport regulations as ammonium nitrate as it is not as classed as a ‘dangerous good’	■ May burn crops if applied at rates that are too high ■ Can cause soil acidification ■ Prone to leaching ■ Alkaline conditions stimulate the loss of urea as ammonium gas
Calcium ammonium nitrate	■ Suitable for acid soils ■ Not classified as a ‘dangerous good’ ■ Good alternative to ammonium nitrate as, of all the fertilisers, it most closely resembles ammonium nitrate	■ Not suitable for alkaline soils ■ Can only be applied by banding or broadcasting, as it contains calcium carbonate, which is insoluble
Calcium nitrate	■ Good solubility ■ Neutral effect on pH	■ Highly hygroscopic (absorbs water from air)

Triple superphosphate	■ Higher phosphorus content than single superphosphate but contains little sulphur	
Mono ammonium phosphate (technical grade, which is soluble)	■ Main phosphorus source used in fertigation ■ Better for germinating seeds and emerging seedlings than DAP because it contains less nitrogen	■ Ordinary grade is less soluble ■ Water high in calcium or magnesium will cause settling
DAP	■ High nitrogen and phosphorus content allows savings in terms of storage, freight and application	
Phosphoric acid	■ Mainly for trickle systems, as a fertiliser and cleaning agent	■ Corrosive acid
Muriate of potash (potassium chloride)	■ Fairly good solubility (35 kg/100 L at 20°C) ■ Cheapest source of potassium	■ Coarse particle size may cause blockages and pump wear ■ Slightly hygroscopic (absorbs water from air)
Potassium nitrate (standard crystal grade)	■ Ideal for supplying nitrogen and potassium by fertigation ■ Fairly good solubility (32kg/100 L) ■ Low salinity hazard ■ Used when chloride in muriate of potash may be detrimental to soils or leaves ■ Compatible in solution with calcium fertilisers	■ Needs to be dissolved in hot water during cold weather
Sulphate of potash (standard crystal or fine grade is better than granular grade)	■ Fair solubility (11 kg/100 L) ■ Used when chloride in muriate of potash may be detrimental to soil or leaves	■ More expensive than muriate of potash but use in fertigation is increasing ■ Needs to be dissolved in hot water during cold weather

Appendix 12:
Advantages and disadvantages of inorganic and organic fertilisers

[McConnell et al (2003)]

	Inorganic fertilisers	Organic fertilisers
Advantages	■ Nutrients are quickly available ■ Nutrients are concentrated ■ Nutrient content is consistent and known ■ Transport, handling and application are easy ■ Blends can be tailored to match needs ■ Timing of application can be flexible ■ Nutrients applied can be limited to only those required	■ Improve soil structure, texture and tilth ■ Improve moisture retention ■ Can control soil erosion ■ Can control weeds ■ Can have a effect similar to lime amendment ■ Increase nutrient availability ■ Can be a good single source of nutrients ■ Provide nutrients for several years after application ■ May lock-up off-target pesticide sprays ■ Increase populations of soil organisms ■ Increase nitrogen fixation
Disadvantages	■ Manufactured from non-renewable energy sources ■ Manufacturing process is very energy-intensive ■ No organic matter is added to the soil ■ May be hazardous to handle and apply	■ Slow release of nutrients can cause problems with nutrient leaching ■ Phosphorus can be supplied in a form that is more prone to leach than other forms of phosphorus ■ Difficult to transport ■ Composition can be highly variable and unpredictable ■ Increased likelihood of emissions of greenhouse gases ■ May can contain toxic metals (animal manures) ■ May be a source of pathogens (animal manures)

Appendix 13:
Poultry manure

Table 1. Advantages and disadvantages of raw poultry manure.

Advantages	Disadvantages
■ Inexpensive ■ Provides a wide range of plant nutrients ■ Good for soil conditioning (soil quality) ■ 3.0% to 4.0% nitrogen ■ Able to release nitrogen steadily over 4 to 6 weeks ■ Good for new land situations (soil conditioning) ■ Increases organic matter in soil ■ Makes use of a waste product	■ Breeding ground for stable fly ■ May compromise food safety – raw manure can contain human diseases ■ Nutrient balance inappropriate for crop production ■ Unused nutrients leach to groundwater ■ Use only permitted from June to August inclusive in stable fly-affected shires (Gingin, Wanneroo, Joondalup, Armadale, Kwinana, Cockburn, Rockingham and Murray) – however, can be used elsewhere all year ’round ■ High nitrogen levels potentially reduce soil carbon, as biological activity is increased, accelerating the conversion of organic carbon to carbon dioxide ■ May introduce weed seeds and/or pathogens ■ May contain large amounts of soil, straw, sawdust or wood chips ■ Composition can be variable

Table 2. Advantages and disadvantages of alternatives to raw poultry manure.

