1994

Understanding Fertilisers - Course Notes

Margaret Graham

John Burt

Neil Lantzke

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Understanding Fertilisers

COURSE NOTES

A course run by the Department of Agriculture,
Western Australia, November 1993

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Understanding Fertilisers

CHAPTER 1

INTRODUCTION

1.1 Introduction

Welcome to the Course!

The course will be run over two days with a two hour session on each day. Time is allowed at the end of each day for questions and informal discussion.

The aim of the course is to provide you with more detailed information that will allow you to refine and improve your fertiliser program. Applying the correct amount of nutrient increases yield and quality. Over–fertilising is a waste of money and may lead to pollution of groundwater.

We hope you enjoy the next two days. Please feel free to ask questions and provide us with feedback on how you think the course can be improved.

1.2 Course outline

DAY 1

1. **Introduction** – Bob Paulin (3.00–3.10 p.m.)

- Set scene and outline course contents

2. **What fertiliser nutrients do** – Margaret Graham (3.10–3.30 p.m.)

   Part 1 – Macro Elements

- What is a Macro Element?
- The function of Macro Elements in plants
- Deficiency symptoms
- Effect of soil type, pH and concentrations of other nutrients on availability of specific nutrients

3. **Composition of fertilisers** – John Burt (3.30–4.00 p.m.)

- Nutrient content of various fertilisers
- Forms of nutrient, losses and relative costs
- Solubility of fertilisers
- Fowl manure
  - composition
  - life of nutrients contained in fowl manure
  - effect on soil organic matter content and nutrient/water holding ability

4. **How to calculate how much of each nutrient is being added**

   – Neil Lantzke (4.00–4.45 p.m.)

- Why we need to do this
- How to do it
- Worked example to explain method
- Unworked example for practice in class

5. **Question time** – Margaret Graham (4.45–5.00 p.m.)

DAY 2

6. Soil types, soil testing and plant analysis – Neil Lantzke (3.00–3.10 p.m.)

- Major soil types on Coastal Plain
- Movement of nutrients on different soils
- Soil testing
- Plant analysis

7. What fertiliser nutrients do – Margaret Graham (3.10–3.30 p.m.)

Part 2 – Trace Elements

8. Department of Agriculture fertiliser recommendations

– John Burt (3.30–3.45 p.m.)

- How they are formulated
- How to interpret them

9. Calculate how much of each element you apply to two of your crops

– All staff (3.45–4.30 p.m.)

- Course participants examine their own fertiliser programs

10. Discussion – Margaret Graham (4.30–5.00 p.m.)

- How to improve a fertiliser program

11. Drinks and informal discussion

- Feedback on course content and how to improve
- Is there a need for a more detailed course?

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Understanding Fertilisers

CHAPTER 2

WHAT FERTILISER NUTRIENTS DO

I'd like this back please

2. THE FUNCTION OF NUTRIENTS IN PLANTS by Margaret Graham

Before talking about the function of nutrients in plants, it is important to understand a little about the nutrients themselves, the organisation of plants and major reactions that take place inside them.

2.1 The chemistry of plant nutrients

The way that plant nutrients behave is dependent on their chemistry. Before you can understand plant nutrition, you need to understand some basic chemistry.

Chemists have given each of the elements a symbol, so that they can write about them in 'shorthand'. The symbols that describes plant nutrients are listed in Table 1.

Table 1. Plant nutrients and their chemical symbols

Element	Chemical symbol	Typical content in broccoli tops at harvest	Absorbed as
Carbon	C		CO_2
Oxygen	O		CO_2, H_2O
Hydrogen	H		H_20
Nitrogen	N	5.0%	NO_3^- (nitrate), NH_4^+ (ammonium)
Phosphorus	P	0.8%	$P_20_4^{3-}$ (phosphate)
Potassium	K	3.5%	K^+
Sulphur	S	0.7%	SO_4^{--} (sulphate)
Calcium	Ca	2.9%	Ca^{++}
Magnesium	Mg	0.5%	Mg^{++}
Chlorine	Cl	2.5%	Cl^-
Copper	Cu	5 ppm	Cu^{++}, Cu^+
Zinc	Zn	7–0 ppm	Zn^{++}
Manganese	Mn	100 ppm	Mn^{++}
Iron	Fe	100 ppm	Fe^{++}
Boron	B	50 ppm	$B(OH)_3$ (boric acid)
Molybdenum	Mo	0.4 ppm	MoO_4^{--} (molybdate)

Some of the elements rarely occur on their own. They are almost always found in a molecule with other elements. Examples of this are nutrients like nitrogen, which is usually combined with oxygen to form the nitrate ion, whose chemical symbol is NO_3^-, or with hydrogen to form the ammonium ion, whose chemical symbol is NH_4^+.

Most fertilisers are sold as salts. In chemistry, salts are compounds formed between elements or ions with opposite charges. For instance, common salt is made up of sodium and chloride. NaCl is the formula, and it is made up of Na^+ and Cl^-. In the same way, potassium nitrate is made up of K^+ and NO_3^-. Its formula is KNO_3.

Many salts will dissolve in water to produce a solution in which the constituent ions are present separately. However, other salts are extremely insoluble, e.g. calcium sulphate.

2.2 Nutrition of plants by photosynthesis

The raw materials needed in greatest quantities by plants are carbon dioxide and water. These two compounds supply the carbon, oxygen and hydrogen that are the predominant elements in organic molecules (carbohydrates, lignins etc.).

Carbon dioxide is obtained directly from the air through pores in the leaves of plants (called stomata) while water is absorbed from the soil through the plant's roots.

When a plant photosynthesises, it uses the energy of the sun to join carbon dioxide and water together to make carbohydrates, the basic building blocks of the plant.

After the carbohydrates are manufactured in the leaves they are moved to other parts of the plant, such as the roots where they are 'burnt' for energy. This energy is used to manufacture proteins, enzymes, hormones and all the other compounds the plant needs in order to grow (Figure 1).

Photosynthesis in the leaves

↓

Move the carbohydrate to other parts of the plant

↓

Manufacture energy from the carbohydrate

↓

Use the energy and nutrients to manufacture proteins, enzymes, hormones and other compounds

Figure 1. Simplified picture of the energy pathways in a plant.

2.3 Mineral nutrition of plants – macroelements and microelements

Carbon dioxide and water are not the only nutrient materials required by a plant. Other elements also enter into the composition of the plant. These are the mineral elements required by the plant.

Fertilisers supplement the soil's natural fertility to supply the mineral nutrition of plants i.e. mineral nutrition is what this course is all about.

Mineral nutrients are often broken into two groups, depending on the quantity in which plants use them. Those with high concentrations in plants are called macroelements. Nutrients which are required in very small quantities are called microelements.

In general, the macroelements are part of the major building blocks of plants and are involved in the most vital process, while microelements are required in small quantities for special functions.

Macronutrients are measured in per cent (%), while micronutrients are measured in 'ppm' (parts per million).

Most people are very familiar with percentages. One per cent means one part in one hundred, or 1/100. 'Ppm', or parts per million are not so well understood. It means one part in one million, or 1/1,000,000.

Table 1 shows typical nutrient concentration in broccoli tops at harvest. In broccoli, 5% of the plant is made up of nitrogen (N), while copper (Cu) is 5 ppm. This means that the plant needs 10,000 times more nitrogen than copper.

To give a sense of scale, think of stockpile of onions. In a pile of 100 tonnes of onions, five per cent would be around 50,000 onions, while 5 ppm is only five onions. Quite a difference!

Note: The term 'mg/kg' means exactly the same as ppm.

2.4 Plant function and nutrients

2.4.1 Plant cells

A plant is made up of many cells. within the cells are a number of different organs, each of which has a separate function. Figure 2 shows a simplified diagram of a plant cell, with the organs contained in it.

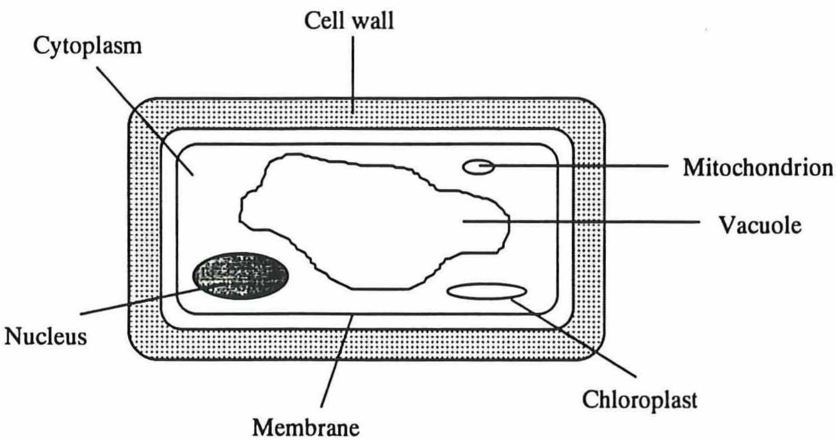


Figure 2. Simplified plant cell.

The organs are:

Cell wall	Maintains the structural integrity of the plant.
Cytoplasm	The living part of the cell in which all chemical reactions occur.
Chloroplast	Contains chlorophyll, the green pigment of plants that allows them to photosynthesise (use the energy of the sun to produce carbohydrate from carbon dioxide and water).
Membrane	A 'fence' around the cell. The membrane keeps unwanted substances out of the cell, and keeps in what the cell needs to function.
Mitochondrion	The engine room of the cell. Carbohydrates produced in photosynthesis are burned here to produce the energy to run the cell.
Nucleus	The 'brain' of the cell, which contains the plant's genetic material.
Vacuole	A 'stockpile' of the plant's needs. Contains dissolved nutrients and waste products.

2.4.2 Role of plant nutrients in plant physiology

For a plant to grow and produce well, all the organs within the cell must be well supplied with the nutrients they require to function. If the chloroplast, is denied magnesium, for instance, its chlorophyll content falls, and the plant can not photosynthesise efficiently. Every nutrient impacts on some activity in the plant's physiology.

Table 3 lists each of the mineral nutrients essential to plant growth and their role in the functions of plant physiology.

Table 3. Summary table showing the role of plant nutrients in plant physiology

Element	Physiological processes	Activator of enzyme
Nitrogen	Basic building block Constituent of proteins	
Phosphorus	Energy transfer Membrane integrity	
Potassium	Translocation Stomatal opening	+
Sulphur	Constituent of proteins	
Calcium	Membrane maintenance Strength of cell walls	+
Magnesium	Constituent of chlorophyll	+
Chlorine	Maintenance of electrical neutrality Internal turgor	
Copper	Lignin synthesis	
Zinc	Hormone metabolism (Auxin) Production of proteins	+
Manganese	Energy production	+
Iron	Electron transport Constituent of chlorophyll	
Boron	Translocation of carbohydrates	
Molybdenum	Nitrate reduction	

* Enzymes are proteins that drive the chemical reactions in plants. Many enzymes require a metal to act as an activator before they can do their job, and this table indicates which nutrients are important as enzyme activators.

2.5 Mobility of nutrients within plants

Some deficiency symptoms always show up in the older leaves of the plant, some in the younger leaves, while others are not so specific in the part of the plant they affect.

The part of the plant showing symptoms is determined by whether the nutrient is mobile in the plant or not (Table 4). Mobile nutrients, such as nitrogen can be re–mobilised by the plant from old leaves to young growing tissues. The plant sacrifices old leaves so that it can continue growing.

Thus, the old leaves become pale first, while the top of the plant remains green.

With immobile elements, such as iron, deficiency symptoms show up first at the growing point, which becomes very pale in the case of iron deficiency. The plant cannot remobilise iron, so the young tissues are affected by the lack of supply first.

Table 4. Mobility of nutrients within plants

Mobile	Variably mobile	Immobile
Nitrogen	Sulphur	Calcium
Phosphorus	Copper	Manganese
Potassium	Zinc	Boron
Magnesium	Molybdenum	Iron

2.6 Effect of soil pH on nutrient availability

Figure 3 shows how soil pH affects the uptake of plant nutrients on mineral soils. When soil pH is extreme, it interferes with the ability of plants to extract nutrients. Each nutrient is affected differently, some become unavailable at very high pH (e.g. iron, manganese etc.), while others are unavailable in acidic soils (e.g. magnesium).

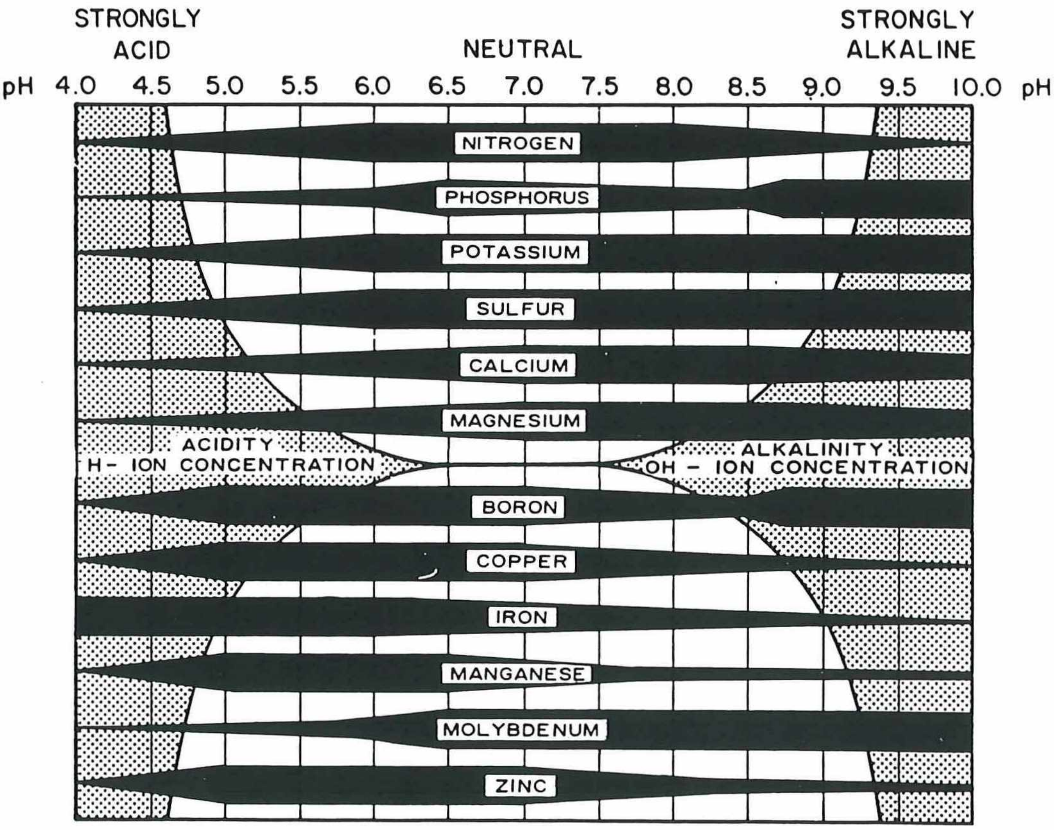


Figure 3. Effect of soil pH on nutrient availability.

