Comparative Assessment of Shallow Injection and In Field Acidification of Slurry - SyreN System

Summary:

This report provides a comprehensive comparison of shallow injections and in-field acidification for slurry management, focusing on both agronomic performance and wider environmental and operational factors. While both methods effectively reduce ammonia emissions, acidification offers several advantages:

- Greater working width and application speed
- Less soil disturbance and lower risk of sward damage
- Lower energy and fuel consumption
- Additional nutrient value through Sulfur, Phosphorus and Manganese availability
- Enhanced compatibility with precision farming tools and ESG reporting
- Potential integration of inhibitors for improved nitrogen retention
- Documented safety and regulatory approval for acid handling systems like SyreN and AutoZap

Particularly in regions like the Netherlands, where low soil pH dominates over 50% of farmland, acidification demonstrates elevated efficiency and can potentially reduce nitrogen deposition in Natura 2000 areas by over 30%compared to injection. Given the system's flexibility, lower cost, and sustainability benefits, acidification presents a robust, scalable, and climate-smart alternative to traditional injection.

Acidification and shallow injection both offer valid benefits for reducing nutrient losses and improving fertilizer value. However, from a practical and environmental management standpoint, acidification offers greater flexibility, wider applicability, and additional co-benefits (e.g. Yield increase and better NUE, GHG reduction, reduced compaction, odor control, additive injection, extensive ESG documentation).

Recommendation: In systems where working width (compaction – capacity), flexibility, or grassland preservation are important, acidification should be prioritized. Where P retention and runoff protection are top priorities, injection remains relevant.

Further field trials on acidic soil effect on deposition to Natura 2000 areas are recommended. SyreN System can document the ammonia depositions to Natura 2000 areas, and it can replace modeling systems and deliver a valuable tool for compliance with regulatory requirements and reduce costly farm buy-out schemes. Because of low pH soils on approximately 50% of the agricultural area in the Netherlands - 80 % of Natura 2000 buffer zones - the effectiveness of acidification is expected to be significantly enhanced under these conditions. So far, indicated in one study with a significant effect R=53 %. If this effect is confirmed, a 30 % increased reduction of ammonia emission in Natura 2000 area can be expected with a potential cost reductio of 7 billion € in buy-out Schemes.

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1.Introduction

This report is prepared for policymakers, administrative authorities, and researchers in the Netherlands as part of the revision of the RAV technology list. Its aim is to present a structured, evidence-based comparison of slurry injection and in-field acidification as competing methods for reducing ammonia emissions, improving nitrogen use efficiency, and ensuring sustainable nutrient management.

The report presents a structured comparison of two widely used ammonia mitigation strategies: shallow injection and in-field acidification of slurry. While both are effective in reducing NH_3 emissions, this analysis focuses on non-emission-related factors to support policy, farm-level decision-making, and environmental trade-offs.