Type of manure	Advantages	Disadvantages
Conditioned (composted) poultry litter	■ Eliminates human pathogens ■ Stable fly will not breed in it ■ Can be used all year 'round	■ Less nitrogen (3% as compared to 3.5–4.5%) ■ Nitrogen less available ■ Price is higher (similar to that of compost)
Compost	■ Stable fly will not breed in it ■ Can be used all year 'round ■ Weed seeds are made non-viable ■ Has a low carbon-to-nitrogen ratio (improves nitrogen availability) ■ Increases soil nitrogen and carbon, improving soil structure and fertility	■ 1–1.5% nitrogen ■ Nitrogen less available than in conditioned poultry litter ■ Price is higher
Pelleted products	■ Similar or higher nitrogen levels compared with raw poultry manure ■ At recommended application rates, fly breeding is acceptable ■ Can be used all year 'round ■ Contains known nutrient ratios ■ Does not introduce weed seeds and pathogens ■ Easier to apply than raw manure	■ Time required for pellets to physically break down may reduce nutrient availability ■ The process of pelletising manure can be energy-intensive ■ Most expensive
Fertiliser nitrogen	■ Can control nitrogen application levels ■ Stable fly will not breed in it ■ Can be used all year 'round	■ Water soluble, so easily leached

Appendix 14: *Fertiliser application*

Benefits/limitations of different application methods

[Hutchison (2002); Harris (2006); Lantzke & Calder (2004)]

The benefits and limitations of various methods of fertiliser application – including banding, broadcasting, fertigation, boomspray, drip irrigation and foliar applications – are shown in Table 1.

Table 1. Advantages and limitations of various fertiliser application methods.

	Advantages	Limitations
Banding	■ High rates of fertiliser can be accurately placed when the crop has a rapidly increasing demand for fertiliser ■ Granular or bulky organic fertilisers can be used ■ Produces higher yields than broadcast applications at lower application rates ■ Allows the use of solid fertilisers that do not dissolve in water – organic and inorganic fertilisers can be applied ■ Reduces wastage by applying fertiliser to the root area only ■ Suitable for distributing solid fertilisers	■ Fertilisers are prone to volatilisation (particularly manures, urea or ammonium nitrate, so the fertiliser needs to be incorporated soon after application by way of irrigation or tillage to prevent/reduce volatilisation) ■ Likelihood of nutrient run-off and leaching is increased ■ Requires higher labour input and more fuel than fertigation ■ Uniformity of application can be poor ■ Placement often not suitable for young crops (may damage crops or be placed too far from roots) ■ Not suitable for use after row closure
Broadcasting	■ Granular or bulky organic fertilisers can be used ■ Solid fertilisers that do not dissolve in water can be used – thus, both organic and inorganic fertilisers can be applied ■ Relatively fast to apply ■ Fertiliser can be applied after row closure, when access to roots is often best	■ Inefficient, as placement is erratic and widespread ■ Higher rates of fertiliser required than for other methods ■ Produces lower yields from same rates of fertiliser used in banding (in some cases) ■ Fertilisers prone to volatilisation ■ Increased likelihood of nutrient run-off and leaching ■ Fertiliser applied to areas outside the root zone is wasted ■ Requires higher labour input and more fuel than fertigation ■ Uniformity of application can be poor ■ Granules can lodge in leaves, causing burning

Table 1. Advantages and limitations of various fertiliser application methods *(cont)*.

	Advantages	Limitations
Fertigation	■ Savings in terms of fuel, equipment, labour and fertiliser ■ Greater accuracy of application ■ Smaller and more frequent applications possible ■ Quick absorption of nutrients by plants ■ Less leaching, because nutrients are applied in small quantities and often ■ Less burning because fertiliser is diluted ■ Nutrients can be applied when conditions are too wet for tractors ■ Less mechanical damage to crops ■ Effective method of applying top-dressings of nutrients to crops, especially once the rows have closed over	■ Uniformity in irrigation system required ■ Erratic application in windy conditions ■ Fertilisers may settle and block or corrode the irrigation system ■ Only soluble fertilisers can be used ■ Bacterial and algal slimes that grow on nutrients may block the system ■ Weed problems may be greater ■ More water may need to be applied ■ Overdosing of crops with mixed maturities can occur ■ Disease problems may be higher when sprinklers are used ■ Only limited rates of application possible with boom or sprinkler spraying, to avoid foliar damage ■ Precision timing required to achieve uniform coverage without excessive leaching
Boomspray	■ Applies soluble fertilisers more efficiently than fertigation ■ Suitable for situations where sprinkler layout results in poor uniformity of distribution ■ Increases accuracy compared to other methods of fertiliser placement in windy conditions ■ Less spray drift ■ Suitable for application to young crops	■ Sprayer must be adjusted and calibrated to suit different canopy types and sizes ■ Only relatively low rates of fertiliser application possible without wash-off to avoid crop damage ■ If high rates of fertiliser are applied, this must be done with sprinklers activated

Table 1. Advantages and limitations of various fertiliser application methods *(cont)*.

