

Review

Optimizing Nitrogen Fertilization in Potato (*Solanum tuberosum* L.) Cultivation: A Review Regarding Inhibitor Use, Multifaceted Assessment Indicators, and Pathways to Sustainable Intensification

Myrto Chatzitriantafyllou , Panteleimon Stavropoulos , Stavroula Kallergi , Antonios Mavroeidis, Ioannis Roussis , Stella Karydogianni, Dimitrios Bilalis *  and Ioanna Kakabouki * 

Laboratory of Agronomy, Department of Crop Science, Agricultural University of Athens, 11855 Athens, Greece; stud120006@aua.gr (M.C.); stavropoulosp@aua.gr (P.S.); stud119079@aua.gr (S.K.); antoniosmauroeidis@gmail.com (A.M.); roussis@aua.gr (I.R.); karydogianni@aua.gr (S.K.)

* Correspondence: bilalis@aua.gr (D.B.); i.kakabouki@aua.gr (I.K.)

Abstract

Potato (*Solanum tuberosum* L.), the world's fourth most significant food crop, faces a critical sustainability challenge: meeting escalating global demand while mitigating the substantial environmental footprint of its production. Potato exhibits high nitrogen requirements, which makes conventional fertilization significantly inefficient, with nitrogen use efficiency (NUE) being below 40%, contributing to severe environmental losses, including nitrate leaching and nitrous oxide emissions. In this comprehensive review, global research is examined regarding enhanced-efficiency nitrogen fertilizers, such as nitrification inhibitors (NIs), urease inhibitors (UIs), and slow-released fertilizers, which promote a pivotal strategy for sustainable potato cultivation. An extensive analysis is provided exploring the biochemical mechanisms of these inhibitors, their complex interactions with potato physiology, and also their impact on tuber yield, quality, and environmental footprint. These insights are combined with sustainable strategies to optimize nitrogen fertilization in potato cropping systems. Lastly, essential knowledge gaps, such as ongoing soil-health impacts and climate-change interactions, are underlined, and future directions of research are proposed to advance inhibitor utilization on potato production.

Keywords: potato (*Solanum tuberosum* L.); nitrogen; nitrogen use efficiency; inhibitors; indicators; sustainable cultivation



Academic Editors: José A. González-Pérez and Alessio Adamiano

Received: 5 February 2026

Revised: 4 March 2026

Accepted: 5 March 2026

Published: 7 March 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

1. Introduction

1.1. The Evolution of Potato Cultivation and Its Global Importance

Potato (*Solanum tuberosum* L.) appears to be the fourth most significant food crop globally, following rice, maize, and wheat [1]. This annual plant, which belongs to the Solanaceae family, traces its roots back to the Southern American Andes. Its cultivation is estimated to have begun around 8000 to 10,000 years ago in Southern Peru [2,3]. In Europe, the potato appeared in Spain after the Columbian exchange, with the earliest records of its cultivation dating to sixteenth century [4]. According to Swamy [5], potatoes are broadly both cultivated and consumed around the world with more than 5000 known potato varieties. The major potato-producing countries are China, India, Russia, Ukraine, and the United States [6]. Among these countries, the United States is exceptional in its high productivity, with its commercial yield per hectare ranging from 45 to 50 tons between 2014 and 2024, while the yield per hectare in the other major countries was substantially less,

ranging from 15 to 25 tons per hectare [1] (Figure 1). In 2023, potato production worldwide reached 387 million tons, highlighting the crop's crucial role during a period with a severe food-security crisis and a continuously growing population [7].

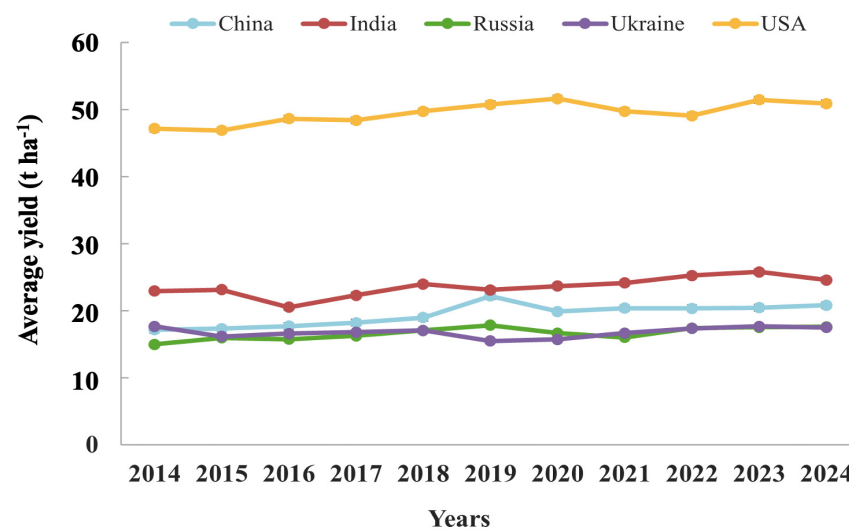


Figure 1. Average potato yield trends in the top five potato-producing countries (2014–2024) [1].

