Incitec Pivot Fertilisers

Nitrogen

1. INTRODUCTION AND SUMMARY

Nitrogen is one of the most commonly limiting nutrients in agriculture. A deficiency of nitrogen will affect both the yield and quality of pastures and crops. It is an important constituent of protein, and is essential in animal nutrition.

Apart from carbon (C), hydrogen (H) and oxygen (O), which are derived from air and water, nitrogen (N) is required by plants in greater quantity than any other nutrient.

Nitrogen is the only one of nutrients derived from the soil that exists as a gas in its natural state.

Legumes are able to fix nitrogen in the nodules on their root systems from the soil air. This is a symbiotic process, involving *Rhizobium* bacteria.

Other plants are reliant on the soil and fertiliser for their nitrogen.

2. NITROGEN IN SOILS

2.1 Forms

Nearly all the nitrogen present in the soil originated from the atmosphere which is 78 % nitrogen (N_2). The rocks and minerals from which soils are formed do not contain nitrogen.

Most of the nitrogen present in the soil is in the form of organic matter. Soil organic matter accumulates in fertile soils, high rainfall areas and in cool temperate environments. It is lower in infertile soils, arid environments, and in the tropics.

By world standards, Australian soils are low in organic matter, typically containing less than 5% organic matter (1 – 3% organic carbon).

The nitrogen in organic matter is not available for plant uptake. Before organic nitrogen can be taken up by plant roots, it must first be converted to simple inorganic forms, a process known as mineralization, which is described below.

2.2 Soil Processes involving Nitrogen

2.2.1 Mineralization

The conversion of soil organic matter to inorganic forms is known as mineralization. It is a biological process involving soil organisms such as bacteria and fungi that occurs more quickly when the soil is warm and moist. Cultivation, which aerates the soil, hastens mineralization.

Organic nitrogen is firstly converted to ammonium (NH^{+}_{4}) and then to nitrate (NO_3^-). The second step is known as nitrification.

2.2.2 Fixation / Adsorption

Fixation or adsorption is the attraction of charged ions onto the surface of clay and organic colloids in the soil. Ions may also be fixed into the crystal lattices of clays.

Ions are either positively charged (cations) or negatively charged (anions).

The soil's Cation Exchange Capacity (CEC) is a measure of its adsorptive capacity and ability to hold and retain positively charged cations.

Ammonium (NH^{+}_{4}) ions, which are positively charged, are tightly held or sorbed onto soil colloids and are therefore resistant to leaching.

This is the reason why anhydrous ammonia (NH_3), a gaseous fertiliser, can be injected directly into the soil. Ammonia has a strong affinity for water. On injection into the soil, it combines with soil moisture to form ammonium ions, as depicted in the following equation. The ammonium is then attracted to and held on the surface of soil colloids.

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

In contrast to ammonium and negatively charged phosphate ions ($H_2PO_4^-$ and HPO_4^{2-}), the nitrate anion (NO_3^-) is not strongly attracted to soil colloids, and is subject to leaching.

Some soils, e.g. certain red volcanic soils, have a high anion exchange capacity at depth and can store an appreciable amount of nitrate deep in the profile.

2.2.3 Immobilization

Plants compete for nutrients with other soil organisms, e.g. bacteria. Once nutrients are taken up by soil organisms and incorporated into microbial protein, they are at least temporarily unavailable for uptake by plant roots, i.e. they are immobilized.

Immobilization of nitrogen occurs when cereal stubble, trash and other plant material with a high carbon:nitrogen (C:N) ratio are added to the soil. Because such materials are low in nitrogen, soil bacteria which attack and break down the stubble and trash are forced to get their nitrogen from elsewhere, i.e. the soil.

Immobilization does not occur (or is much less likely to occur) where the residues of legume crops and green

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manure crops are returned to the soil. These have a high nitrogen content and a lower C:N ratio.

Immobilization of nutrients in the topsoil occurs more rapidly where trash is incorporated into the soil, rather than being left on the soil surface. Burying the trash exposes it to more soil and microbes.

Immobilized nutrients are not lost from the soil system. They become part of the soil biomass and organic matter and are a component of its fertility. Some immobilized nutrients subsequently become available for plant uptake on the death and decay of soil microbes. The remainder becomes part of the soil humus.

In their virgin state, humus is the major store or reserve of nitrogen, phosphorus and sulfur in the soil. As humus decomposes, nutrients are released.

2.2.4 Leaching

Leaching occurs when nutrients are leached or washed through the soil beyond the root zone of plants. Nutrients lost in this way may reach and contaminate ground-water.

Nitrate is subject to leaching. Ammonium is not. High concentrations of nitrate in groundwater are of concern on environmental and health grounds, and may reflect inefficient fertiliser practices.

Should the groundwater re-enter streams or surface waterways, it may contribute to excessive weed growth and algal blooms.

Animal and human health may be affected if water high in nitrate is drunk from wells or bores. Nitrate combines with haemoglobin in the blood, reducing its ability to transport oxygen.

Leaching losses are most likely to occur on free-draining sandy soils, in areas of high rainfall and where excessive irrigation water is applied.

In vegetables, leaching losses are often higher after harvest, while the land is being fallowed, than during the growing season. Vegetables are often harvested in their peak vegetative stage, leaving high concentrations of residual nitrogen in the soil, with nothing to take it up.

Leaching is less likely to occur on heavier textured clay and loam soils.

Nitrate can be leached from the topsoil deeper into the soil profile on clay soils, but provided it is not leached too deeply, this nitrogen can be used, along with stored soil moisture, as plant roots grow into the sub-soil.

2.2.5 Denitrification

Under anaerobic (waterlogged) conditions, certain soil microbes, deprived of a source of oxygen (O_2) in the soil air, are forced to obtain oxygen from other sources. Niitrate (NO_3^-) can be reduced to gaseous nitrous oxide compounds (NO_X) or molecular nitrogen (N_2), which are then lost to the atmosphere.

One of these gases is N_2O, and while it makes up a small part of the total, it is a powerful greenhouse gas.

Denitrification is most likely to occur on clay soils on flood plains, i.e. where both internal and external drainage are poor.

Where practical, timing fertiliser application so that it is not applied during the wet season (unless this coincides with the major growing season) will reduce denitrification (and leaching) losses.

Denitrifying bacteria are most active at warm temperatures and where soil organic matter is present to feed on.

Denitrification losses from applied fertiliser might be reduced to some extent by placing fertiliser deeper into the soil, where organic matter levels are lower and the soil is cooler.