	Advantages	Limitations
Drip irrigation	■ Allows high frequency of irrigation, thereby maintaining optimum soil moisture content in the root zone ■ Irrigation possible regardless of wind conditions ■ Lower pressures generally required, as well as lower flow per unit area, so smaller mains and laterals necessary ■ Maintains soil surface structure more effectively than do other types of irrigation ■ Less labour required to operate ■ Less water lost due to soil surface evaporation ■ Travel for field operations such as spraying and harvesting is unrestricted ■ Crop foliage remains dry, leading to a reduction in foliar diseases, reduced loss of applied pesticides and less leaf burn where saline water is used for irrigation ■ Effect of saline irrigation water on crops reduced as there is no foliage absorption of salt ■ Water with a higher salt content can be used, as evaporation losses are minimal ■ Allows more efficient use of nutrients, with less risk of nutrient leaching	■ High DU easily destroyed through emitter clogging ■ Salts accumulate at the wetting front ■ Uniformity in irrigation system required ■ Only soluble fertilisers can be used ■ Overdosing of crops with mixed maturities is possible ■ On sandy soils, irrigation scheduling must be precise and frequent, to avoid large fertiliser losses due to poor wetting pattern of drip ■ The row lengths necessary to minimise variation in output are relatively short
Foliar application	■ Applies nutrients directly to foliage ■ Useful for applying micro-nutrients and correcting minor deficiencies ■ Can be applied concurrently with fungicides or pesticides ■ If soil conditions are unfavourable, trace elements applied to soil will be bound before the plant can utilise them – foliar applications bypass this problem	■ Fertiliser must be soluble ■ Fertiliser can be washed from the foliage by rain or irrigation applications ■ Costs for labour and fuel are higher than for fertigation ■ Application must be when evaporation is low ■ Not all nutrients can be supplied this way – soil applications should provide over 90% of the quantity of each major nutrient ■ Leaf area must be large enough to intercept sufficient spray

Note: spray droplets from spray equipment can vary in size from 50 to 550 µm. Optimum droplet size is generally between 70 and 250 µm, as this provides a good balance between reducing drift and achieving effective canopy penetration. Nozzle type, wear and pump pressure can all affect droplet size.

Type of application/fertiliser placement

[Phillips & Hawson (1986); Burt (2001); Poffley (1995); Jarvis et al *(1996); Mason* et al *(1996); McPharlin & Hegney (1997); Hills & Miller (2000); Penny & Miller (2000b); Francis* et al *(2001); McPharlin (2001); Phillips* et al *(2001); McPharlin (2003b); Incitec Pivot (2004a)]*

The type and quantity of fertiliser to be applied, as well as the crop growth stage, will affect the method of application of fertiliser (Table 2). Excess fertiliser applied in the wrong place, at the wrong time or in the wrong form can easily leach or be washed into groundwater. In order to minimise the loss of fertiliser into the environment, as much of the applied fertiliser as possible should be taken up by the crop. Most vegetable crops are fast-growing but lack extensive root systems. Therefore, to ensure that the crop makes maximum use of the fertiliser, application must be accurate in terms of rate and placement. Banding or dropping and incorporating fertiliser close to plants, using an accurately calibrated fertilising or planting implement, are the best methods of pre-plant fertiliser application on most soils apart from light sands.

Table 2. Methods of fertiliser application and their suitability to crop age.

	Most suitable crop age
Banding	Older crops when leading up to row closure, as the root system can use fertiliser placed between rows
Broadcasting	Pre-planting and young, direct-sown crops (avoids fertiliser granules lodging in leaf axils)
Fertigation and boomsprayer	All crop ages, but tends to be used more often after row closure
Foliar fertilising	Later in the crop's life – usually after about 3 weeks of age when leaf area is sufficient to intercept the spray
Boom spray	Best for established seedlings of transported crops up to 28 days after planting

- **Element mobility must be considered**. Potassium and nitrogen are very mobile and require only surface placement. However, the trace elements copper, zinc, molybdenum and manganese are very immobile and must be placed below the soil surface so roots can reach them.
- **If fertilisers come into contact with crop seed, this can delay or reduce germination**. The effect is usually due to a high concentration of salt from dissolved fertiliser around the seed, with soluble nitrogen fertilisers having a greater effect than the less soluble phosphate fertilisers. If banding at seeding, the toxic effects on germination can be avoided by banding fertilisers away from the seed or by topdressing (approximately 5 cm away from seed).
- **Nitrogen fertilisers should never be banded below the seed** as they leach easily.
- For brassica crops, fertilising via an implement mounted on the planter to measure the fertiliser accurately and incorporate it into the seed-bed (strip incorporation) is better than banding.

