Perth Region NRM
Coordinating sustainable agricultural outcomes

Understanding nitrogen fertilisers for vegetable production on sands

Introduction

Nitrogen is required by vegetables in large quantities and if crops are not supplied with sufficient nitrogen then yield can be greatly reduced. Fertilisers make up about 10% of the total cost of production for most vegetable crops. It is therefore important that growers do not over fertilise and apply the optimum amount of fertiliser.

Nitrogen is one of the 14 essential nutrients that plants require from the soil. For most growers it is the most important nutrient as it greatly affects growth. However, it can be rapidly leached past the root zone on sandy soils, or become lost to the air, thus becoming unavailable to the current or subsequent crops. Nitrogen is used by plants as a major building block of amino acids, proteins and enzymes.

This factsheet will give you a greater understanding of nitrogen fertilisers so that you can develop a fertiliser program that suits your situation. It also provides information on how to fertilise more efficiently and minimise losses to the environment, thereby reducing overall nitrogen fertiliser costs.

Nitrogen deficiency and toxicity

Crops with severe nitrogen deficiency grow poorly and generally have small, pale leaves. The oldest leaves are the first to show deficiency symptoms (yellowing) as nitrogen is re-mobilised by the plant from old leaves to the young growing tissue where it is most needed. Nitrogen deficiency may be difficult to determine from visual symptoms alone, particularly if it is not severe, but the crop growth and yield can be affected.

Figure 1 is a photograph of a fertiliser trial which shows how insufficient nitrogen can greatly affect carrot growth. Be aware that similar symptoms to nitrogen deficiency can result from cold weather and root damage caused by disease, nematodes or insects.

Nitrogen toxicity is characterised by necrotic tissue (fertiliser burn) at the tip and margins of the leaf.

Figure 1 Nitrogen fertiliser trial on carrots at Medina Research Station. The plot in the foreground has received very little nitrogen and the crop is deficient *(Photo: A McKay, DAFWA)*

Figure 2 Vegetable crops grown on sands require regular applications of nitrogen *(Photo: N Lantzke)*

Figure 3 is a hypothetical yield response curve that shows how increasing the rate of nitrogen fertiliser affects the yield.

In section A the crop has not received enough nitrogen and deficiency symptoms are visible. Yield at harvest is greatly reduced. In section B the crop has not received enough nitrogen but there are no visible symptoms. The yield at harvest will be reduced.

In section C the crop has received adequate nitrogen fertiliser. Growers should aim to apply sufficient fertiliser to be within this range to ensure maximum growth and yield. In section D excessive fertiliser has been applied, but there are no toxicity symptoms. Maximum yield has been obtained but fertiliser costs are higher than they need to be. In Section E excessive fertiliser has been applied, the crop shows toxicity symptoms and the yield is reduced.

How do you determine how much nitrogen fertiliser to apply?

1. Use leaf or petiole analysis.
2. Refer to recommendations in DAFWA publications and the *Good Practice Guide*, by vegetablesWA.
3. Conduct small scale fertiliser trials on your farm.
4. Understand the nitrogen cycle and how it impacts on your fertiliser practices.

The nitrogen cycle

Nitrogen is contained in fertilisers and manures but is also found in the soil, in plant material, in the atmosphere and, in some cases, in the groundwater. Nitrogen can convert from one form to another and then become available to plants. The nitrogen cycle (see Figure 4) explains the processes by which nitrogen is converted to its various forms. These transformations are influenced by soil properties, climate and management practices. It is important that growers have an understanding of the nitrogen cycle so that they can fertilise their crop efficiently.