2.2.6 Volatilization

Volatilization is the gaseous loss of ammonia (NH_3) from the soil surface to the atmosphere. It occurs when ammonium (NH_4^+) ions react with hydroxyl (OH^-) ions to from ammonia, and is depicted by the following equation.

$$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$$

Fertilisers that contain or form ammonium ions (NH_4^+) are subject to volatilization loss. This includes urea, ammonium nitrate, urea ammonium nitrate solution (UAN), ammonium sulfate, DAP and MAP. Volatilization also occurs from urine patches.

All the nitrogen in fertilisers such as Urea, ammonium sulfate and DAP is subject to volatilization loss.

In the case of ammonium nitrate, only half the nitrogen (that present in the ammonium form) is subject to volatilization loss.

Three quarters of the nitrogen in UAN (that present as urea and ammonium) is subject to volatilization loss. The one quarter present as nitrate is not.

Urea is not subject to volatilization loss until such time that it has been converted to the ammonium form. A naturally occurring enzyme, urease, is responsible for this transformation. While the nitrogen in urea remains in the form of urea, it is not subject to volatilization loss.

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Urease activity is associated with organic matter. It is higher in soils where organic matter levels are high and there is a lot of trash.

Volatilization is dependent on the presence of hydroxyl (OH^-) ions. These may be naturally present in the soil, of formed form the fertiliser.

Hydroxyl and hydrogen (H^+) ions are formed when water (H_2O) dissociates. In neutral soils, with a pH of 7, hydroxyl and hydrogen ions are present in equal amounts.

$$H_2O \rightarrow H^+ + OH^-$$

Volatilization losses are typically higher on alkaline soils (characterized by an abundance of hydroxyl ions) than on acid soils in which hydrogen (H^+) ions dominate.

On acid and neutral soils, volatilization losses tend to be higher from fertilisers that have an alkaline reaction on soil pH in the immediate vicinity of the granules, e.g. urea and DAP.

On alkaline soils, where there are plenty of hydroxyl ions to start with, volatilization losses from ammonium sulfate can be just as great, if not higher, than from urea.

Moisture is necessary to dissolve the fertiliser in the first instance, in order for volatilisation to proceed. This may come from overnight dew, or light showers of rain.

Ammonia volatilization losses occur when the soil begins to dry, e.g. in the heat of the morning. If all the adsorption sites for ammonium (NH_4^+) at the soil surface are fully utilised, ammonia will be lost as a gas.

Hot dry windy conditions can exacerbate the loss (once the fertiliser has dissolved).

If the fertiliser is applied into the soil, or carried into the soil by rain or irrigation, the ammonium ions will be exposed to more soil colloids and adsorption sites. Volatilization losses will be all but eliminated.

Where irrigation is available, the fertiliser should be applied immediately before irrigating, or with the irrigation water.

In rain grown pasture and forage crops, nitrogen fertiliser should be applied when rain is forecast.

As little as 5 mm of rain, provided it is received in the one fall, may be sufficient to wash the fertiliser into the soil where there is little or no ground cover. 10 mm or more may be required where there is more ground cover, and up to 25 mm with a dense green cane trash blanket.

Volatilization losses can commence within hours of applying fertiliser to the soil surface.

Losses are variable. They may be minimal for several days after application. On the other hand, large losses may be experienced within 24 hours of application if conditions are favourable for loss.

In summary, factors that contribute to volatilization loss are:-

- Light showers and heavy dews – enough to dissolve the fertiliser, but not enough to wash or carry it into the soil;
- Warm days – which increase evaporative conditions and dry out the soil surface;
- Bare soil – a crop or pasture canopy can slow down wind speed at the soil surface. There may also be some direct leaf uptake of ammonia:
- High soil pH – which contributes hydroxyl ions;
- Low CEC (Cation Exchange Capacity) – with fewer adsorption sites for ammonium ions;
- And in the case of urea, high soil organic matter and urease activity.

2.3 Effect on Soil pH

The long term effect of nitrogen fertilisation, be it from bag nitrogen, the growth of legumes, or the mineralization of soil organic matter, is to acidify the soil. The immediate and short term effects may be different.

Immediate Effect

The pH of fertiliser solutions, be it in a spray or mixing tank, or around fertiliser granules when they first dissolve in soil moisture, may bear little resemblance to the long term effect that the fertiliser has on soil pH.

With many products, the initial effects are attributable to residual or un-reacted ammonia or acid from the manufacturing process being present in the final product.

Urea, for example, is alkaline. It contains traces of ammonia, having been made by reacting ammonia with carbon dioxide.

Gran-am (granulated ammonium sulfate) is acidic. This is attributable to the presence of residual sulphuric acid. Gran-am is produced by reacting ammonia with sulfuric acid.

Short Term Effect

Anhydrous Ammonia is strongly alkaline or caustic. It reacts with soil moisture to form hydroxyl ions, and in doing so raises the soil pH.

$$NH_3 + H_2O \rightarrow NH_4^+ + OH^-$$

Urea has a similar effect on soil pH. Urea is made from ammonia and carbon dioxide. Upon application, the initial reaction involving urea in the soil, under the influence of the

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soil enzyme urease, is basically a reversal of its manufacture, to form ammonium carbonate. This is the salt of a strong alkali (ammonia) and a weak acid (carbonic acid or soda water). The carbon dioxide is liberated as a gas, leaving ammonia in solution, which behaves the same way as if it was applied as Big N, to form ammonium and hydroxyl ions.

Diammonium phosphate (DAP) also has an alkaline effect at the site of the granule, while monoammonium phosphate (MAP) an acid effect. This reflects the relative amounts of ammonia and phosphoric acid used in their manufacture. As the name suggests, twice as much ammonia is used in the production of DAP [$(NH_4)_2HPO_4$] as is used for MAP ($NH_4H_2PO_4$).

Long Term Effect

While nitrogen fertilisers vary in their immediate effect on soil pH, the long term effect of improving the soil's nitrogen fertility, whether by the use of fertiliser nitrogen or by growing legumes, is to acidify the soil.

When nitrogen compounds are nitrified to nitrate (NO_3^-), the negatively charged nitrate ion has to be balanced by a positive charge in the form of a proton or hydrogen (H^+) ion.

