The Effects of Using Anhydrous Ammonia to Supply Nitrogen to Vegetable Crops

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Summary

Anhydrous ammonia is a high nitrogen (82%) fertiliser, which is currently widely used in the cotton and grain industries in Australia. It is a product that needs to be handled correctly as there can be OH&S issues. Anhydrous ammonia is applied using specialised equipment, which could be a barrier to use by vegetable growers. Supply locations are focused around grain and cotton production areas. Anhydrous was found to have beneficial effects on soil microbes, nitrifying bacteria and worms. Anhydrous ammonia is converted in the soil initially to ammonium, which can be held in soils and resist leaching.

There was very little research found on the use of anhydrous ammonia in vegetable crops in Australia. AHR reports on an observational trial comparing the use of anhydrous ammonia to calcium nitrate as a source of nitrogen on baby spinach on a commercial farm Cowra, NSW.

In conclusion, the review found there is potential for anhydrous ammonia to be used as a source of nitrogen for vegetable crops but that it was more suited to row crops than crops such as baby leaf, which require more even distribution of nitrogen across the beds.

Introduction

Proper nitrogen management (N) on vegetable farms is essential for the health of the crop, soil and ecosystem. It has long been recognised that groundwater with nitrate from fertiliser origin is a serious environmental issue in areas of intensive agriculture around the world. Areas of intensive vegetable production typically produce two to three crops annually, with frequent irrigation and N applications, sometimes at rates that far exceed the rate of N removal of the harvested product[1]. Nitrogen fertilisers interact with soils and plants in different ways, and understanding this is key to achieving the most profitable use of nitrogen. Anhydrous ammonia is a N fertiliser that interacts with the soil clay particles and moisture in a way that increases the retention in the soil and reduces leaching into ground water.

At normal room temperature and pressure ammonia is a gas, under high pressure it converts to a liquefied gas, and this is how it is transported and applied to the soil. Anhydrous ammonia has a high affinity to water and on application to the soil it combines with soil moisture to produce ammonium ions. The following reaction occurs:

$$\mathbf{NH_3 + H_2O \rightarrow NH_4^+ + OH^-}$$

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.[2]

Anhydrous ammonia is normally used as a pre-plant fertiliser to supply nitrogen in broadacre cereals and cotton. It is applied directly under the seed or as side dressing. Anhydrous ammonia can have beneficial effects on soil microbes, nitrifying bacteria and worms. It can also increase N retention in the soil, reducing nitrate leaching, resulting in nitrogen-use-efficiency benefits. Caution needs to be used when applying anhydrous ammonia, as it can be toxic to seeds and plant roots.

Anhydrous ammonia has resulted in yield advantages in broad acre cereals and cotton in

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1 Hartz, T., W. Bendixen, and L. Wierdsma, *The value of pre-sidedress soil nitrate testing as a nitrogen management tool in irrigated vegetable production.* HortScience, 2000. **35**(4): p. 651-656.

2 Incitec Pivot. *Big N Agronomy Guide*. Available from: http://bign.com.au/Big N Fertiliser/Big N Agronomy Guide.

Australia; it has also been used to increase yields in vegetable crops such as potato, sugar beet, cabbage, lettuce, tomato, radish, beans and spinach.

Anhydrous ammonia use in vegetable crops

Incorporating anhydrous ammonia into vegetable cropping systems could provide a range of benefits to producers such as increased soil health, reduced cost, increased yield and reduced environmental impact from a reduction in nitrate leaching.

In New Zealand, yield and tissue composition comparison were made on lettuce, radish and baby spinach after application of urea, sulphate of ammonia and anhydrous ammonia. Anhydrous ammonia compared favourably with other forms of N for radish, Cos lettuce and spinach. Anhydrous ammonia produced significantly higher radish dry weight in the field compared to urea and the control. When anhydrous ammonia was applied in low-temperature months of June and July, yields were significantly higher than all other treatments as anhydrous ammonia stimulated plant growth and increased recovery of nitrogen from soil[3].

Anhydrous ammonia has been found to be effective in row crops such as potatoes, sugar beets, and cabbage. In cabbage, 200kg/ha of anhydrous ammonia produced the maximum yield of first grade cabbage heads compared to 200kg/ ha of calcium nitrate[4].

