Figure 1 - Anhydrous ammonia 'BIG N' being applied into rows.
Photo courtesy of Incitec-Pivot Fertiliser.

Anhydrous ammonia has also been more effective than calcium ammonium nitrate in potato production due to the slow release of available N in wet winters[4]. Highest yields occurred when injected 1–3 weeks before planting or sowing[5].

In sugar beet, yields were on average 7.4 t/ha higher with anhydrous ammonia compared to urea and urea-ammonium nitrate (Table 1). During high precipitation (260mm) after application, urea yielded 11.2t/ha less than anhydrous ammonia due to leaching of nitrate from the soil[6].

In cabbage, tomatoes and beans anhydrous ammonia proved as effective as ammonium nitrate and sodium nitrate and superior for beans. In tomatoes, a split application at 15cm gave significantly greater yields than a single application at the same depth[7].

Residual nitrogen

Another advantage of the use of anhydrous ammonia is the residual N in the soil that becomes available for the subsequent crop. In a six-year trial on potatoes, sugar beets and maize – comparing anhydrous ammonia and calcium nitrate – it was found that high residual N after application of anhydrous ammonia resulted in increases in yield to the following winter wheat[8].

Anhydrous ammonia has also been used to suppress root-knot nematode. The addition of anhydrous ammonia to olive pomace reduced the C:N ratio of soil (increased N content), reduced phytotoxicity to tomato plants, supressed nematodes and increased microbial activity of the soil. This was advantageous over the traditional use of urea as urea's high solubility meant that it leached out of the soil[9].

Table 1 - Comparison of form of nitrogen and method of application on yield of sugar beet in North Dakota, USA[16].

NITROGEN SOURCE	METHOD OF APPLICATION	ROOT YIELD (t/ha)
Average of 4 years		
Urea	Surface	43.9
Urea-ammonium nitrate	Surface	+2.2
Ammonium nitrate	Surface	+4.0
Ammonia	Injected	+7.4
Average of 2 years		
Urea	Surface	48.6
Urea	Injected	+7.2
Urea- ammonium nitrate	Surface	+0.7
Urea- ammonium nitrate	Injected	+5.4
Ammonia	Injected	+7.4

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Other benefits of using anhydrous ammonia

Stability of nitrogen in the soil

After the anhydrous ammonia reacts with water in the soil to produce ammonium, the nitrogen is locked into the soil exchange complex and will not leach out of the soil with water. Nitrogen will only leach out of the root zone after nitrification, and is due to the process of soil microbes converting ammonium to nitrate. Once converted to nitrate, the nitrogen is readily available for uptake from plants.

Vegetable grower Ed Fagan (Mulyan Farms) found the the main benefits of retention of N from anhydrous ammonia in vegetable crops are: (1) the nitrogen remains available to the crop until harvest (2); residual nitrogen moves down the soil profile slightly, but remains in the root zone (0-30cm). This residual N is then available for a subsequent crop because it is not lost to deep leaching or volatilisation.

Studies on corn in the USA in a sandy loam, found that using anhydrous ammonia to supply nitrogen reduced nitrate leaching by 56%, from 43 kg N/ha to 19kg N/ha, compared to urea-ammonium[10].

Earthworms

When anhydrous is applied, initially, approximately 15% of the earthworm population is killed. However, anhydrous increases the amount of available nutrients, resulting in gradual increase in earthworms in the application zone. After this, numbers multiply quickly due to fertile conditions, 6-8 weeks after injection; the total numbers are normally higher than originally present[11].

Figure 2 - Anhydrous ammonia 'BiG N' application equipment using tines. Photo courtesy of Incitec-Pivot Fertiliser.

The increase in earthworm numbers is due to added N increasing biological activity resulting in enhanced earthworm growth and sexual activity. Increase in earthworm numbers has been shown to increase soil aggregation, improved soil structure, increased water infiltration, increased soil aeration, assist in plant residue decomposition and increase microbial mineralisation cycles[12].

Table 2 - Earthworm numbers post anhydrous application per square metre[16].

AMMONIA APPLICATION RATE (KG/HA)		
	0	**55**
Earthworms	98	292
Cocoons	62	98
Total	160	390

Soil Microbes

Initially, a high concentration of ammonia and an increase in soil pH following application reduces microbial biomass carbon and protozoa by about half, while ammonia and nitrate bacteria are unchanged[13]. Five weeks later, microbial biomass and protozoa numbers recover, with a minimal impact in the long-term[13].