In essence, the mineralization of nitrogen fertilisers can be likened to adding nitric acid (HNO_3) to the soil. The overall nitrification process is complex, and involves a number of steps. For ammonia, it may be simplified as follows:

$$NH_3 + 2O_2 \rightarrow H^+ + NO_3^- + H_2O$$

Straight nitrogen fertilisers such as anhydrous ammonia, urea and ammonium nitrate are equal in their effect on soil pH per kg of applied nitrogen.

Ammonium sulfate, which contains both nitrogen and sulfur, is two or more times more acidifying per kg of nitrogen. Its transformation in the soil can be summarized as follows.

$$(NH_4)_2SO_4 + 4O_2 \rightarrow 4H^+ + 2NO3^- + SO4^{2-} + 2H_2O$$

When ammonium sulfate is nitrified, two protons are produced for each nitrate ion, twice as many as for anhydrous ammonia and urea. The use of ammonium sulfate can be likened to adding two acids to the soil, nitric acid and sulfuric acid (H_2SO_4).

Fertilisers such as calcium nitrate and potassium nitrate do not acidify the soil. The nitrogen they contain is already in the nitrate form and is balanced with calcium and potassium ions. They do not form or release hydrogen ions.

$$Ca(NO_3)_2 \rightarrow Ca^{2+} + 2NO_3^-$$

$$KNO_3 \rightarrow K^+ + NO_3^-$$

The Acidification Process

Nitrogen fertilisers have little or no effect on soil pH on most heavy-textured clay soils in Australia's inland cropping areas, e.g. the Darling Downs, northern and central NSW Slopes and Plains, and the Wimmera. These soils are strongly buffered and generally contain free lime (calcium carbonate). They are able to resist change in soil pH.

On light-textured sandy soils, the use of nitrogen fertilisers will cause the soil pH to gradually decline.

Productive legume pastures have the same effect on soil pH as nitrogen fertilisers. It matters little whether the nitrogen is fixed synthetically in a factory, or biologically in the nodules on the roots of legumes.

In legume based pastures, soil acidification is often attributed to the use of superphosphate. The effect superphosphate has on soil pH, however, is an indirect one. Superphosphate itself has little or no effect on pH. It is the nitrogen fixation by legumes that occurs in response to its use that causes acidification.

As discussed previously, the formation of nitrate ions in the soil is accompanied by hydrogen ions or protons, which are responsible for acidity.

When nitrate is taken up by plant roots, or lost through leaching, it will be accompanied by cations, so that the number of negative charges balances with the number of positive charges.

Nitrate (NO_3^-) taken up by plant roots is accompanied by cations such as ammonium (NH_4^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}). If nitrate is lost through leaching, it will be accompanied by hydrogen ions, or other cations such as calcium.

The gradual loss of calcium and other cations through crop removal and leaching, and their replacement with hydrogen ions, causes the topsoil to become more acidic.

The leaching of hydrogen ions from the topsoil into the subsoil causes it to become more acid as well. Subsoil acidification can be minimized or prevented by maintaining the pH of the topsoil near neutral, so there are few hydrogen ions to leach.

Where acidification occurs in crops and pasture, lime needs to be applied on a regular basis to maintain the soil pH at a satisfactory level as part of a balanced fertiliser program.

Where alkaline irrigation water with a high Calcium Carbonate Saturation Index is used, it will generally be unnecessary to apply lime to the soil to manage the pH.

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3. NITROGEN IN PLANTS

3.1 Uptake

Plants take up most of their nutrients in simple inorganic forms.

Nitrogen is mainly taken up from the soil by roots as nitrate (NO_3^-), although ammonium (NH_4^+) may also be taken up in appreciable amounts by certain plants, particularly if it is the only source available.

Plant uptake of negatively charged anions, e.g. nitrate (NO_3^-), phosphate (HPO_4^{2-} and $H_2PO_4^-$), sulfate (SO_4^{2-}) and chloride (Cl^-) is in balance with that of the positively charged cations, e.g. ammonium (NH_4^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^+).

Given the quantity of potassium and other cations taken up by plants, more nitrogen tends to be taken up as nitrate than as ammonium, to keep the number of positive and negative charges in balance. This is the reason why there is a need to include nitrate fertilisers in hydroponic solutions.

Nevertheless, there are situations where ammonium is taken up in appreciable quantities. Examples are:

- In the seedling stages in cereals and other crops in which the ammonium phosphates (MAP and DAP) are used as planting fertilisers. The positively charged ammonium (NH_4^+) ions promote the uptake of the negatively charged phosphate (HPO_4^{2-} and $H_2PO_4^-$) ions, whereas the use of nitrate (NO_3^-) at this stage would compete with the phosphate ions for plant uptake, and suppress their uptake.
- In lowland or flood irrigated (paddy) rice. Where the soil is permanently flooded and air (oxygen) is excluded from the soil, the transformation from ammonium (NH_4^+) to nitrate (NO_3^-) is blocked, while any nitrate that is present will be denitrified or lost. Rice that is grown under upland or dryland conditions behaves like other crops, and utilizes nitrate nitrogen.
- Sugarcane is another crop that is able to utilize ammonium nitrogen.

In addition to their roots, plants are able to take up nitrogen through their leaves.

There are limits to the amount of nitrogen that can be applied in this way without burning the foliage. Foliar sprays are therefore used to supplement, rather than replace soil applications of nitrogen fertiliser.

Urea is commonly used in foliar sprays. Plants are able to absorb it directly into their leaves.

3.2 Nitrogen Fixation by Legumes

Some free-living and symbiotic organisms, e.g. *Rhizobium* bacteria in the root nodules on legumes, have the ability to fix molecular nitrogen (N_2) from the soil air into forms that can be used by the host plant.

Legumes play an important role in farming systems. Most legume-based pastures and legume grain crops are self-sufficient in nitrogen, overcoming the need to apply nitrogen fertiliser.

In rotations, legumes are used to enrich the soil with nitrogen, for the benefit of the non-leguminous crops that succeed them.

3.3 Function

Nitrogen is essential in the formation of chlorophyll (the green pigment in plants) which converts sunlight into carbohydrate. A shortage of nitrogen inhibits plants in the basic function of trapping energy.

Nitrogen is a major constituent of protein. A shortage of nitrogen not only affects yield, but also the quality of forage, grain, vegetables, fruit and nuts.

3.4 Deficiency Symptoms

Nitrogen is mobile within the plant. When its supply is low, it is transferred from the older to the younger plant tissue so deficiency symptoms are seen first in the older leaves of the plant. This distinguishes nitrogen from sulfur deficiency, the symptoms of which are similar in many respects, but because sulfur is less mobile in the plant, symptoms of sulfur deficiency appear first in the young tissue. Nitrogen and sulfur are both important constituents of protein.

