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Liquid Ammonia Injection in Soil: A New Frontier in Nitrogen Management for Indian Agriculture

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Abstract

Nitrogen is essential for crop growth and productivity, yet improving nitrogen-use efficiency and minimizing fertilizer losses remain major challenges in modern agriculture. Another method of nitrogen delivery is the injection of liquid ammonia, which is anhydrous ammonia containing around 82% nitrogen by weight and is injected below the soil surface with specialised equipment.

Ammonia combines with moisture in the soil to generate ammonium. Ammonium can attach to soil exchange sites and is then transformed to nitrate by microbial action. When appropriately managed, subsurface placement can reduce direct ammonia losses to the atmosphere and increase nitrogen availability inside the crop root zone. Green ammonia, made using renewable energy, might help cut emissions related with fertiliser production. Recent government-supported demonstrations in India under the Khet Bachao Abhiyan have created an interest in the evaluation of this technology. However, its performance is dependent on soil conditions, application procedures, equipment and crop requirements.

Introduction

Nitrogen is one of the most important nutrients required for crop growth. It plays a vital role in chlorophyll formation, photosynthesis, protein synthesis and vegetative development. In India, urea is a major source of nitrogen fertilizer, but improving the efficiency with which crops use applied nitrogen remains an important challenge. Nitrogen losses, inappropriate fertilizer application and imbalanced nutrient management can increase cultivation costs and affect the environment. Against this background, liquid ammonia injection into soil is receiving renewed attention as an alternative method of supplying nitrogen to crops. The technology involves placing ammonia below the soil surface using specialized application equipment rather than spreading conventional fertilizer on the surface.

In October 2026, the Indian Council of Agricultural Research (ICAR) reported field demonstrations of green ammonia for mustard cultivation in Haryana as part of efforts to evaluate alternative nitrogen-management strategies.

What is liquid ammonia and why is it used as a fertilizer?

Ammonia is a chemical substance composed of nitrogen and hydrogen, denoted by the formula NH_3. Anhydrous ammonia comprises roughly 82% nitrogen by mass and can be maintained and conveyed as a liquid under pressure. This elevated nitrogen content renders it a potent, concentrated nitrogen fertiliser. Upon introduction into damp soil, ammonia interacts with soil moisture and transforms into ammonium ions (NH_4^+), which can be held by negatively charged soil particles and then accessed by plants (Jackson and Chang, 1947; Hanna *et al*., 2005). Soil microorganisms can subsequently transform ammonium into nitrate via nitrification, offering an alternative nitrogen source for crop absorption. Anhydrous ammonia should be differentiated from aqua ammonia, which consists of ammonia in a water solution, due to its varying concentrations and handling protocols. Green ammonia is synthesised utilising renewable energy sources to mitigate the greenhouse gas emissions linked to traditional ammonia production, despite both variants sharing the identical chemical formula (Ojelade *et al*., 2023; Ye and Tsang, 2023).

How does ammonia injection work?

Liquid ammonia injection uses specialized equipment to place ammonia beneath the soil surface. The equipment delivers the material through an applicator into a narrow zone below the surface, after which the soil is closed to limit ammonia escape (Figure 1). Subsurface placement is intended to limit ammonia loss to the atmosphere. However, the effectiveness of this approach depends on soil texture, moisture, injection depth, equipment design and proper closure of the injection furrow. Hanna *et al.* (2005) found that ammonia losses varied substantially with injector type and soil texture, demonstrating the importance of suitable application conditions

The process can be understood in four stages

1. Subsurface placement: Specialized equipment places ammonia below the soil surface which reduces direct exposure to the atmosphere.

2. Conversion in soil: Ammonia reacts with soil moisture and forms ammonium ions in soil.

3. Retention and transformation: Some ammonium is retained on soil exchange sites, while soil microorganisms gradually convert it into other nitrogen forms.

4. Crop uptake: Plant roots absorb available nitrogen and use it for growth, chlorophyll formation and biomass production.

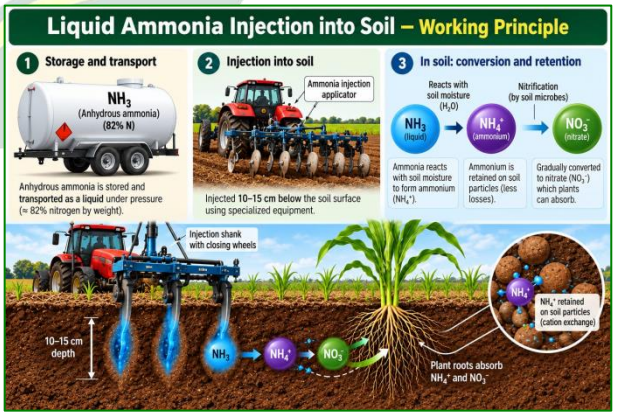


Fig. 1. Conceptual illustration of the working principle of liquid ammonia injection

The required placement depth and application conditions depend on the soil, moisture status, equipment and product formulation. This

technology must be operated by trained personnel using equipment designed for ammonia service; it is not suitable for improvised or manual application.