Broadcasting

- **Fertiliser should be cultivated or watered into the surface soil** soon after spreading when using this method. However, a full irrigation is not recommended, as a proportion of the nutrients may be leached below the root zone. It is preferable if a full irrigation occurs before the fertiliser is spread, followed by a light top-up irrigation after spreading. Care must be taken to ensure enough irrigation after broadcasting to fully dissolve the fertiliser granules and wash them off the foliage; otherwise, the foliage may be damaged.
- **Always incorporate, or 'wash in', ammonium sources of nitrogen** because nitrogen can be lost to the atmosphere as ammonia gas (volatilisation) if applied to the soil's surface without any incorporation. This is particularly the case on alkaline soils. All the nitrogen in urea and ammonium sulphate, and half of that in ammonium nitrate, is subject to volatilisation.
- **Phosphorus-containing fertilisers can be effectively applied to light and sandy soils by broadcasting before planting**. Coastal sands with a yellow sub-soil are usually suitable for pre-planting application, whereas soils with a white sub-soil are not. On the latter soils, low-solubility phosphorus fertilisers may be more efficiently applied by broadcasting up to row closure. Where phosphate must be applied later than this, broadcasting is rarely suitable and a soluble form of fertiliser such as mono-ammonium phosphate may be used in trickle or low-volume systems, adjusting the nitrogen rates accordingly.
- **Lime is applied by topdressing the block before planting or between crops, followed by its incorporation into the top 10 cm of soil, or deeper**. Lime has a low solubility, so mixing it with soil increases the rate of reaction. It must be physically in contact with moist, acid soil for the acidity to be neutralised. Higher rainfall means a faster lime reaction.

Fertigation

- With fertigation, soluble fertilisers that supply essential nutrients to vegetables are distributed through sprinkler or trickle irrigation systems or by a boomspray.
- **Fertilisers for fertigation must be water-soluble, must not react adversely with other fertilisers or salts in the irrigation water and should contain low levels of chloride**. The following rules of thumb are useful in determining the solubility of fertiliser salts in water, although there may be exceptions:
  - **ammonium, nitrate, potassium, sodium and chloride salts** (for example, calcium nitrate) **are soluble**;
  - **oxides, hydroxides and carbonates** (for example, calcium carbonate and magnesium carbonate) **are insoluble**;
  - **all sulphates are soluble, apart from calcium sulphate** (that is, gypsum).

Water quality and having other fertilisers in the solution may affect the solubility of some fertilisers. Usually, solubility is reduced when two or more fertilisers are dissolved together. An exception is urea and ammonium nitrate; when the two are together in solution, solubility is enhanced. (For more on preparing fertilisers for fertigation and fertiliser solubility, refer to the section that follows.)

Never mix the following or the fertilisers will precipitate (settle out) and block the system.

- Fertilisers containing calcium with sulphates or phosphates (in other words, do not apply calcium nitrate with magnesium or potassium sulphate).
- Phosphoric acid with fertilisers containing calcium or magnesium, or phosphoric acid with copper, iron, manganese and zinc sulphates.
- Nitrogen with the disinfectants calcium hypochlorite and sodium hypochlorite (used for controlling algae, bacteria and fungi in trickle irrigation systems) or chloroamines, which are toxic, will form.

- **Fertiliser is applied in the final stages of irrigation**, so most of it is retained within the rooting zone of the plant.
- **Fertigation is followed by the application of water for 2 to 5 minute**, to wash the fertiliser off the plants and into the soil, and to flush irrigation pipes and valves (fertilisers are corrosive).
- **Fertigation can be used to apply nutrients to leaves** (foliar fertilising), in which case the nutrients are absorbed into the plant by the leaves. This is best done by spraying suitable products rather than by application through a sprinkler system. However, because plants are adapted to feeding through their roots and also because the surface of leaves is waxy, plants cannot take up nutrients quickly by this means. Further, a high concentration of nutrient solution may burn the leaves or reduce the efficiency of any pesticides applied (they are often applied with fertigation). Solutions containing chloride and ammonium are among those most likely to burn plant foliage, the latter more so if the water is alkaline. Foliar fertilising is most suitable for correcting proven deficiencies, especially in magnesium and trace elements. Although identification of the deficiency, followed by spraying with the correct nutrient, may correct the problem, with some trace elements (such as iron and zinc) by the time the deficiency is visible it may be too late to correct.

Calculating the amount of product per tank

$$\text{Amount of product/tank} = \frac{\text{recommended rate per 100 L x tank capacity (L)}}{100}$$

$$\text{Amount of product/tank} = \frac{\text{recommended rate/ha x tank capacity (L)}}{\text{Output of sprayed (L/ha)}}$$

Boomspraying as an alternative to sprinkler fertigation

- **Recommended when the uniformity of the irrigation system is low** or in windy areas where wind speeds reduce sprinkler distribution uniformity to unacceptable levels.
- **After nutrient application, sprinklers need to water the crop for 2 to 5 minutes** to wash the fertiliser from the leaves and into the soil. Fertilisers for boomspray application should be mixed using the same guidelines as for fertigation. Fertilisers containing nitrite, such as potassium nitrate, are relatively safe to spray over foliage without wash-off at rates of up to 40 grams per litre.