The main symptoms of nitrogen deficiency are:

- Stunted growth and reduced tillering in grasses and cereals;
- Pale green or yellow colour of the leaves, or dominance of other pigments such as orange or red;
- Low protein content of grain and herbage.

Legumes display similar symptoms, and root nodules will be absent, or poorly developed. Poor nodulation may be attributable to a variety of causes, such as deficiency of molybdenum, or the lack of a suitable inoculum.

3.5 Excess

Excess nitrogen can interfere with the uptake and utilization of other nutrients. It may also stimulate excessive vegetative growth, delaying the reproductive (flowering and seeding) stage. This may result in lodging and reduced yields in a wide range of crops, e.g. potatoes. In sugarcane, the sugar content may be depressed.

Care needs to be exercised with the placement of nitrogen fertiliser. Too much nitrogen, applied with or in close proximity to crop seeds, transplants or tree trunks, can burn plant roots. This can set back crop growth, and in extreme cases, result in poor germination and establishment, the loss of seedlings and trees.

There may also be environmental impacts as a result of miss-applying nitrogen. If nitrogen is applied or becomes available in the soil in excess of crop requirements, the unused nitrate nitrogen may be lost through leaching or denitrification in the event that heavy rain is received.

Loss may occur during the growing season or after harvest while the land is being fallowed.

3.6 Nutrient Removal

Considerable amounts of nitrogen are removed in harvested plant produce, more than any other nutrient, with the exception of potassium in a few crops.

Examples of the amount of nitrogen typically present in the grain from various crops are shown in the following table.

Crop	**kg N / t grain**
Rice	13 - 20
Sorghum	15
Maize	17
Barley	16 - 20
Wheat *	20 - 23
Sunflower	25 - 35
Canola	30 - 40
Chickpea	50
Lupin	50 - 60
Soybean	60 - 65

* For soft wheat, the figure may be as low as 14 kg/t N.

Nitrogen is essential to animals as well as plants. It is a constituent of protein and is removed in animal products, e.g. meat and milk.

4. CRITICAL LEVELS OF NITROGEN IN SOILS AND PLANTS

4.1 Soil Analysis

Soil tests for organic carbon provide an indication of the reserves of nitrogen in the soil (as most of the nitrogen in the soil is contained in the soil organic matter). This nitrogen, however, is not available for plant uptake until it has been mineralized to simple inorganic forms (ammonium and nitrate). The rate at which it becomes available is extremely variable.

An assessment of the organic matter's carbon:nitrogen (C:N) ratio provides some indication of potential availability of the nitrogen that it contains. The lower the C:N ratio the more easily it is mineralized.

In annual crops, the amount of plant available nitrogen in the soil can be determined before planting by taking a soil sample towards the end of the fallow period and measuring the amount of nitrate nitrogen that is present.

As nitrate is mobile in the soil, and can be leached down the profile, it is best to sample the sub-soil as well as the topsoil. Soil samples should be taken to 60 or 90 cm, or to the depth of the wetting front.

The topsoil will still need to be sampled to asses the need for other nutrients such as phosphorus.

4.2 Plant Tissue Analysis

Analyses for nitrogen can be performed on various plant tissues at various growth stages, e.g. for nitrate nitrogen in sap; for nitrate nitrogen and total nitrogen (% N) in leaves during the growing season; and for total nitrogen in the harvested produce, e.g. grain protein.

Optimum total nitrogen concentrations show considerable variation between plant species, plant parts, and growth stages, but are often in the range of 2 to 5% N on a dry weight basis.

5. NITROGEN FERTILISERS

5.1 History

Since the birth of civilisation and agriculture, fertilisers have been applied to the soil to improve plant growth. In early times, plant and animal wastes, e.g. dung, bones, and the ash from fires, were returned to the soil. These materials

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provided many essential plant nutrients, including nitrogen. Some civilisations also recognised the value of legumes to enrich the soil with nitrogen.

From early in the 19th century, naturally occurring Chilean Nitrate of Soda (sodium nitrate) was used as a nitrogen fertiliser.

Ammonium sulfate (Sulfate of Ammonia) was also used from the 19th century, becoming available with the advent of the Industrial Revolution. It was the first synthesized nitrogen fertiliser.

Ammonium sulfate is a by-product of the steel industry. It is produced during the coking of coal. The gas from the coke ovens contains ammonia vapour, which is sprayed with dilute sulfuric acid to form ammonium sulfate.

Sulfate of Ammonia became the main nitrogen fertiliser, and remained so until well into the 20th century.

In 1909, two German scientists, Fritz Haber and Carl Bosch developed a large scale economic process for synthesising ammonia, a gas rich in nitrogen. This marked the birth of the modern nitrogen fertiliser industry, although it wasn't until after World War II, when demand for nitrogen fertilisers exceeded the supply from natural occurring sources and as by-product Sulfate of Ammonia, that large scale synthetic production of nitrogen fertilisers took place.

In Australia, the major nitrogen fertiliser used up to the 1950s was Sulfate of Ammonia, in crops such as sugarcane.

It was not until the 1960s that major investments in nitrogen fertiliser plants were made in Australia.

One of the plants built in the late 1960s was the Incitec Pivot plant at Gibson Island, Brisbane, at which ammonia, urea and granulated ammonium sulfate (Gran-am) are made. This is Australia's only urea plant.

Incitec Pivot also operates an ammonia plant at Phosphate Hill in north-west Queensland, at which high analysis ammonium phosphate fertilisers (MAP and DAP) are produced.

Australia is not self-sufficient in nitrogen fertilisers and considerable quantities are imported to augment local production.

Nitrogen fertilisers are now being used more extensively than in the past. They are used in grain, cotton, sugarcane, horticulture and on intensively managed pastures. Western Australia and New South Wales are the major cropping States.

Globally, the fertiliser industry consumes up to 2% of the world's energy, and about 5% of the natural gas. Nitrogen (N) fertilisers account for 94% of this energy use, while 3% each is attributable to phosphorus (P) fertilisers and potassium (K) fertilisers.

Without synthesized nitrogen fertilisers, the world would not be able to sustain its current population. Famine and starvation would be widespread. It is estimated that 30 – 40% of the world's population is sustained by the Haber Bosch process. It accounts for about half the nitrogen in our bodies.