In addition to its production, the potato exhibits high nutritional value, substantial yield dynamics, and broad adaptivity to a wide range of environments. These qualities make potatoes a key crop for humanity [8]. Beyond being a considerable source of carbohydrates, potatoes contain dietary fiber, a plethora of vitamins (C, B1, B2, B6, and B9), essential minerals (potassium, magnesium, and iron), as well as carotenoids, and phenolic acids [9–13].

It requires a lot of nitrogen (N) input to achieve high tuber yield as well as quality in potato production [14]. Approximately 1% to 4% of plant dry matter consists of nitrogen, and it is responsible for plant growth [15]. Nitrogen, a valued nutrient for potatoes, presents a distinct effect on vegetative growth, chlorophyll synthesis, and photosynthetic efficiency. It also ensures proper tuber formation and crop yield [16,17]. Across diverse locations, soil types, and varieties, total N uptake of potatoes extends from 168 to 448 kg N/ha, with 60% of this amount stored in the tubers [18]. Furthermore, potatoes exhibit low nitrogen use efficiency (NUE), which typically ranges between 40% and 60%; as a result, producers often overapply fertilizer to secure the crop's yield [19]. Excessive application of insufficient nitrogen fertilization in potato production is prone to environmental losses [8,20].

1.2. Global Dependence on Nitrogen Fertilizers and Environmental Consequences

Rising food demand driven by a rapidly increasing global population will place agricultural systems under significant pressure [21]. As a consequence, dependence on synthetic fertilizers has been expanding. According to Song et al. [22], fertilizer utilization has been increasing at an annual rate of 1.3% between 2019 and 2023, highlighting agriculture's need for nutrients to support both crop productivity and food security. The global market is dominated by nitrogen fertilizers, especially urea-based fertilizers, serving as a key element for promoting plant development and supplying important nutrients [23]. Even though they enhance crop yield, their effectiveness remains quite low, with only 30–50% of applied N being assimilated by plants during the growing season [24]. Ghosh et al. [25] reported that potato production requires a substantial amount of N input in order to reach an adequate yield, which usually is exceeded by excessive fertilization.

The heavy application of N fertilizers has an adverse impact on the environment and soil. Large proportions of nitrogen inputs are lost through ammonia (NH₃) volatilization,

and lead to nitrate (NO_3^-) leaching, gaseous emissions, air pollution, soil degradation and water eutrophication (Figure 2) [26–28]. Furthermore, excessive N application exhibits as a significant economic cost to farmers in potato production [29].

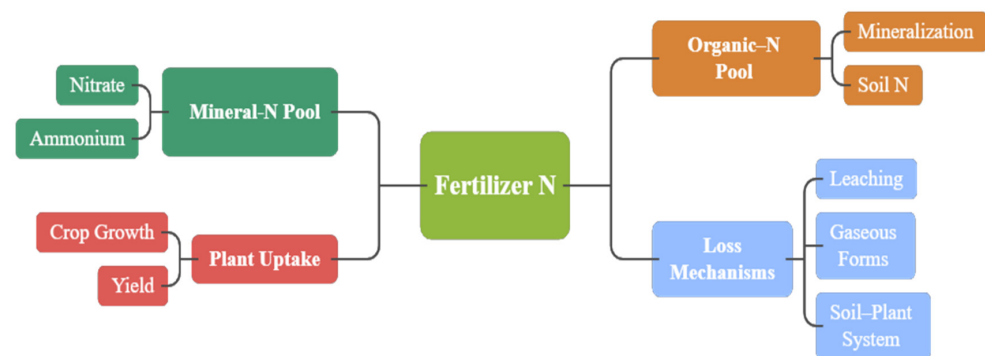


Figure 2. Illustration presenting the fate of the applied nitrogen fertilizer in the soil.

1.3. Need for Efficient Nitrogen Strategies in Potato Cropping Systems

To address the above challenges, sustainable nitrogen management has arisen as a key strategy in order to ensure food security and minimize environmental pollution [30]. The aim of sustainable N management is to improve N inputs to meet the specific crop needs while enhancing productivity and ecological resilience [31]. All these objectives align with the goals of the European Green Deal, which focuses on substantially reducing the use of fertilizers by 20% and nutrient losses by 2030 [32–34]. According to the regulations, achieving sustainable intensification in potato production requires complete nitrogen management approaches that focus on nitrogen use efficiency and overall system enhancement [35,36]. One promising approach could be the adoption of enhanced-efficiency fertilizers, including nitrification (NI) and urease (UI) inhibitors, slow-release fertilizers (SRFs), and also their combination. They are characterized by both minimizing N losses to the environment and allowing crops to utilize nitrogen effectively [37].