In potatoes, a review of 22 experiments using anhydrous ammonia found that in nearly all trials, yield increases were found. Anhydrous ammonia increased yield compared to solid fertilisers by 0.5t/ha in 6 trials, 1.9t/ ha in 8 trials and by 5.9t/ ha in 6 trials [5]. 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[6]. Highest yield have been found when injected 1-3 weeks before planting or sowing [7].

In sugar beet, yields were on average 7.4 t/ ha higher with anhydrous ammonia than urea and urea-ammonium nitrate (Table 2). During high precipitation (260mm) after application, urea

[3] Thomas, M.B., *Anhydrous ammonia in vegetable cropping: I. Vegetative response to various application rates.* New Zealand Journal of Experimental Agriculture, 1973. **1**(3): p. 261-266.
[4] Steen, T.N., *Anhydrous ammonia for winter cabbage.* Tidsskrift for Planteavl, 1979. **83**(3): p. 278-286.
[5] Van Burg, P.F.J.v. and J.H. Schepers, *Ammonia injection as a method of nitrogen fertilization. 10. Results from experimental plots of industrial potatoes 1964-1970.* Stikstof, 1972. **6**(70): p. 416-418.
[6] Van Burg, P.F., G.D.V. Brakel, and J.H. Schepers, *The agricultural value of anhydrous ammonia on arable land: experiments 1963-1966.* Netherlands Nitrogen Technical Bulletin, 1967. **3**: p. 1-39.
[7] Van Burg, P.F.J., J.H. Schepers, and G.D. Van Brakel, *Ammonia injection as a method of nitrogen fertilization. 7. Date of injection in spring.* Stikstof, 1967. **5**(55): p. 351-4.

yielded 11.2t/ ha less than anhydrous ammonia due to leaching of nitrate from the soil[8].

In cabbage, tomatoes and beans anhydrous ammonia proved as effective as ammonium nitrate and sodium nitrate, proving superior for beans. In tomatoes a split application at 15cm gave significantly greater yields than a single application at the same depth [9].

Another advantage of the use of anhydrous ammonia is the residual N in the soil that is available for the subsequent crop. In a six-year trial fertilising potatoes, sugar beets and maize with anhydrous ammonia and calcium nitrate, it was found that high residual N after anhydrous resulted in increases in yield to the following winter wheat [10]. 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 it leached out of the soil[11].

Table 1. Comparison of form of nitrogen and method of application on yield of sugar beet in North Dakota, USA[8].

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

[8] Draycott, A.P. and D.R. Christenson, *Nutrients for sugar beet production: Soil-plant relationships*. 2003: CABI.
[9] Campbell, J.A., *Anhydrous ammonia as a source of nitrogen for cabbage, tomatoes, and beans.* Proceedings. American Society for Horticultural Science, 1950. **56**: p. 253-6.
[10] Nemec, A., *The inclusion of autumn application of anhydrous ammonia in the reserve fertilization system.* Rostlinna Vyroba, 1973. **19**(7): p. 703-712.
[11] Rodriguez-Kabana, R., et al., *Mixtures of olive pomace with different nitrogen sources for the control of Meloidogyne spp. on tomato.* Journal of Nematology, 1995. **27**(4SUPP): p. 575-584.

Application of anhydrous ammonia

Conventionally, anhydrous ammonia is applied as a pressurised liquid, which converts to a gaseous form 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.

With COLD FLO® technology, Big N can be applied under a wide range of soil conditions. In COLD FLO® converters, ammonia is converted to gaseous phase and then chilled, resulting in about 85% converting back to liquid (Figure 1).

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.[12]

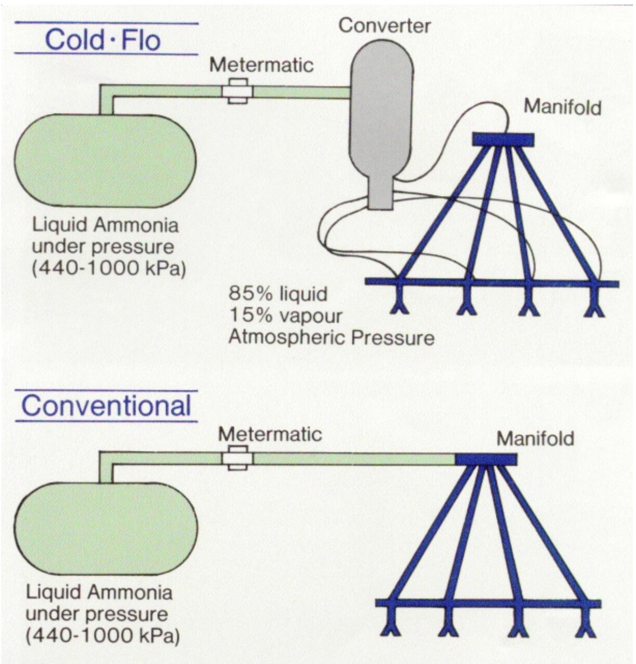

Figure 1: Comparison of COLD FLO and conventional application[3].