5.2 Product Analyses

The analyses of the commonly used nitrogen fertilisers marketed by Incitec Pivot Fertilisers are shown in the following table.

Analyses of Incitec Pivot Nitrogen Fertilisers

Product	Chemical Name	% N	% P	% S	% Ca
Big N	Anhydrous ammonia	82			
Urea	Urea	46			
Easy N	Urea ammonium nitrate solution	42.5 (w/v)			
Cal-Am	Calcium ammonium nitrate	27			8
Gran-am	Ammonium sulfate	20.2		24	

Nitrogen is also present as a constituent in other fertilisers, such as MAP and DAP, which are used as phosphorus fertilisers.

Urea, Cal-Am and Gran-am are also used in Blends

5.3 Big N - 82% N

The raw materials for the manufacture of ammonia (NH_3) are natural gas, water and atmospheric nitrogen. Natural gas is used as a source of hydrogen (H), which is combined with nitrogen (N) to form ammonia.

Natural gas is also consumed as an energy source, the reaction occurring at high temperature and pressure.

Ammonia is one of the world's most commonly manufactured inorganic chemicals. Number one on this list is sulfuric acid, which, like ammonia, is used extensively in the fertiliser industry. Sulfuric acid is used to acidulate phosphate rock in the manufacture of phosphorus fertilisers.

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Ammonia is used as an agricultural fertiliser and for industrial purposes. Most, however, is used in the synthesis of other compounds, including urea and ammonium nitrate. In Australia, the main use of ammonium nitrate is in the preparation of explosives.

Ammonia is also reacted with phosphoric acid to make MAP and DAP, and with sulfuric acid to make ammonium sulfate (Gran-am).

Anhydrous Ammonia (Big N) is used for direct application as a fertiliser in many inland grain and cotton growing areas in New South Wales and Queensland. Big N is the most concentrated nitrogen fertiliser available. It is stored, transported and applied directly into the soil as a liquefied gas. It is economical and easy to apply, with a minimum of stoppages to refill equipment.

5.4 Urea - 46% N

Urea [$CO(NH_2)_2$] is manufactured by reacting ammonia (NH_3) with carbon dioxide (CO_2).

$$NH_3 + CO_2 \rightarrow CO(NH_2)_2 + H_2O$$

While manufactured synthetically, urea is an organic molecule, and does occur in nature. Dark green growth in urine patches in nitrogen deficient pasture and forage crops is attributable to responses to compounds such as urea.

Urea is by far the most commonly traded and used nitrogen fertiliser in the world. It has achieved this position because it is relatively easy to manufacture and it has a high analysis. At 46% N, urea is the most concentrated solid nitrogen fertiliser, reducing freight and application costs. It is an economical source of nitrogen.

Urea is not classified as a Dangerous Good as ammonium nitrate is, nor does it have the same security concerns.

Urea has good storage characteristics and can be blended with many other commonly used fertilisers, such as DAP, MAP and Muriate of Potash.

Urea is incompatible in dry blends with ammonium nitrate and superphosphate.

5.5 EASY N - 42.5% N w/v

EASY N is Urea Ammonium Nitrate Solution (UAN) solution. It is manufactured by dissolving urea and ammonium nitrate in water. Together, these products have greater solubility in water than either on its own, allowing a concentrated nitrogen solution to be prepared. Half the nitrogen in EASY N is present as urea, half as ammonium nitrate. EASY N has a specific gravity of 1.32 at 20^0 C and contains 42.5% N w/v (425 g/L N on a volumetric basis), or 32 % N w/w (320 g/kg N on a gravimetric basis).

As a source of nitrogen, EASY N costs more than Urea in Australia. It is used where liquids provide convenience and flexibility in application.

EASY N is particularly suited for use in fertigation programs, where it can be injected directly into the irrigation water. This saves time in dissolving solid fertilisers to prepare fertiliser solutions.

Fertigation is becoming increasingly popular in horticultural crops, allowing fertiliser to be applied continually during the growing season, using the little and often approach.

EASY N can also be applied through a boom spray, providing more uniform soil coverage than can be achieved with a spinner broadcaster using solid fertilisers.

In sugarcane, EASY N can be used to apply nitrogen late in the season using high clearance tractors, when fertilising with a conventional fertiliser box is no longer possible.

5.6 Ammonium Nitrate

Ammonium nitrate (NH_4NO_3) is produced by using ammonia to produce nitric acid, and then reacting the acid with ammonia. It contains 34% N. Half the nitrogen is in the ammonium form, half as nitrate.

Ammonium nitrate is classified as a Dangerous Good (Class 5.1 Oxidising Agent) and must be transported and stored in accordance with the Australian Dangerous Goods Code (Road & Rail).

Incitec Pivot Fertilisers once sold a fertiliser grade ammonium nitrate product known as **Nitram**, but no longer markets this product.

In its place the company imports and sells Calcium Ammonium Nitrate (CAN), under the name of Incitec Pivot **Cal-Am**.

Calcium Ammonium Nitrate is comprised of 80% ammonium nitrate and 20% calcium carbonate. It contains 27% N, and is not classified as being a Dangerous Good.

Cal-Am, however, is classified as being Security Sensitive in Australia, as it may potentially be misused in the illicit preparation of explosives. Those who wish to purchase, transport and use it must be licensed to do so. It will not be supplied to those not licensed to receive it.

Security Sensitive Ammonium Nitrate (SSAN) legislation applies to any solid fertiliser containing more than 45% ammonium nitrate.

In order to offer customers a range of ammonium nitrate based fertilisers that are not subject to SSAN regulatory

Nitrogen

requirements, Incitec Pivot Fertilisers offers a range of blended fertilisers containing up to 55% Cal-Am (equivalent to 45% ammonium nitrate). Gran-am (granulated ammonium sulfate) is often added to these blends to bolster the nitrogen content, along with other fertilisers such as DAP and Muriate of Potash.

One such blend is **Cal-Gran**, a blend comprised of 55% Cal-Am and 45% Gran-am. Cal-Gran contains 23.9% N.

Product	**Dangerous Good**	**Security Sensitive**	**% N**
Nitram	Yes	Yes	34
Cal-Am	No	Yes	27
Cal-Gran	No	No	23.9

Ammonium nitrate fertilisers cost more than urea (per kg N), and do not have near as good storage characteristics. They are not widely used. They are used by some farmers in preference to urea where:

- A quick response is required to side or top-dressed nitrogen (as nitrate), e.g. in vegetable crops with a short growing season, and in winter forage crops where the conversion from ammonium to nitrate in the soil is slowed by cold soil temperatures.
- In rain grown crops where the potential for ammonia volatilization losses are high, and fertilisers are to be surface applied without incorporation.