2.7 Vital statistics of essential plant nutrients

Details concerning each of the essential plant nutrients follows. Please be aware that this list is only a summary. Individual crops and even cultivars can sometimes manifest very different deficiency symptoms from the norm. There are a number of excellent colour atlases of plant deficiency symptoms. These are listed in the bibliography of the end of these notes.

Nitrogen

Critical concentration	3.5%
Function	Major building block of amino acids, proteins and enzymes.
Deficiency symptoms	Poor growth. Yellow leaves, starting with old growth.
Similar symptoms result from	Cold weather (purple/pink colours in brassicas) Waterlogging. Root damage (disease/nematodes/insects/fertiliser burn).
Commonly seen in	All crops.
Absorbed as	NO_3^- , NH_4^+ (Nitrate, ammonium).
Present in	• Urea • Agran • Sulphate of ammonia • Potassium nitrate • Mixed fertilisers • Fowl manure

Phosphorus

Critical concentration	0.35%
Function	Has a key role in the energy functions of the plant. Occurs in membranes and co–enzymes.
Deficiency symptoms	Poor growth (small stunted plants). Dark green or blue green old foliage. Red, purple and brown colours often develop.
Similar symptoms result from	Low temperatures. Drought. Root pests.
Commonly seen in	Brassicas, strawberries etc.
Absorbed as	$P_2O_4^{3-}$ (phosphate)
Present in	• Superphosphate • Double superphosphate • Mono–ammonium phosphate (MAP) • Phosphoric acid • Mixed fertilisers • Fowl manure

Magnesium

Critical concentration	0.2%
Function	A major constituent of chlorophyll. The most common activator of enzymes concerned with energy metabolism.
Deficiency symptoms	Interveinal chlorosis (yellowing) beginning on older leaves, giving a mottled appearance. The larger veins normally remain green.
Similar symptoms result from	Virus infection. Manganese deficiency.
Specific crops	Brassicas – may develop brilliant orange, yellow and purple colours, especially on the underside of the leaves. Legumes – the leaf margin can remain green.
Commonly seen in	Carrots, broccoli, lettuce, cucumber. Seen more frequently where no fowl manure is used.
Absorbed as	Mg^{++}
Present in	• Magnesium sulphate (epsom salts) • Kieserite • Mixed fertilisers • Fowl manure

• Dolomite

Potassium

Critical concentration	2.0%
Function	A major cell base, and probably important in balancing positive and negative charges within the cell. An activator of several enzymes.
Deficiency symptoms	Old leaves curl up or down. Marginal scorch of older leaves. Poor flavour, colour and keeping quality in fruiting crops (strawberries, capsicum, melons).
Similar symptoms result from	Wind damage. Chloride toxicity.
Commonly seen in	Cabbage, brussels sprouts.
Absorbed as	K^+
Present in	• sulphate of potash 1st letter upper case • muriate of potash • potassium nitrate • mixed fertilisers • fowl manure

Sulphur

Critical concentration	0.2%
Function	A constituent of amino acids, and therefore proteins and enzymes. Volatile compounds containing sulphur contribute to the characteristics smells given off by onions, mustards etc.
Deficiency symptoms	New growth in uniformly golden yellow. Foliage is frequently stiff and erect.
Similar symptoms result from	Iron deficiency.
Specific crops	Brassicas – young growth cupped and deformed.
Commonly seen in	Rarely seen in Western Australia.
Absorbed as	SO_4^{--}
Present in	• sulphate of potash • superphosphate • mixed fertilisers • fowl manure

Calcium

Critical concentration	1.0%
Function	Part of the makeup of cell walls.
Deficiency symptoms	Cupping and tipburn or extensive blackening of growing points and young leaves. Appearance of water soaked areas across leaves, petioles or stems which then collapse.
Similar symptoms result from	Frost damage. Some herbicides.
Specific crops	Lettuce – tipburn Cabbage – tipburn Celery – blackheart Capsicum/tomato – blossom end rot
Commonly seen in	Lettuce, cabbage, celery, strawberries, cucumbers (associated with rapid growth in hot weather, and dry soil).
Absorbed as	Ca^{++}
Present in	• Lime • Gypsum • Calcium nitrate • Mixed fertilisers

Dolomite

Iron

Critical concentration	50 ppm
Function	Integral part in transfer of energy in photosynthesis associated with many proteins. Essential for the synthesis of chlorophyll.
Deficiency symptoms	Uniform or interveinal chlorosis of young leaves, which become progressively paler and paler. The youngest leaves can be almost white.
Similar symptoms result from	Manganese deficiency.
Commonly seen in	Spring onions (especially in late spring) tomatoes, sweet corn 'Lime induced chlorosis' is common, and is caused when high pH stops plants from taking up iron.
Absorbed as	Fe^{++}
Present in	• Iron sulphate • Iron chelate

Manganese

Critical concentration	20 ppm
Function	Acts as an activator for many enzymes. Important in electron transport.
Deficiency symptoms	Interveinal chlorosis which begins on new leaves, but can soon spread to others. The smallest veins stay green, giving a very distinct pattern.
Similar symptoms result from	Iron deficiency. Magnesium deficiency.
Commonly seen in	Beans, onions, peas etc.
Absorbed as	Mn^{++}
Present in	• Manganese sulphate • Mixed fertilisers • Fowl manure

Zinc

Critical concentration	20 ppm
Function	Activator for a number of enzymes. Important in regulating the levels of plant hormones (auxins).
Deficiency symptoms	All deficiencies interfere with growth, but zinc does so with dramatic impact. Rosetting, twisting of young growth, 'little leaf' etc.
Similar symptoms result from	Virus. Hormonal herbicides.
Commonly seen in	Tomatoes (particularly when over fertilised with phosphorus), cucurbits.
Absorbed as	Zn^{++}
Present in	• Zinc sulphate • Zinc chelate • Super copper zinc and molybdenum

Copper

Critical concentration	5 ppm
Function	A component of several enzymes.
Deficiency symptoms	Very dependent on species, and several suffer yields loss without symptoms appearing (e.g. carrots).
Commonly seen in	Carrot, lettuce and onion.
Absorbed as	Cu^{++}
Present in	• Copper sulphate • Copper chelate • Super copper zinc molybdenum

X

Boron

Critical concentration	20 ppm
Function	Plays a regulatory role in carbohydrate synthesis and relocation of carbohydrates within the plant.
Deficiency symptoms	Brittle tissues which crack easily, hence there is crosswise cracking across the petioles of leaves. Death of growing point and distortion and blackening of new leaves.
Symptoms on particular crops	Brassicas – hollow stems and interveinal chlorosis. Carrots – 'five o'clock shadow' on carrots roots.
Similar symptoms result from	Some hormonal herbicides.
Commonly seen in	Brassicas, celery, carrots, beets.
Absorbed as	$B(OH)_3$ (Boric acid).
Present in	• Borax • Solubor

Molybdenum

Critical concentration	0.1 ppm
Function	The metal activator for a number of important enzymes.
Deficiency symptoms	Usually only seen on brassicas.
Symptoms on particular crops	Brassicas, particularly cauliflower – 'whiptail' – the blade of new leaves becomes very thin and twisted, until only the midrib is seen. Growing point becomes blind. Cupping and interveinal necrosis.
Similar symptoms result from	Sudden cold can cause blindness in growing tips, without the associated malformation of the leaf blades.
Commonly seen in	Cauliflower, particularly when grown on acidic soils.
Absorbed as	MoO_4^{--} (Molybdate).
Present in	• Sodium molybdate • Super copper zinc and molybdenum

Chlorine

Chlorine deficiency is unknown in crops which have been grown in the soil.

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Understanding Fertilisers

CHAPTER 3

COMPOSITION OF FERTILISERS

3. COMPOSITION OF FERTILISERS
by John Burt

3.1 Production

Fertilisers available for horticulture in Western Australia are either imported or produced in Perth. CSBP and Farmers Ltd market six special and five general fertilisers for horticulture and they are all produced in Perth with the exception of urea which is imported. Their total sales are less than 50,000 tonnes of horticultural fertilisers per year, compared with 1,500,000 tonnes per year of agricultural fertilisers in Western Australia.

Plants consist of 16 essential nutrients (see Section 2.1 Table 1). The 12 nutrients essential for plant growth which are sold in fertilisers in Western Australia may include the following, but these comprise less than 0.5–1% of the fresh weight of the plant:

Main elements	–	nitrogen, phosphorus and potassium calcium, magnesium and sulphur
Trace elements	–	boron, copper, iron, manganese, molybdenum and zinc

The main weight of the plant is composed of carbon, hydrogen and oxygen which are derived from air and water. In addition, plants need trace amounts of chlorine which is supplied in the water and is sometimes at a toxic level.

All fertilisers sold in Western Australia must be registered by the Department of Agriculture. Nutrients must have a minimum concentration to be included on the label, i.e. main elements – greater than 0.5%; trace elements – greater than 0.001–0.01%. Spot checks are made to determine whether the laboratory analysis is similar to the analysis on the label. The content of heavy metals (i.e. lead, cadmium or mercury) should also be below a minimum level.

For the last 20 years, all fertilisers used in Australia have had their analysis expressed as the basic element, whereas overseas they may still be expressed in the oxide form. This may give the impression that some imported, unregistered, fertilisers contain a higher level of nutrient than the Australian standard. If expressed as potassium oxide (K_20), or phosphorus oxide (P_20_5), convert to potassium and phosphorus by multiplying by 0.83 and 0.44 respectively. It should be pointed out that it is unusual to find unregistered fertilisers being marketed in Western Australia. Occasionally the amounts of the pure element and the oxide form may both expressed on the label of imported registered fertilisers especially for potassium.

Solid fertilisers may be sold in the following forms in Western Australia:

(a) Compound – Fertilisers are granulated and contain many nutrients. Every granule has the same analysis. Many imported fertilisers are available in this form.

(b) Granulated – Fertilisers are granulated and usually contain many nutrients. The granules may have the same analysis for the main and minor elements, but may differ slightly for the trace elements.

(c) Bulk blends – These are not granulated. The fertiliser consists of a blend of different types of nutrients and particle sizes, and may segregate when spread. This form is uncommon for horticultural fertilisers.

(d) Single composition – The fertiliser may be of uniform type and consist of 1–2 nutrients only. It may be in crystal form, or be granulated for easier spreading.

Liquid fertilisers are not commonly used in horticulture in Western Australia and mainly include fertilisers applied directly to the leaves or to the soil through trickle systems.

Some fertilisers containing 1–2 nutrients may be sold in various grades. Ordinary grade is the cheapest material, but may contain some impurities. Occasionally, it may be necessary to purchase some fertilisers in the more expensive technical grade if better solubility is required, especially for trickle systems (i.e. mono ammonium phosphate).

Some trace elements are sold in the chelated form. Nutrients in this form may be slightly more available than the ordinary form, but often the latter give equally good results and are much cheaper.

3.2 Main nutrients

3.2.1 Nitrogen (N)

Nitrogen is the nutrient which will give the maximum response in growth and yields, when applied to vegetable crops.

Nitrogen is held in the soil in organic matter or on soil particles, and is then released into the soil as ammonium and nitrate ions or is supplied to the soil by using organic manures or synthetic fertilisers.

Use nitrogen with care as over application may reduce yields and leaching into the groundwater may contaminate public drinking supplies.

Ammonium nitrogen (NH_4^+)

Ammonium ions are positively charged and are held in the soil on organic matter or clay particles, which are both negatively charged. On sandy soils of the Swan Coastal Plain, ammonium nitrogen is leached more than on other soil types, but is not leached as much as nitrate nitrogen. Ammonium nitrogen is usually converted into nitrate nitrogen in the soil solution as follows:

$$\underset{\text{(ammonium)}}{NH_4^+} \rightarrow \underset{\text{(nitrite ion)}}{NO_2^-} \rightarrow \underset{\text{(nitrate ion)}}{NO_3^-}$$

When applied by fertilisers, ammonium ions are converted to nitrate ions within three weeks in warm moist soil.

The nitrate ion is the main form of nitrogen taken up by plants in the soil, but ammonium ions are also absorbed through the roots. In the plant, nitrate ions are converted back into ammonium ions and then to proteins.

Ammonium ions may be converted into ammonia gas, especially in limed or alkaline soils, and be lost into the air.

Ammonium ions will compete with other positively charged ions such as calcium, magnesium and potassium for uptake into the roots. Excessive amounts of ammonium or potassium ions in the soil may decrease calcium uptake in the plant. This may lead to blossom end rot and tip burn in tomatoes, capsicums, cauliflowers, lettuces and other vegetables, because these disorders are partly due to a shortage of calcium within the plant.

Ammonium ions are directly supplied by fertilising as follows:

(a) Poultry manure.