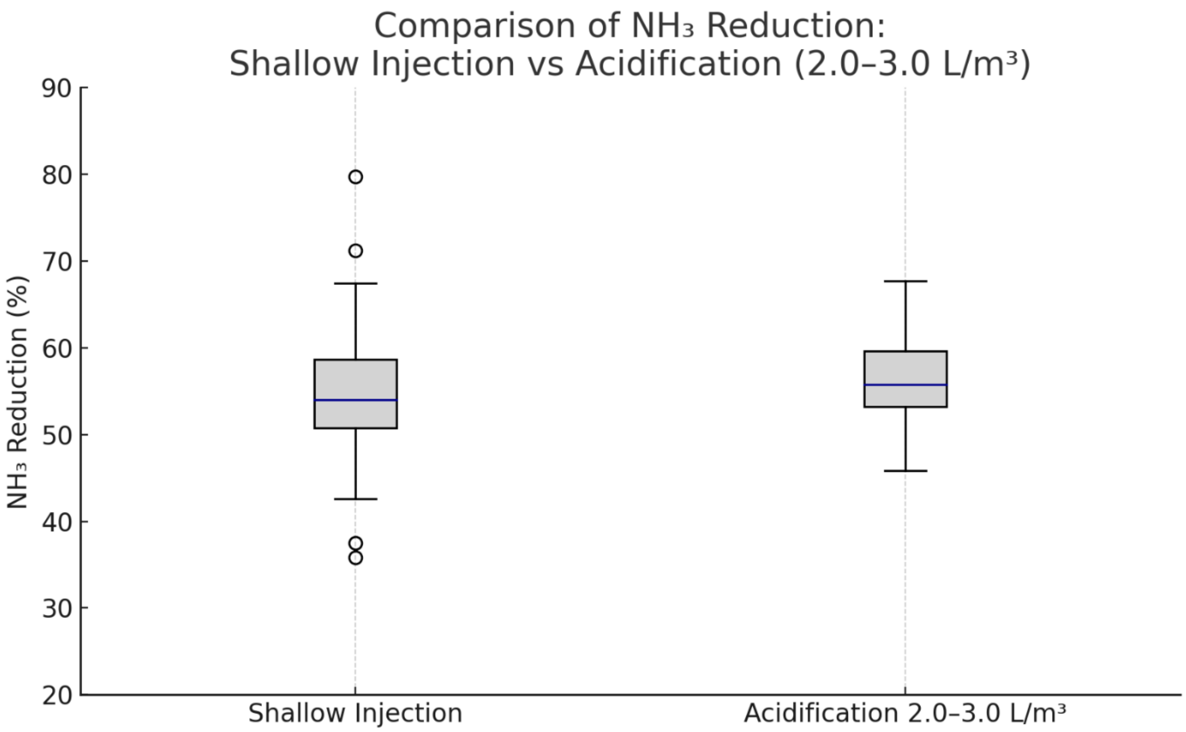

Figure 1: Boxplot comparison showing NH_3 emission reductions for shallow injection and acidification at 2.0–3.0 L/m³. While median reductions are similar, acidification exhibits tighter consistency with less variability, supporting reliable performance under field conditions.

An analysis of 27 research studies with over 60 trails comparing **in-field acidification with injection** provides a strong foundation for understanding the real-world differences between these systems. This data set forms the basis for several conclusions throughout this report and is visualized in the comparative figure above, highlighting emission reduction consistency and operational variability.

While both methods have been recognized as mitigation technologies, the analysis clarifies that **acidification cannot be integrated with injection systems**. The reason is that acidifying slurry significantly increases slurry volume during application, which causes the narrow slots created by disc injectors to **overflow**. This not only nullifies the purpose of injection application but also introduces operational risks and negates the emission-reduction benefit intended by injection. Furthermore, injections under these circumstances can result in undesirable slurry exposure to plant tissue and contaminate silage and fodder crops. If not needed, the injection slots are negative with severe soil disturbance and significantly increased subsidence and CO_2 release.

2. Overview of Techniques

Shallow Injection:

Incorporates slurry below the soil surface using narrow slots (~30 cm spacing) and 8 to 12 m with.

Acidification:

Applies sulfuric acid (typically 2.0–3.0 L/m³) directly into the slurry during spreading, lowering its pH to 6.3 – 6.0 and using 12 to 36 m with.

3. Agronomic and Practical Factors

Crop compatibility limitations for injection:

Shallow injection is often **unsuitable for use in growing crops** beyond grasslands due to the mechanical disturbance and physical damage caused by the disc coulters. This is particularly problematic for cereals, maize, and legumes, where injections can harm root zones and above-ground biomass. Acidification, applied via trailing hose / shoe systems, avoids such damage and can be safely used across a wide range of crop types without compromising plant health or yield.

Yield effects:

Comparative trials show that acidification often results in equal or higher crop yields than shallow injections, particularly on grassland. Average yield increases range from **+400 to +1100**

kg DM/ha for acidification, while injection can cause sward damage that offsets nitrogen efficiency gains. On cereals, the yield effect is more variable, but generally neutral to slightly positive for acidification. Injection is seldom used for other growing crops and lack comparative trails.

4. Soil and Nutrient Considerations

Micronutrient availability:

Acidification may enhance the availability of certain micronutrients, particularly **manganese (Mn)**. In sandy soils with naturally low Mn availability, the drop in pH caused by acidification can increase Mn solubility, leading to improved uptake by crops. This can support better growth, especially in sensitive crops like cereals and maize.

Fertilization cost savings:

The sulfate added through acidification not only helps reduce ammonia emissions but also contributes to plant-available sulfur nutrition. This can partially or fully replace the need for separate sulfur fertilization (e.g., ammonium sulfate), leading to **cost savings on commercial fertilizer inputs**, especially in sulfur-deficient regions.