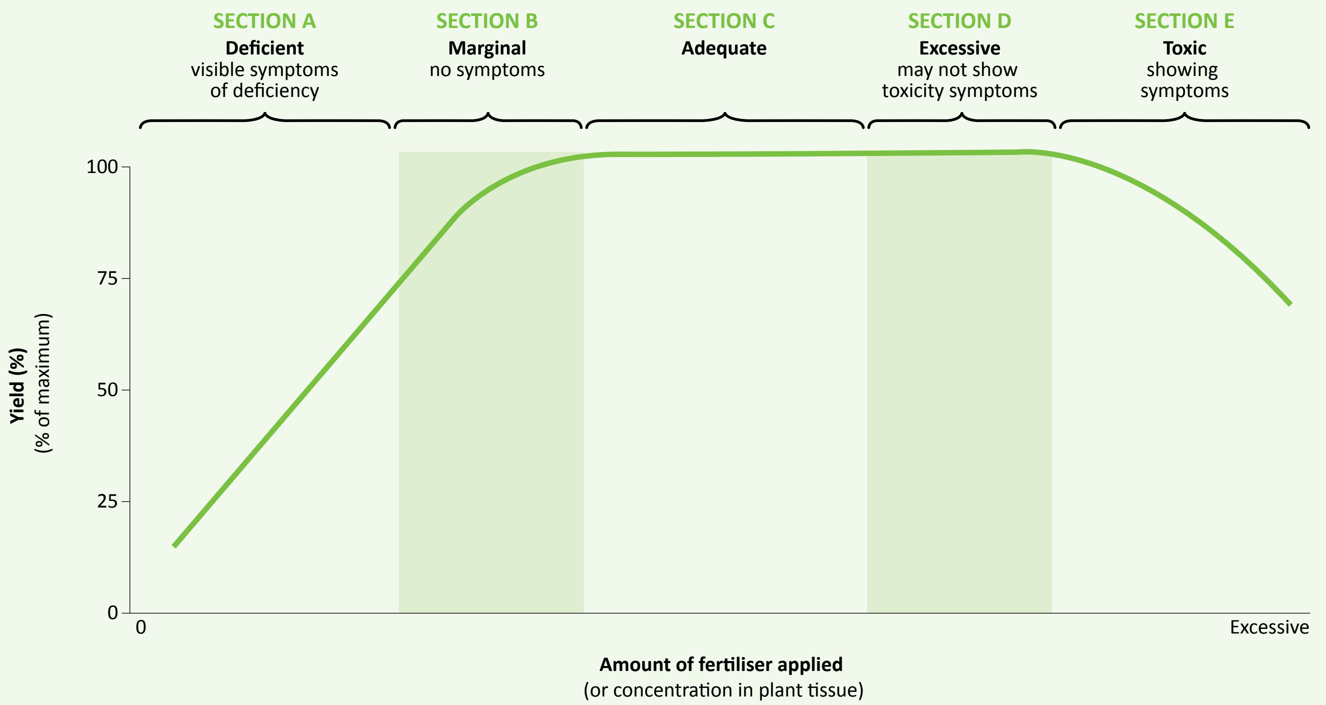

Figure 3 Yield response curve for fertiliser application
Source: Adapted from McLaughlin et al *(1999)*