1.4. Objectives and Scope of the Review

The primary objective of this review is to comprehensively synthesize scientific knowledge regarding enhanced nitrogen fertilization strategies in potato cultivation. Particularly the types, biochemical mechanisms, and efficacy of nitrogen fertilizer inhibitors, such as nitrification inhibitors, urease inhibitors, and slow-release fertilizers, will be analyzed, evaluating their effectiveness in diverse potato-production systems compared to conventional fertilizers. This evaluation will focus on the impacts on potato productivity, NUE parameters, and environmental footprint. A key novelty of this review lies in the combined addition of yield, nitrogen-related, and environmental indicators to assess nitrogen management strategies like enhanced-efficiency fertilizers. Furthermore, the study will address critical knowledge gaps, such as the impacts on soil health, environment interactions, and economic barriers of using inhibitors and will propose alternative pathways and future research focusing on enhancing inhibitor use in potato production. Primarily, this review highlights that there is currently a limited number of research articles examining simultaneously potato cultivation and N inhibitor use, underlining the necessity for advanced analyses.

2. Nitrogen Fertilizer Inhibitors

2.1. The Significant Role of Nitrification Inhibitors

Nitrification inhibitors (NIs) are compounds that obstruct the microbial oxidation of ammonium (NH_4^+) to nitrate (NO_3^-), which is a significant mechanism of ammonia-oxidizing microorganisms [38,39]. These fertilizer synergists are responsible for extending

the presence of ammonium in the soil, and by that improve nitrogen use efficiency while synchronizing N availability with crop demand [40,41]. Besides mitigating nitrate leaching, nitrification inhibitors contribute to reducing nitrous oxide (N_2O) emissions. Nitrous oxide is classified as a greenhouse gas and represents a small fraction of total N losses [42,43].

A wide range of commercial nitrification inhibitors has been developed, among which dicyandiamide (DCD), 3,4-dimethylpyrazole phosphate (DMPP), and 2-chloro-6-(trichloromethyl)pyridine (Nitrapyrin) are frequently used in agricultural systems [44,45]. Dicyandiamide is considered as the most commonly utilized nitrification inhibitor due to its high water solubility, low volatility, and compatibility with urea and other nitrogen fertilizers [38,46]. In contrast, DMPP is a newer inhibitor characterized by lower ecotoxicity, which could also be mixed with N fertilizers [47].

Recent studies have shown that nitrification inhibitors could exhibit nitrate-leaching and N_2O -emissions reduction by 30–50% and 34–49%, respectively [48]. The aforementioned environmental advantages are usually linked to improving yield responses, which could vary depending on cultivated species, soil characteristics, nitrogen fertilizers and the use of specific inhibitors [49–52]. Overall, nitrification inhibitors constitute as a promising approach for enhancing nitrogen use efficiency while mitigating nitrate leaching and N_2O emissions in cropping systems.

2.2. Urease Inhibitors: Delaying Urea Hydrolysis

Urease inhibitors (UIs) are effective in reducing NH_3 losses by slowing the hydrolysis of urea [53–55] and increasing the amount of applied N retained in the soil [56]. According to Soumare et al. [57], the hydrolysis of urea takes place in two steps. Urea is initially transformed into ammonium carbonate, which then is split into CO_2 and ammonium ions. Thus, urease inhibitors play an important role in delaying these reactions, thereby providing more time for urea to distribute into the soil and be absorbed by the crop roots [58]. Arshdeep Singh et al. [59] investigated a plethora of both chemical and physical compounds regarding their ability to inhibit soil urease activity. However, the most broadly successful urease inhibitor is the N-(n-butyl) thiophosphoric triamide (NBPT). Studies have shown that the use of NBPT could reduce NH_3 volatilization from applied urea by up to 66% [28].

Cantarella et al. [44] noted that due to its proven effectiveness, the global NBPT market has increased at an average annual rate of approximately 16% over the last ten years. Furthermore, regulatory frameworks have officialized the utilization of some other urease inhibitors. According to Regulation No 2003/2003, approved compounds in the EU include N-(n-butyl) thiophosphoric triamide (NBPT), N-(2-nitrophenyl) phosphoric acid triamide (2-NPT), and mixtures of NBPT with N-propyl-thiophosphoric triamide (NPPT) at a 3:1 ratio (Figure 3) [45].