Foliar fertilising

- Urea in the low-biuret form (less than 0.4% biuret), potassium nitrate and a range of minor elements in sulphate and chelate forms can be used for foliar application. In many cases, it is safer to apply these without wetting agents at recommended rates, but for crops with waxy or upright leaves – such as brassicas and onions – a 'soft' wetting agent such as Agral 600® may be needed for the product to adhere to the foliage.
- **Never apply foliar fertilisers when plants are under stress** (for example, when they are in need of water or during the heat of the day).

Preparation of fertilisers for fertigation*

Some fertilisers may require stirring in the tank or initial dissolving in hot water. Fertilisers must **not** be added to the tank until it is half full.

The solubility of fertilisers in water varies. As a guide, aim for no more than 50% of the maximum solubility of a fertiliser in water (Table 3) when preparing fertiliser solutions. Good agitation and a fine particle size will allow a fertiliser to dissolve more quickly, although the maximum solubility of a given fertiliser in water does not change. Nitrate fertilisers (for example, urea, ammonium nitrate, potassium nitrate and calcium nitrate) are endothermic, meaning that when dissolved in water they cause the temperature of the solution to fall. This makes it harder to dissolve such fertilisers, as solubility is reduced in cold water.

Mixed fertilisers, while occasionally applied through sprinkler irrigation systems, are not applied through trickle irrigation systems. This is because mixed NPK fertilisers are more expensive than individual nutrients, have low solubility and may cause blockages in the irrigation equipment. Nitrophoska Perfect (15% nitrogen, 2.2% phosphorus, 16.6% potassium and 1.2% magnesium plus trace elements) is the most soluble NPK fertiliser and the one used most for fertigation. A compatibility chart for common fertilisers used in fertigation is shown in Table 4.

***Not all fertilisers are suitable for fertigation due to their **insolubility**.*

Table 3. Solubility of some commonly used fertilisers.

Chemical Name	Maximum solubility in water (kg/100 L @ 20°C)
Urea	105
Ammonium nitrate	192
Ammonium sulphate	75
Monoammonium phosphate	37
Monopotassium phosphate	23
Superphosphate	2
Potassium chloride	34
Potassium nitrate	32
Potassium sulphate	11
Calcium nitrate	129
Magnesium sulphate	71
Zinc sulphate	44

Table 4. Compatibility chart for common fertilisers used in fertigation *[Agritopic (2004)].*

	Urea	Ammonium nitrate	Ammonium sulphate	Monoammonium phosphate	Monopotassium phosphate	Potassium nitrate	Potassium sulphate	Potassium chloride	Calcium nitrate	Magnesium sulphate	Copper, iron, manganese or zinc sulphate	Metallic chelates	Sodium molybdate
Urea		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ammonium nitrate	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Ammonium sulphate	✓	✓		✓	✓	✓	✓	✓	x	✓	✓	✓	✓
Monoammonium phosphate	✓	✓	✓		✓	✓	✓	✓	x	x	x	✓	✓
Monopotassium phosphate	✓	✓	✓	✓		✓	✓	✓	x	x	x	✓	✓
Potassium nitrate	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Potassium sulphate	✓	✓	✓	✓	✓	✓		✓	x	✓	✓	✓	✓
Potassium chloride	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Calcium nitrate	✓	✓	x	x	x	✓	x	✓		x	x	✓	x
Magnesium sulphate	✓	✓	✓	x	x	✓	✓	✓	x		✓	✓	✓
Copper, iron, manganese or zinc sulphate	✓	✓	✓	x	x	✓	✓	✓	x	✓		NR	✓
Metallic chelates	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	NR		✓
Sodium molybdate	✓	✓	✓	✓	✓	✓	✓	✓	x	✓	✓	✓	

✓ *= compatible; X = incompatible (precipitate will form); NR = not recommended.*

Note: fertilisers should be checked for insoluble impurities before use, because if such impurities are present they will block filters, nozzles and emitters.

Appendix 15:
Care of equipment

Equipment calibration *[Price* et al *(1997); Fromm (2003)]*

As discussed in the chapter on Nutrition management, all fertiliser spreaders (including boomsprays, fertigation equipment, spreaders and broadcast machinery) require careful calibration and must be recalibrated each season, as the products they distribute change in size and/or consistency each year. In addition, wear and tear on machinery will affect spreading rates from season to season, even if the same product is put through the machine each time. Most machinery comes with detailed manufacturer's instructions regarding calibration and maintenance. It is important to keep good records of same, in order to identify problems and ensure regular equipment calibration and maintenance.

Calibrating spreaders or row crop planters

Information from manufacturers on the settings required to apply a selected quantity of fertiliser using their equipment is generally fairly accurate. To check the calibration of combines or row crop planters, take the following steps.

- Place some of the fertiliser to be used in the box.
- Tie bags over the fertiliser tube outlets so that all fertiliser going down the tubes is collected.
- Drive the machine over a measured minimum distance of 100 metres while releasing fertiliser.
- Remove the bags and weigh each individually, to determine the average amount collected.

Any tube that releases at least 5% more or 5% less than the average needs to be recalibrated.

The rate of fertiliser emitted by spreaders, combines or row crop planters can be determined by totalling the weight of all fertiliser collected in the bags (in kilograms), then measuring the total width covered by the fertiliser box (in metres) and applying the following formula.