In one study, anhydrous ammonia compared to urea application, increased the microbial diversity for both bacteria and fungi in the soil.[13] The microbial diversity in the soil is critical to the maintenance of the soil's health and quality as a wide range of organisms are involved in important soil functions[14] – important processes such as soil structure formation, decomposition of organic matter, toxin removal and cycling of carbon, nitrogen, phosphorus and sulphur, as well as playing a role in suppressing soil-borne plant diseases and promoting plant growth[14].

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How do you apply anhydrous ammonia to vegetable cropping soils?

The effectiveness of anhydrous ammonia can vary dependent on soil type, moisture in the soil and climatic conditions. Moisture is not critical for the retention of ammonia in the soil as clay and organic matter provide long-term ammonia retention sites. High moisture content of the soil provides proper soil physical conditions to ensure rapid and complete sealing of the injection channel and a short-term reservoir of ammonia (initial capacity)[22].

Soil texture is a major factor in the retention of ammonia; the highest retention being in fine textured clay soils, lowest in coarse sandy soils, while the greatest loss of ammonia is in dry sandy soils. However, if placement of ammonia is correct and the injection point is sufficiently covered with soil, anhydrous ammonia can be just as effective in dry, sandy soils. Theoretically, soil with high clay content and moisture are most suited for retention; in the field these soils can lose a high proportion of ammonia if the soil is cloddy and does not provide coverage of the injection furrow[22].

Soil pH affects the ability of the soil to react chemically with ammonia. Under acidic conditions clay minerals are the most attractive sites, while under alkaline conditions organic matter is more effective[22]. Soil pH also influences the partitioning between NH_3 and NH_4+. Following injection, NH_3 reacts with water and releases hydroxyls that raise the pH of the soil in the retention zone.

The nitrification of NH_4+ on the other hand releases hydrogen ions, which reduces the pH levels to original levels or lower[15]. The pH of the soil at injection has been shown to influence retention percentage. At pH below 6, 92% of N injected into the soil was retained, while the pH above 7.5, only 64% was retained. This is because low pH favours ammonia conversion to ammonium. However, rate of nitrification was higher in soils with pH above 7.5- at low pH, N is more readily retained in the soil as ammonium, but at high pH, N is more readily converted to nitrate by bacteria.[15]

What equipment do you need?

The need for specialised equipment could be a limiting factor for the widespread adoption of anhydrous ammonia in vegetable cropping systems. Pressure vessels are needed for the storage and safe handling of the gas. These vessels require significant investment and need to be regularly inspected. Specialised application equipment is also needed.

Conventional application equipment applies anhydrous ammonia as a pressurised liquid, which converts to gas immediately upon application. This is due to a pressure drop, which results in 50% liquid and 50% vapour. This conversion to gaseous form means that ammonia can be lost to the atmosphere if the soil does not flow freely around the application time, limiting usefulness in minimum tillage operations or in cloddy beds.[16]

In COLD FLO® converters, ammonia is converted to gaseous phase and then chilled, resulting in about 85% converting back to liquid (Figure 3). [16]

When COLD FLO® is used, the higher liquid percentage allows for "greater residence time" as liquid ammonia, resulting in greater coverage by the soil, increased absorption by the soil and decreased losses to the atmosphere. With COLD FLO® technology, Big N can be applied under a wider range of soil conditions.[16]

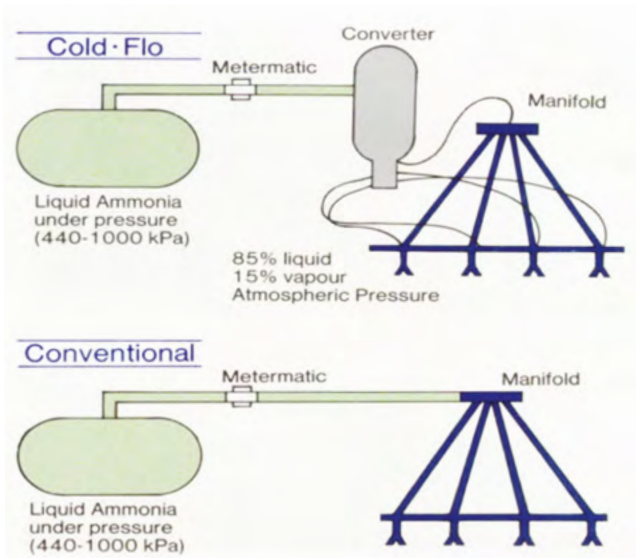

Figure 3 - Comparison of COLD FLO and conventional applicatio r[16]