(b) Ammonium nitrate or calcium ammonium nitrate.

(c) Sulphate of ammonia.

(d) Urea (above a soil temperature of 5°C, urea is catalysed by an enzyme to form ammonium ions within 2–7 days. The conversion from ammonium ions to nitrate ions is a rapid process).

(e) Mixed fertilisers.

Nitrate nitrogen (NO_3)

Nitrate ions are positively charged and are not held strongly on exchange sites. This means that if they are not absorbed by plants, they are readily lost by leaching into the lower depths of the soil.

Nitrate ions may also be lost into the air as nitrogen gases in soils which are waterlogged or have insufficient oxygen.

Nitrate ions are directly supplied in:

(a) Ammonium nitrate.

(b) Calcium ammonium nitrate.

(c) Potassium nitrate.

(d) Calcium nitrate.

(e) Mixed fertilisers.

Nitrate ions are indirectly applied from urea and all fertilisers containing ammonium.

Vegetable trials which compared ammonium nitrate, urea and sulphate of ammonia as sources of nitrogen at Carnarvon and Manjimup showed no significant differences in yields when the same amount of nitrogen was applied. Similar results have been obtained with wheat crops in Western Australia.

The characteristics of the main nitrogenous fertilisers, excluding NPK fertilisers, are as follows:

Table 1. Comparison of pure nitrogen fertilisers for topdressing crops

Item	Ammonium nitrate 'Agran'	Sulphate of ammonia	Urea
Cost $/tonne in Perth	587	276	425
% Nitrogen	34	21	46
Cost $/tonne of pure nitrogen	1,726	1,314	924
Main advantages			
	Reported to be quicker acting and longer lasting than urea.	24% cheaper than ammonium nitrate.	46% cheaper than ammonium nitrate.
			Excellent for fertigation systems.
	Very high solubility (191 kg/100 L at 20°C).	High solubility (71 kg/100 L at 20°C).	High solubility (105 kg/100 L at 20°C).
		Mainly suitable for alkaline soils, as it will decrease the pH more than urea or ammonium nitrate	Moderate salinity hazard.
			Moderate acidifying effect.
Main disadvantages			
	More expensive than urea.	Increases acidity of acid soils.	May burn crops if applied at too high rates (apply at 26% lower rate than ammonium nitrate to supply the same amount of nitrogen).
	Special transport requirements. (May explode during trucking or storage in combination with distillate or oil.)	Should not be applied to recently limed soils due to nitrogen loss.	When applied in solid form, Urea may lose 5–10% nitrogen to the air, if it is not washed in with sprinklers within 6 hours.
	Higher salinity hazard than urea or sulphate of ammonia.	May increase problems with tip burn and blossom end rot.	

Table 2. Comparison of other nitrogenous fertilisers

Name	Total N%	Cost $/tonne	Cost $/tonne of pure nitrogen	Other nutrients	Comments
Basammon Extra 25	25	628.50	2,514	Sulphur	Slow acting nitrogen.
Calcium Ammonium nitrate (Nitrogen)	27	500	1,851	7–14% calcium	Suitable for acid soils.
Calcium Nitrate (Nitrosprint)	15.5–17.0	618	3,987	19% calcium	Applied to leaves of some crops i.e. strawberries, lettuces, celery to supply calcium. Also used in hydroponics.
Complete Blue Special	12	680	5,666	11	
Horticulture Special	9	441	4,900	9	
Potassium Nitrate	13	780	6,000	39% potassium	Applied as a topdressing to supply nitrogen and potassium.
Mono Ammonium–Phosphate	12	1,340	11,166	22.6% phosphorus	Also good source of soluble phosphorus.
Nitrophoska Perfect	15	717	4,780	8	
Nitrophoska TE	12	618	5,150	10	
NPK Blue Special	11.8	660	5,593	7	
Potato E	3.5	326	9,314	3	
Rustica	12	560	4,666	9	

3.2.2 Phosphorus (P)

Phosphorus is an important nutrient which is required for root development, cell division quality and yield. It is usually applied in a single application, before planting, in the form of poultry manure, mixed fertilisers or superphosphate, although it may be applied in two applications (before and after planting) on Bassendean sands.

In other parts of the world, phosphorus is a nutrient which does not leach readily, but leaching of phosphorus is a major problem on soils of the Swan Coastal Plain. This results in problems with marine life and a buildup of blue–green algae and odours in waterways due to high phosphorus levels. Leaching is less important on Spearwood soils where phosphorus is held by high levels of iron, aluminium and calcium in the soil. It is most serious on Bassendean sands but there are indications on these soils that the addition of poultry manure or 'red mud' (by–product of aluminium refining) will help to reduce leaching of phosphorus.

Many sources of phosphorus are difficult to dissolve in water (superphosphate has a solubility of 2 kg/100 litres).

Phosphorus fertilisers have no effect on the pH of the soil and a very low salt index.

The level of phosphorus is expressed on the label as amount of water soluble phosphorus and citric soluble phosphorus. The latter supplies phosphorus at a slower rate than water soluble (W.S.) phosphorus.

The use of mixed NPK fertilisers in topdressings is expensive. These contain phosphorus which is not usually needed as a topdressing on Spearwood and Karrakatta soils and this may increase levels of phosphorus run–off into waterways.

The main sources of phosphorus are as follows:

Table 3. Comparison of phosphorus fertilisers

Name	% Phosphorus	Cost $/tonne	Cost $/tonne of pure phosphorus	Other nutrients	Comments
Superphosphate	9.1	245	2,692	Calcium Sulphur Slight Zinc	May contain toxic levels of cadmium (heavy metal).
Super Copper Zinc	8.2	344	4,195	Calcium Sulphur Copper Zinc	Formulated for wheatbelt, not horticulture.
Blood and Bone ('Gro–Wel')	3.0	510	17,000	5% nitrogen	
Mono Ammonium Phosphate (technical grade)	22.6	1,340	5,929	12% nitrogen	Soluble for trickle systems (technical grade). Also used in hydroponics. Ordinary grade is soluble for sprinkler systems and is much cheaper.
Mono Potassium Phosphate	22.8	1,640	7,192	28.8% potassium	Soluble. Mainly used in hydroponics.
Most NPK fertilisers	5–6	560–680	11,272	8–11	
Nitrophoska Perfect	2.2	717	32,590	8	NPK fertiliser with low phosphorus to reduce leaching of this nutrient.
Phosphoric acid	27.0	1,640	6,074	–	Corrosive acid. Mainly suitable for trickle systems, or hydroponics for correcting pH (add acid to water).

3.2.3 Potassium

Potassium is absorbed by plants more than any other nutrient. It is an important nutrient for quality, and to make the plant more resistant to diseases and drought. It is applied mainly as a topdressing.

Potassium leaches through the soil more than phosphorus, but less than nitrogen. There have been no problems so far with contamination of potassium into the groundwater, as high levels do not cause problems in drinking water supplies or with marine life in waterways.

There is competition with calcium, magnesium and ammonium ions for absorption into the plant. High amounts of potassium may lead to more problems with tipburn, blossom end rot and magnesium deficiency in various crops.

Potassium fertilisers have little effect on the pH.

Solubility of fertilisers containing potassium is lower than nitrogen, but much higher than phosphorus fertilisers. Some sources of potassium fertilisers may vary in solubility.

The main sources of potassium are as follows.

Table 4. Comparison of potassium fertilisers

Name	% Potassium	Cost $/tonne	Cost $/tonne of pure potassium	Other nutrients	Comments
Muriate of Potash (Potassium chloride)	49.8	405	813	High level of chloride (45%) may cause problems with salt-sensitive crops such as strawberries and lettuces.	Fairly good solubility for sprinkler systems (35 kg/100 litres). Usually spread by machine.
Sulphate of Potash	41.5	570 (ordinary grade) 650 (granulated grade)	1,373	17% Sulphur. Less than 1.5% chloride (therefore used on salt sensitive crops).	69% more expensive than Muriate of Potash but usage is increasing. Granulated form may be spread by machine. Fair solubility of 11 kg/100 kg. May dissolve poorly or settle out in cold conditions.
Potassium Nitrate	38.0	790 (standard) prilled form is more expensive. Increasing in cost.	2,079	13% nitrogen. Contains no chloride.	Good fertiliser for supplying nitrogen and potassium in topdressings through sprinklers. Fairly good solubility (32 kg/100 litres). Low salinity hazard. Prilled form may be spread by machine.
Mono Potassium Phosphate	28.8	1,640	5,694	22.8% phosphorus	Soluble. Mainly used in hydroponics.
Main NPK fertilisers	14–16	560–680	4,133	8–11	

3.2.4 Calcium (Ca)

Calcium is the main cation in soils and is often overlooked in fertilisers programs. It is often added to acidic soils to increase the pH.

It is an immobile nutrient in the plant and there are often problems with supply of calcium to fruits and leaves especially under certain climatic conditions (i.e. high temperatures). Poor movement of calcium within the plant is a major cause of blossom end rot in tomatoes, capsicums and water melons and tip burn in celery, lettuces and brassica crops.

Calcium nitrate is often sprayed onto the leaves to correct the above problems, but control is often difficult as the calcium may be applied too late and is difficult to apply to the heart leaves of some vegetables.

3.2.5 Magnesium

Magnesium is usually absorbed by plants more than phosphorus and is often deficient on Perth sands, especially where there are high levels of calcium and potassium.

Magnesium deficiency is readily corrected by soil or foliar applications using the following fertilisers.

Table 5. Comparison of magnesium fertilisers

Name	Cost $/tonne	% Magnesium	Cost $/tonne of pure magnesium	Comments
Magnesium Sulphate (Epsom salts)	625	9.6	6,510	Applied to soil or leaves.
Kieserite (granular form of Epsom salts)	660	12.6	5,238	Applied to soil.
Calmag, Dolomite (65% calcium carbonate, 35% magnesium carbonate)	560	10.0	5,600	Usually applied to soil at 2.5 t/ha to increase pH of soil.
Magnesium nitrate	1,460	9.3	15,698	Mainly used in hydroponics. Also contains 10% nitrogen.

3.2.6 Sulphur

Deficiency of sulphur is rare as the nutrient is a constituent in many types of fertilisers i.e. superphosphate, sulphate of potash, Epsom salts.

3.3 Trace elements

Trace elements are needed by plants in very small quantities and there is a danger of toxicities with boron and molybdenum or induced deficiencies (phosphorus deficiency caused by too much iron) if some of these are applied at excessive rates. Copper, manganese and zinc are often applied in fungicides to control diseases.

Boron, iron, manganese and zinc are likely to be deficient in alkaline soils and molybdenum in acid soils.

Trace elements are applied in small amounts and costs are not high.

Trace elements may be applied to the soil or leaves using the following fertilisers but this is not an exhaustive list:

Trace element	Fertilisers
Boron	Borax, Solubor, Polybor Spray Boron
Copper	Copper Sulphate
Iron	Iron Chelate Sequestrene Ferrous Sulphate
Manganese	Manganese Sulphate Mantrac Tecmangan
Molybdenum	Sodium Molybdate
Zinc	Zinc Sulphate Zincsol Zintrac

3.4 Mixed fertilisers

There are a large number of fertilisers containing 9 to 12 of the main nutrients needed by plants, especially NPK. These are expensive compared with using single nutrients, but are a convenient source of supply where the grower is unsure of the individual nutrients which need to be applied. There is the danger with frequent use of mixed fertilisers that toxicities may be caused by over–application of nutrients which have already been applied in other fertilisers. Contamination of the groundwater and waterways with an oversupply of nitrogen and phosphorus is also a constant problem on the Swan Coastal Plain.

Some of the mixed fertilisers in Table 6 have low solubility in water and may be applied through sprinklers but not through trickle systems.

It is unusual to find a mixed fertiliser which contains all of the twelve elements essential for plant growth.

The main mixed fertilisers used in horticulture in the Perth area are as follows.

Table 6. Comparison of mixed fertilisers

Fertiliser	Price ($/tonne)	N	P	K	Ca	Mg	Other nutrients	Comments
Agroblen	2,940	19	2.1	8.3	-	1.8	-	Lasts 12–14 months. Used in strawberries.
Complete Blue Perfect	650	15	2.2	16.6	-	1.2	B, Fe, S, Zn	Low phosphorus. Fairly soluble for sprinkler systems
Complete Blue Special	680	12	5.2	14.1	2.2	1.2	B, Cu, Fe, Mn, Mo, S, Zn	High ammonium–nitrogen. Potassium in sulphate form. Contains all main nutrients.
Hort Special	441	9	3.5	7.4	√	-	Cu, Fe, Mn, Mo, S, Zn	Potassium in chloride form.
Nitrophoska TE	623	12	5	14	5.0	1.2	B, Cu, Fe, Mo, S, Zn	Potassium divided between chloride and sulphate forms.
Nitrophoska Perfect	717	15	2.2	16.6	-	1.2	B, Fe, Mo, S, Zn	Potassium in sulphate form. Low phosphorus. Fairly soluble for sprinkler systems.
NPK Blue Special	660	11.8	6.0	15.6		1.0	Cu, Mn, S, Zn	High ammonium. Potassium in sulphate form.
Potato E	326	3.5	7.0	6.6	15.0	-		Potassium in chloride form.

Table 6. Comparison of mixed fertilisers continued ...

Fertiliser	Price ($/tonne)	N	P	K	Ca	Mg	Other nutrients	Comments
Polyfeed	1,365	19	8	16	–	–	B, Cu, Fe, Mn, Mo, Zn	Suitable for sprinkler and trickle systems
Rustica	560	12.0	5.0	14.1	2.3	2.0	B, Cu, Mn, S, Zn	High ammonium nitrogen. Potash divided between chloride and sulphate forms.