Sulfur contribution: Acidification adds sulfate (SO_4-S), which benefits sulfur-deficient soils but must be managed under 40–50 kg/ha regulatory caps.

Phosphorus mobility:

Injection may reduce P losses via runoff, while acidification increases soluble P in slurry, especially below pH 6.0. However, this increased P solubility is an advantageous in **land-based nutrient management systems**, where **P availability for crop uptake is critical** and where runoff risks are minimal. In such systems, acidification supports more efficient P use and may reduce the need for mineral P fertilizers.

Heavy metals:

Acidification may mobilize Zn and Ni slightly, particularly on sandy soils.

Soil pH buffering:

Injection does not affect soil pH; acidification can reduce pH locally but is buffered over time.

5. Infrastructure and Cost Considerations

Ongoing German MuD project (Sauer+ 2022–2027):

As part of a 5-year national innovation initiative, the Sauer+ project under the German "MuD" (Model and Demonstration Projects - https://saeureplus.de/) program is currently evaluating in-field acidification across **8 federal states (Bundesländer)** using **8 SyreN systems**. This comprehensive trial series is designed to document the **sustainability, profitability**, and **operational performance** of acidification technologies such as SyreN. The project supports broader knowledge transfer, contributes to policy dialogue, and provides scientific validation to further mainstream acidification as a reliable alternative to injection across the EU. It is now in its 3th year of operation.

Recognition and EU integration:

The SyreN system has EU-BAT, VERA verification and ETV Cerification. It has received **15 international Awards for sustainability, CSR** and innovation in agriculture. It is currently recognized as one of the **12 most advanced and accepted RENURE systems in the European Union**, further supporting its qualification under nutrient recycling and emission reduction frameworks.

Odour control additives – iron sulfate:

In addition to sulfuric acid, the SyreN system supports the use of **iron sulfate ($FeSO_4$)** as an additive to enhance odor control during slurry application. Iron sulfate helps bind hydrogen sulfide and other odorous compounds, making it a useful complement in situations with high odor sensitivity or community proximity. The system's additive tank makes it possible to inject such supplements directly into the slurry stream.

Nitrogen inhibitor integration:

The SyreN system includes an **additive tank** that allows for the optional injection of **urease and nitrification inhibitors** during slurry application. This enables further stabilization of nitrogen in the soil and extends the agronomic benefit of slurry beyond pH control. When used in combination with acidification, these additives support even greater nitrogen retention, reduce greenhouse gas emissions, and enhance compliance with integrated nutrient management strategies. This include optional injection of **urease and nitrification inhibitors** during slurry application. Commonly used products include **Vizura®, N-Lock™, and Piadin®**, all of which have demonstrated effectiveness in stabilizing nitrogen and reducing emissions. This enables further stabilization of nitrogen in the soil and extends the agronomic benefit of slurry beyond pH control. When used in combination with acidification, these additives support even greater nitrogen retention, reduce greenhouse gas emissions, and enhance compliance with integrated nutrient management strategies.

Ammonia emission documentation importance in the Netherlands:

In especially the Dutch context, documentation of ammonia emissions is valuable due to the **difficulty of accurately measuring mobile volatilization from field applications**. Technologies like e-missioN, which offer real-time data tracking and transparent reporting on ammonia emission and use of nitrogen, are critical tools for enabling regulatory compliance and stakeholder trust. Such tools help overcome the limitations of conventional model-based measurement systems in one of Europe's most regulated and nitrogen-sensitive farming landscapes.

ESG compliance and documentation:

For Integrated Environmental and Agricultural (IEA) farms and others seeking to meet **Environmental, Social, and Governance (ESG)** standards, detailed documentation of nutrient use, emissions, and application accuracy is essential. Precision systems such as e-missioN not only fulfill regulatory requirements but also support ESG reporting and farm sustainability certification efforts.