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Figure 5 - Side view of the knifepoint for anhydrous ammonia and granular seed/ fertiliser on the application equipment on the commercial vegetable farm in Cowra, NSW.

Figure 6 - Front view of the knifepoint for anhydrous ammonia and granular seed/ fertiliser on the application equipment on the commercial vegetable farm in Cowra, NSW.

What are the health risks associated with using anhydrous ammonia?

Ammonia is a caustic, toxic gas with powerful corrosive action on tissue. In a US study, 30% of all chemical burns admitted to hospital were a result of anhydrous ammonia. Ammonia exposure can lead to dangerous inhalation and third-degree burns to the body.

Ammonia is a pungent gas and can be detected at 53 mg/L. A concentration of 100 mg/L is tolerable for several hours; coughing and laryngospasm occurs at about 1700 mg/L and it can be fatal at 2500 mg/L. If exposure lasts for 30 minutes at 5000ppm, rapid respiratory arrest occurs.[17] However, in most cases, ammonia can be detected before any injury occurs. Exposure should be treated immediately by removing contaminated clothes and washing the affected area in water for at least 20 minutes.

Farm workers need to be educated of the potential risks of anhydrous ammonia, treatments and how to properly use equipment. Farm operators should be familiar with and follow the BIG N® Farmer operational manual[18].

Other potential risks and issues associated with using anhydrous ammonia

Potential for crop damage

Anhydrous ammonia can be phytotoxic to seeds and growing plants. The placement of anhydrous ammonia is important to avoid toxicity to seeds and young plants. When fertilisers are placed close to seeds or plants, the osmotic pressure of the soil increases, which can cause injury to plants.

The "salt index" refers to the effect of a fertiliser compared to sodium nitrate, which has a rating of 100. Any material with a high salt index must be used with care. Anhydrous ammonia has a salt index of 47.1; this is relatively low compared to other common fertilisers such as calcium nitrate (52.5) and urea (75.4)[19]. However, careful placement of anhydrous ammonia is essential to ensure it is not phytotoxic to seed and young plants.

Cost

The initial cost of application and storage equipment is a barrier to adoption of anhydrous ammonia in the vegetable industry. Depending on the size, equipment can cost $20,000-30,000. On average, it cost $2000 per metre of BIG N equipment. Cost of anhydrous per tonne of N is near parity to urea, however it contains a much high % N concentration. As with any adoption of new technology, initial cost occur, long-term savings can occur on cost per unit of nitrogen.

Commercial availability

Anhydrous ammonia is available in Australia as "Big N" supplied solely by Incitec-Pivot Fertilisers. The main users of Big N are grain and cotton growers and therefore anhydrous ammonia is not available in all cropping districts. This means that only vegetable farms located close to grain and cotton growing regions are likely to have anhydrous ammonia available.

Nitrous oxide emissions

The emission of nitrous oxide is highly dependent on soil type, tillage regime, nitrogen source, placement, timing and rate. Application of anhydrous ammonia to soils has had varied results in relation to nitrous oxide (N_2O) emissions.

Anhydrous ammonia, ammonia sulphate, urea and calcium nitrate were compared on a wheat crop on silty clay loam. The areas where anhydrous ammonia was knife-injected pre-plant had higher N_2O emissions (2.08kg N Ha) compared with ammonium sulphate (1.31kg N ha). However, these anhydrous ammonia treatments demonstrated the highest nitrogen use efficiency due to available ammonium in the root zone.[20] Anhydrous ammonia applied as pre-plant fertiliser to corn crops on silty clay loam soils resulted in 2.45kg N/ha in nitrogen emissions. This is reduced by up to 65% by reducing the rate of application from 202kg/ha to 145Kg/ha.[21]

N_2O is a greenhouse gas, being attributed to deleterious effects on global warming and destruction of the ozone. Environmental stewardship needs to be maintained, this can include only applying when weather and soil conditions are permitting, ensuring the injection channel is fully enclosed by soil. Hence, reducing emissions of N_2O.