3.5 Organic manures

Table 7. Deep litter poultry manure

Source	Mainly ex broilers – 30 million in Western Australia. These are kept for 35–45 days in sheds. Deep litter contains one third jarrah sawdust, and sometimes contains pine saw dust.
Availability	40,000 tonnes per year, often short in winter.
Price	Price $34/tonne ($15/cubic metre in 1992) delivered by agents in Perth area.
Extent of current use	Used on majority of market gardens in Perth area, mainly for pre–planting but also as topdressings.
Effect on water holding capacity	Good.
pH	8.0
Nutrient content	Nitrogen 2–4.5% (average 3%), phosphorus 0.4–1.7% (average 1%) and potassium 0.6–1.6% (average 1.25%). Calcium 2–10% (average 5%), magnesium 0.3–1.2% (average 0.5%), sodium 0.4–0.6% (average 0.5%). High iron, adequate manganese and zinc, low boron, copper and molybdenum.
Other information	
Rates	15–50 cubic metres per hectare before planting.
Toxicities	High rates can cause ammonium toxicity, especially as topdressing
Lifespan	4–6 weeks.
Other	Major problems are phosphorus and nitrogen leaching into the groundwater and fly–breeding in warm months. Minor problems are introduction of weeds and odours. Bigger demand in winter, as it is claimed that it warms the soil.

Table 8. Cage-bird manure

Source	There are 650,000 layers in the Perth area which are kept for up to 72 weeks in cages. Manure contains no sawdust.
Availability	Total 33,000 tonnes per year of which an estimated 7,000 tonnes is pelletised as Dynamic Lifter.
Price	$28/cubic metre in 1992, delivered by agents.
Extent of current use	Mainly used by growers south of Swan River. Used by all mushroom growers. Not much is used on market gardens as it is more expensive than deep litter and poultry farms make more profit by selling in 33 litre bags to householders 'at the gate'.
Effect on water holding capacity	Fairly good
pH	Alkaline
Nutrient content	3.6% nitrogen, 1.4% phosphorus and 1.5% potassium 9.5% calcium, 0.8% magnesium, 0.6% sulphur, 0.87% chloride. Adequate iron, manganese and zinc; low boron, copper and molybdenum.
Other information	
Rates	20% lower rates than deep-litter manure, applied pre-plant.
Toxicities	High rates can cause ammonium toxicity especially as top dressing.
Lifespan	3-4 weeks.
Other	Major problems are phosphorus and nitrogen leaching into the groundwater and fly-breeding in warm months. Minor problems are introduction of weeds, and odours.

Table 9. 'Dynamic Lifter'

Source	Mainly ex cage birds but mixed with deep litter, composted, dried then pelletised by 'Dynamic Lifter' at Jandakot.
Availability	10,000 tonnes per year in Western Australia, mainly used in home gardens and landscaping.
Price	Standard $320/per tonne in 1992. Mixed with blood and bone $410 per tonne.
Extent of current use	Used by a few growers, especially from autumn to winter.
Effect on water holding capacity	Fair.
pH	7.4 (alkaline)
Nutrient content	Nitrogen 3.0% (standard), 4.0% blood and bone mix.
	Phosphorus 2.5% (standard), 3.2% blood and bone mix.
	Potassium 1.7% (standard), 1.0% blood and bone mix.
	7% calcium, 1% magnesium and 1% sulphur.
	Adequate iron, manganese and zinc. Low boron, copper and molybdenum.
Other information	
Rates	2 to 3.5 tonnes per hectare, applied pre–plant.
Other	Easy to handle and apply. No weeds. Expensive compared with poultry manure. Contains 72% organic matter.

Table 10. Densified poultry manure – 'DPM'/'Dynamite'

Source	Jarrah sawdust/deep litter, composted pelletised and dried by Lucerne Feeds, Carabooda.
Availability	1,500 tonnes per year in 1992 sold by 'Richgro' and 'WA Salvage' mainly for home gardens and landscaping.
Price	$200/tonne in 1992.
Extent of current use	Producer is promoting usage for market gardening.
Effect on water holding capacity	Fair.
pH	8.15 (Alkaline).
Nutrient content	3.7% nitrogen, 1.1% phosphorus and 1.2% potassium.
	2.6% calcium, 0.77% magnesium, copper, iron, manganese and zinc.
Other information	
Rates	Producer recommends 1.5 tonnes per hectare every 4–6 weeks, applied pre-plant.
Other	Easy to handle and apply. No weeds. Contains 85% organic matter. Expensive compared with poultry manure.

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Understanding Fertilisers

CHAPTER 4

HOW TO CALCULATE HOW MUCH OF EACH NUTRIENT IS BEING ADDED WHEN FERTILISER IS APPLIED

4. HOW TO CALCULATE HOW MUCH OF EACH ELEMENT IS BEING APPLIED TO YOUR CROP
by Neil Lantzke

4.1 Introduction

This chapter outlines how to calculate how much of each element you are adding to your crop. You need to know how many kilograms of each element is being applied per hectare in order to:

- compare the rates you are using with other growers and Department of Agriculture recommendations, and see whether you are putting on too much or too little;
- compare one fertiliser with another e.g. Urea vs Agran vs NPK type fertilisers;
- determine how much of any new fertiliser you should apply.

4.2 Steps involved to calculate the rate of element applied

Step 1 Enter the types of fertilisers applied to the crop and dates of application on the Fertiliser Record Sheet (Table 1).

Step 2 Enter the rate of each fertiliser applied on each application date. In kilograms per bay (or kg per area being fertilised).*

Step 3 Calculate the total kilograms of each fertiliser applied throughout the crop's life (kg per bay or area fertilised). Transfer these figures to Column (B) in Table 2 – Element Applied Sheet.

Step 4 Convert the number of kilograms of fertiliser you apply per bay to kilograms of fertiliser per hectare. To do this multiply the figure in Column (B) by 10,000 and divide by the area of the bay or area being fertilised (m^2).

[Remember 1 hectare = 10,000 m^2 and 1 acre = 4,082 m^2.]

Step 5 Convert kilograms of fertiliser per hectare to kilograms of element per hectare.

- Refer to the table on the inside flap of this file to see the percentage of each element within each fertiliser. The composition of fowl manure is also shown in this table.
- Multiply figure in Column (C) by the % of element within the fertiliser and divide by 100.

Step 6 Repeat steps 4 and 5 for all the fertilisers applied. Remember compound fertilisers such as NPK blue, NPK red, Nitrophoska and Potato E contain more than one element.

Step 7 Sum the individual contributions of each element to obtain a total amount of each element applied.

---

* Fowl manure

To convert m^3 of fowl manure (moist) to kilograms (dry) multiply by 300.
(Fowl manure contains 25% moisture and 1 m^3 weighs 400 kg.)

Examples

The following pages give three examples of how to calculate how much of each element is being applied in a fertiliser program. The first example is completed. We will work through it in class and explain the steps involved. Examples 2 and 3 are incomplete. You will work through them, with assistance, during the class. They provide you with an opportunity to practice converting fertiliser to element.

Example 1

Example 1 is a completed worksheet which calculates how much nitrogen, phosphorus and potassium a cabbage grower is applying in his fertiliser program.

EXAMPLE 1

Table 1. Fertiliser Record Sheet

Crop: Cabbage **Variety:** Arixos **Soil type:** Karrakatta sand

Bay No.: **Sowing date:** **Transplanting date:** 4/10/92

Harvest date: 13/12/92 **Area of bay or bays to be fertilised:** $13m \times 100m = 1300m^2$

Rate of application (kg/bay or kg/area fertilised)

Type of fertiliser	Date of application																		Total kg of fertiliser applied per bay (or per fertilised area)
Inorganic	30/9	7/10	14/10	21/10	28/10	3/11	10/11	17/11	24/11	1/12	8/12								
Super-phosphate	100																		100
Urea		10	10	10	10	10	10	10	10	10	10								100
Potassium Sulphate		12	12	12	12	12	12	12	12	12	12								120
Nitrophoska TE							10	10	10										30
Organic																			
Fowl Manure	600																		600
$(2m^3)$																			

EXAMPLE 1

Table 2. Element Applied Sheet

(A) Type of fertiliser	(B) Total kg of fertiliser applied per bay (or per fertilised area) from Fertiliser Record Sheet	(C) kg of fertiliser per hectare $(B) \times \frac{10{,}000}{\text{Area fertilised}}$	(D) kg of element per hectare $(C) \times \frac{\%\text{ of element within fertiliser}}{100}$						
			Nitrogen (N)	Phosphorus (P)	Potassium (K)	Other elements			
Inorganic									
Super-phosphate	100	769		70					
Urea	100	769	353						
Potassium Sulphate	120	923			383				
Nitrophoska TE	30	320	38	16	45				
		Sub total	391	86	428				
Organic									
Fowl Manure	600	4615	138	46	58				
		Total	529	132	486				

Example 2

Calculate how much nitrogen, phosphorus and potassium is applied by a carrot grower using the fertiliser program outlined on the following page. He is concerned about boron and magnesium deficiency in his carrots. Also calculate how much boron and magnesium he puts on. Use the Element Applied Sheet provided.

EXAMPLE 2

Table 1. Fertiliser Record Sheet

Crop: Carrots **Variety:** Nandor **Soil type:** Spearwood sand

Bay No.: **Sowing date:** 1/3/93 **Transplanting date:**

Harvest date: July **Area of bay or bays to be fertilised:** 5000m²

Rate of application (kg/bay or kg/area fertilised)

Type of fertiliser	Date of application																		Total kg of fertiliser applied per bay (or per fertilised area)
Inorganic	28/2	14/3	21/3	28/3	4/4	11/4	18/4	25/4	2/5	9/5	16/5	23/5	30/5	6/6	13/6				
Superphosphate	600																		600
Agran							30		30		30		30		30				150
Potassium Nitrate		13	25	25	25														88
NPK Red							60		60		60		60		60				300
Magnesium Sulphate	25				25						25								75
Borax	6				3						3								12
Organic																			

EXAMPLE 2

Table 2. Element Applied Sheet

(A) **Type of fertiliser**	(B) **Total kg of fertiliser applied per bay (or per fertilised area)** from Fertiliser Record Sheet	(C) **kg of fertiliser per hectare** $(B) \times \frac{10,000}{\text{Area fertilised}}$	(D) **kg of element per hectare** $(C) \times \frac{\text{\% of element within fertiliser}}{100}$						
		5000m² .	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Mg .	B Other elements		
Inorganic Super ~~[illegible]~~	600	1200		109.2			2.64 .		
Agran ~~[illegible]~~	150	300	10.2						
Potassium nitrate	88	178	23.5 .		66.8				
NPK Red	300	600	~~78~~	36 .	96 ~~[illegible]~~				
MgSO4	75	150				15			
Borax.	12	24			162.8 .				
		Sub total	203.5	145.2	~~220.4~~	15	2.64 .		
Organic									
		Total	203.5	145.2	162.8	15	2.64 .		

Example 3

Calculate on the following two pages, how much nitrogen, phosphorus and potassium is applied by a cucumber grower who applies to a 100 m x 25 m area the following:

- *Preplant*

Fowl manure at 4 m^3 on 26/10/92.

Superphosphate at 125 kg on 26/10/92.

- *Post Plant*

Agran at 15 kg per week for 15 weeks, starting 2 weeks after planting. Muriate of Potash at 12 kg per week for 15 weeks starting 2 weeks after planting. Sowing date is the 1 November.

EXAMPLE 3

Table 1. Fertiliser Record Sheet

Crop: Cucumber **Variety:** **Soil type:**

Bay No.: **Sowing date:** ~~26~~ 1/11/9~~2~~ **Transplanting date:**

Harvest date: **Area of bay or bays to be fertilised:** 100 x 25m = 2500m²

Rate of application (kg/bay or kg/area fertilised)

Type of fertiliser	Date of application																		Total kg of fertiliser applied per bay (or per fertilised area)
Inorganic	26/10																		
Superphosphate	125																		125
Pigran		15x15kg																	225
Muriate of potash		15x12kg																	180
Organic																			
Fowl manure	1200																		1200
4m³																			

mg/kg
/1000/

EXAMPLE 3

Table 2. Element Applied Sheet

(A) **Type of fertiliser**	(B) **Total kg of fertiliser applied per bay (or per fertilised area)** from Fertiliser Record Sheet	(C) **kg of fertiliser per hectare** $(B) \times \frac{10,000}{\text{Area fertilised}}$	(D) **kg of element per hectare** $(C) \times \frac{\text{\% of element within fertiliser}}{100}$						
		2500m²	Nitrogen (N)	Phosphorus (P)	Potassium (K)	Mg	Cl	Other elements Ca	
Inorganic									
Super(P)	125	500		45.5					
Agran	225	900	306						
Muriate of K	180	720			358.5				
		Sub total							
Organic									
Fowl Manure	1200	4800	144	48	60	36	48	2	
		Total	450	93.5	418.5				

TO CONVERT THE AMOUNT OF AN ELEMENT BACK TO A FERTILISER

Department of Agriculture recommendations are often quoted as kilograms of element per hectare (e.g. apply 500 kg of nitrogen per hectare). The following steps show how to calculate how much of a particular fertiliser needs to be applied in order to supply a crop with a certain amount of an element.

If you decide to change from one fertiliser to another (e.g. Urea to Agran or sulphate of potash to muriate of potash) you will need to calculate how much of the new fertiliser needs to be applied in order to supply the same amount of element as you previously applied. Example 5 shows how to do this.

Steps

1. Convert kg of element per hectare to kg of fertiliser per hectare

Multiply the amount of element by 100 and divide the percentage of the element in the fertiliser to be used (see the table on the inside flap of this file for the percentage composition of different fertiliser types.

2. Convert kg of fertiliser per hectare to kg of fertiliser per bay (or area to be fertilised)

Multiply kg of fertiliser per hectare by: $\frac{\text{area of bay to be fertilised } (m^2)}{10000}$

3. Calculate the amount of fertiliser to be applied per application

Divide the number of kilograms of fertiliser to be applied to that crop by the number of applications of fertiliser (assuming equal amounts of fertiliser are to be applied in each application).