Nutrient applied (kg/ha) =
weight of fertiliser collected (kg) x 10,000
÷ **distance travelled (m)**
x **width covered by fertiliser box (m)**

For example, if 6.54 kilograms of a fertiliser were collected from a 4-metre combine over 100 metres, then:

Nutrient applied (kg/ha) =
6.54 x 10,000
÷ 100
x 4 = 163.5 kg/ha.

It is important to remember that spreader widths will vary with bare ground and crop height, so the effective spread width should be measured. This is because large particles spread further than small ones. Therefore, an overlap may have to be allowed for.

Calibrating boomsprayers

The nozzle tips on boomsprayers are constructed from various materials, so rate of wear will vary accordingly. A brass tip may only last 5 to 10 hours when wettable products are used, whereas harder tips may last more than 50 hours using the same product. All nozzles should be calibrated once every 50 hours and, where there are variations of more than 10% from the average, they need to be replaced. Spray patterns should be checked at regular intervals, as should the cause of any irregularity. Calibrating the boom involves the following steps.

- Set the pressure to the required level.
- Using a measuring cylinder, measure the output (in mL) per nozzle for 60 seconds. Any nozzle that varies by more than 10% from the average should be replaced. Make note of the average output (**V** mL).
- Measure a distance of 100 metres in the field to be sprayed. Record in seconds (**T** sec) the time that it takes to travel this distance (repeat at least three times, using the same tractor and travelling at the same speed) and average the results.
- Measure the distance (in cm) between nozzles (**D** cm). Output, expressed as L/ha, can now be calculated using the following formula.

Boomspray output (L/ha) = **V** x **T** ÷ **D** x **6**

For example, let us say the boomspray nozzles have an output of 700 mL/minute, the time taken for the tractor to travel 100 metres is 36 seconds (8 kilometres per hour) and the distance between nozzles is 50 cm.

Boomspray output (L/ha) = **700** x **36** ÷ **50** x **6** = **84 L/ha**

Note: if low volumes of water are used, nozzle angles should be increased. If water volumes are greater than 50 L/ha, use 80° or 100° nozzles. A nozzle of 80° produces larger droplets and is good for applying fertilisers to bare ground. However, when applying foliar nutrients 110° is preferred, as the smaller droplets produced are less likely to drip off the leaves.

Maintenance of equipment

[Burt (2001); Incitec Pivot (2004a,b)]

- **Fertilisers are corrosive** (nitrate more so than most), so most mixing tanks should be made from polypropylene, fibreglass or stainless steel. Mixing tanks constructed from mild steel, phospho-bronze or yellow brass should be avoided, and stainless steel fittings should be used wherever possible.
- **Machinery and metering devices should be thoroughly cleaned following fertiliser application** – sufficient water should be poured through to dissolve and remove any fertiliser particles or residues. This must be done immediately after use, to prevent residues drying out on filters and in nozzles. Moreover, equipment should be cleaned in an area where collection of run-off is possible. Spray mixture should not be left in a unit overnight.

- **Water should be applied to equipment for 2 to 5 minutes after fertigation**, to prevent damage from nutrient deposits that may corrode lines and equipment, as well as causing blockages. Urea in particular can clog the system if not flushed out. Leaving fertiliser in the lines also encourages algal growth.
- **Before any repairs are undertaken, thorough washing/cleaning of machinery is essential, to remove build-up, deposits and caking**. Within machinery, fertiliser dust may come into contact and mix with oils and lubricants. Fertiliser can also build up in confined spaces (such as around shafts and bearings). When hot repair work (such as welding, cutting or straightening) is undertaken on machinery that has been used to handle or apply nitrate fertilisers, extreme care must be exercised – particularly when welding on the hollow shafts of screw conveyors, augers and applicators.
- **Before equipment is calibrated**, the function of pumps, bypass valves, taps and the pressure gauge should be checked, along with the cleanliness of the filters (which should be of the right type), hoses and the tank. In addition, all connections should be checked for leaks.

Appendix 16:
Correct fertiliser storage

Fertiliser storage

[Hutchison (2002); Penny & Gartner (2002;) Incitec Pivot (2004b)]

The following points outline good fertiliser storage practices.

- All fertilisers should be stored in covered field binds or sheds, to keep them dry and prevent contact with the ground, thereby preventing run-off or leaching.
- Bagged fertiliser should also be stored in a covered shed with a sealed floor.
- The property should be fenced and secured, to prevent unauthorised access.
- Stocks of fertilisers, manures, pesticides and soil amendment materials should be kept to the minimum required.
- Storage areas/facilities need to be weather-proof, to prevent run-off.
- Fertilisers should not be stored near heat sources (such as open flames, steam pipes and radiators) or other combustible materials (such as flammable liquids).
- Fertilisers must not be stored with urea.
- In a fire, the fertiliser storage area should be flooded with water.
- Empty fertiliser bags should be disposed of appropriately.
- All oxidising agents (such as potassium nitrate and ammonium nitrate) must be stored in accordance with **Australian Standard AS 4326-1995 (The storage and handling of oxidising agents)**. Stores that carry oxidising agents in amounts above a certain quantity must be placarded and display the Hazchem Code, UN Number and Dangerous Good Class 5.1 oxidising agent diamond. In addition, such a property should be fenced and secured, to prevent unauthorised access.