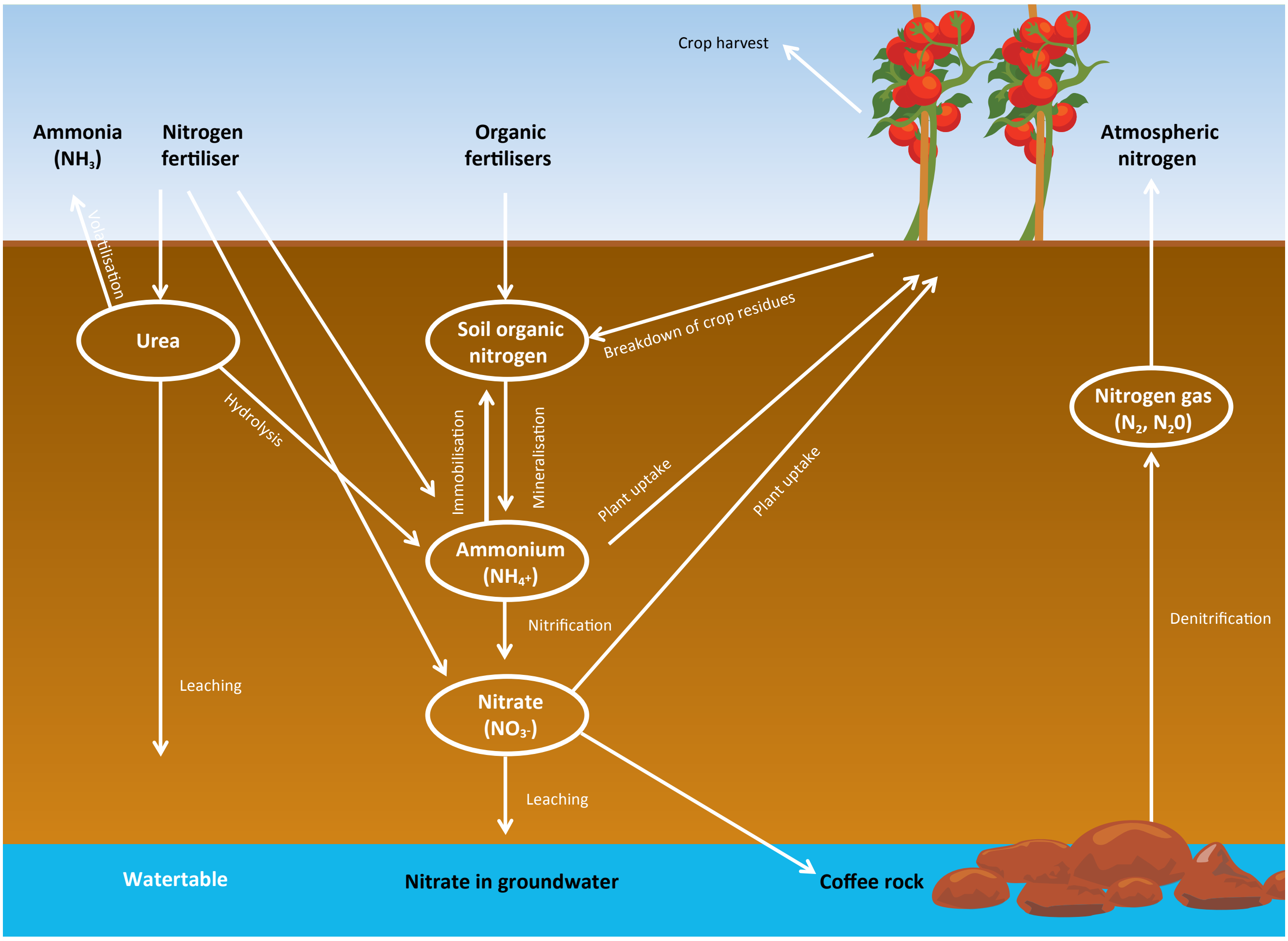

Figure 4 The nitrogen cycle for vegetable production on sands
Source: N Lantzke

Components of the nitrogen cycle

Nitrogen fertiliser

The sandy soils found on the Swan coastal plain have very low natural levels of nitrogen. If nitrogen is not applied as an inorganic fertiliser or as organic fertilisers such as manure, then the crop will grow poorly and will not be marketable.

Nitrogen fertiliser usually contains nitrogen in one or more of the forms shown in Table 1.

Plants can take up nitrogen in either the nitrate or ammonium form. They cannot take up urea or organic nitrogen directly, since these forms must first be converted by soil bacteria to nitrate or ammonium.

Table 1 Common forms of nitrogen fertilisers

Form of nitrogen	Examples of fertilisers
Nitrate	Calcium nitrate, potassium nitrate, urea ammonium nitrate
Ammonium	Ammonium sulphate, urea ammonium nitrate, di ammonium phosphate (DAP), mono ammonium phosphate (MAP)
Urea	Urea, urea ammonium nitrate
Organic nitrogen	Manures, compost and legumes

Note: Mixed NPK fertilisers may contain nitrogen in the ammonium or nitrate form.

Nitrate

Nitrate ions are weakly held by all soils, but in particular by sands. They move in the soil solution and if they are not absorbed by plants, they can be readily lost through leaching. Nitrate can be leached past the root zone by a single, heavy rainfall event or by excessive irrigation.

Ammonium

Ammonium is not readily leached from soils. The ammonium ion has a positive charge and is held by clay particles and organic matter which contain negative charges on their surface. On the sandy soils of the Swan coastal plain, ammonium is leached more than on other soil types (due to their low clay content), but is not leached as readily as nitrate.

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. 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.

Urea

Urea must be converted by bacteria to ammonium or nitrate before it can be taken up by plants. This process of converting urea to ammonium is known as urea hydrolysis. Above a soil temperature of 5 degrees Celsius, urea forms ammonium ions within 2–7 days. Urea has no charge and can also be leached from sands almost as readily as nitrate.