Example 4

A farmnote says to apply 500 kg of nitrogen per hectare to a cauliflower crop. How much fertiliser should a grower apply if he intends to apply Urea in 14 weekly applications? The area to be fertilised is a bay 12 m x 100 m.

Step 1. Convert kg of element per hectare to kg of fertiliser per hectare

$$500 \text{ kg} \times \frac{100}{46} = 1087 \text{ kg of Urea}$$

(where 500 is the kg of Nitrogen to be applied. Urea is 46% Nitrogen.)

Step 2. Convert kg of fertiliser per hectare to kg of fertiliser per bay

$$1087 \text{ kg} \times \frac{1200 \text{ m}^2}{10000} = 130 \text{ kg of Urea/bay}$$

(where 1200 m^2 is the area to be fertilised.)

Step 3. Calculate the amount of fertiliser to be applied per week

$$\frac{130 \text{ kg}}{14} = 9.3 \text{ kg of Urea/week/bay}$$

Example 5

A grower using the fertiliser program outlined in Example 1 decides to use muriate of potash rather than sulphate of potash and Nitrophoska as his source of potassium fertiliser. How much muriate of potash should he apply each week?

Step 1. Convert kg of element per hectare to kg of fertiliser per hectare

$$428 \text{ kg} \times \frac{100}{49.8} = 859 \text{ kg of muriate of potash/ha}$$

(where 428 kg of inorganic potassium was applied and muriate of potash is 49.8% potassium.)

Step 2. Convert kg of fertiliser per hectare to kg of fertiliser per bay

$$859 \text{ kg} \times \frac{1300 \text{ m}^2}{10000} = 112 \text{ kg of muriate of potash/bay}$$

Step 3. Calculate the amount of fertiliser to be applied per week

$$\frac{112 \text{ kg}}{10} = 11.3 \text{ kg of muriate of potash/week/bay}$$

(where 10 weekly applications are required.)

NOTE As Nitrophoska contains other elements in addition to potassium additional nitrogen may have to be applied.

Homework

Enter the fertiliser program for two of your crops on the blank Fertiliser Record Sheets provided at the back of this file in Appendix 1. Fill in the types of fertilisers used, date of application and rate of application. Calculate the number of kilograms of each major element. If possible, choose from the following crops: carrots, potatoes, cauliflowers, cabbage, lettuce and onions.

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Understanding Fertilisers

CHAPTER 5

SOIL TYPES AND SOIL TESTING

5. SOIL TYPES, SOIL TESTING AND PLANT ANALYSIS
by Neil Lantzke

5.1 Soil types of the Swan Coastal Plain

The following describes the major soil types of the Swan coastal plain. Their extent and capability to support horticulture is briefly discussed.

The distribution of the soil types on the Swan coastal plain follows a general pattern as a sequence of bands of soil systems which run parallel to the coast.

The map on the next page shows the soil systems of the Swan coastal plain, south of Perth.

The Quindalup system

This system forms a narrow strip, usually less than 1 km wide, immediately inland from the coast. It consists of a series of dunes containing sand similar to beach sand. These dunes are unsuitable for horticulture because of their high pH, exposure to salt spray, low groundwater quality, often steep slopes, low fertility and poor moisture holding ability.

The Spearwood system

This system consists of a series of low rises extending in a belt parallel to, and generally within 10 km of the coast. It includes the reddish brown Spearwood sands and yellow Karrakatta sands. The majority of the market gardens on the Swan coastal plain occur on this system. These soils are easily worked, occupy a milder climate zone nearer the coast and generally have plentiful supplies of good quality groundwater at shallow depths. Their slightly higher clay content results in better nutrient and water holding capacities than the poorer Bassendean sands. However, the nutrient and water holding capacities of this soil are low compared to heavier textured soils.

The Spearwood sands are usually red–brown in colour and generally have limestone within 1 m of the soil surface. Their pH is neutral to alkaline. The original vegetation was dominated by Tuart. The soils are well drained and have a good ability to hold onto phosphorus. As the depth to watertable is usually greater than 3 m, these soils present very little phosphorus pollution risk.

The Karrakatta sands are either yellow (yellow phase Karrakatta), or pale yellow (grey phase Karrakatta), with limestone at between 1 m to 10 m below the soil surface. They have a pH between six and seven.

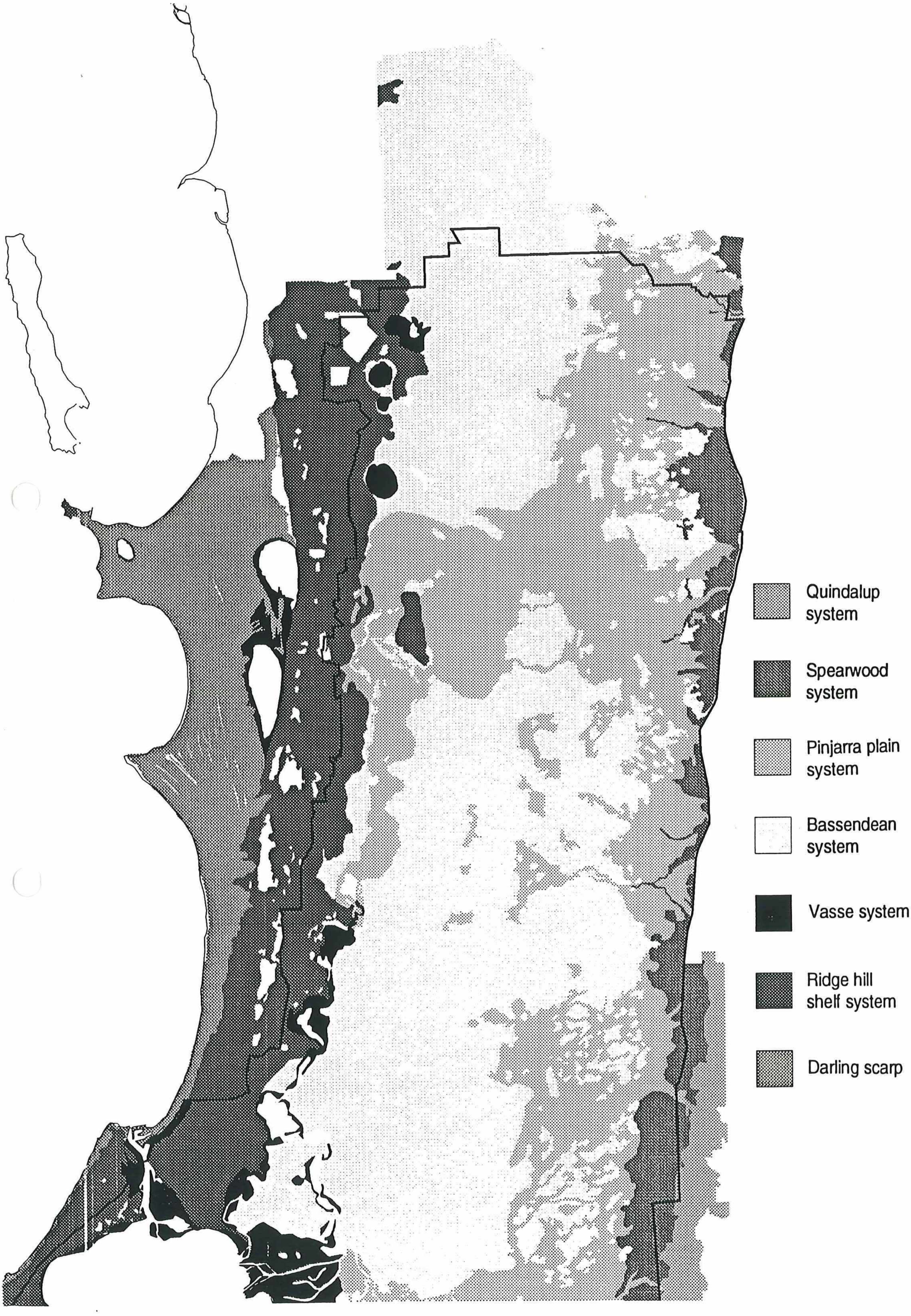
The native vegetation is jarrah and red gum with some banksias. Both soils are well drained. There is little phosphorus pollution risk on the yellow Karrakatta sands because of their good retention ability and considerable depth to groundwater.

The grey Karrakatta sands may present some pollution risk because of their lower phosphorus retention ability. The pale yellow colour indicates a lower concentration of iron and aluminium oxides which are important in holding phosphorus. However, the watertable is generally deep (seven to ten metres) and in many cases the soil becomes more yellow with depth.

The Bassendean system

This system comprises low sandy rises and undulating sandplain with leached grey sands and many small swamps and depressions.

Bassendean sands form a belt between 6 km and 8 km wide, through the centre of the Swan coastal plain. They are characterised by banksia, native christmas tree, paperbark (on wet areas) and the occasional redgum.



Soil systems south of Perth

Horticulture is being increasingly practiced on these soils as high land prices and the lack of available land, force growers to move from the more favoured Spearwood system. The Bassendean sands have very low nutrient and water retention properties. The Department of Agriculture is currently conducting trials on market gardens with gypsum amended red mud (from Alcoa) in an attempt to improve the nutrient retention abilities of these soils. Liming is required to raise the pH.

The Bassendean system can be broken into three soil types (soil series).

The Joel series

Flat, low–lying areas containing dark grey sand over bleached white sand which sits on top of an iron organic pan or coffee rock layer. This pan generally occurs at depths from 50 cm to in excess of two metres. The watertable is shallow and areas often become inundated during winter. In their native state these soils have little ability to retain phosphorus. However, the underlying iron organic pan has a very good ability to retain phosphorus and may greatly reduce the amount of leaching from properties. The building up of these soils with organic matter improves their ability to retain phosphorus.

The Gavin series

These consist of low rises and dunes of bleached pale sands usually found in association with the Joel series. These rises are commonly only two or so metres higher than the surrounding plain. The depth to iron–organic pan is variable, ranging from about 50 cm to in excess of five metres. The watertable is generally at depths below two metres.

In their native state these soils have little ability to retain phosphorus. The building up of these soils with organic matter improves their ability to retain phosphorus.

The Jandakot series

This soil type often occurs on large dunes and rises and is most common in the west of the Bassendean system, immediately east of the Spearwood system. The soil profile consists of a grey sand over a white sand. This often grades into a pale yellow to yellow sand at variable depth. This soil is well drained with watertables rarely reaching within three metres of the surface.

Phosphorus is rapidly leached from pale, sandy topsoil. Where a yellow subsoil occurs soils of the Jandakot series have reasonable phosphorus retention ability.

The Herdsman system

The Herdsman system occurs as small areas, often between the Spearwood and Bassendean systems.

These are low–lying, poorly drained areas, often forming terraces around the major rivers or on the bed of old wetlands. They can vary from organic sands to black peaty loams. Once drained these soils are well suited to vegetable production. These soils were some of the first used for horticulture on the Swan coastal plain. Sub soil moisture enabled summer cropping of these swamps without irrigation.

Due to their organic matter, these soils generally had a good ability to retain phosphorus. However, high watertables and rapid drainage mean that they are likely to lose considerable amounts of applied phosphorus.

The Pinjarra plain system

The Pinjarra plain system consists of a flat, generally poorly drained, alluvial plain and stretches from the foothills, westward to the Bassendean dunes, a distance of up to 12 km.

The soils are variable and range from deep, sandy duplex soils to red loams and grey clays. The majority of the soils on the Pinjarra plain are poorly drained and hence are unsuitable for horticulture. The notable exceptions are the terraces of the more recent alluvial soils which have been deposited immediately adjacent to drainage systems such as the Swan, Murray, Harvey, Brunswick, Collie, Capel and Carbanup rivers.

The soils of these well drained terraces are most commonly reddish brown loamy sands and sandy loams. Areas of deep yellowish brown loamy sands also occur.

These alluvial soils are used for table grapes, wine and citrus production in the Swan Valley, for vegetable production in the south west, e.g. the Jindong area and for citrus at Harvey.

Horticulture on the Pinjarra plain soils is unlikely to present a phosphorus pollution risk. These soils generally have a high phosphorus retention ability.

The loss of areas of these prime horticultural soils to urban and rural residential expansion is an important issue.

5.2 Movement of nutrients on different soils

Nitrogen

Nitrogen is poorly held by all sandy soils. Within seven days of application the majority of any nitrogen fertiliser is leached by irrigation water from the root zone. Heavy winter rains may leach applied nitrogen past the root zone within one or two days of application.

To combat losses by leaching, growers should apply nitrogen in as small and frequent applications as possible.

The Department of Agriculture is currently conducting trials with fertigation systems that allow daily application of nitrogen. Results indicate that lower rates of nitrogen can be used to produce better quality crops. This is because the concentration of nitrogen in the soil stays roughly the same throughout the crop's life rather than fluctuating wildly.