[12] Big N Techical points. Available from: http://bign.com.au/Big N Fertiliser/Big N Technical Guide.

Figure 2. Application equipment using discs. Photo courtesy of Incitec Pivot Fertilisers.

The ammonia retention zone

The retention zone – the area of soil immediately affected by application – has been found to be 5–7.5cm across a wide range of soil types. 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.[13]

Research into the use of anhydrous ammonia in vegetable cropping found that it could be phytotoxic – 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. Increasing rates of N decreases rates of germinations. However, placing anhydrous ammonia 7.5cm to the side of the seed optimised absorption for babyleaf spinach, lettuce and radish. Placement further away from this significantly reduces absorption by 3–4 weeks[14]. For crops such as potatoes, tomatoes and sugar beet placement of 15cm away from the seed is recommended. Careful placement of fertiliser is needed as placing Big N directly underneath the seed can reduce germination.

Following application, the adsorption of ammonia by the soil produces an ammonia concentration and pH gradient. 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

[13] Havlin, J.L., et al., *Soil fertility and fertilizers: An introduction to nutrient management*. Vol. 515. 2005: Pearson Prentice Hall Upper Saddle River, NJ.
[14] Thomas, M., *II. Effects of anhydrous ammonia placement on root growth, phytotoxicity, and nutrient uptake.* New Zealand Journal of Experimental Agriculture, 1973. **1**(3): p. 267-274.

centre of the application band until the ammonium is completely nitrified or a pH is low enough to be a limiting factor (Figure 2)[3].

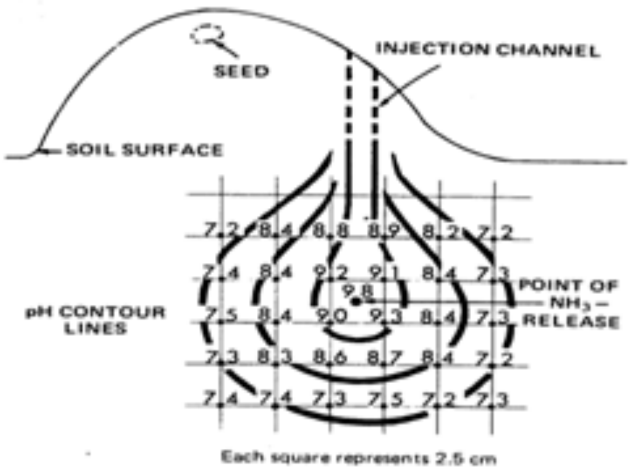

Figure 3. The ammonia retention zone.[3]

Application equipment

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.

In some regions, ammonia injectors are rented out to farmers to spread the cost. This is useful if there is not a long delay between N application and sowing.[15]

Retention of ammonia

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) [2].

Soil texture is a major factor in the retention of ammonia. The highest retention being in fine textured clay soils, lowest in course sandy soils. The greatest loss of ammonia is in dry sandy soils. However, if placement of ammonia is correct and the injection point is sufficiently

[15] Angus, J.F., et al., *Effects of banded ammonia and urea fertiliser on soil properties and the growth and yield of wheat.* Crop & Pasture Science, 2014. **65**(4): p. 337-352.

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[2].

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[2]. 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[16]. 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 contained in the soil and ammonium, but at high pH, N is converted to nitrate more readily.[16]

Figure 4. Anhydrous ammonia Big N application equipment using tines. Photo courtesy of Incitec Pivot Fertilisers.

[16] Benke, M.B., et al., *Retention and nitrification of injected anhydrous NH3 as affected by soil pH.* Canadian Journal of Soil Science, 2012. **92**(4): p. 589-598.