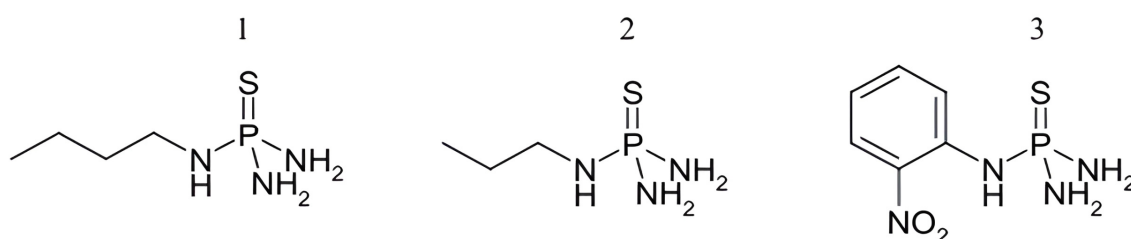


Figure 3. Chemical structures illustrating urease inhibitors including: 1—NBPT, 2—2-NPT, 3—NPPT [45].

2.3. Slow- and Controlled-Release Fertilizers Improving Nitrogen Use Efficiency

An alternative solution mitigating the environmental impact of overusing nitrogen fertilizers could be slow-release fertilizers (SRFs). These fertilizers are distinguished by the

ability to release nutrients progressively, improving plant uptake and lowering environmental footprint (Figure 4) [60,61], and they include controlled-release fertilizers (CRFs) and smart-release fertilizers.

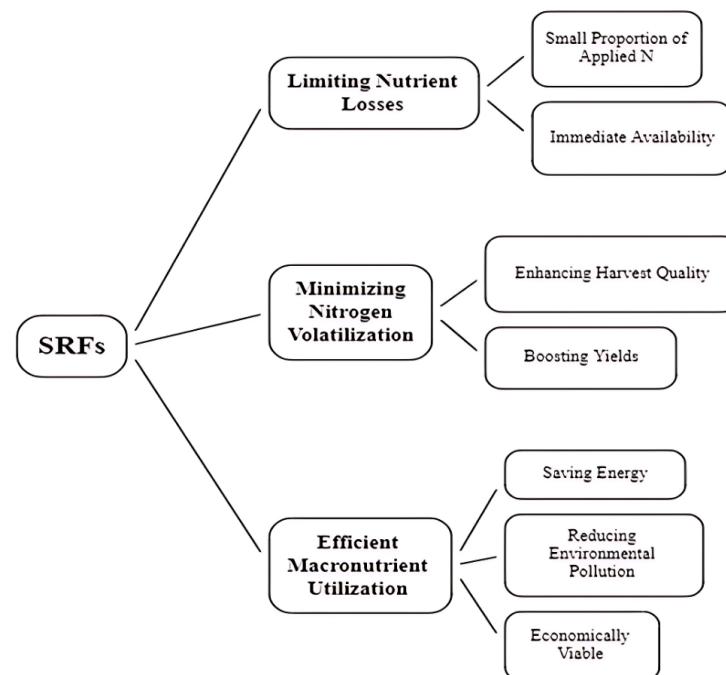


Figure 4. The benefits of using slow-release fertilizers (SRFs).

Several studies revealed that SRFs adjust nutrient supply by either decreasing solubility of minerals in water or delaying nutrient release in the soil [62,63]. Furthermore, to accomplish these results, many other methods have been evaluated, such as loading minerals into carriers, coating applications, and physical or chemical interactions [64,65]. According to Beig et al. [66], coating technology is mostly preferred because of its effectiveness and ability to accurately regulate nutrient release rates by adjusting coating thickness.

The significant role of controlled-release fertilizers (CRFs) is enabling the synchronization of nutrient supply with plant demand, by minimizing the quantity and frequency of applied fertilizers [67]. Studies noted that CRFs could enhance nitrogen use efficiency, limit N losses in the rhizosphere, and reduce the cultivation costs in potato cultivation [68]. Similarly, polymer-coated urea (PCU) emerges as a useful slow-release fertilizer for potato systems [69] and could be used as an alternative to conventional split nitrogen applications in order to minimize nitrate leaching. Gao et al. [70] found that PCU increased tuber yield relative to traditional fertilizers, and improved NUE. We recognize that PCU could be presented as a practical strategy for improving both potato productivity and environmental footprint.

2.4. Case Studies Demonstrating the Effectiveness of Enhanced-Efficiency Fertilizers in Potato Cultivation

The application of several nitrification and urease inhibitors has been assessed in both improving N use efficiency and reducing N losses in potato production, with their effects being presented in the following table (Table 1). Souza et al. [71] conducted a two-year experiment investigating whether ammonium sulfate nitrate with nitrification inhibitor could increase tuber yield and NUE compared to conventional urea fertilization. They found that split application of ASN combined with DMPP at 75% of recommended dose (urea 160 kg N ha⁻¹) significantly increased fresh tuber yield by 14% relative to split urea treatment. Furthermore, this approach reduced N surplus by 30–70 kg N ha⁻¹,

contributing to lower nitrogen losses. Another study demonstrated that sustainable N management in potato production could be accomplished by using DCD at a 25% reduced rate (262.5 kg N ha⁻¹). Tuber yield was increased by 5% compared to the full conventional dose, while nitrogen use efficiency was improved by 56% and N₂O emissions were least [72]. These findings demonstrate that N inputs could be lowered without sacrificing yields, with additional benefits for potato quality and environment sustainability.