Demonstration and education resources – Hof Vogelsang videos:

Practical demonstrations of acidification systems such as SyreN, AutoZap, and the e-missioN platform are available via a series of videos recorded at Hof Vogelsang. These include:

Establishment of field trails with SyreN System

https://youtube.com/watch?v=HWnwlPcw5DU&si=FOK8nY0DNNlNmr9V

Control of slurry spreading

https://www.youtube.com/shorts/SsKe3slRb64

e-missioN

https://www.youtube.com/shorts/LoYNR_MtXiE

Acidification – SyreN System

https://www.youtube.com/shorts/D5EVipz8HXI

Swefelsauer als stikstofhämmer:

https://youtube.com/shorts/QS7sez3gJg0?si=SxD1YL6cc6meKmMY

Acidification, NIRS and e-missioN

https://www.youtube.com/shorts/ZxYUVjYPFfM

Results from acidification 2024

https://www.youtube.com/watch?app=desktop&v=1NO3o1lvz3U

Precision farming and documentation – e-missioN System:

The e-missioN system integrates real-time monitoring of ammonium nitrogen efficiency (NPA) during slurry application. It utilizes data from over +600 ammonia emission trials with 30.000 measurements and combines NIR slurry characteristics, GPS tracking, weather data, and pH measurements to deliver high-resolution maps of nitrogen efficiency, ammonia emission and application accuracy. The system enables dynamic adjustment of mineral fertilizer rates post-application through VRA (Variable Rate Application) maps and generates full documentation for regulatory compliance and sustainable nutrient management. When paired with acidification, the system allows for optimal timing and quantification of acid benefit. This makes e-missioN a powerful tool for reducing overlap, improving yield, reducing GHG and enabling smart fertilizer planning in line with climate goals.

AutoZap filling system:

The AutoZap system is a specialized, vacuum-controlled safety valve for handling concentrated sulfuric acid during IBC tank filling. It includes an automatic shut-off trigger, a particle filter, and pressure-limiting components to ensure safe operation between 1–2 bar. AutoZap is designed to reduce human exposure risk, increase operator efficiency, and minimize acid spillage during transfer. It always refill to same level, from different residual volumes, facilitating knowing when the driver should expect a need for change of IBC tank. The system can be mounted on trucks and has proven compatible with acidification operations in field conditions.

Regulatory compliance and transport flexibility:

The SyreN system is approved for **ADR-compliant sulfuric acid transport in Germany**, meeting European safety regulations. In other countries such as Holland, Sweden, Finland, Polen, Baltic states and Denmark, exemptions exist for agricultural use of acid under certain conditions, allowing **safe and simplified use without full ADR regulation**. This enhances logistical flexibility for acidification deployment at farm level.

Logistical simplicity:

One key advantage of shallow injection is that it avoids the **need to handle, transport, and store sulfuric acid**. This reduces logistical complexity, especially for farms without dedicated infrastructure or training for safe acid management. It also eliminates the need for acid delivery coordination and safety oversight.

Material durability and safety:

Modern acidification systems are constructed using **non-corrosive materials** for all parts in contact with sulfuric acid. This includes acid-resistant plastics (Teflon), 316 stainless steel components, and chemically treated hoses. These materials have proven durable over more than **15 years of operational use** in commercial settings. Importantly, there have been **no reported safety incidents** in Denmark or other countries with regulated acidification systems, highlighting their long-term reliability and safety under field conditions.

To further improve operator and road safety, the SyreN system can be equipped with **camera-based safety systems** that assist with **traffic visibility** and **secure pick-up and docking of IBC acid tanks**, minimizing risk during refilling and transport operations.

Investment costs:

Acidification systems typically require an investment of **around €80,000**, depending on configuration and working width (e.g., boom-mounted SyreN systems). In contrast, a shallow injection setup for a 12-meter working width generally costs **€100,000 or more**, due to the need for heavier construction and soil-engaging components. This difference can influence farm-level adoption decisions, especially for smaller or mixed-crop farms. Acidification systems typically require an investment of **around €80,000**, depending on configuration and working width (e.g., boom-mounted SyreN systems). The **SyreN Light version** has been developed for field trial plots, research settings, or use with smaller tractors and slurry tankers. This lightweight configuration offers lower entry cost with prices starting from **€60,000**, depending on specific equipment needs.

Weight and soil compaction:

Shallow injection equipment is significantly heavier than acidification systems, due to reinforced frames and components required to penetrate soil. This added weight can increase **soil compaction risks**, particularly under moist field conditions. In contrast, acidification systems mounted on booms or trailing hose systems are lighter and distribute weight more evenly, reducing impact on soil structure and enabling operation during a wider range of field conditions.

Maintenance:

Higher for injection systems due to moving parts and soil contact.