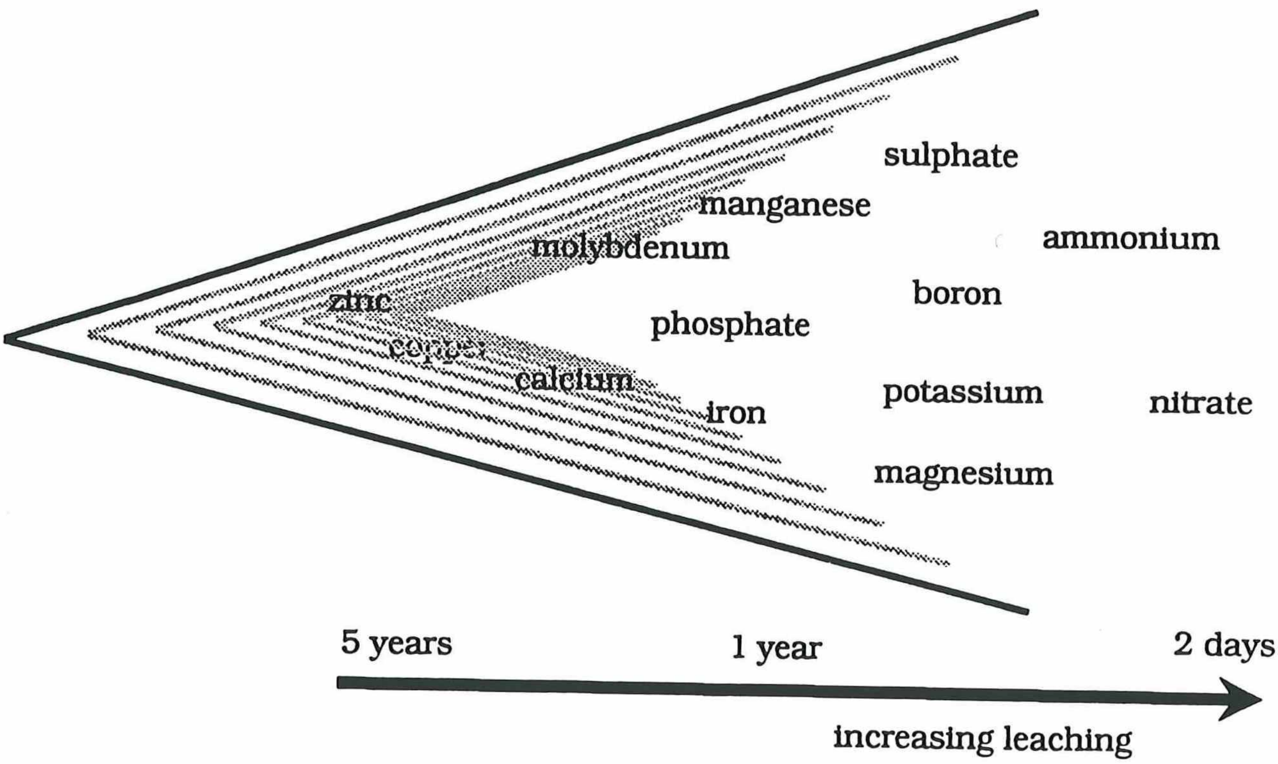
It is essential to have a reasonably uniform irrigation system to reduce nitrogen leaching. If uniformity is poor, some areas of the garden are overwatered in order to supply enough water to the drier spots. This excess water drains below the root zone taking nutrients with it. Uniform irrigation is critical if crops are to be fertigated, as on properties with poor irrigation systems some areas of the garden may receive twice as much nutrient as other areas.

Another method of reducing the amount of nitrogen lost by leaching is to use slow release fertilisers. These fertilisers release nutrients over an extended period (e.g. three months) and have the advantage of keeping the nutrient concentration at a roughly constant level. One application may be applied per crop. The results from Department of Agriculture trials on Brassica crops showed that although lower rates of slow release fertiliser could be used to grow a crop, the cost of the fertiliser made them uneconomic.

Phosphorus

The ability of the soils to hold phosphorus differs widely. Soils such as the Spearwood sands, the yellow Karrakatta sands and the loamy textured soils have a good ability to hold phosphorus. The iron and aluminium oxides in these soils (indicated by the red and yellowish colours) can 'fix' or bind phosphorus making it unavailable for leaching. Soil phosphorus levels can build up in these soils following fertiliser application to the point where phosphorus does not need to be applied to every crop. Soil testing should be used to determine how much phosphorus is required. Applying phosphorus at a set rate to each crop on these soils may not

How readily are nutrients leached in sandy soils?



be necessary. Soil test standards which indicate how much fertiliser to add at what soil test level have been developed for carrots, cauliflowers and lettuce (see Tables 2, 3 and 4). Refer to Farmnote 26/91 for information on soil testing.

The pale Bassendean sands have a poor ability to retain phosphorus. They have very little clay, iron and aluminium within them to which phosphorus can bind. In recently developed properties on Bassendean sands the majority of any applied phosphorus is leached by irrigation from the root zone within 1 to 3 months of application. Heavy rainfall increases the speed of leaching. Phosphorus should be applied in at least two applications per crop's life on these soils.

Building up these soils with organic matter such as fowl manure and the portion of the crop that is not harvested allows these soils to retain moderate levels of phosphorus. Phosphorus is able to bind the organic matter thus preventing it from leaching. Building up organic matter levels also increases the soil's ability to retain other nutrients and moisture. As organic matter breaks down nutrients become available at a slow rate for plant use. The role of building up organic levels on these poorer sandy soils should not be under–estimated.

Potassium

Potassium is held more strongly than nitrogen in our sandy soils but less strongly than phosphorus. Loamy soils with a higher percentage of clay have a good ability to hold potassium. Little research has been done to determine how frequently potassium should be added on the coastal sands. Traditionally, for ease of application, potassium has been added at the same time as nitrogen application i.e. weekly to every 10 days.

Table 1. Suggested frequency at which nutrients should be applied

	Frequency of application	
Element	Karrakatta sands (Yellow)	Bassendean sands (Pale)
Nitrogen	At least once per week	At least once per week
Phosphorus	Once per crop[1]	At least 2 times per crop
Potassium	Once per week	Once per week
Magnesium	2 to 3 times per crop	2 to 3 times per crop
Boron	Once per crop[2]	Once per crop[2]
Calcium	Depends on crop[3]	Depends on crop[3]
Iron	Every 18 months	Every 18 months
Manganese	Every 18 months	Every 18 months
Copper	Every 18 months	Every 18 months
Zinc	Every 18 months	Every 18 months
Molybdenum[4]	Every 18 months	Every 18 monts

1. Unless soil test levels indicate phosphorus is not required.
2. Apply Borax two times per crop to Boron sensitive crops such as carrots, Brassicas, lettuce and onions.
3. For most crops extra calcium is not required due to high levels in the soil or because of liming. Apply calcium three times per crop to fruit crops (e.g. tomatoes, melons, pumpkins, strawberries).
4. Apply two sprays of sodium molybdate per crop to Brassicas.

5.3 Soil test standards for carrots, cauliflowers and lettuce

After a number of years of phosphorus application the level of phosphorus in the soil can build up. The amount of phosphorus that needs to be applied to obtain maximum yield can be reduced according to the soil test level.

Soil testing should be conducted prior to planting. Allow about 2 to 3 weeks for results to be returned from the laboratory (refer to Farmnote 26/91 "Soil testing for vegetable production on the coastal plain").

Unfortunately, to date the research showing the appropriate quantities of phosphorus to add has only been completed for three crops (carrots, cauliflowers and lettuce) on one soil type (the yellow Karrakatta sand). However the tables below do give an indication of how much phosphorus to apply to other crops on other soil types.

The level of phosphorus required on the red–brown Spearwood sands will be slightly greater than that on the yellow Karrakatta sands because of greater fixing of phosphorus. The levels of phosphorus required by crops on Bassendean sands will be similar to those on yellow Karrakatta sands. However phosphorus application should be split into two or more applications during the crop's life. This is due to the greater rate of phosphorus leaching on these pale sands.

Note

Laboratories use several different methods to test for soil phosphorus. The recommendations below are only valid if the Colwell method is used. Ask for the Colwell test when you submit your samples.

Table 2. Phosphorus required for maximum yield of cauliflowers at different soil test levels on a yellow Karrakatta sand

Soil test (ppm P)	Phosphorus* * (kg/ha)	Superphosphate (kg/ha)
Over 45	24	264
40–45	37	407
25–40	54	593
30–35	65	714
25–30	86	945
20–25	102	1,121
15–20	118	1,296
10–15	128	1,406
5–10	134	1,473
0– 5	140	1,538

* Remember to include the contribution of phosphorus from any fowl manure added.

Table 3. Phosphorus required for maximum yield of carrots at different soil test levels on a yellow Karrakatta sand

Soil test (ppm P)	Phosphorus* (kg/ha)	Superphosphate (kg/ha)
Over 60	25	275
55–60	36	396
50–55	49	538
45–50	62	681
40–45	75	824
35–40	87	956
30–35	100	1,099
25–30	112	1,231
20–25	125	1,374
15–20	138	1,516
10–15	150	1,648
5–10	163	1,791
0– 5	163	1,791

Table 4. Phosphorus required for maximum yield of lettuce at different soil test levels on a yellow Karrakatta sand

Soil test (ppm)	Phosphorus* (kg/ha)		Superphosphate (kg/ha)	
	Winter	Summer	Winter	Summer
Over 120	0	0	0	0
110–120	23	19	250	209
100–110	40	33	435	363
90–100	58	50	632	527
80– 90	74	62	817	681
70– 80	91	76	1000	835
60– 70	125	104	1372	1143
50– 60	140	117	1543	1286
40– 50	157	131	1728	1440
30– 40	174	145	1912	1593
20– 30	191	159	2096	1747
10– 20	208	173	2284	1903
0– 10	213	178	2347	1956

* Remember to include the contribution of phosphorus from any fowl manure added.

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Understanding Fertilisers

CHAPTER 6

DEPARTMENT OF AGRICULTURE FERTILISER RECOMMENDATIONS

6. RECOMMENDATIONS FOR APPLYING FERTILISERS TO VEGETABLES ON THE SWAN COASTAL PLAIN
by John Burt

6.1 FERTILISING - BEFORE PLANTING USING POULTRY MANURE

Broiler or deep litter manure supplies useful amounts of all essential nutrients as well as increasing organic matter levels in the soil. However, extra levels of the trace elements boron and molybdenum may be required on boron and molybdenum sensitive crops (see Table 1).

Do not apply high rates of poultry manure as this will increase costs and result in high losses of nutrients into the groundwater. On acid soils, apply lime at least one month before poultry manure otherwise this will result in losses of ammonium into the air.

Poultry manure is not used for all crops. For instance, it is not used, or is used in low amounts prior to planting beans, carrots, cucurbits, onions, parsnips and radish. However, it is beneficial to apply poultry manure to previous crops.

Apply and incorporate into the soil unpelletised poultry manure within 1–4 days of planting as follows:

Established garden – Maximum of 30 cubic metres per hectare per crop (approximately 13 tonnes per hectare) with a maximum of 75 m^3/ha for all crops per year. With strawberries, apply a maximum of 50 m^3 before planting. An application of 30 cubic metres per hectare will supply 331 kilograms per hectare of nitrogen, 103 kg per hectare of phosphorus, 129 kg per hectare of potassium and 77 kg per hectare of magnesium. This calculation is based on poultry manure, which weighs 2.25 cubic metres per tonne and contains 22.5% moisture.

New garden – Maximum of 50 m^3/ha/crop to a maximum of 120 m^3/ha for all crops in first year.

– Maximum of 45 m^3/ha/crop to a maximum of 100 m^3/ha for all crops in second year.

Thereafter, as for the established garden.

The effects of nutrients last for four to six weeks following application of poultry manure. With most crops, it is necessary to commence weekly fertigation or broadcasting with low rates of nitrogen or potassium at three weeks after planting.

Pelletised manure may also be applied before planting and is easier to store and handle than unpelletised manure. Pelletised manure is applied at 2 to 3.5 tonnes/ha. This is lower than unpelletised manure as the pellets are more expensive and also denser. There is less danger of leaching of nutrients into the groundwater with these low rates. Pellets have a low moisture content and there are no dangers of fly breeding providing the pellets are incorporated into the soil before planting.

6.1.1 Fertilising before planting where poultry manure is not used

Apply magnesium sulphate and trace elements to the soil every eighteen months as follows:

Magnesium sulphate	50–100 kg per hectare
Manganese sulphate	25 kg per hectare
Ferrous sulphate	18 kg per hectare
Copper sulphate	18 kg per hectare
Zinc sulphate	18 kg per hectare
Borax	18 kg per hectare
Sodium molybdate	2 kg per hectare

These may be applied through the irrigation system if this gives uniform application, or by mixing and applying with superphosphate. More frequent use of some trace elements may be required if some crops are known to be sensitive to deficiencies of some trace elements (see Table 1).

Apply superphosphate before planting on Spearwood and Karrakatta soils. On Bassendean soils, split the applications between pre–planting and post–planting. The second application may be by using superphosphate or a mixed fertiliser containing phosphorus.

The recommended levels of phosphorus are shown in Table 1 for various crops. These levels may be reduced if a soil test shows high levels of phosphorus in the soil.

A small amount of superphosphate may also be needed where poultry manure is used if an analysis of the poultry manure shows less than 1% phosphorus or if the rate of poultry manure is less than 30 cubic metres per hectare.

Trials on the Swan Coastal Plain with banding of phosphorus within the soil close to the seeds or plants have not been successful with the exception of onions.

6.2 FERTILISING – AFTER PLANTING

The most suitable system of fertilising after planting is to apply nitrogen or potassium every 1–2 weeks by hand or machine or every 5–10 days by fertigation. In addition, magnesium, calcium and some trace elements may be needed on some crops. The use of mixed fertilisers containing 9 to 12 nutrients is expensive compared with the above system and may result in excessive levels of phosphorus being applied to the groundwater. Mixed fertilisers are more suitable on Bassendean sands, preferably using a fertiliser which contains a low level of phosphorus (see Section 3.4, Table 6).

Where poultry manure is not used, it will be necessary to commence applications of nitrogen and potassium within 2 to 3 days of planting.

6.2.1 Fertigation

Fertigation is the application of dissolved fertilisers through sprinkler systems or trickle systems. It is the preferred method of application for all crops, especially after closing in of the row. It is mainly used to apply nitrogen and potassium as topdressings, but may also be used to apply magnesium, calcium and trace elements. It offers savings in fertilisers, labour and equipment and results in less burning of crops, less leaching of nutrients and few losses of nutrients to the air.

Fertigation is only suitable if the irrigation system applies water and nutrients uniformly. The irrigation system should also allow different fertigation rates to be applied to different crops, or crops at different growth stages.

Fertilisers may also be applied as a soluble solution by using a boom sprayer.