Table 1. Effects of enhanced-efficiency fertilizer use on potato yield, nitrogen use efficiency, and environmental losses compared to conventional fertilizers across different studies.

Inhibitor	N Application Rate	Yield	NUE	NO ₃ ⁻ Leaching	N ₂ O Emissions	References
		Compared to Unfertilized Control	Compared to Fertilized Control Without Inhibitor	Compared to Fertilized Control Without Inhibitor		
DCD	Urea: 262.5 kg N ha ⁻¹ (split-applied)	↑ 143%	↑ 5%	↑ 56%	-	Lowest cumulative emissions Egypt [72]
DMPP	AS/AN: 120 kg N ha ⁻¹ (split-applied)	↑ 104%	↑ 14%	↑ 50%	↓ (indicated by reduced N sur-plus)	Brazil [71]
NBPT	Urea: 195 kg N ha ⁻¹	↑ 36%	↑ 2%	↑ 2%	-	- Russia [73]
PCU	Urea: 150 kg N ha ⁻¹	↑ 35%	↑ 18%	↑ 208%	-	- China [70]
PCU	AS/AN: 280 kg N ha ⁻¹ (split-applied)	↑ 17%	↑ 6%	↑ 6%	↓ 39%	- Wisconsin, USA [74]
DMPSA + NBPT	Urea: 325 kg N ha ⁻¹	No significant effect		↑ 13%	↓ 25%	↓ 62% Minnesota, USA [75]
DCD + NBPT	Urea: 280 kg N ha ⁻¹	No significant effect		↑ 2%	-	Significant reduction North Dakota, USA [25]

Abbreviations: AS/AN, ammonium sulphate nitrate. The percentages are presented as average values with one decimal of the increase or decrease in yield and various indicators. All the data is derived from tables, figures and graphs from research papers demonstrating the approximate values as mean of sites/years/replications.

Previous research has demonstrated the agronomic benefits of urease inhibitors in potato production. The study by Vizirskaya et al. [73] investigated the effect of a urease inhibitor (NBPT) in an irrigated potato cropping system. The application of urea with NBPT increased total yield and marketable yield by 35.6% and 43%, respectively, compared to the control.

Gao et al. [70] conducted a two-year experiment evaluating the effect of polymer-coated urea (PCU) on potato tuber yield, NUE, and quality characteristics compared to urea. PCU applied at 150 kg N ha⁻¹ increased total tuber yield and marketable yield by 18% and 3%, respectively, compared to urea. Potato N uptake and nitrogen release from PCU was synchronized during growing season, resulting in greater vitamin C and starch content in tubers, while reducing sugars. In a study by Campbell et al. [74], the effects of enhanced-efficiency fertilizers were also examined in potato cropping systems over three growing seasons. They reported that polymer-coated urea (PCU) reduced nitrate leaching by 39% and increased potato tuber yield by 6%, compared to conventional split-applied ammonium sulphate nitrate (280 kg N ha⁻¹). The effectiveness of PCU was strongly influenced by the weather conditions during the experiment and by the amount of fertilizer

applied by the producers. They found that the application of PCU should be synchronized with the presence of rainfall to achieve optimal results and minimize nitrate leaching in the soil [74].

The combination of nitrification and urease inhibitors stands as a promising strategy to simultaneously enhance nitrogen use efficiency, yield, and environmental degradation by applying excessive N fertilization in potato cropping systems [28,36]. Souza et al. [75] mentioned that the combined application of DMPSA and NBPT resulted in a reduction in nitrate leaching and nitrous oxide emissions, while increasing soil nitrate availability and overall nitrogen recovery. However, the high input of fertilizer did not result in increased tuber yield. These findings are further supported by a couple of studies showing that the co-application of the above inhibitors could also minimize N₂O emissions [76,77]. Notably, Ghosh et al. [25] found that combined DCD and NBPT at 280 kg N ha⁻¹ significantly minimized both N₂O emissions and ammonia volatilization compared to urea.

3. Assessment Indicators of N Management

According to recent studies, enhancing nitrogen use efficiency and coordinating N supply with crop demand complicate optimum nitrogen management in potato cropping systems [36,78]. In many cases, excessive nitrogen application could result in environmental degradation, lower economic efficiency and tuber quantity and quality [79]. To address this problem, a multifaceted assessment approach is crucial for appraising the impacts of N fertilization practices, which often include agronomic, environmental, and quality aspects. This could provide a thorough basis aiming to determine the optimum nitrogen level and management strategies [36]. Combining agronomic, environmental, NUE and yield metrics is specifically important for potato cultivation, to compare conventional fertilizers to enhanced efficiency strategies, while paving the way for sustainable pathways that balance productivity and environmental stability.