The science: What actually happens to anhydrous ammonia when it is applied to soils?

When applied to soils, anhydrous ammonia is initially converted to ammonium, which can be held in the soil and resist leaching. Anhydrous ammonia combines with soil moisture to produce ammonium which can either be taken up by plants, or converted to nitrate.

The following reaction occurs:

$$NH_3 + H_20 \rightarrow NH_4+ + OH-$$

Ammonia gas (NH_3) combines with water in the soil to produce ammonium nitrogen (NH_4+), plus hydroxide ions (OH-).

Ammonia gas (NH_3) is highly reactive and ionises to ammonium (NH_4+) ions in the presence of water. Ammonium ions have a high positive charge and as such are attracted to negatively charged surfaces such as clay particles and organic matter. This strong attraction reduces the loss of ammonia to the atmosphere or by leaching into the soil. Ammonium is then converted into nitrate (NO_3-) by soil microbes, allowing it to move with soil moisture.[20]

How far does anhydrous ammonia spread in the soil?

This is *called the retention zone.* It is the soil which is immediately affected by application. The retention zone is about 5–7.5cm wide, depending on soil type. The soil in the retention zone undergoes drastic changes in chemical, biological, and physical soil properties. These include an increase of NH_3 and NH_4+ concentrations, pH increase to 9 or above, NO_2- increases, lower population of soil microbes and solubilisation of soil organic matter.[23]

Following application, the ammonia is absorbed by the soil, which produces ammonia concentration and pH gradients. Nitrification begins at the outside edge of the ammonia band where the ammonia concentration and pH are favourable for nitrifying organisms. As the concentration of ammonia and pH decreases, the rate of nitrification increases towards to the centre of the application band until the ammonium is completely nitrified or a pH is low enough to be a limiting factor.

Anhydrous ammonia can be phytotoxic to vegetable crops inhibiting seed germination, as well as being toxic to growing plants. It is important, therefore, to know the distribution of crop roots to ensure that the fertiliser is placed at the point of greatest absorbance. The placement of anhydrous ammonia is dependent of the type of crop. For example, 7.5cm has been found to be optimal for babyleaf spinach and radish, while 15cm is optimal for potatoes, tomatoes and sugar beet. Careful placement of fertiliser is needed as placing Big N directly underneath the seed reduced germination.[24]

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Figure 7 - Anhydrous ammonia observational trial showing babyleaf spinach after application of anhydrous ammonia on the right and calcium nitrate on the left.

CASE STUDY: Anhydrous ammonia trial on babyleaf spinach in Cowra, NSW

Cowra vegetable grower Ed Fagan, has long been interested in the potential benefits of using anhydrous ammonia to supply nitrogen to vegetable crops. Ed had been using anhydrous on his broadacre crops for a while and wondered whether the benefits he saw in wheat, might translate into benefits for his horticultural crops.

Ed gave it a try on popcorn and other crops, where he noticed higher yields, and also that there seemed to be more residual nitrogen in the soil after the crop that a subsequent crop could use.

To test this idea Ed and Applied Horticultural Research set up an observational trial at Mulyan Farms to collect preliminary data comparing the use of anhydrous ammonia with calcium nitrate as the primary source of nitrogen for a babyleaf spinach crop.

The objective of the trial was to measure the impact of either anhydrous ammonia or calcium nitrate applied pre-plant to supply nitrogen for babyleaf spinach on yield, leaf N levels, soil nitrate and ammonium N through crop development.

The data from the trial showed that nitrogen applied as anhydrous ammonia remained in the soil – mainly in the nitrate form – and was mostly in the top 15cm, especially early in crop development (Table 3).

The nitrogen was effectively taken up by the shallow-rooted spinach crop, reducing the amount of nitrate in the top 15cm by the time the crop was harvested (6 weeks after sowing). There was some movement of nitrate-N down to the 15–30cm depth, but it did not leach further down the profile (30–45cm).