Organic fertilisers

Organic fertilisers, such as manures and compost contain nitrogen. Poultry manure has been widely used in the past on vegetable properties on the Swan coastal plain. Due to the breeding of stable fly in manure it has now been banned for use in shires around Perth. Refer to the section on 'Poultry Manure' for further information.

Compost is organic matter that has undergone the composting process to produce a more stable organic material. Composts contain humus which increase a soil's ability to hold many nutrients. Composts also contain a large diversity of micro-organisms that may reduce pathogens. Composts slowly release nitrogen into the soil solution but, unless applied at very high rates they are unable to meet the nitrogen requirements of a fast growing vegetable crop. Composts can improve the structure of the soil so that the soil forms aggregates and becomes more friable. However, on sands such as those found on the Swan coastal plain, there is no soil structure (i.e. sands contain single grains) so compost will not improve the structural condition of the soil. Refer to Paulin and O'Malley (2008) for further information on the use of composts on vegetables.

Soil organic nitrogen

The organic matter in the soil on a vegetable property is derived from decaying plant residues from previous crops and from any additions such as poultry manure or compost. As the organic matter breaks down it may release nitrogen. Figure 4 shows how organic nitrogen is transformed to ammonium through the process of mineralisation. Ammonium can then be taken up by plants or be transformed by bacteria in the soil to nitrate.

The rate of decomposition of organic matter is increased by warm and moist conditions. Cultivating the soil helps break up decomposing organic matter and the aeration also assists the breakdown.

Nitrogen mineralisation

Different types of organic matter have differing abilities to add nitrogen to the soil. The ratio of carbon-to-nitrogen (C:N) in the organic materials provides information on whether there will be an immediate net increase in available nitrogen or a temporary decrease in available nitrogen when the material undergoes decomposition.

When the C:N ratio is less than about 25:1, such as in legume crops, a net increase in available nitrogen can be expected when the micro-organisms decompose that material.

However, if the C:N ratio is greater than about 25:1, such as in straw, an initial temporary decrease in available nitrogen upon decomposition is likely. This is termed **immobilisation**, or the nitrogen drawdown effect, and occurs because the microbes need additional nitrogen to utilise all the carbon in the organic matter. In order to prevent temporary nitrogen deficiency in the crop an additional, basal application of nitrogen should be applied to the soil to help breakdown organic material with a high C:N ratio. After a few weeks the immobilised nitrogen in microbial bodies can be mineralised back into the inorganic form and will become available for plant uptake.

Nitrification

Ammonium is transformed by bacteria in the soil to form nitrate. In warm and wet conditions the majority of ammonium is converted to nitrate within 4–7 days. As ammonium is converted to nitrate, hydrogen ions are released which can result in an increase in soil acidity. This can be overcome by applications of lime.

Denitrification

Under conditions of low oxygen and high organic matter bacteria respire nitrate to produce nitrous oxide ($N_2$0) and nitrogen gas (N_2). These environments may include waterlogged soils and groundwater with coffee rock. Nitrous oxide is a greenhouse gas and its global warming potential is 300 times that of carbon dioxide.

Gerritse (1990) found that "Nitrate is very effectively denitrified in the groundwater system under Bassendean sands. Apparently supplies of organic carbon in the soil and groundwater are sufficient to sustain denitrification of urban inputs". Urban inputs from unsewered areas are in the order of 200–300 kg N/ha/year which are about half that of vegetable cropping. It is therefore likely that much of the nitrogen leached from horticultural properties on Joel sands (white sands over coffee rock with a shallow depth to the water table) could be denitrified.

Hydrolysis of urea and volatilisation

For plants to absorb nitrogen from urea it must first be converted to ammonium. This occurs in two processes. Firstly urea is converted to ammonia and carbon dioxide. Then ammonia reacts with water in the soil to form ammonium. It is important that the urea is watered into the soil otherwise the ammonia will likely escape to the atmosphere due to volatilisation. This problem is more common in broadacre cropping where the farmer may apply urea and there is not sufficient rainfall to wash the fertiliser into the soil. Vegetable growers should always irrigate immediately after applying urea.