Note. Cal-Am contains 8% calcium, as carbonate, the same form as in lime. Calcium carbonate is insoluble and will be of no immediate benefit to crops and pasture when side or top-dressed during the growing season.

Calcium carbonate is added to Cal-Am as a dilutant, so that the end product can be declassified as being a Dangerous Good, not for its nutritive value to plants.

5.7 Gran-am - 20.2% N

Gran-am (granulated ammonium sulfate) is manufactured in Brisbane by reacting sulfuric acid with ammonia, and granulating the finished product. It contains 20.2% nitrogen (N) and 24% sulfur (S). The sulfur is present as sulfate, the form taken up by roots, so the sulfur is immediately available to plants.

While ammonium sulfate was once the world's most commonly used nitrogen fertiliser (up to the middle of the last century), Gran-am is not commonly used as a nitrogen fertiliser these days, on account of its low analysis and higher price (per kg of N) compared to urea.

When used as a nitrogen fertiliser, Gran-am supplies sulfur in excess of crop requirements. Gran-am contains approximately equal amounts of nitrogen and sulfur whereas plants take up about ten times more nitrogen than sulfur.

Nowadays, Gran-am has two primary uses:

- As a source of nitrogen (N) in NPK Blends for horticulture.
- As a source of sulfur (S) in balanced fertiliser programs.

Where nitrogen and sulfur are required, Gran-am is an economical way to apply part of the nitrogen (in combination with other nitrogen fertilisers) and all the sulfur the crop requires.

5.8 Other Inorganic Fertilisers

Nitrogen is present in combination with other nutrients in many fertilisers, including:

- Diammonium phosphate (DAP);
- Monoammonium phosphate (MAP);
- Potassium nitrate;
- Calcium nitrate.

Calcium nitrate has two uses:

- As a calcium fertiliser in fertigation programs and in foliar sprays;
- As a non-acidifying nitrogen fertiliser for soil application through drip and trickle irrigation systems and under-tree sprinklers.

5.9 Organic Fertilisers

Where available, it makes good sense to recycle organic wastes and manures from feedlots, dairies, poultry houses, abattoirs, food processing plants and sewage treatment plants. Organic wastes contain nitrogen and other nutrients, but have an overall low and variable analysis, and may be difficult to apply. To minimise transport costs, it is best to use them close to their source.

The nitrogen they contain is not all immediately available for plant uptake, and may not all become available during the growing season of the crop to which they are applied, or in the first year after application. This generally necessitates higher nitrogen application rates than would be used if inorganic and synthesized nitrogen fertilisers were used.

Nitrogen

Nitrogen that becomes available after harvest when the land is bare may potentially be lost should heavy rain fall during the fallow period.

6. APPLICATION

6.1 The Four Rs

Nitrogen, both that applied as fertiliser, and that mineralized from soil organic matter, is subject to loss from agricultural fields, more so than for other nutrients.

Nitrogen can be lost in water (leaching, surface run-off), and in gaseous forms to the atmosphere.

Consequently, it requires careful management, with attention to the Four Rs:

- Right Source
- Right Rate
- Right Time
- Right Place

IPF through the Agronomy in Practice Training courses have considered a Fifth R: Right Agronomy. The fact that nutrient stewardship relies on, and can be most successful only when other management and agronomic factors like weeds, diseases, varieties/hybrids, soil water, irrigation, and pests are all managed well is duly recognised.

6.2 The Right Source

The cost per kg of nitrogen (N) and ease of application are major considerations when it comes to choosing which nitrogen fertiliser to use.

In Australia, the most economical sources of nitrogen are anhydrous ammonia (Big N), in those districts in which it is available, and urea.

The nitrogen in combination with phosphorus in DAP and MAP, and in combination with sulfur in Gran-am, is also economically priced.

Not surprisingly, efforts are focused on how to best use these products, rather than on alternative nitrogen fertilisers.

In those areas in which it is available (the inland cropping areas of NSW and Qld), Big N is used to apply nitrogen pre-plant in cotton and grain crops.

Urea is widely used for pre-plant application, side and top-dressing, and in blends. More nitrogen is applied as urea than in any other form.

Ammonium nitrate based fertilisers, e.g. Cal-Gran, are used by some in preference to urea where:

- A quick response is required to side or top-dressed nitrogen in short season vegetable and winter forage crops;
- Atmospheric volatilization losses of ammonia may be high following the surface application of fertiliser in rain-grown crops.

DAP and MAP are used to supply starter nitrogen in planting fertilisers.

EASY N is used where the convenience of a liquid is required. It may be applied direct to the soil and in fertigation programs.

Soluble Solid or Solution Grade fertilisers are also used in fertigation programs, and in foliar sprays. Products with a small particle size will dissolve more readily than granular grades.

As with dry application to the soil, urea is the most commonly used fertiliser where nitrogen solutions are to be prepared.

Cal-Am cannot be used in the preparation of fertiliser solutions, as it contains 20% calcium carbonate, which is insoluble.

Calcium nitrate is used as a non-acidifying nitrogen fertiliser in fertigation programs where drip and trickle irrigation systems and under-tree sprinklers are used, to avoid soil acidification around the emitters.

Foliar sprays are used to supplement rather than replace soil applications of nitrogen. Foliar sprays would burn the foliage if attempts were made to use them as the sole means of applying nitrogen. There are exceptions. Citrus trees may be fed through the foliage, and high volume sprays are applied to pineapples through booms, though in the latter case, much of the spray runs off the foliage and is taken up by crop roots from the soil.

Urea is the most commonly used nitrogen fertiliser in foliar sprays. A low biuret grade should be used in horticultural crops where urea is applied at high rates and/or repeated sprays are made.

6.3 The Right Rate

Getting the rate right is often the most difficult and important part of any fertiliser program. Too little and yield and quality may be compromised. Too much, and unnecessary investment in fertiliser will have been incurred, and the unused nitrogen may be lost. This often occurs after harvest, while the land is being fallowed.

Soil and plant tissue analysis, and computer based decision support tools are used to help determine appropriate

Incitec Pivot Fertilisers

Nitrogen

fertiliser rates. Nitrogen rates are extremely variable, depending on the crop or pasture to be grown, the soil's inherent fertility and organic matter level, the use of legumes in crop rotations, residual nutrients left over from the previous crop, stored soil moisture, rainfall and seasonal conditions, irrigation, expected yields and commodity prices.