Potential benefits for agriculture

1. Concentrated nitrogen supply

With approximately 82% nitrogen by weight, anhydrous ammonia contains more nitrogen per unit mass than many commonly used solid fertilizers. This may reduce the mass of fertilizer material that needs to be transported for an equivalent nitrogen dose, although specialized storage, transport and application costs must also be considered.

2. Subsurface placement and nitrogen retention

Placing ammonia below the soil surface can reduce its direct exposure to the atmosphere. Research has shown that ammonia retention is affected by application depth, soil texture, moisture and other soil conditions (Jackson and Chang, 1947). Proper injection and sealing are therefore essential; subsurface application does not guarantee that all applied nitrogen will be retained.

3. Potential improvement in nitrogen-use efficiency

Positioning nitrogen within the soil may improve its availability to crop roots when application is properly timed and managed. But improved nitrogen-use efficiency cannot be anticipated from the application strategy alone. This must be proven by comparisons of crop output, plant nitrogen uptake and nitrogen losses at equal rates of nitrogen.

4. Potential role of green ammonia

Green ammonia may reduce greenhouse-gas emissions associated with fertilizer production when renewable energy is used effectively. Its overall environmental performance depends on the energy source, production process, transport and storage. Field performance and life-cycle emissions should both be evaluated before claiming a sustainability advantage.

Government initiatives: Green ammonia demonstrations under Khet Bachao Abhiyan

The evaluation of green ammonia through field demonstrations. Krishi Vigyan Kendra (KVK), Mahendergarh of Chaudhary Charan Singh Haryana Agricultural University, Hisar is demonstrating about 300 acres of mustard in Khatodhara village of Mahendergarh district, Haryana (ICAR, 2026a). The trials will assess the use of green ammonia as an alternate nitrogen supply to conventional urea-based management. Scientists are examining crop establishment, growth, productivity, nitrogen use efficiency and economic viability. Officials of ICAR have underlined the importance of collection of systematic data on yields, fertiliser consumption, cultivation expenses and returns before reaching judgements regarding the usefulness of the technology for farmers.

At the national level, a plan announced for the Rabi 2026 season envisaged green-ammonia demonstrations across approximately 10,000 acres in 37 districts of six states. These initiatives are intended to generate evidence under different agricultural conditions and help determine whether the technology can provide a practical nitrogen-management option. The

nationwide Khet Bachao Abhiyan-Rabi 2026 was launched from Taraori in Karnal district, Haryana, on 22 October 2026, with activities scheduled through 30 November 2026 as shown in figure 2. The campaign promotes soil-health awareness, balanced fertilizer use based on soil testing, crop diversification and sustainable farming practices (ICAR, 2026b). Green ammonia is among the technologies being considered within the broader focus on efficient and responsible nutrient management. These government-supported demonstrations are an important step in evaluating the technology. However, the reported acreage describes the scale of the trials, not proof that green ammonia has already outperformed conventional fertilizers.



Fig. 2. Field demonstration of ammonia injection at Taraori, Karnal

Challenges and safety considerations

Despite its potential, ammonia injection presents important technical and safety challenges.

- **High handling risk:** Anhydrous ammonia is a hazardous, pressurized chemical. Contact can cause severe burns to the skin and eyes, while inhalation can seriously damage the respiratory system. Storage tanks, transfer systems, applicators and protective equipment must meet appropriate safety requirements.

- **Requirement for specialized machinery:** The injection of ammonia demands specialised equipment capable of safely handling the chemical and accurately positioning it below the soil surface. This may result in increased cost, maintenance, training and service requirements.

- **Dependence on field conditions:** Soil moisture, texture, temperature, and the sealing of the injection furrow affect ammonia retention and nitrogen accessibility. Inadequate positioning may result in nitrogen depletion or harm to crops.

- **Need for economic evaluation:** Lower fertiliser costs are not assured by high nitrogen content alone. Nitrogen supply, application and machinery expenses, transportation, storage, crop production, and net returns must all be taken into consideration in a fair comparison.

- **Environmental performance:** Although subsurface placement can reduce certain losses, ammonia use does not automatically prevent nitrate leaching, nitrous oxide emissions or other nitrogen-related environmental impacts. These outcomes must be measured under local conditions.

What evidence is needed before wider adoption?

Field trials should compare ammonia injection with conventional nitrogen sources at equivalent

nitrogen rates. Researchers should record crop growth, grain or fodder yield, nitrogen uptake, nitrogen-use efficiency, nitrogen losses, fertilizer and machinery costs and net returns. Multi-location and multi-season evaluations will be particularly important because soil and climate conditions can strongly influence performance. For green ammonia, an additional assessment of production-related greenhouse-gas emissions and the energy used in manufacturing and transport would help establish its environmental advantage over conventional ammonia.

Conclusion

Liquid ammonia injection offers a concentrated method of supplying nitrogen directly below the soil surface. Its integration with green ammonia production may provide opportunities to reduce emissions associated with fertilizer manufacturing. However, its potential benefits must be validated through systematic field evaluation of nitrogen-use efficiency, crop productivity and nitrogen losses. Safety, machinery availability, application costs and economic returns to farmers also require careful assessment. Therefore, liquid ammonia injection should be considered an emerging nitrogen-management option rather than an established replacement for conventional urea fertilization.

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