Leaching and nitrates in groundwater

The leaching of nitrate from horticultural properties on the Swan coastal plain has resulted in high nitrate concentrations in the groundwater below many properties. This is of concern for two reasons:

1. Potential health problems for people drinking water with high nitrate levels.
2. Groundwater feeds lakes and rivers and the high nitrogen concentrations may cause algal blooms or affect the vegetation and aquatic life in these water bodies.

Nitrogen use efficiency of vegetable crops grown on the Swan coastal plain

Table 2 shows typical nitrogen application rates used by vegetable growers on the Swan coastal plain. The table also shows how much nitrogen is removed by each crop. It can be seen that only about a third of the nitrogen that is applied is removed in the harvested crop.

Table 2 Rates of nitrogen fertiliser application for vegetables grown on the Swan coastal plain and removal of nitrogen in the harvested crop

Type of horticulture	Yield (t/ha/crop)	Application rate (kg N/ha/crop)	Crop removal (kg N/ha/crop)	Residual N (kg/ha/crop)	Percentage of nitrogen applied that is removed in the harvested product
Market gardens		**486**	**135**	**351**	**28**
Carrots	60	320	86	234	27
Cauliflower	30	500	109	391	22
Celery	100	550	151	399	27
Lettuce	50	300	120	180	40
Onions	60	400	147	253	37
Potatoes	55	550	184	366	33
Tomatoes	100	650	148	502	23

Source: Adapted from Lantzke (1997)

The leaching of nitrate occurs in other fertilised crops however the amount leached is generally less than that measured from vegetable properties on the Swan coastal plain. For example, in cereal cropping about 40 to 50 % of the nitrogen that is applied is taken up by the plant. The higher rate of leaching from vegetable properties on the Swan coastal plain can be largely explained by the very sandy nature of the soil, heavy winter rainfall and in some cases, poor fertiliser and irrigation practices.

Nitrogen fertilisers commonly used by vegetable producers

Vegetable growers use a wide range of nitrogen fertilisers. Tables 3 and 4 provide a summary of the characteristics of some of these fertilisers.

Vegetable trials at Medina Research Station (Kwinana), Carnarvon and Manjimup which compared ammonium nitrate, urea and sulphate of ammonia as sources of nitrogen showed no significant differences in crop yields when the same amount of nitrogen was applied. Urea is usually the cheapest and most concentrated source of nitrogen.

Poultry manure

Poultry manure has been widely used in the past on vegetable properties on the Swan coastal plain. However, due to the breeding of stable fly in poultry manure, its use has been greatly restricted. Within the shires and cities of Wanneroo, Swan, Joondalup, Gingin, Chittering, Kalamunda, Armadale, Rockingham, Cockburn, Harvey, Kwinana, Serpentine-Jarrahdale, and part of the Shire of Murray, the transportation of poultry waste and its use as horticulture manure are banned at all times of year unless it is treated to stop stable fly breeding.

Poultry manure is a cheap source of fertiliser that contains a wide range of the essential plant elements that are released as the manure breaks down (see Table 5). Manure also helps to build up the organic matter content of the soil which improves the nutrient holding ability of the soil.

However as a fertiliser, poultry manure does have a number of limitations:

1. Unknown or variable nutrient content.
2. Nutrient content may not match the crops requirements, resulting in excess amounts of some nutrients being applied.
3. It is usually applied before crops are planted and incorporated into the soil. Crops are usually planted one to two weeks later to prevent ammonia toxicity. During this period there is rapid release of nitrogen and much of this nitrogen becomes unavailable to the crop due to leaching or loss to the atmosphere (volatilisation).

Table 3 Comparison of three nitrogen fertilisers commonly used by vegetable growers

Item	Urea	Sulphate of ammonia	Urea ammonium nitrate (e.g. Flexi N)
Cost $/tonne (2014)	$1045	$715	$770
% nitrogen (w/w)	46%	21%	32%
Cost $/tonne of pure nitrogen	$2272	$3404	$2406
Main advantages	• Cheap • High solubility (105 kg/100 L at 20 C)	• Mainly suitable for alkaline soils, as it will decrease the pH more than urea or UAN • High solubility (71 kg/100 L at 20°C)	• Cheap, easy to handle • Liquid
Main disadvantages	• May burn crops if applied at high rates • Urea may lose nitrogen to the air if it is not washed in with sprinklers	• Increases acidity of soils • May increase problems with tip burn and blossom end rot	• Need to be set up for fertigation