3.1. Yield and Agronomic Indicators in Potato Cropping Systems

Cooper et al. [80] mentioned that yield of several crops is mainly affected by the cultivation practices, environmental conditions, and their genetic composition. Hence, yield-based agronomic indices serve as a beneficial tool for estimating potato productivity and assessing the effects of the aforementioned factors. Recent studies demonstrated that these indicators could provide significant information for researchers and farmers, in order to optimize fertilization strategies while improving both tuber yield and quality [81,82]. In potato cropping systems, the yield-based indicators encompass several metrics including tuber number per plant, average tuber weight, marketable tuber yield, and total tuber yield (Table 2) [83,84].

Table 2. Yield-derived indicators for assessing potato performance.

Index	Definition	Formula	Unit	Reference
Tuber number per plant	Average number of tubers per plant	TTN/NP	Tubers plant ⁻¹	[83,84]
Average tuber weight	Total tuber yield divided by total number of tubers	TTY/TTN	kg tuber ⁻¹	
Marketable tuber yield	Weight of tubers meeting quality and market standards	MTW/PA	kg ha ⁻¹	
Total tuber yield	Total weight of all harvested tubers per unit area	TTW/PA	kg ha ⁻¹	

Abbreviations: TTW, total tuber weight (kg); PA, plot area (ha); MTW, marketable tuber weight (kg); TTY, total tuber yield (kg ha⁻¹); TTN, total tuber number; NP, number of plants.

Tuber number per plant (TN) represents the average number of tubers formed per plant, while average tuber weight (ATW) is usually expressed as the total tuber yield divided by total number of potato tubers. Total tuber yield (TTY) represents the total weight of all harvest tubers including marketable and unmarketable tubers, per unit of plot area [83,84]. According to Liu et al. [85], N fertilization increases TTY in potato cultivation up to an optimum rate, and beyond that excess N does not affect yield. Furthermore, marketable tuber yield (MTY) is a yield index providing the weight of potato tubers that have achieved both quality and market criteria per plot area [83,84]. Pszczółkowski et al. [86] noted that marketable yield is a crucial metric describing the economically valuable part of harvest for growers.

3.2. The Substantial Impact of Nitrogen Use Efficiency Indicators

Whether the nitrogen source is a commercial fertilizer or any other form, Nitrogen Use Efficiency (NUE) stands as a key element for assessing potato production [87] and involves a wide range of calculations [88]. The complication of this index lies in the numerous sources of nitrogen that impact crop growth, the interaction between N availability in soil, plant genetics, and the effect of management, weather, and climate conditions [89,90]. Calculating NUE for only one growing season gives significant insights into a specific crop and environment [91]; however, using several indicators is preferable for a thorough evaluation, including potato [92]. Congreves et al. [91] categorized many indicators into groups, which are used to assess the nitrogen applied efficiency.

The category of fertilizer-based NUE indicators includes numerous indices including agronomic efficiency, partial factor productivity, partial nutrient balance, apparent crop removal efficiency and nitrogen balance intensity (Table 3) [91], which are characterized by the quantity of the applied N fertilizer relative to several crop parameters, such as nitrogen content, yield and even aboveground biomass [92].

Table 3. Various fertilizer-based indices with their formulas and definitions.

Index	Abbreviation	Calculation	Unit	Definition	Reference
Agronomic efficiency	AE	$(TY - TY_0)/F$	kg tuber yield kg^{-1} N	The contribution of N fertilizer towards tuber yield compared to no N application	[72,91,92]
Partial factor productivity	PFP	TY/F	kg tuber kg^{-1} N	The expression of tuber yield per unit of N applied	[72,91,92]
Partial nutrient balance	PNB	TNU/F	kg N kg^{-1}	The ratio between tuber N content and the N applied	[72,91,92]
Apparent crop removal efficiency	CREM	$(TNU - TNU_0)/F$	kg N kg^{-1}	The amount of N fertilizer applied assimilated by tubers	[71,72]
Nitrogen Balance Intensity	NBI	$TY - F$	kg N ha^{-1}	The difference between N input and tuber yield	[72,91,92]

Abbreviations: TY, tuber yield with applied N ($kg\ ha^{-1}$); TY_0 , tuber yield without applied N ($kg\ ha^{-1}$); F, N fertilizer application ($kg\ N\ ha^{-1}$); TNU, tuber nitrogen uptake with applied N ($kg\ N\ ha^{-1}$); TNU_0 , tuber nitrogen uptake without applied N ($kg\ N\ ha^{-1}$); TPU, total plant nitrogen uptake with applied N ($kg\ N\ ha^{-1}$); TPU_0 , total plant nitrogen uptake without applied N ($kg\ N\ ha^{-1}$).