Nitrogen fertilisers

- **Typically, nitrate fertilisers such as urea and granulated ammonium sulphate do not store as well as other nitrogen fertilisers**. This is because they readily absorb moisture from the atmosphere, which affects methods of handling and storing them.
- **Nitrate fertilisers must not be carried or stored near substances that carry a fire risk** (such as fuel, hay, grain, agricultural chemicals and timber), as heat from a fire causes nitrate fertilisers to release oxygen, adding to the fire's intensity.
- **Storage facilities for nitrates should be constructed from materials of low flammability and must be dry and well-ventilated**. If wooden pallets are used, these must be of hard-wood. Concrete floors are recommended; however, ammonium nitrate may react with the calcium compounds in concrete to form calcium nitrate and calcium nitrate aluminate. This can leave the surface of the concrete pitted and pot-holed. An epoxy coating can be used to protect

concrete in areas not subject to heavy traffic. Asphalt floors are more resistant to corrosion but should contain no more than 7% bitumen as a binder.

- **Solid fertilisers containing ammonium nitrate should NOT be stored in areas exposed to direct sunlight or under tarpaulins** (which may cause degradation of the product). Instead, they should be kept in a cool, shaded indoor area.

Lime

Storing lime correctly is essential as good-quality lime contains fine and very fine particles that can easily blow away. The methods described below are not suitable for long-term storage of lime.

- **Artificial stabilisers**: Crustex® and Gluon® can be mixed according to their manufacturers' guidelines and sprayed onto lime heaps. Generally, to cover a 100-tonne lime heap, 20 L of Gluon® mixed with 400 L of water, or 20 L of Crustex® to 300 L of water, can be used.
- **Fertiliser**: a mix of an ammonium-based fertiliser and water, at a rate of one part fertiliser to five parts water, can be sprayed onto lime heaps. If the ratio of fertiliser used is less than that recommended, the crust that forms on the lime heap will not last as long. In general, the greater the concentration of fertiliser in water, the longer the heap will remain stabilised. To cover a 40-tonne lime heap, 60 kg of fertiliser should be mixed with 300 L of water, while for a 100-tonne heap, 120 kg of fertiliser mixed with 600 L of water will be necessary. Trials using ammonium-based fertilisers such as Agras® and ammonium sulphate have shown that these products stabilised lime heaps the longest, with the fertiliser crusts lasting from 6 to 8 weeks, despite being subjected to, on average, 14 kilometre per hour winds at Jurien Bay.
- **Ground holes**: lime can also be stored in holes in the ground, provided they are large enough and that the lime is easily removable.
- **Straw/hay bunkers**: three-sided bunkers constructed of hay or straw bales, with the open side facing away from prevailing winds, are also suitable for lime storage. Lime stockpiled inside the bunker can be covered with tarpaulins to prevent wind erosion.
- **Tarpaulins** can also be used to cover lime heaps.

Poultry manure

If the moisture levels in poultry manure are incorrect it should not be stored in large piles, as it will heat up and lose nitrogen and organic matter. If this occurs, the litter will appear blackened or have an ashy grey colour. In extreme situations, large piles of poultry manure have been known to ignite by spontaneous combustion. Stacks of poultry manure should be no more than 1.8 metres high. (If in doubt, consult the guidelines for stable fly management, as well as local shire regulations for the storage of poultry manure.)

Stock records

All fertiliser deliveries and usage should be recorded and regular stock checks carried out. With good records you always know what is on hand. Some growers buy fertiliser as they require it, negating the need for a large storage area and reducing the risk of contamination.

Appendix 17:
Coefficient of uniformity and distribution uniformity

[Hutchison (2002)]

It is important that a sprinkler system applies water evenly, so that all areas of a crop receive similar amounts of moisture and nutrients. However, it is not possible for all areas to receive exactly the same amount of water. 'Sprinkler uniformity' is the term used to describe how evenly water is applied by overhead irrigation.

Sprinkler pressure and nozzle size (addressed in the March 2006 issue of *WA Grower*) are two important factors affecting sprinkler uniformity. Others include sprinkler type, sprinkler and lateral spacing, and wind strength and direction.

Sprinkler uniformity is described mathematically by the simple terms ' coefficient of uniformity' ('CU') and 'distribution uniformity' ('DU'). The uniformity of an irrigation system can be measured using catch containers placed in a grid pattern between sprinklers and laterals to measure application rates, with the measurements subsequently used to calculate the CU and DU.

Accepted international design standards for irrigation uniformity are a CU greater than 85% and a DU greater than 75%. The easiest way to describe these measurements is as follows: **the higher the CU or DU, the greater the area receiving the average amount of water and the smaller the area being over- or under-watered**.