Benefit of anhydrous ammonia

The soil environment

Soil microbes

The short-term effects on soil microbes i.e. the time taken for anhydrous ammonia to be completely converted to nitrate have been well studied. Due to the drastic changes that the soil undergoes in the retention zone, populations of microorganisms are effected. Initially, the high concentration of ammonia and increase in soil pH in the retention zone reduces microbial biomass carbon and protozoa by about half, while nitrifying bacterial populations increase. Five weeks later, microbial biomass slightly recovers, with a small impact in the long-term. However, protozoa numbers are reduced by up to 45% due to sensitivity to ammonia[15].

When compared to urea application, anhydrous ammonia increased the microbial diversity for both bacteria and fungi in the soil.[17] The microbial diversity in the soil is seen to be critical to the maintenance of the soils health and quality, as a wide range of organisms are in important soil functions[18]. The microorganisms in the soil are involved in 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 is suppressing soil-borne plant diseases and promoting plant growth[18].

Protozoa in the soil are also important, as they are key components of the soil community and regulate population of soil micro flora and contribute to decomposition, mineralisation and nutrient cycling[5]. The initial decrease in soil microbial biomass and increase in pH also results in increased soil-dissolved organic carbon, as organic matter is made soluble [5].

Anhydrous ammonia has been shown to reduce populations of fungi, bacteria and nematodes[19]. Research indicates anhydrous ammonia can supress soil-borne pathogens. Anhydrous ammonia has been shown to rapidly kill *Phymatotrichopsis omnivorum* that causes *Phymatotrichum* root rot, also known as cotton root, one of the most destructive and difficult to control soil-borne diseases. *Fusarium roseum and Fusarium solani* populations also declined to zero within the ammonium retention zone, with no recovery until 225 days after injection[20].

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[17] Biederbeck, V., et al., *Soil microbial and biochemical properties after ten years of fertilization with urea and anhydrous ammonia.* Canadian Journal of Soil Science, 1996. **76**(1): p. 7-14.

[18] Garbeva, P. J. A., et al ., *Microbial diversity in soil: selection of microbial populations by plant and soil type and implications for disease suppressiveness.* Annu. Rev. Phytopathol, 2004. **42**: p. 243-270.

[19] Eno, C.F., W.G. Blue, and J.M. Good, *The effect of anhydrous ammonia on nematodes, fungi, bacteria, and nitrification in some Florida soils.* Soil Science Society of America Journal, 1955. **19**(1): p. 55-58.

[20] Smiley, R., R. Cook, and R. Papendick, *Anhydrous ammonia as a soil fungicide against Fusarium and fungicidal activity in the ammonia retention zone.* Phytopathology, 1970. **60**(8): p. 1227-1232.

It is evident that anhydrous ammonia influences the microbial communities in the soil. The main effect is in the retention zone, a very small portion of the soil. In the long-term, the populations within the retention zone are not affected, if not increased. Repeat application along the same injection point could have an impact on microbial communities by reducing the pH of the soil. Changes in soil pH can have a large effect on microbial communities[21]. Bacterial communities tend to significantly decrease as soil pH declines, while fungal communities tend to increase in population[22].

Earthworms

As with microorganisms, the drastic change that occurs in the retention zone of ammonia influences earthworm numbers. Initially, earthworm numbers are reduced due to these changes in the soil environment. However, once numbers recover, application of anhydrous ammonia has been shown to dramatically increase the number of earthworms.

When anhydrous is applied, approximately 15% of the earthworm population is killed. After this, 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 and the total numbers normally grow higher than they were there originally[23].

Increases in earthworm numbers are 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[24].

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21 Lauber, C.L., et al., *Pyrosequencing-based assessment of soil pH as a predictor of soil bacterial community structure at the continental scale.* Applied and environmental microbiology, 2009. **75**(15): p. 5111-5120.

22 Rousk, J., P.C. Brookes, and E. Bååth, *Contrasting soil pH effects on fungal and bacterial growth suggest functional redundancy in carbon mineralization.* Applied and Environmental Microbiology, 2009. **75**(6): p. 1589-1596.

23 Johnson, J.W. and C. Hudak, *Most asked agronomic questions.* Ohio State University Extension, 1999.

24 Deibert, E. and R. Utter, *Earthworm populations related to soil and fertilizer management practices.* Better Crops, 1994. **78**(3): p. 9-11.

Table 2. Earthworm numbers post-anhydrous application per square metre [24].

	Ammonia Application rate (kg/Ha)	
	0	55
Earthworms	98	292
Cocoons	62	98
Total	160	390

Stability of nitrogen in the soil

After the reaction of ammonia with water 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 and leaching with water runoff.