The AE addresses how much tuber yield is improved by N application. PFP is an NUE index providing the overall productivity of applied nitrogen fertilizer on potato cultivation. PNB could be assessed at both maturation and harvest stage and describes the fraction of

N fertilizer application that is accumulated within the potato tubers [71,72]. CREM is an NUE indicator representing the increase in tuber N uptake per unit of N application rate during the maturity and harvest stages. Lastly, the NBI index conceptualizes the difference between the amount of N removed as tuber yield relative to the applied N fertilizer [72,91].

The plant-based indices are defined by the allocation of plant tissue N towards crop yield or yield nitrogen, providing information that is not specified by fertilizer-based indicators [91]. For potato cultivation, this group includes nitrogen utilization efficiency, apparent crop recovery efficiency and nitrogen harvest index (Table 4). NUtE describes the nitrogen content yield regarding the N acquired by potato plants. REN is the NUE indicator expressing the differences in total N uptake per unit of N fertilizer applied. Furthermore, NHI relate the N allocated to tuber yield regarding to the potato plant N [72,91,92].

Table 4. Plant-based indicators and their associated calculation and interpretation.

Index	Abbreviation	Calculation	Unit	Definition	Reference
Nitrogen utilization efficiency	NUtE	TY/TPU	kg tuber kg ⁻¹ N uptake	Reflects how effectively plant N uptake is transformed into yield	[71,72,91]
Apparent crop recovery	REN	(TPU – TPU ₀)/F	kg N ha ⁻¹	The fraction of applied N fertilizer taken up by potato plant	[71,72,91]
N harvest index	NHI	TNU/TPU	%	The substantial proportion of potato N partitioned to tubers	[72,91,92]

Abbreviations: TY, tuber yield with applied N (kg ha⁻¹); TY₀, tuber yield without applied N (kg ha⁻¹); F, N fertilizer application (kg N ha⁻¹); TNU, tuber nitrogen uptake with applied N (kg N ha⁻¹); TNU₀, tuber nitrogen uptake without applied N (kg N ha⁻¹); TPU, total plant nitrogen uptake with applied N (kg N ha⁻¹); TPU₀, total plant nitrogen uptake without applied N (kg N ha⁻¹).

Additionally, soil-based indicators are characterized by N fertilizer inputs and soil contributions to the plant, which are mostly affected by the nitrogen dynamics and soil management (Table 5) [91]. The NUpE defines the result of total potato N uptake per unit of fertilizer applied and NUE could be expressed as the result of nitrogen uptake efficiency and nitrogen utilization efficiency.

Table 5. Soil-based indices with their formulas and definitions.

Index	Abbreviation	Calculation	Unit	Definition	Reference
Nitrogen uptake efficiency	NUpE	TPU/F	kg N kg ⁻¹	The amount of N fertilizer utilized by the potato plant	[71,72,91]
Nitrogen use efficiency	NUE	(NUpE × NUtE)	kg tuber kg ⁻¹ N	The potato biomass produced per unit of applied N	[72,91,92]

Abbreviations: TY, tuber yield with applied N (kg ha⁻¹); TY₀, tuber yield without applied N (kg ha⁻¹); F, N fertilizer application (kg N ha⁻¹); TNU, tuber nitrogen uptake with applied N (kg N ha⁻¹); TNU₀, tuber nitrogen uptake without applied N (kg N ha⁻¹); TPU, total plant nitrogen uptake with applied N (kg N ha⁻¹); TPU₀, total plant nitrogen uptake without applied N (kg N ha⁻¹).

3.3. Environmental Indicators for Nitrogen Dynamics in Potato Production

Environmental sustainability is a critical concern in modern potato production. N losses occur via gaseous emissions and leaching, both of which have implications for climate change and water quality [34,93]. Kemmou & Amanatidou [94] demonstrated nitrous oxide as a dominant greenhouse gas influencing both climate variability and depletion of the ozone layer. As a result of extensive use of chemical fertilizers, soils have become a

significant source releasing N_2O , which is mostly created in microbial processes [95]. In addition, excess fertilizer application that is not assimilated by plants leads to nitrate leaching and ammonia emissions [96]. A study by Varga et al. [34] highlighted that the potato's uneven N demand and canopy development are strongly connected to the level of nitrate leaching and N_2O emissions. Hence, constrained root-nutrient capacity and high early-season nitrogen supply could contribute to spare soil mineral N, which will increase the danger of leaching and nitrous oxide losses.

Alfaro Valenzuela et al. [97] determined the quantity of applied nitrogen as fertilizer converted to N_2O using an emission factor. It is estimated by subtracting the emissions from the unfertilized treatment from the amount of nitrous oxide emitted from the fertilized treatment and expressing the results as a percentage of the overall quantity of applied nitrogen. Furthermore, the N_2O emissions intensity was expressed as the ratio of aggregate N_2O -N emissions per unit to dry matter yield of the crop. A study by Jiang et al. [98] quantified the NO_3^- accumulation in soil by analyzing the concentration of nitrate, the soil water content, and the depth of the soil. This method was used to assess the nitrate storage prior to any possible leaching into groundwater.