Testing sprinkler uniformity involves placing a grid of evenly spaced catch cans or rain gauges between sprinklers. Around 20 to 25 cans is enough, but more will give a clearer indication of the pattern of irrigation and how even it really is. To conduct the uniformity test, the irrigation system should be run for at least 20 minutes, with the amount of water (measured in millimetres) that has collected in each can then determined (see Figure 1). If rain gauges are used, the measurements are easily visible on the side. If catch cans with straight sides that don't taper in or out are used, then a metal rule is suitable for measuring the depth of the water. Alternatively, a measuring cylinder can be used to measure the volume of water, with the depth then calculated from this.

Figure 1. An example of catch-can readings from a uniformity test.

4	3	8	6	4
5	6	7	3	3
6	6	9	4	3
5	5	6	5	4
4	4	6	4	4

Calculating uniformity

Step 1. Divide the number of cans (25 in the example in Figure 1) by 4 (to calculate 25%, or a quarter, of the total):

25 ÷ 4 = 6.25.

If you don't get a whole number, round down to the closest whole number (here, 6).

Step 2. Put the catch can readings in order from lowest to highest, or circle the lowest 25% of values:

3, 3, 3, 3, 4, 4, 4, 4, 4, 4, 4, 4, 5, 5, 5, 5, 6, 6, 6, 6, 6, 6, 7, 8 & 9.

Step 3. Calculate the average of the lowest 25% of catch can readings (in this case 6) by adding up the first six readings (values) from the numbers you have put in order from lowest to highest, or the six values circled, then divide them by the number of cans in the lowest quarter (in this case 6). So:

3+3+3+3+4+4 = 20, and 20 ÷ 6 = **3.34** *(write this number down).*

Step 4. Add up all the values and divide them by the number of cans or rain gauges used, to arrive at the average amount of water applied during the test. So:

3+3+3+3+4+4+4+4+4+4+4+4+5+5+5+5+6+6+6+6+6+6+7+8+9 = 118, and 118 ÷ 25 = **4.72** *(write this number down).*

Step 5. The DU is the average of the lowest 25% of applied depths divided by the average of all the applied depths. So, in the example above, the DU is:

3.34 ÷ 4.72 x 100 = **70.7%.**

As the DU in this example falls below the internationally accepted standard mentioned earlier, the system requires improvements to achieve a DU of greater than 75%.

Because conditions will differ each time a uniformity test is conducted, it is important that details of the conditions in which a test was run are recorded, and that the same test is repeated in a range of conditions. The aim is to have a system that is uniform in most conditions.

Calculating a figure for CU is slightly more complicated (see Table 1) but, if necessary, local DAFWA irrigation officers can assist.

Table 1. Calculating DU, CU and sprinkler application rate *[adapted from McConnell* et al *(2003); Hutchison (2002)].*

	DU	CU	Application rate
Definition			
	The percentage of the average of the lowest 25% of the application rate compared to the average application rate of the sprinklers.	This is an estimate of the uniformity of the sprinkler pattern based on the average of the entire area.	The amount of water applied for a given length of time.
Accepted standard			
	Greater than 75%.	Greater than 85%.	
Formula			
	DU = (average lowest 25% of applied depths) / (average of all applied depths x 100)	CU = 1 – (average deviation of all applied depths) x 100 / (average of all applied depths)	
	1. Work out how many cans make up 25% of those used. 2. Add the lowest quarter, or 25%, of applied depths. 3. Calculate the average of the lowest quarter of applied depths. 4. Calculate the average depth of water of all the cans. 5. Divide the lowest quarter average by the average of all the readings and multiply by 100.	1. Using a calculator or computer, work out the average deviation of all applied depths (in Micro-soft Excel, if all values are put into column A, this might appear as =AVEDEV(A1:A25). 2. Work out the average of all applied depths (in Excel, this might appear as AVERAGE(A1:A25). 3. Divide the results of step 1 by the results of step 2. 4. CU = 1 minus the answer to step 3 x 100.	If a uniformity test has been done, the actual application rate can be calculated. Actual application rate = 60 min/test run time x average application rate (from DU or CU calculation). An estimate can also be obtained by dividing the output of the sprinkler by the lateral spacing and the emitter spacing.
Important note			
	Emphasises areas that receive the least water.	Over- and under-watered areas are treated in the same way, to determine the evenness of irrigation.	Not all water coming out of the sprinkler makes it to the ground – up to 30% can evaporate. Deducting 20% from the estimated value will result in a close estimate of the actual application rate if the uniformity is high.

Calculating application rate

To calculate the hourly application rate of a sprinkler system, divide 60 (minutes) by the time taken to conduct the uniformity test (in minutes), then multiply the answer by the average of all the catch-can readings (that is, the average amount of water applied during the test). So, using the figures from the example outlined above:

60 ÷ 20 = 3, and 3 x 4.72 = **14.16 mL/hour**.