Source: Adapted from Agriculture Western Australia (1996)

Table 4 Comparison of other nitrogenous fertilisers

Name	Total N%	Cost $/tonne (2014)	Cost $/tonne of pure nitrogen	Number of other nutrients	Comments
Calcium nitrate	15.5	1012	6529	19% calcium	Applied to leaves of some crops i.e. strawberries, lettuces, celery to supply calcium. Good solubility in water. Highly hygroscopic (absorbs water from air if not stored well).
Potassium nitrate	13.4	1672	12477	39% potassium	Applied to supply nitrogen and potassium.
Mono ammonium-phosphate	12	2640 technical grade	22000	22.6% phosphorus	Also good source of soluble phosphorus. Irrigation water high in calcium or magnesium will cause precipitation.
Di ammonium-phosphate	17.5	1320 ordinary grade	7543	20% phosphorus	Source of soluble phosphorus. Water high in calcium or magnesium will cause precipitation.
Horticulture special	9	1232	13689	9	Contains P, K, Mg and trace elements
Nitrophoska	12	1675	13958	10	Contains P, K, Mg and trace elements
Hydro complex	12	1320	11000	8	Contains P, K, Mg and trace elements

Source: Adapted from Agriculture Western Australia (1996)

Table 5 Nutrient content of deep litter poultry manure

Macro elements	Nitrogen 2–4.5% (average 3%)
	Phosphorus 0.4–1.7% (average 1.3%)
	Potassium 0.6–1.6% (average 1.4%)
	Calcium 2–3% (average 2.4%)
	Magnesium 0.2–0.5% (average 0.3%)
	Sodium 0.4–0.6% (average 0.5%)
Trace elements	High iron (average 540 ppm), adequate manganese (average 360 ppm) and zinc (average 260 ppm), boron (average 16 ppm), copper (average 30 ppm) and molybdenum (average 8 ppm).

Source: Adapted from Agriculture Western Australia (1996)

Figure 5 shows the conversion of poultry manure to ammonia and nitrate during the winter months in a sandy soil at Medina Research Station (Phillips 2001). The graph shows that ammonia in the soil quickly decreases in concentration as it is either converted to nitrate by bacteria or lost to the atmosphere through volatilisation. The nitrate concentration increases from a low level 8 days after the manure has been applied to a peak level 22 days after application (due to nitrification of the ammonium). After 43 days there is little nitrogen in either the ammonia or nitrate form left in the soil. During warmer weather the time taken for these processes is likely to be reduced.

Following the application of poultry manure at rates of 30 to 50m^3/hectare, growers wait one to two weeks before