Fertigate at the end of irrigation as this will result in less leaching. Water in for ten minutes after fertigation.

Electric or hydraulic injection systems offer the best system of application. By–pass systems are cheap but may not apply uniform flow rates.

The main fertilisers used in fertigation in Western Australia are as follows:

Nitrogen	–	ammonium nitrate, urea
Potassium	–	Potassium nitrate
		Potassium chloride
		Potassium sulphate

Nitrogen and potassium fertilisers may be applied together.

Do not mix fertilisers containing calcium with sulphates or phosphates as this may result in precipitation i.e. do not apply calcium nitrate with magnesium sulphate.

6.2.2 Application of solid fertilisers

Fertilisers may be broadcast by machine if the fertiliser has good granulation and spreads easily. Avoid broadcasting on wet crops, to sweet corn and advanced crops which are heading. Broadcasting is most suitable for beetroot, dwarf beans, carrots, onions, parsnips, potatoes, radish, swedes and turnips.

Band application close to the plants by hand or machine is suitable for most crops up to closing in the rows and offers savings in fertilisers with young plants and less loss of nutrients into the groundwater.

Broadcast and band application should be followed by at least 30 minutes irrigation.

Nitrogen and potassium fertilisers may usually be mixed as solid fertilisers and applied together if necessary, but addition of superphosphate will cause 'caking'. The most compatible nitrogen fertiliser for mixing with superphosphate is sulphate of ammonia.

6.2.3 Feeding through the leaves (foliar fertilising)

Trials in many countries with foliar fertilising using proprietary fertilisers have largely been unsatisfactory and in some cases yields have declined. The reasons for this are that plants are adapted to feeding through their roots. The waxy surface of leaves do not allow nutrients to be taken up quickly. Too high a concentration may burn the leaves or reduce the efficiency of any pesticides applied with the fertilisers.

Feeding through the leaves cannot replace efficient feeding of fertilisers through the soil. Trials by the Department of Agriculture, Victoria showed that nitrogen was the most successful foliar nutrient, followed by potassium. A mixture of potassium nitrate (1.5 kg/100 litres) plus urea (0.5 kg/100 litres) plus Agral 60 wetting agent (1 mL/litre) was superior to proprietary foliar fertilisers and was about five times cheaper. The best results were obtained under cold conditions and using fine misting sprays and when it was too late to apply soil fertilisers. However, it was essential that foliar fertilisers were applied in conjunction with a balanced fertiliser supply to the soil. Lettuce, spinach, silver beet, tomatoes, beans and radishes were the most responsive crops to foliar fertilising.

Foliar fertilising is also suitable for correcting proven deficiencies due to magnesium and especially trace elements, which only need small amounts of fertiliser to correct a deficiency. In this case, identification of the deficiency and spraying with the correct nutrient may correct the problem, although with some trace elements (i.e. iron, zinc) it may be too late to correct

the deficiency when it becomes visible. Apply the following fertilisers to correct deficiencies, although many other proprietary fertilisers (see Section 3) may also be used:

Calcium	–	calcium nitrate at 8 grams per litre
Magnesium	–	magnesium sulphate at 10 grams per litre
Boron	–	borax at 5 grams per litre
Copper	–	copper sulphate at 2 grams per litre plus lime
Iron	–	iron chelate at 2 grams per litre
Manganese	–	manganese sulphate at 8 grams per litre
Molybdenum	–	sodium molybdate at 1–2 grams per litre
Zinc	–	zinc chelate at 4 grams per litre

There are also a number of proprietary liquid fertilisers which may be applied to supply all of the six trace elements and often together with nitrogen, calcium or magnesium.

6.2.4 Topdressings of poultry manure

Topdressings of poultry manure are not recommended for the following reasons:

1. After establishment, nutrients are supplied more economically and efficiently, with less leaching into the groundwater, by small but regular applications of inorganic fertilisers containing nitrogen and potassium. Applications of poultry manure are less uniform as topdressings and contain 1% phosphorus which is best applied in poultry manure before planting and will result in increased losses into the groundwater if applied after planting. During topdressing, the optimum ratio of nitrogen to potassium to apply for most crops is 1:1.2 whereas the ratio of nitrogen (average 3%) to potassium (1.25%) in poultry manure is 2.4:1.

2. Crops may be damaged by high applications of poultry manure due to ammonium toxicity.

3. Topdressings of poultry manure are usually not worked into the soil and as a result, flies may breed on the surface deposits. This is a major issue in the City of Wanneroo.

6.3.1 Crop recommendations

Recommendations for applying fertilisers, before and after planting, to the main crops on established Spearwood and Karrakatta sands are shown in Table 1. This shows two programs:

Program A. Poultry manure followed by topdressings of nitrogen and potassium commencing weekly from three weeks after planting, plus other minor and trace elements which may be required.

Program B. Poultry manure is not used and weekly topdressings of nitrogen and potassium are commenced two days after planting, plus other minor and trace elements which may be required. More attention to application of minor and trace elements may be needed with this program as poultry manure is not applied.

2. The rates apply to average conditions and the number of applications need to be adjusted for winter or summer conditions. Rates also need to be decreased for early growth and towards harvest, with highest rates applied when half–grown.

3. Over–application of fertilisers may cause toxicities and reduce yields, and will be more expensive and increase leaching of nutrients into the groundwater and waterways.

4. On Karrakatta soils, if a soil analysis test for phosphorus shows that levels are high, reduce the amount of applied phosphorus according to the soil test standards outlined in Section 5.

Table 1.

Crop	Before planting		After planting					Trace elements
	Fowl manure Cubic metres per hectare	Phosphorus kg/ha	Total nitrogen kg/hectare		Total potassium kg/hectare		Minor elements	
	(A)*	(B)*	(A)	(B)	(A)	(B)		
Beetroot	30	100	25 kg per hectare x 8 applications = 200	25 kg per hectare x 11 applications = 275	30 kg per hectare x 8 applications = 240	30 kg per hectare x 11 applications = 333		Borax at 10 kg/hectare applied pre–plant and half–grown. Manganese applied to leaves on alkaline soil.
Broccoli	30	80	28 x 10 = 280	28 x 13 = 364	28 x 10 = 280	28 x 13 = 364	Apply magnesium to leaves if symptoms appear.	Borax applied at 15 kg/ha before planting. Molybdenum applied to seedlings and young plants on acid soils. Manganese applied to leaves on alkaline soil if symptoms appear. Molybdenum applied to seedlings and young plants on acid soils.
Cabbage	30	50	35 x 9 = 315	35 x 12 = 420	15 x 9 = 135	15 x 12 = 180		
Capsicums	30	100	20 x 20 = 400	20 x 23 = 460	25 x 20 = 500	25 x 23 = 575	Calcium nitrate in hot weather.	

Crop	Before planting		After planting					Trace elements
	Fowl manure Cubic metres per hectare	Phosphorus kg/ha	Total nitrogen kg/hectare		Total potassium kg/hectare		Minor elements	
	(A)*	(B)*	(A)	(B)	(A)	(B)		
Carrots (Nantes)	0	100		12.5 x 24 = 300 (winter) 17 x 15 = 250 (summer)		15 x 24 = 360 (winter) 20 x 15 = 300 (summer)	Magnesium sulphate at 50 kg/hectare before planting.	Borax at 15 kg/ha applied before planting and when half–grown.
Cauliflowers	30	100	25 x 11 = 275	25 x 14 = 350	30 x 11 = 330	30 x 14 = 420	Magnesium sulphate applied at 200 kg per hectare on acid soils. Calcium nitrate may be applied to leaves of some varieties to control tip burn.	Molybdenum applied to seedlings and plants on acid soils. Borax applied at 15 kg/ha before planting and at half–grown. Manganese applied to leaves on alkaline soil if symptoms appear.

Crop	Before planting		After planting					Trace elements
	Fowl manure Cubic metres per hectare	Phosphorus kg/ha	Total nitrogen kg/hectare		Total potassium kg/hectare		Minor elements	
	(A)*	(B)*	(A)	(B)	(A)	(B)		
Celery	30	100	33 x 12 = 400	33 x 15 = 500	33 x 12 = 400	33 x 15 = 500	Calcium nitrate applied weekly for last month in summer. Magnesium applied monthly to leaves.	Borax applied at 15 kg/ha before planting and monthly to leaves (2 sprays). Manganese and zinc applied (weekly) to leaves if symptoms appear.
Chinese cabbage	30	100	20 x 10 = 200	20 x 13 = 260	25 x 10 = 250	25 x 13 = 325	Calcium nitrate applied to leaves in hot weather. Magnesium sulphate applied at 50 kg/ha before planting.	Manganese applied to leaves if symptoms appear. Borax applied at 10 kg/ha to soil before planting on alkaline soils. Molybdenum applied to leaves of young plants

Crop	Before planting		After planting					Trace elements
	Fowl manure Cubic metres per hectare	Phosphorus kg/ha	Total nitrogen kg/hectare		Total potassium kg/hectare		Minor elements	
	(A)*	(B)*	(A)	(B)	(A)	(B)		
Cucumber	30	100	25 x 8 = 200	25 x 11 = 275	30 x 8 = 240	30 x 11 = 330	Magnesium sulphate applied at 50 kg/ha before planting.	Molybdenum applied to leaves of young plants on acid soils. Zinc applied to leaves twice weekly in summer if symptoms appear. Manganese applied to leaves on alkaline soils if symptoms appear.
Lettuce	30	100	25 x 10 = 200	25 x 13 = 325	35 x 10 = 350	35 x 13 = 455	Magnesium sulphate at 10 kg/ha applied weekly to soil.	
Onions	0	100 (may be banded with seed)		12 x 24 = 288		17 x 24 = 408		Manganese applied monthly to leaves. Zinc and iron applied weekly to leaves if symptoms appear.

Crop	Before planting		After planting					Trace elements
	Fowl manure Cubic metres per hectare	Phosphorus kg/ha	Total nitrogen kg/hectare		Total potassium kg/hectare		Minor elements	
	(A)*	(B)*	(A)	(B)	(A)	(B)		
Potatoes	30	100	17 x 14 = 252	18 x 17 = 306	22 x 14 = 308	22 x 17 = 374	Magnesium sulphate at 50 kg/hectare before planting and half–grown.	
Rock melon	30	80	20 x 9 = 180	20 x 12 = 240	28 x 9 = 252	28 x 12 = 336		Molybdenum applied to young plants on acid soils. Zinc applied to leaves if symptoms appear.
Strawberries	50	100	15 x 49 = 735 per year	15 x 52 = 780 per year	27 x 49 = 1323 (Sulphate form)	27 x 52 = 1404 (Sulphate form)	Apply calcium nitrate at 10 kg/ha and magnesium sulphate at 5 kg/ha per week.	

Crop	Before planting: Fowl manure Cubic metres per hectare (A)*	Before planting: Phosphorus kg/ha (B)*	After planting: Total nitrogen kg/hectare (A)	After planting: Total nitrogen kg/hectare (B)	After planting: Total potassium kg/hectare (A)	After planting: Total potassium kg/hectare (B)	After planting: Minor elements	Trace elements
Tomatoes	30	150	20 x 17 = 340	20 x 20 = 400	28 x 17 = 476	28 x 20 = 560	Calcium nitrate applied to leaves in hot weather. Magnesium sulphate applied monthly at 100 kg/ha.	Manganese applied to leaves if symptoms appear. Zinc applied weekly to leaves in summer on alkaline soils with high soil phosphorus. Iron applied weekly to leaves if symptoms of yellow leaves at top of plant.
Water melons	30	80	13 x 10 = 130	13 x 13 = 169	20 x 10 = 200	20 x 13 = 260	Magnesium sulphate at 100 kg/ha applied every three weeks to soil.	Molybdenum applied to young plants on acid soils. Zinc applied to leaves if symptoms appear.
Zucchini	30	100	22 x 11 = 242	22 x 14 = 308	30 x 11 = 333	30 x 14 = 420		Molybdenum applied to young plants on acid soils.

6.3.2 Applying various rates of Nitrogen and Potassium as top dressings

The amount of nitrogen and potassium fertilisers that need to be applied to supply various rates of nitrogen and potassium are as shown in Table 2.

Table 2. Applying various rates of Nitrogen and Potassium

Rate kg/hectare of pure nitrogen or potassium	Amount of fertiliser kg per hectare	
	Nitrogen	Potassium
10	29.4 kg ammonium nitrate	20.1 kg potassium chloride
	21.7 kg urea	24.1 kg potassium sulphate
	76.9 kg potassium nitrate	26.3 kg potassium nitrate
15	44.1 kg ammonium nitrate	30.1 kg potassium chloride
	32.6 kg urea	36.1 kg potassium sulphate
	115.4 kg potassium nitrate	39.5 kg potassium nitrate
20	58.8 kg ammonium nitrate	40.2 kg potassium chloride
	43.4 kg urea	48.2 kg potassium sulphate
	153.8 kg potassium nitrate	56.6 kg potassium nitrate
25	73.5 kg ammonium nitrate	50.2 kg potassium chloride
	54.3 kg urea	60.2 kg potassium sulphate
	192.3 kg potassium nitrate	65.8 kg potassium nitrate
30	88.2 kg ammonium nitrate	60.2 kg potassium chloride
	65.2 kg urea	72.3 kg potassium sulphate
	230.8 kg potassium nitrate	78.9 kg potassium nitrate
35	102.9 kg ammonium nitrate	70.3 kg potassium chloride
	76.1 kg urea	84.3 kg potassium sulphate
	269.2 kg potassium nitrate	92.1 kg potassium nitrate

These rates apply to **one** hectare (10,000 square metres).

The ratio of nitrogen to potassium in potassium nitrate (1:2.9) is unsuitable for this fertiliser to be used by itself. With most vegetable crops, extra nitrogen needs to be applied to ensure a ratio of nitrogen to potassium of approximately 1:1.2.