Delaying the nitrification of ammonia with nitrification inhibitors can be beneficial for cropping systems. The use of nitrapyrin, a nitrification inhibitor, reduced nitrification (increase NH_4^+) and improved N retention in the retention zone. Nitrate leaching outside of the retention zone was also decreased with the use of a nitrification inhibitor[25]. However, these are not currently commercially available in Australia.

Vegetable grower Ed Fagan (Mulyan Farms) has been using anhydrous ammonia on popcorn and more recently in babyleaf spinach. The main benefits he has noticed 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[26].

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. The use of the nitrification inhibitor nitrapyrin was found to reduce nitrate leaching by a further 18%.[27]

[25] Kidwaro, F.M. and K.D. Kephart, *Retention of nitrogen from stabilized anhydrous ammonia in the soil profile during winter wheat production in Missouri.* Communications in Soil Sc. and Plant Anal, 1998. **29**(3-4): p. 481-499.
[26] Rogers, G. (2016) The use of anhydrous ammonia on babyleaf spinach, Cowra NSW. Applied Horticultural Research www.ahr.co.au
[27] Motavalli, P.P., K.W. Goyne, and R.P. Udawatta, *Environmental Impacts of Enhanced-Efficiency Nitrogen Fertilizers.* Crop Management, 2008. **7**(1).

Crop yields

In Australia, crop yield advantages have been found in broad acre cereals and cotton. In comparison with urea, anhydrous ammonia has consistently resulted in yield increases. In cereal cropping systems in southern Australia, shallow pre-sowing of anhydrous ammonia has resulted higher yield compared to the equivalent urea application in wet conditions, suggesting anhydrous ammonia results in higher crop yields than urea when conditions suit[15].

In broad acre cereals, yields were 0.68 tonnes/Ha higher after application of anhydrous ammonia in Northern NSW, resulting in an $110/ha increase in gross margins after the cost of anhydrous ammonia was considered.[28] In cotton, yield increases of seed cotton from 3104 kg/ha to 3203kg/ha were observed using urea and anhydrous ammonia, respectively. Cotton boll number, weight and seed index were highest with anhydrous ammonia at 100kg N/ha[29].

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.

[28] Grains research and Development Corporation *Gas and liquid fertiliser drives yield gains at Tulloona.* https://grdc.com.au/Media-Centre/Over-the-Fence/2015/08/Gas-and-liquid-fertiliser-drives-yield-gains-at-Tulloona

[29] Suryavanshi, G.B. and A.V. Tendulkar, *Studies on effect of anhydrous ammonia on irrigated summer cotton KOP-498 in comparison with urea fertilizers.* Journal of Cotton Research and Development, 1993. **7**(2): p. 372-375.

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.

Risk of anhydrous ammonia

Ammonia toxicity

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[30].

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)[30]. However, careful placement of anhydrous ammonia is essential to ensure it is not phytotoxic to seed and young plants.

Not only can anhydrous ammonia reduce germination of seeds, it can also effect crop establishment by affecting root and shoot elongation. High concentration of ammonia in the soil can result in a significant reduction in both root and shoot elongation in many crops. If the rate of root extension is below the rate of drying soil, poor growth occurs[2]. Roots also become

[30] Lorenz, O.A. and D.N. Maynard, *Knott's handbook for vegetable growers*. 1988: John Wiley & Sons.

stunted, branched around the seed, thicker and have a scorched appearance at the tip. This may lead to problems with uptake of other nutrients such as phosphorous, zinc and copper[2].

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.

Cost

Anhydrous ammonia has low handling and application cost and direct application to the soil without further manufacturing cost has made it one of the most economical forms of nitrogen. The transport cost of ammonia per unit of N is relatively low. It is also more convenient to handle on-farm than solid fertilisers as it can be pumped from delivery vehicles to farm implements. Applying anhydrous ammonia at the time of sowing also saves sowing cost and time of a separate fertiliser application[15].

However, large initial cost can occur for the purchase of equipment storage and application equipment. Depending on the size, equipment can cost $20,000–$30,000. On average, it costs $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. Therefore, there can be saving in the long-term on cost per unit of nitrogen.