Nitrogen rates in rain-grown non-legume grain crops typically range from 25 to 125 kg/ha N. Higher rates are used in irrigated crops, usually in the range of 75 - 200 kg/ha N.

In forage crops and nitrogen-fertilised grass pastures, a typical nitrogen rate per application is 50 kg/ha N. The number of applications made each year depends on such factors as the stocking rate, the amount of rainfall received, and whether irrigation is available. In total, nitrogen fertilised grass pastures often receive around 180 kg/ha/annum N. Irrigated pastures receive more.

Most vegetable crops will receive between 100 and 200 kg/ha N, tree crops and vines between 50 and 200 kg/ha N.

Plant sugarcane requires 80 - 150 kg/ha N, while ratoon sugarcane needs 120 - 200 kg/ha N. Fully irrigated ratoon crops in the Burdekin may receive 200 - 250 kg/ha N. Average rates in sugarcane across all crop classes and districts are in the range of 150 – 180 kg/ha N.

6.4 THE RIGHT TIME

Nitrogen can be applied to the soil pre-plant, at planting, or during the growing season (side or top-dressings), as foliar sprays, or a combination of these methods.

Applying all the nitrogen at the one time may predispose it to loss and adversely affect plant growth, either by burning the roots or foliage, or promoting excessive vegetative growth.

For example, applying all the nitrogen at planting in rice depresses grain yield. It needs to be split with some being applied at panicle initiation.

Split applications of nitrogen often improve crop recovery of applied nitrogen and reduce losses, particularly on sandy soils and in high rainfall areas.

In crops, it is customary to apply some starter nitrogen at planting, in combination with other nutrients, e.g. phosphorus. The ammonium phosphate fertilisers (MAP and DAP) are ideal for such use.

When the balance of the nitrogen is applied depends on many factors, such as the crop, soil type, seasonal variations in rainfall, and whether irrigation is available.

Northern Grain Growing Districts

In the inland cropping areas of northern NSW and Qld, pre-plant applications are used, for both summer and winter crops. The soils are mostly heavy textured clays so leaching is unlikely to occur. Applying nitrogen pre-plant allows the nitrogen to be carried into the soil by rain during the fallow period, where it is stored along with soil moisture.

Top-dressing winter grain crops in the spring in these areas is not an option. Nitrogen fertiliser applied during the spring can be left stranded in dry top-soil and be positionally unavailable to crop roots. August is on average the driest month of the year.

Applying nitrogen into the soil pre-plant also eliminates the risk of volatilization loss. Surface-applied nitrogen that is not followed up by rain or irrigation shortly after application is subject to such loss.

Denitrification may occur if the soil becomes waterlogged for several days. This is most likely to occur over summer, when heavy rain is most likely to be received, and soil temperatures are high.

Pre-plant application for winter grain crops should be deferred in poorly drained soils where denitrification is likely, e.g. from January and February to later in the fallow period.

Southern Grain Growing Districts

In southern Australia, the climate is Mediterranean, and the rainfall winter dominant. Winter cereals can be top-dressed in spring with greater confidence that rain will be received to carry the fertiliser into the soil.

Winter cereals should be top-dressed during the early–mid tillering stage. Later application will have a greater effect on grain protein than on grain yield.

Maize

Maize is mostly grown in areas of favourable summer dominant rainfall. On the eastern Darling Downs, nitrogen can be applied pre-plant. In areas such as the Atherton Tableland in north Queensland, and the NSW North Coast, nitrogen is side-dressed. This should be done within four weeks of planting.

Vegetables

In irrigated vegetable crops, nitrogen is side-dressed during the growing season, in one or more applications. Where fertigation is practised, this can be done each time the crop is irrigated, using the little and often approach.

Nitrogen

Forage Crops

In forage, hay and silage crops, the initial application of nitrogen can be made pre-plant.

Nitrogen can then be top-dressed after grazing or cutting and before regrowth occurs, provided moisture conditions are favourable for regrowth. This ensures nitrogen is available to promote regrowth, and minimizes wheel track damage.

Sugarcane

In plant sugarcane, starter nitrogen is applied in the planting fertiliser (normally a blend of DAP and Muriate of Potash), and the balance of the nitrogen is applied at "closing in" as urea.

In ratoon sugarcane, a complete NPK fertiliser, normally a blend of Urea, DAP and Muriate of Potash, is applied shortly after harvest.

Tree, Vine and Plantation Crops

In tree and vine crops, nitrogen is normally applied, in combination with other nutrients, at the start of and during the early stages of the main growth period. Late application may affect fruit set and quality.

Pasture

In nitrogen fertilised grass pastures, nitrogen fertiliser application is split into a number of applications throughout the main growing season, and is typically applied after grazing or cutting for hay.

Where nitrogen is applied to rain-grown crops and pasture and it can not be incorporated, it is best to apply it when rain is forecast, particularly when using urea. This minimizes the risk of ammonia volatilization loss. Volatilization losses are virtually eliminated if the fertiliser can be washed into the soil.

Where nitrogen fertiliser is top-dressed onto flood irrigated pasture, or applied in the irrigation water in furrow-irrigated crops, e.g. cotton, the tail-water should be contained for re-use, and not allowed to enter streams. Excess nutrients in surface water may contribute to weed growth and algal blooms.

6.5 The Right Place

Paying attention to fertiliser placement can enhance plant root uptake and recovery, reduce off-site losses, and minimizes the risk of crop damage.

Soil Incorporation/Surface Application

If practical, nitrogen fertilisers should be applied into, or incorporated into the soil shortly after application, e.g. by mechanical means or irrigation, rather than left on the soil surface. This eliminates the risk of volatilization loss, and minimizes loss in surface run-off should heavy rain fall after application.

Soil incorporation, however, is not always possible, e.g. in non-irrigated pasture and forage crops, and when top-dressing rain-grown winter cereals during the growing season.

In rain grown situations where fertiliser is broadcast on the soil surface, nitrogen fertiliser should be applied when the prospects for rain are good.

Use at Planting

When nitrogen is applied at planting, it is usually in combination with other nutrients such as phosphorus. As phosphorus is immobile in the soil, it needs to be banded with or near the seed so that the crop roots have early access to it. This dictates that other nutrients be applied in the same way.

While some starter nitrogen at planting is beneficial, too much nitrogen will add to the osmotic or salt effects near the seed, and can delay and even prevent germination and emergence. This necessitates split applications of nitrogen. It can not usually all be applied at planting.