The amount of ammonium nitrate or urea plus potassium nitrate to supply this ratio is shown in Table 3.

Table 3. Rates of Nitrogen fertilisers plus Potassium Nitrate to give a Nitrogen:Potassium ratio of 1:1.2

Rate kg/hectare of pure nitrogen plus pure potassium (1:1.2)	Ammonium nitrate kg/ha	or	Urea kg/ha	plus	Potassium nitrate kg/ha
10 kg/ha nitrogen + 12 kg/ha potassium	17.4	or	12.8	plus	31.6
15 kg/ha nitrogen + 18 kg/ha potassium	26.1	or	19.2	plus	47.4
20 kg/ha nitrogen + 24 kg/ha potassium	34.8	or	25.6	plus	63.2
25 kg/ha nitrogen + 30 kg/ha potassium	43.5	or	32.0	plus	79.0
30 kg/ha nitrogen + 36 kg/ha potassium	52.2	or	38.4	plus	94.8
35 kg/ha nitrogen + 42 kg/ha potassium	60.9	or	44.8	plus	110.6

Table 4 compares the costs for applying various nitrogen and potassium fertilisers to apply 10 kg/ha nitrogen and 12 kg/ha potassium at a ratio of nitrogen to potassium of 1:1.2.

Table 4. Comparison of fertiliser costs to give a Nitrogen:Potassium ratio of 1:1.2

	Fertilisers costs to supply 10 kg nitrogen plus 12 kg potassium per hectare (nitrogen/potassium ratio of 1:1.2)	Total $
1.	17.4 kg/ha of ammonium nitrate ($10.20) + 31.6 kg/ha potassium nitrate ($25.00)	35.20
2.	29.4 kg/ha of ammonium nitrate ($17.30) + 28.9 kg/ha potassium sulphate ($16.50)	33.80
3.	12.8 kg/ha of urea ($5.00) + 31.6 kg/ha of potassium nitrate ($25.00)	30.00
4.	29.4 kg/ha of ammonium nitrate ($17.30) + 24.2 kg of potassium chloride ($9.80)	27.10
5.	21.7 kg/ha urea ($9.20) + 28.9 kg/ha of potassium sulphate ($16.50)	25.70
6.	21.7 kg/ha urea ($9.20) + 24.2 kg/ha of potassium chloride ($9.80)	19.00

The cheapest combination is to use a mixture of urea and potassium chloride (Muriate of potash) to supply a nitrogen:potassium ratio of 1:1.2, and this would also apply to other ratios of nitrogen and potassium.

A combination of urea plus potassium sulphate would be the best combination on chloride–sensitive crops.

6.5 Hydroponic production

Hydroponic systems in greenhouses or protected enclosures allow good control over irrigation, fertilisation and nutrient run–off into the groundwater and waterways.

There are two types of systems in hydroponics:

(a) Run to waste, where a nutrient solution is applied 2–10 times per day through a media (i.e. sawdust, perlite, rockwool), in order to give a nutrient run–off of 20%.

(b) Nutrient film technique in which a nutrient solution is recycled 24 hours per day to plants which have their roots in bare channels.

With both these systems, the same nutrient solution is used. A typical nutrient solution (Huett, Department of Agriculture, New South Wales) would have the following composition:

Table 5. Concentration of nutrients in typical hydroponic solution

	Parts per million	Comments
Nitrogen	150	90% in nitrate form
Phosphorus	35	
Potassium	255	
Calcium	140	
Magnesium	30	
Sulphur	52	
Boron	0.5	
Copper	0.05	
Iron	4.00	In chelate form
Manganese	0.50	
Molybdenum	0.02	
Zinc	0.10	

This is made by using two stock solutions (A and B) in which calcium and iron in stock solution A are separated from other nutrients in stock solution B, especially phosphates, in order to prevent precipitation in the concentrated solution. There are no problems with mixing these chemicals in diluted form. The composition of the stock solutions A and B is shown in Table 6.

Table 6. Example of fertilisers used in typical hydroponic stock solutions

Stock solution	Fertiliser	Grams per litre
A	Calcium nitrate	109
A	Iron chelate	5.6
B.	Mono ammonium phosphate	8.7
B.	Potassium di hydrogen phosphate	16.3
B	Potassium nitrate	133.3
B	Magnesium sulphate	58.1
B	Boric acid	0.350
B	Zinc sulphate	0.20
B	Copper sulphate	0.0350
B	Sodium molybdate	0.010

To 1,000 litres of solution, add 3.4 litres stock A solution and 3.4 litres of stock B solution to give the composition shown in Table 5.

6.6 Organic production

Most organic growers sell under the logo of a certifying organic organisation such as NASAA, Biological Farmers of Australia or the Biodynamics Association of Australia. However, at present, there is no legal requirement that a farmer must belong to a certifying organisation in order to label his produce with terms such as 'organic', biodynamic' 'biological' or 'natural'. However, this situation may change in the next two years.

All of the twelve essential elements normally supplied by fertilising can be applied organically, especially with poultry or livestock manures. Inputs of all synthetic fertilisers and pesticides are lower than conventional horticulture. There is also less loss of nutrients into the groundwater and waterways. However, with organic production, it is more difficult to apply nitrogen on its own in topdressings.

Certifying organisations often request that livestock manures are composted to breakdown any harmful chemicals (i.e. antibiotics) used in livestock production. The pelleted forms of poultry manure do not have to be composted.

Blood and Bone supplies nitrogen (5–8%) and phosphorus (3–4%) plus magnesium and some trace elements. It is widely used by organic growers, but sometimes certifying organisations insist that this must be composted. Bloodmeal costs $900/t and is a good source of nitrogen (12.5%), plus lower levels of phosphorus (1.3%) or potassium (0.7%), but is expensive and may be difficult to obtain.

Certifying organisations permit the use of potassium sulphate, lime (calcium) and magnesite (to supply magnesium). All of the six main trace elements may be used if deficiencies have been proven.

DEPARTMENT OF AGRICULTURE
WESTERN AUSTRALIA

Understanding Fertilisers

APPENDICES

Appendix 1.

Answers to Examples 2 and 3.

There is also a blank 'Fertiliser Record Sheet' and 'Element Applied Sheet' which you can use to record and examine your own fertiliser programs.

EXAMPLE 2

Table 1. Fertiliser Record Sheet

Crop: Carrots **Variety:** Nandor **Soil type:** Spearwood sand

Bay No.: **Sowing date:** 1/3/93 **Transplanting date:**

Harvest date: July **Area of bay or bays to be fertilised:** 5000m²

Rate of application (kg/bay or kg/area fertilised)

Type of fertiliser	Date of application																		Total kg of fertiliser applied per bay (or per fertilised area)
Inorganic	28/2	14/3	21/3	28/3	4/4	11/4	18/4	25/4	2/5	9/5	16/5	23/5	30/5	6/6	13/6				
Super-phosphate	600																		600
Agran							30		30		30		30		30				150
Potassium Nitrate		13	25	25	25														88
NPK Red							60		60		60		60		60				300
Magnesium Sulphate	25				25						25								75
Borax	6				3						3								12
Organic																			

EXAMPLE 2

Table 2. Element Applied Sheet

(A) Type of fertiliser	(B) Total kg of fertiliser applied per bay (or per fertilised area) from Fertiliser Record Sheet	(C) kg of fertiliser per hectare $(B) \times \frac{10,000}{\text{Area fertilised}}$	(D) kg of element per hectare $(C) \times \frac{\text{\% of element within fertiliser}}{100}$						
			Nitrogen (N)	Phosphorus (P)	Potassium (K)	Other elements: Magnesium	Boron		
Inorganic									
Super-phosphate	600	1200		109					
Agran	150	300	102						
Pot. Nitrate	88	176	24		67				
NPK Red	300	600	78	36	96				
Magnesium sulphate	75	150				15			
Borax	12	24					26		
		Sub total	204	165	163	15	26		
Organic									
		Total	204	165	163	15	26		

EXAMPLE 3

Table 1. Fertiliser Record Sheet

Crop: Cucumbers **Variety:** Black Prince **Soil type:** Bassendean sand

Bay No.: **Sowing date:** 1/11/92 **Transplanting date:**

Harvest date: **Area of bay or bays to be fertilised:** 2500m^2

Rate of application (kg/bay or kg/area fertilised)

Type of fertiliser	Date of application	kg																	Total kg of fertiliser applied per bay (or per fertilised area)
Inorganic	26/10	14/11	21/11	28/11	5/12	12/12	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2	13/2	20/2			
Super-phosphate	125																		125
Agran		15	15	15	15	15	15	15	15	15	15	15	15	15	15	15			225
Muriate of Potash		12	12	12	12	12	12	12	12	12	12	12	12	12	12	12			180
Organic																			
Fowl Manure	1200																		1200
(4m^3)																			

EXAMPLE 3

Table 2. Element Applied Sheet

(A) **Type of fertiliser**	(B) **Total kg of fertiliser applied per bay (or per fertilised area)** from Fertiliser Record Sheet	(C) **kg of fertiliser per hectare** $(B) \times \frac{10,000}{\text{Area fertilised}}$	(D) **kg of element per hectare** $(C) \times \frac{\text{\% of element within fertiliser}}{100}$						
			Nitrogen (N)	Phosphorus (P)	Potassium (K)	Other elements			
Inorganic									
Super-phosphate	125	500		46					
Agran	225	900	306						
Muriate of Potash	180	720			358				
		Sub total							
Organic									
Fowl Manure	1200	4800	144	48	60				
		Total	450	94	418				

Table 1. Fertiliser Record Sheet

Crop: **Variety:** **Soil type:**

Bay No.: **Sowing date:** **Transplanting date:**

Harvest date: **Area of bay or bays to be fertilised:**

Rate of application (kg/bay or kg/area fertilised)

Type of fertiliser	Date of application																		Total kg of fertiliser applied per bay (or per fertilised area)
Inorganic																			
Organic																			

Table 2. Element Applied Sheet

(A) **Type of fertiliser**	(B) **Total kg of fertiliser applied per bay (or per fertilised area)** from Fertiliser Record Sheet	(C) **kg of fertiliser per hectare** $\frac{(B) \times 10,000}{\text{Area fertilised } (m^2)}$	(D) **kg of element per hectare** $\frac{(C) \times \% \text{ of element within fertiliser}}{100}$						
			Nitrogen (N)	Phosphorus (P)	Potassium (K)	Other elements			
Inorganic									
		Sub total							
Organic									
		Total							

Table 1. **Fertiliser Record Sheet**

Crop: **Variety:** **Soil type:**

Bay No.: **Sowing date:** **Transplanting date:**

Harvest date: **Area of bay or bays to be fertilised:**

Rate of application (kg/bay or kg/area fertilised)

Type of fertiliser	Date of application																		Total kg of fertiliser applied per bay (or per fertilised area)
Inorganic																			
Organic																			

Table 2. Element Applied Sheet

(A) **Type of fertiliser**	(B) **Total kg of fertiliser applied per bay (or per fertilised area)** from Fertiliser Record Sheet	(C) **kg of fertiliser per hectare** $(B) \times \frac{10,000}{\text{Area fertilised}}$	(D) **kg of element per hectare** $(C) \times \frac{\%\text{ of element within fertiliser}}{100}$						
			Nitrogen (N)	Phosphorus (P)	Potassium (K)	Other elements			
Inorganic									
		Sub total							
Organic									
		Total							

Appendix 2.

Glossary

Acidic	Having a pH less than 7.
Alkaline	Having a pH greater than 7.
Carbohydrate	A compound made up of carbon, hydrogen and oxygen e.g. sugars, starch, cellulose.
Chelate	Chemical compound, usually a trace element which is held in a complex form which increases its solubility and helps prevent leaching from the soil.
Chlorophyll	The green pigment of plants which is necessary for photosynthesis.
Chlorosis	Yellowing.
Critical concentration	If the concentration of a nutrient in plant tissues falls below the critical concentration, plant yield will suffer.
Enzyme	A protein produced by plants that speeds up chemical reactions.
Ion	Electrically charged atom or group of atoms in a solution.
Molecule	A group of atoms held together by chemical forces.
Oxide	Compound of a metallic element with oxygen.
pH	A measurement of the acidity or alkalinity of a soil or solution. It is specifically a measure of the hydrogen ion concentration.
Photosynthesis	The process in which a plant uses the energy of the sun to produce carbohydrates.
Stomata	Pores in the surface of leaves which are opened and closed by guard cells.

Appendix 3

Conversion factors

1 hectare	=	2.46 acres
1 hectare	=	10,000 square metres
1 cubic metre of chicken manure	=	300 kg dry weight or 400 kg wet weight
1%	=	10,000 ppm (parts per million)

Appendix 4

Bibliography

1. **Diagnosis of Mineral Disorders in Plants.**

   1987. Volume 3 by G. Winsor and Peter Adams. **Glasshouse Crops.**

   1983. Volume 2 by Alan Scaife and Mary Turner. **Vegetables.**

   London: Her Majesty's Stationery Office.

2. **Plant Nutrient Disorders 3. Vegetable Crops.** 1993. R.G. Weir and G.C. Cresswell.

   Inkata Press, Melbourne, Sydney.

   Available from Butterworth–Heinemann, 271–273 Lane Cove Road, North Ryde, NSW 2113

   Around $30 including postage.

3. **Strawberry Deficiency Symptoms; a visual and plant analysis guide to fertilization.** 1980. A. Ulrich, M.A.E. Mostafa, W.W. Allen.

   Agricultural Experiment Station. University of California, Division of Agriculture and Natural Resources Bulletin 1917.

   Available from Publications, Division of Agriculture and Natural Resources, University of California, 6701 San Pablo Avenue, Oakland, California 94608–1239.

4. **Compendium of tomato diseases.**

   Edited by J.M. Jones *et al.* 1991.

   APS Press.

   Available from The American Phytopathological Society, 3340 Pilot Knob Road, St. Paul, Minnesota 55121, USA.