Health risks

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.[31]

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

[31] Amshel, C.E., et al., *Anhydrous ammonia burns case report and review of the literature.* Burns, 2000. **26**(5): p. 493-497.

anhydrous ammonia, treatments and how to properly use equipment. Farm operators should be familiar with and follow the BIG N® Farmer operational manual [32].

Environmental impacts

Energy use

The production of anhydrous ammonia requires less energy than urea because of its high N concentration, requiring the least amount of processing. There are also environmental benefits from use of anhydrous ammonia in less leaching of nitrates, which can contaminate water supplies and lead to soil acidification.

Nitrous oxide emissions

The emission of nitrous oxide is highly dependent on soil type, crop type, soil organic C content, soil pH, tillage regime, nitrogen source, placement, timing and rate [33]. 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.[34]

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.[35]

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 should include only applying when weather and soil conditions are permitting, ensuring the injection channel is fully enclosed by soil, hence, reducing emissions.

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[32] Big N Farmer Operating Manual. Available from: http://bign.com.au/~/media/BigN/071016_website_-_online_tools_-_farmer_op_manual_-_f.pdf.

[33] Stehfest, E. and L. Bouwman, *N2O and NO emission from agricultural fields and soils under natural vegetation: summarizing available measurement data and modeling of global annual emissions.* Nutrient Cycling in Agroecosystems, 2006. **74**(3): p. 207-228.

[34] Zhu-Barker, X., W.R. Horwath, and M. Burger, *Knife-injected anhydrous ammonia increases yield-scaled N2O emissions compared to broadcast or band-applied ammonium sulfate in wheat.* Agriculture, Ecosystems & Environment, 2015. **212**: p. 148-157.

[35] Omonode, R.A., P. Kovács, and T.J. Vyn, *Tillage and Nitrogen Rate Effects on Area- and Yield-Scaled Nitrous Oxide Emissions from Pre-Plant Anhydrous Ammonia.* Agronomy Journal, 2015. **107**(2): p. 605-614.

Figure 5. Anhydrous ammonia Big N being applied into rows. Photo courtesy of Incitec Pivot Fertilisers.

Conclusions

This reviews the current information on the use of anhydrous ammonia as a source of nitrogen in agricultural crops. Anhydrous ammonia is widely used in Australia for supplying nitrogen to grain and cotton crops. It is high in nitrogen (82%). The availability of anhydrous and equipment for its application is mainly focused around cotton and grain producing areas.

Anhydrous ammonia is a toxic material that must be handled with care. If it contacts the skin it can cause serious burns.

Anhydrous ammonia has beneficial effects on soil microflora, nitrifying bacteria and earthworms.

Anhydrous ammonia is converted to the ammonium form, which, being a positively charged ion, allows it to be held on the soil exchange complex (clay colloids and organic matter); this can be important because it helps to maintain nitrogen in the soil in the root zone of crops. The persistent nature of anhydrous ammonia can be further improved by the addition of nitrification inhibitors to keep the nitrogen in the ammonium form by slowing its conversion into the more water-soluble nitrate.

Anhydrous ammonia performed well as a source of nitrogen for the limited number of vegetable crops which have been assessed, and resists leaching under wet conditions. There can be issues with the limited lateral spread of nitrogen in the soil, leading to variability in babyleaf crops.

The review concludes that anhydrous ammonia does have potential as a nitrogen source for vegetable crops but is more suited to row crops rather than babyleaf crops, where an even distribution nitrogen in the soil is required, although application equipment could possibly be adapted to apply anhydrous ammonia in a way that is more suitable for babyleaf crops.

Recommendations

1. That a best practice and handling guide be produced to guide growers and agronomists on how to use anhydrous ammonia for vegetable crops (completed).

2. That further trials are required to determine the optimum usage pattern for anhydrous ammonia in a range of vegetable crops.

3. The focus of any further research on the use of anhydrous ammonia on vegetable crops be confined to row crops rather than crop such as baby spinach which require an even spread of nitrogen across the bed.

Outputs

Desktop review- The potential of anhydrous ammonia as a nitrogen fertiliser for the vegetable industry.

Fact sheet- The benefits and risk of anhydrous ammonia as a nitrogen fertiliser in vegetable cropping.

Scientific Refereed Publications

Nil.

Intellectual Property/Commercialisation

No commercial IP generated.

Acknowledgements

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Appendices

Appendix 1- Anhydrous ammonia fact sheet for the vegetable industry- Anhydrous ammonia for vegetable crops: Could it be a viable proposition?