In row crops, e.g. sugarcane, vegetables and summer grain crops such as maize, the planting fertiliser should be applied in bands 5 cm to either side of and 5 cm below the seed. Many row-crop planters are equipped to do this, with the fertiliser and seed or planting material being placed apart in the soil through separate delivery hoses.

In winter cereals and other crops planted at narrow row spacings, it is not possible to apply the fertiliser and seed through separate delivery hoses. The amount of nitrogen that can be safely applied in direct contact with the seed varies with such factors as the crop species, row spacing, application equipment and the type of tine, soil texture and moisture at sowing.

Suggested upper rates for nitrogen in wheat and barley sown at narrow (18 - 20cm) row spacings under ideal planting moisture conditions are:

Soil Type	kg/ha N (max.)
Clay	30 - 35
Loam	20 - 25
Sand	10

In general, small seeded crops are less tolerant of nitrogen with the seed than the larger seeded cereal grain crops. Oats, which has a large seed, is more tolerant than wheat and barley, while canola which has a small seed, is much less tolerant. A suggested maximum safe nitrogen rate in direct contact with the seed of canola at 18 cm row spacings is 10 kg/ha N.

Side Dressing

Nitrogen fertiliser should not be applied too close to the crop row when side-dressing row crops, as this may result in root-pruning and set back the crop.

In formed beds, it is better to apply the fertiliser into the side of the beds, rather than the centre of the inter-row space. This allows quick access by roots. The centre of the inter-row space may also be compacted, which can restrict root growth. Also, if drainage is poor, water is more likely to lie in the centre of the furrow, increasing the chance of denitrification.

In ratoon sugarcane, fertiliser is applied soon after harvest and before regrowth occurs. While it is customary to apply fertiliser to the inter-row space, some farmers apply it in the centre of the row.

Tree Crops

In tree crops, nitrogen fertiliser should be spread evenly over the entire root zone so as to avoid root burn, which may occur if the fertiliser is concentrated on too small an area. Apply no closer than 20 cm to the trunk, to just beyond the edge of the canopy.

If applying by machine to a row of trees, spread in a broad band on either side of the row, from close to the trunks to just outside the edge of the tree-line.

7. INHIBITORS

7.1 Urease Inhibitors

Urease inhibitors, as the name suggests, inhibit the activity of the enzyme urease which is responsible for the conversion of urea to ammonium. Once converted to the ammonium form, nitrogen can be subject to loss by volatilization. If this process can be blocked and the nitrogen kept in the form of urea, it is not subject to volatilization loss.

Volatilization loss is only of concern where urea is applied to the soil surface in raingrown crops.

Volatilization losses are avoided if urea can be applied or incorporated into the soil, or watered into the soil by irrigating immediately after application.

In rain-grown crops and pasture, nitrogen fertilisers should be top-dressed when rain is forecast.

The use of ammonium nitrate based fertilisers, or urea treated with a urease inhibitor, e.g. Incitec Pivot Green Urea NV, may help further manage and reduce volatilization losses.

Their use allows more time for rain to come and wash the fertiliser into the soil.

Green Urea NV may provide protection against volatilization losses for up to two weeks.

The effectiveness of urease inhibitors is reduced where urease activity is high, e.g. in trash blankets in ratoon sugarcane.

Urease inhibitors, such as NBPT, the active ingredient in the inhibitor added to Green Urea NV, are of no value in reducing nitrogen other possible loss pathways like leaching and denitrification, which occur over longer time periods of time.

Lastly, Green Urea NV does not change or affect (neither enhance or reduce) the seed safety of nitrogenous fertiliser (i.e. urea) if applied in direct contact with seed in-furrow at planting.

7.2 Nitrification Inhibitors

Nitrification inhibitors inhibit the transformation of nitrogen in the soil from ammonium to nitrate. If nitrogen is kept in the ammonium form, it is resistant to loss by leaching (in sandy soils) and denitrification (in heavy textured soils should they become water-logged).

The nitrification inhibitors used by Incitec Pivot are Entec® (DMPP) and eNpower™ 18:20 (DMPG).

Entec and eNpower are most effective under cool conditions. Its effectiveness or length of persistence is reduced under warm soil conditions. Entec and eNpower may delay nitrification for several months at soil temperatures of 10^0 C and below, but only for a month or less at warmer soil temperatures of 20^0 C and above.

Nitrogen

8. FERTIGATION

Nitrogen is particularly suited to application with the irrigation water (fertigation) during the growing season.

Urea and EASY N (UAN Solution) are the most commonly used fertilisers for this purpose.

Calcium nitrate may be used as a non-acidifying nitrogen fertiliser through drip and trickle irrigation systems, and under-tree sprinklers.

9. FOLIAR SPRAYS

Foliar sprays can be used to supplement, but not replace soil applications of nitrogen.

Urea is the most commonly used nitrogen fertiliser in foliar sprays. A low biuret grade should be used in horticultural crops where urea is applied at high rates and/or repeated sprays are made.

10. NITROGEN IN ANIMALS

Unlike plants, animals cannot synthesise their own proteins. Instead, they are reliant on the correct amount and types of protein in their diet to provide an adequate supply of amino acids. Animals on a protein deficient diet perform poorly.

Ruminants (cattle and sheep) differ from other animals, e.g. pigs and poultry, in that bacteria living in the rumen can synthesise protein from inorganic nitrogen and sulfur compounds consumed by the animal when the diet is deficient in protein, provided the stock have access to adequate amounts of dry food (roughage). When the bacteria pass from the rumen further down the intestinal tract, they are digested, and the protein they contain is utilized by the animal in the same way that protein from other sources is.

Urea is the most commonly used non-protein nitrogen supplement for ruminants.

11. THE ENVIRONMENT

Fertilisers are essential in productive agricultural systems. Without them, the world could not sustain its current population. Famine and starvation would be widespread. More land would need to be farmed, much of it not entirely suitable for agricultural production. Wildlife habitat and wilderness would be lost, and biodiversity reduced.

While few will deny the important role fertilisers have to play in today's society, it is important that they be used in an efficient way, so that unnecessary resources are not wasted in their production and application, and environmental impacts are minimized.

The promotion of Best Management Practices helps achieve this.

FURTHER READING

Other Agritopics are available, including those on Urea, Fertigation, Foliar Fertilisers and Mineral Supplements for Ruminants, which provide more detail on these topics.