Flexibility:

Acidification compatible with both arable and grassland systems using the same spreader.

6. Environmental Trade-Offs (Beyond NH_3)

Foaming effect of acidified slurry:

Acidification of slurry often results in natural **foaming during application**, which forms a temporary barrier on the slurry surface. This foam reduces the slurry's direct exposure to wind and turbulence, thereby **limiting ammonia volatilization** even further. The foaming acts as a passive cover, enhancing the effectiveness of acidification and making the application less sensitive to weather conditions compared to open-surface slurry spreading. The foaming effect is caused by the **chemical release of bicarbonate (HCO_3^-)** from the slurry when it is acidified. This reaction is inevitable and not manually controlled. It does not contribute to extra GHG, as the release is enevitable. The formation of foam as a by-product of this reaction contributes positively to emission reduction and is a unique advantage of acidification systems.

N_2O emissions and denitrification risk:

Shallow injection can promote **anaerobic microsites** in the soil due to its incorporation of slurry below the surface, especially in wet conditions. This can stimulate **denitrification processes** and lead to the formation of **nitrous oxide (N_2O)**, a potent greenhouse gas. In contrast, acidification leaves more dry matter on the soil surface and does not create anaerobic conditions to the same extent. As a result, **acidification carries a lower risk of N_2O emissions**, supporting more sustainable nitrogen use and reducing overall GHG impact.

Fuel and energy use:

Shallow injection requires significantly more **diesel fuel and tractor power**, due to the resistance of dragging injectors through soil and narrower working widths. Acidification systems operate with **lower engine load** and cover more hectares per hour. This results in reduced **CO_2 emissions** per hectare and lower fuel costs. Studies indicate that acidification can reduce diesel use by **20–30%** compared to injection under typical field conditions.

Policy limitations and technical bias:

In the Netherlands, shallow injection is mandatory, and alternative technologies like in-field acidification face legal and political barriers. Despite demonstrated effectiveness, acidification has not been approved due to outdated trials and biased administrative advice, particularly from Wageningen University.

CO_2 emissions and subsidence on polder soils:

Injection practices increase soil aeration and oxidation, significantly accelerating soil subsidence in Dutch polder areas. Estimates show up to **3.6 million tons of CO_2 emissions per year** could be avoided by switching from injection to acidification. In contrast, acidification minimally disturbs the soil and supports climate goals. Injection practices increase soil aeration and oxidation, significantly accelerating soil subsidence in Dutch polder areas. This process not only leads to land loss and increased flood risk but also contributes indirectly to sulfate leaching. As organic matter oxidizes, the mineralization of bound sulfur compounds can add to total SO_4 levels in the soil, particularly under moist conditions.

Sulfate application and soil sustainability:

Concerns over sulfate use with acidification are often overstated. Acidification applies sulfate only when crops can uptake it, unlike the year-round sulfate release caused by soil disturbance from injection. Acidification therefore poses **lower long-term risk of leaching and aquifer contamination**, especially when applied in buffer zones with acidic soils.

Cost-efficiency and scalability:

The switch to acidification with boom systems could reduce Dutch agricultural mitigation costs by **up to €7 billion**, based on investment and emission reduction to Natura 2000 areas, where low pH soil enhance the acidification effect. The cost saving is based on reduced need for farm-buyout schemes. Acidification systems are scalable and deliver faster deployment with less infrastructure than sod injectors. The switch to acidification with boom systems could reduce Dutch agricultural mitigation costs by **up to €7 billion**, based on investment and emission reduction modeling. Additionally, due to the ability to use **wider working widths and faster speeds**, acidification enables **up to 25% more field capacity** per hour compared to injection. This improved capacity translates into lower machinery hours, reduced labor costs, and more efficient seasonal planning.

Methane emissions:

Acidification reduces CH_4 formation from slurry.

Greenhouse gases (overall):

Life-cycle assessments suggest slightly better net effect for acidification.

Water protection:

Injection may offer better P retention; acidification must be cautious on light soils.

Carbon footprint:

Lower energy input per hectare for acidification.

We urge the committee to consider **in-field acidification as an independent, scalable, and climate-aligned solution**, not as a subcategory of injection, and to include it as a distinct entry on the updated RAV list.

We remain at your disposal for clarification, discussion, or on-site demonstration.

Sincerely,

Morten Toft, CEO BioCover A/S, 22.04.2025