The N in the 0–15cm and 15–30cm depths would have been available to a follow-up crop, and was not lost to leaching or volatilisation. These results confirm the potential of anhydrous ammonia in vegetable cropping.

Tissue analysis of the spinach crop at various stages, showed that N% in the anhydrous treated crop ranged from 5.3–6.3%, significantly higher than in the leaves of the calcium nitrate-fed spinach, where the tissue N ranged from 5.1–5.2% (Figure 4).

Table 3 - The amount of nitrogen in the form of nitrate in the soil at a depth of 0-15 cm and 15-30cm during the development of babyleaf spinach crop following the application of anhydrous ammonia 'Big N' and calcium nitrate '$CaNO_3$'.
Note: Top-dressed with Nitrophoska a week before 8- leaf stage (300kg/ha). * represents missing values.

0-15 CM			15-30 CM		
NO3-N (ppm)			NO3-N (ppm)		
	Big N	$CaNO_3$		Big N	$CaNO_3$
Pre-emergence	35	16	Pre-emergence	23	20
Cotyledon	23	20	Cotyledon	21	25
2 leaf	5	7	2 leaf	23	22
2-4 leaf	4	0.5	2-4 leaf	30	17
4-6 leaf	*	*	4-6 leaf	34	12
6-8 leaf	0.5	0.5	6-8 leaf	11	7
8 leaf	9	9	8 leaf	11	5

Figure 8 - The anhydrous ammonia application equipment used in the trial in Cowra, NSW.

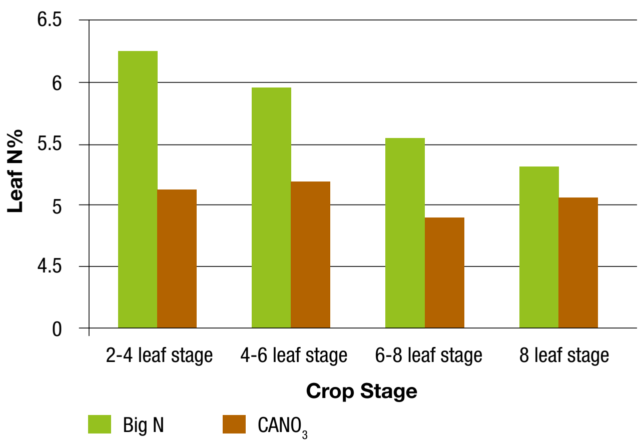

Figure 7 - The amount of leaf nitrogen % during the development of a babyleaf spinach crop following the application anhydrous ammonia 'Big N' and calcium nitrate '$CaNO_3$'. Note: Top-dressed with Nitrophoska a week before 8- leaf stage (300kg/ha).

Conclusions from the trial

The results suggest that anhydrous ammonia may be a viable option for the use as a nitrogen fertiliser in the Australian vegetable industry:

- N was readily available in the soil for uptake by babyleaf spinach
- N did not leach significantly down the soil profile
- Residual N remained in 0–30cm of the soil was available for the following crop.

However, the trial highlighted some potential problems for the shallow-rooted babyleaf spinach crop, especially under the extremely wet conditions that were encountered during the trial.

The anhydrous ammonia, once injected, would have been converted to ammonium very close to the injection point due to the high moisture content of the soil and this would have resulted in quite high ammonium levels in the soil in that area. High levels of ammonium in the soil can lead to nitrogen toxicity, which can damage plants, especially sensitive young babyleaf spinach plants.

Close to the injection point, high levels of nitrogen in the soil would also have resulted in acidification of this soil, leading to some micro nutrients becoming unavailable, and resulting in yellowing of leaves. However, on either side of the injection furrow, optimum levels of N concentration are reached as the ammonium leached through the soil, and further away from the channel, the soil was lacking N as the ammonium is fully bound to soil particles. These effects combined to increase the variability in crop growth.

Summary

Anhydrous ammonia has beneficial effects on soil microbes, nitrifying bacteria and worms. It can also increase N retention in the soil, reducing nitrate leaching, resulting in yield and nitrogen-use efficiency. Anhydrous ammonia is probably more suited to row crops rather than babyleaf crops, where an even distribution nitrogen in the soil is required. It may be possible through the adaptation of application equipment to apply anhydrous ammonia in a way that is more suitable for babyleaf crops.