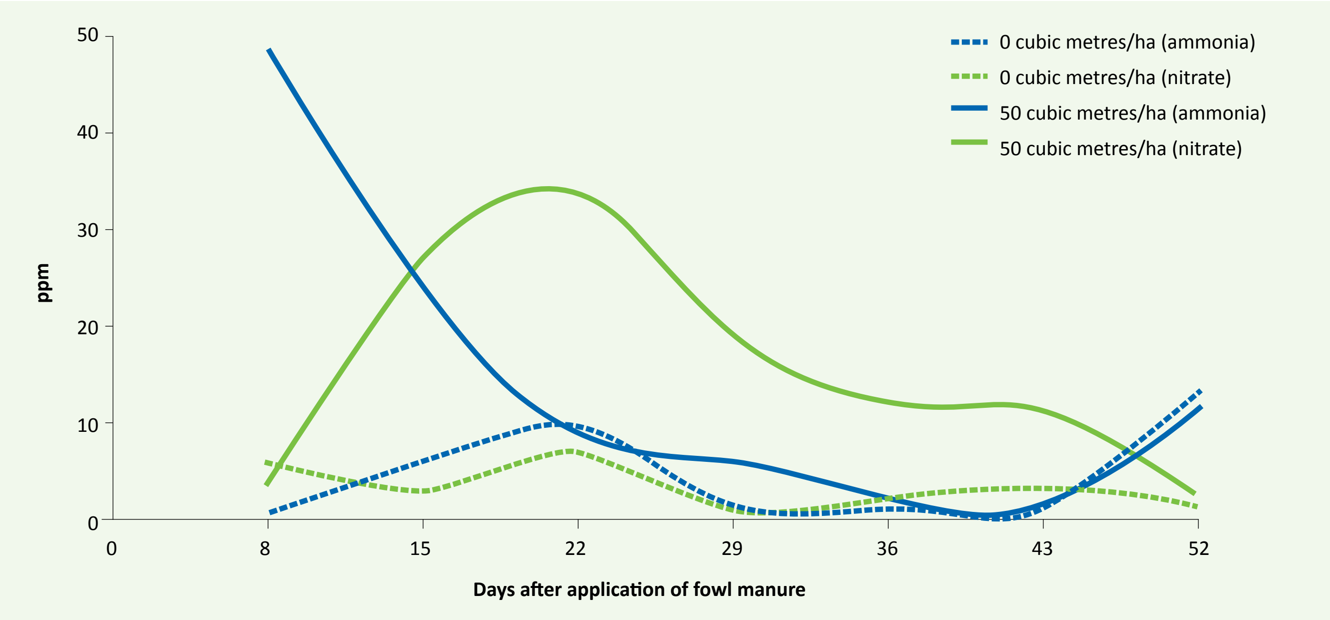

Figure 5 The conversion of poultry manure to ammonia and nitrate during the winter months in a sandy soil at Medina Research Station (Kwinana) *Source: D Phillips (2001)*

planting crops so that the young plants are not damaged by ammonia toxicity. In the first few weeks of their lives vegetable crops require very low amounts of nitrogen. Phillips (2001) estimates that a young lettuce crop will take up about 6 kg of nitrogen/hectare during this period.

An application of poultry manure at a rate of 30 m^3/ha weighs about 12000 kg. Assuming 3% nitrogen by weight this equates to about 360 kg of nitrogen/hectare. It is obvious that applying poultry manure at these typical rates is a large overdose of nitrogen that will lead to considerable losses through leaching. In addition, losses to atmosphere through volatilisation from poultry manure can be as great as 50% (Goldspink 2000).

Developing a crop fertiliser program

Growers need to be able to develop a fertiliser program that suits their particular situation. There is no single correct fertiliser program and many approaches may deliver a good outcome. The nitrogen requirements of a vegetable crop will depend on factors such as crop stage, soil type, time of year and the uniformity of the irrigation system. In order to compare your fertiliser program with recommendations provided by the Department of Agriculture and Food, Western Australia or with another vegetable producer you will need to convert your fertiliser application rates into kilograms of nitrogen per hectare. Refer to Appendix 1 for information on how to do this. Alternatively, refer to the Fertiliser Calculator on the Department of Agriculture and Food Western Australia web site (**www.agric.wa.gov.au/soils/fertiliser-calculator**)

Nitrogen requirements vary with crop stage

Young vegetable crops require considerably less nitrogen than older crops. At this stage the plant root system does not cover the whole vegetable bed and is shallow in depth. This makes it difficult to apply fertiliser efficiently to the root zone without incurring large losses due to leaching. This is particularly true on sands which have a poor ability to retain nitrogen.

As the crop matures it will require increasing amounts of nitrogen to sustain rapid growth. The root system becomes more extensive and is able to access a much greater proportion of nitrogen applied to the vegetable bed.

Methods of fertiliser application
(adapted from Phillips *et.al.* 2001)

The most appropriate method for applying fertiliser varies with the type of crop and its growth stage.

Broadcasting

Broadcasting is best suited for pre-planting applications such as superphosphate and compost. It can also be used on direct sown or transplanted crops when they are very small because fertiliser granules will not lodge in leaf axils, and cause crop damage. Only granular or bulky organic fertilisers are suitable for this method and it can be inefficient because placement is erratic and widespread.

Banding

Banding is well suited to row crops in the weeks leading up to row closure. It enables high rates of fertiliser to be accurately placed for a crop with a rapidly growing fertiliser demand. It is only suitable when the crop has a large enough root system to use fertiliser placed between rows.

Boom spraying

Boom spraying can be used to apply foliar (leaf absorbed) nutrients or as an alternative to broadcasting on young crops. It is far more accurate than a fertiliser spinner, except in windy conditions. There are limits on the rates that can be applied without foliage damage if overhead irrigation is not employed at the same time as spraying.

