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The Role of Urease Inhibitors in Improving Nitrogen Use Efficiency and Promoting Carbon Sequestration in Agricultural Soils

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Abstract

This review examines how urease inhibitors delay urea hydrolysis, reduce ammonia volatilization and improve nitrogen use efficiency (NUE). Better nitrogen retention can support crop growth and increase carbon inputs from residues and roots. However, the contribution to sustained soil organic carbon (SOC) sequestration remains uncertain. Inhibitor performance depends on soil, climate and fertilizer management. Integrated, long-term studies are needed to assess nitrogen conservation, carbon storage, microbial processes and farm-level trade-offs.

Introduction

Urea contains 46% nitrogen and is widely used in agriculture. Rapid urease-catalysed hydrolysis can cause ammonia losses and reduce fertilizer efficiency. Urease inhibitors, especially NBPT, temporarily slow this process. Improved nitrogen retention may increase biomass and root-derived carbon inputs, linking nitrogen management with soil fertility and potential carbon storage.

Contradictions, limitations and research gaps

Reported reductions in nitrogen losses and N_2O emissions vary with soil properties, climate and dominant loss pathways. Benefits can be limited where ammonia volatilization is naturally low.

Direct, long-term field evidence for sustained SOC stock increases remains limited. Higher biomass inputs do not by themselves prove carbon sequestration.

Research priorities include microbial diversity and carbon stabilization, interactions with manure, compost and biochar, future climates, conservation systems, and economic and environmental trade-offs.Such multidisciplinary studies are essential for fully understanding the contribution of urease inhibitors to sustainable and climate-smart agricultural systems .

Table 1. Main urease inhibitors

Characteristics and effects on nitrogen transformations

Inhibitor	Category	Mechanism of action	Effects on nitrogen
NBPT(N-(n-butyl)thiophosphoric)	Urease inhibitor	Converted to active NBPTO, which inhibits the nickel-containing urease active site.	Delays hydrolysis by about 7–15 days, depending on soil conditions. Reduces NH_3 loss and improves N retention.
NPPT(N-(n-propyl)thiophosphoric triamide)	Urease inhibitor	Suppresses urease activity. Often combined with NBPT.	Slows conversion of urea to ammoniacal N, limiting NH_3 losses and improving N availability.
2-NPT(N-(2-nitrophenyl)phosphoric triamide)	Urease inhibitor	Phosphoric triamide derivative with urease-inhibiting activity.	Temporarily delays hydrolysis and may reduce NH_3 volatilization.
Natural inhibitors(polyphenols,flavonoids,humic substances and plant extracts)	Natural urease inhibitors	Polyphenols, flavonoids, humic substances and plant extracts. Often less effective than NBPT.	May delay hydrolysis and reduce NH_3 loss. Effectiveness varies.

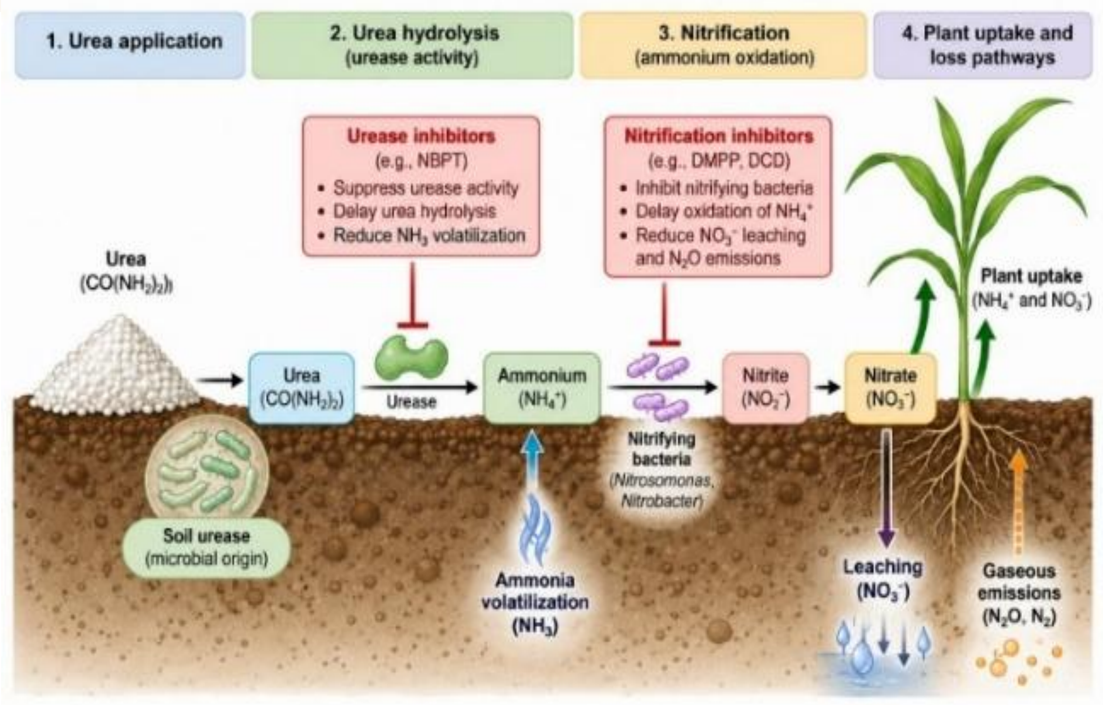


Figure 1. Effect of urease and nitrification inhibitors on urea breakdown in soil

Table 2. Factors affecting effectiveness

Factor	Conditions	Performance	Agronomic implication
Soil pH	Acidic to alkaline	Benefits often greater in neutral–alkaline soils with higher NH_3 risk.	Greater N retention where volatilization risk is high.
Soil texture	Sand, loam, clay	Water retention, aeration and N movement influence responses.	Adapt treatment to soil-specific N losses.
Organic matter	Concentration and microbial activity	Can increase urease activity and accelerate inhibitor degradation.	Variable persistence and effectiveness.
Temperature	Low to elevated	Warm conditions speed hydrolysis and NBPT degradation.	Adjust fertilizer timing in warm weather.
Moisture	Dry to excessively wet	Moderate moisture generally favors performance. Extremes can limit it.	Favorable moisture supports N conservation.
Rainfall / irrigation	Water amount and timing	Water after application moves urea into soil and limits NH_3 exposure.	Potentially greater N recovery.
Application method	Surface or incorporated	Surface urea generally benefits most. Incorporation lowers relative benefit.	Target high-risk surface applications.
Application timing	Relative to rainfall or irrigation	Treated urea before suitable water supply may improve N retention.	Align N availability with crop demand.
Crop residues	No-till and residue cover	Surface residues can increase urease activity and volatilization risk.	Potentially greater benefits in residue-rich systems.
Crop species	Roots, growth stage and N demand	Crop traits influence uptake and response to treated fertilizer.	Potential gains in uptake, yield and NUE.

Conclusions

Urease inhibitors can improve NUE by delaying hydrolysis and reducing NH_3 loss. Increased biomass may support SOC inputs, but sustained carbon storage requires long-term validation. Use should be tailored to local conditions and integrated with crop and soil management.