Fertigation

Fertigation can be used throughout the crop life but tends to be used more after row closure. It is a cheap and effective method of distributing nutrients which allows regular application. The main disadvantage is that the application of water and hence fertiliser can be non-uniform, particularly in windy conditions. In addition, if different crops or crops at different growth stages are on the same irrigation shift, then this can result in overdosing on the crop or crop stage that has the lowest fertiliser requirement.

The 3-Phase method for growing vegetable crops on sandy soils

Researchers at the Department of Agriculture and Food, Western Australia have developed the 3-Phase approach to achieving high vegetable yields and quality while increasing fertiliser use efficiency. This is achieved by using different application methods at different crop stages. In the Crop Establishment Phase, fertiliser applications are applied twice weekly using broadcasting or a boom spray. In the Rapid Growth Stage, fertiliser is banded adjacent to the crop so that it can readily access the nutrients. In the Maturation Phase, nitrogen is fertigated weekly.

Soil and plant tissue (leaf analysis)

Soil tests are not a reliable guide to determine nitrogen fertiliser requirements. Soil test results usually correlate poorly with yield because of the rapid leaching of nitrogen and transformations within the soil. Leaf and petiole (leaf stalk) tests are an important technique for predicting nitrogen deficiency in vegetable crops. These tests can be used to monitor how a fertiliser program is performing and whether a poorly growing area is a consequence of nutrient deficiency or toxicity. Sap testing kits provide a quick method to determine the nitrogen status of a crop.

Water analysis

The leaching of nitrogen from vegetable farms on the Swan coastal plain has resulted in high nitrate concentrations in the groundwater below many properties. Vegetable growers on the Swan coastal plain irrigate their crops using this ground water. Growers should measure the nitrogen concentration of their irrigation water and if significant concentrations are present then the fertiliser programs need to be adjusted to account for this source of nutrient. The amount of nitrogen applied will not be constant over the year as irrigation volumes are much lower during the winter months when rainfall is pre-dominant. Refer to Lantzke (1995) for information on how to calculate the quantity of nitrogen your groundwater is supplying your crop.

Effect of irrigation practices on nitrogen leaching

Many vegetable properties on the Swan coastal plain have irrigation systems that apply water with a poor distribution uniformity. Some areas within the sprinkler wetting pattern may receive greater than twice as much water as other areas. This excess water pushes nitrogen past the crops root zone. The uniformity of the irrigation usually becomes worse under windy conditions. In addition to ensuring the distribution uniformity is as uniform as possible, growers need to schedule their irrigation to ensure the applied volumes equal crop requirements. Refer to the DAFWA website (www.agric.gov.au) for evaporation based scheduling and soil moisture monitoring.

If nitrogen is fertigated via an irrigation system that has a poor uniformity then this nitrogen will also be applied non uniformly. When fertigating irrigation shifts should contain crops that require the same or similar amounts of nitrogen as different crops or the same crop but at different growth stages require different amounts of nitrogen fertiliser. Fertiliser spreaders and boom sprays that are used to apply fertiliser need to be properly set up and calibrated.

By making improvements in this small scale variability the crop nitrogen use efficiency can be increased by 10 to 15% (Singh 2005). Precision farming techniques that result in improvements in application uniformity will allow the grower to use less nitrogen and result in reductions in nitrogen losses to the environment.

Appendix 1 How to calculate how much nitrogen (element) is being applied to your crop

You need to know how many kilograms of each element is being applied per hectare in order to:

1. Compare the rates you are using with DAFWA recommendations and with other growers to see whether you are putting on too much or too little;
2. Compare one fertiliser with another e.g. Urea vs UAN vs NPK type fertilisers; and
3. Determine how much of any new fertiliser you should apply.

Step 1	Convert the number of kilograms of fertiliser you apply per bay to kilograms of fertiliser per hectare. To do this multiply the total kilograms of each nitrogen fertiliser you apply per crop by 10,000 and divide by the area of the bay or area being fertilised (m^2).
Step 2	Convert kilograms of fertiliser per hectare to kilograms of element per hectare. Multiply the percentage of nitrogen within the fertiliser and divide by 100. Refer to percentage of nitrogen in that fertiliser on the side of the bag or other reference.
Step 3	Repeat step 2 for all the fertilisers that contain nitrogen that were applied.
Step 4	Sum the individual contributions from each nitrogen fertiliser to obtain a total amount of each element applied.

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