Despite its substantial contribution to ammonia emission, the potato has not drawn enough attention, probably because of its excessive nitrogen inputs and complicated fertilization methods [99,100]. Many studies have presented information regarding NH_3 emissions reduction in grains; however, data on NH_3 volatilization in potatoes do not exist [101]. This could be explained by the exhibition of different root structures and nutrient uptake capacity, which often results in complex NH_3 emission motifs [24]. The emissions ratio is a critically important concept to quantify the amount of NH_3 volatilization losses relative to the quantity of applied nitrogen fertilization in a cropping system, and it is expressed in percentage [101,102].

4. Discussion

4.1. The Positive Effect of Enhanced Efficiency Fertilizers and the Use of Nitrogen Indicators in Potato

This comprehensive review assessed the significance of optimizing nitrogen management with the purpose of meeting the high demands of both potato productivity and environmental sustainability. Combining global research, the positive impact of enhanced efficiency fertilizers, such as nitrification inhibitors, urease inhibitors, and slow-release fertilizers is distinguished by improving potatoes' characteristic low nitrogen use efficiency, while minimizing the environmental degradation.

Various studies present the positive impact of these fertilizers, offering the potential for improving nitrogen use efficiency and tuber yields, while reducing environmental losses [74,103]. Research by Souza et al. [71,75] reported this, showing a significant decrease in N_2O emissions and nitrate leaching via the use of nitrification inhibitors or the double application of urease and nitrification inhibitors. The aforementioned results are consistent with the findings of Recio et al. [76], where these practices mitigated N_2O emissions; however, NO_3^- leaching was not assessed. According to Liu et al. [104], their value lies in both reducing the availability of substrates for nitrification and preventing ammonia and nitrate oxidation. Additionally, studies of Vizirskaya et al. and Ghosh et al. [25,73] exhibited significant yield increases when using inhibitors. Corrochano-Monsalve et al. [105] highlighted that the level of tuber yield improvement is associated with the soil properties, the irrigation practices, the quantity of applied inhibitors, and nitrogen fertilizers.

In addition to the role of enhanced-efficiency fertilizers, the assessment of these technologies only by using yield or cost factors as a metric carries many risks. This review highlights the importance of implementing a complete evaluation methodology including

agronomic, environmental and nitrogen-efficiency factors. Agronomic indicators, such as total and marketable tuber yield, reflect the financial stability of individual producers or groups of producers, and NUE indices describe the crop response to fertilizer application, while helping farmers reduce additional costs. Regarding environmental indices, they pose as a significant metric keeping potato cultivation in step with the policies of European Green Deal [33].

4.2. Possible Limitations and Constrains of Enhanced Efficiency Fertilizers

The cost of enhanced-efficiency fertilizers represents a crucial limitation factor in the agriculture sector and could possibly hinder the replacement of conventional nitrogen fertilizers like urea [103]. Da Costa Leite et al. [106] assessed the economic outcome of implementing urea with urease inhibitor (NBPT) in cotton cultivation under tropical conditions. They noted that the use of NBPT increased significantly the production cost of cultivation by up to 2.9%, depending on the concentration of the inhibitor during the growing season. However, its higher cost could be justified under specific weather conditions that enhance nitrogen uptake of the cotton plant and minimize nitrate leaching, even if yields are not increased.

In another study by Wang et al. [107], the economic viability of enhanced efficiency fertilizers was evaluated in corn cultivation. The co-application of nitrification and urease inhibitors (NBPT + DMPP) resulted in total benefit of \$23.4 per ha, due to improved crop yields and reduced environmental losses like NO_3^- leaching. After subtracting the cost of the inhibitors, the net profit was substantial, with a nearly 6.4% increase in revenue compared to urea fertilizer. It is important to highlight that all these results do not directly refer to potato cultivation, and therefore the findings may not be universally applicable.

The environmental fate of enhanced-efficiency fertilizers is determined by a complex interaction of physiological properties, climate conditions, and soil characteristics in various agricultural systems [108]. According to Peters and Thiele-Bruhn [109], the persistence of the inhibitors in soil depends on both physiochemical properties and environmental conditions. Urease inhibitors have short longevity, and their degradation process is achieved in microbially rich soil and affected by high temperatures, whereas nitrification inhibitors such as DCD exhibit a broader range of persistence in soil [108]. The leaching of inhibitors and slow-release fertilizers into groundwater is determined by their persistence and mobility in the soil [108]. Wang et al. [108] found that urease inhibitors such as NBPT and 2-NPT exhibit very low leaching risk, remaining in the upper layer of soil. Regarding nitrification inhibitors, DCD is extremely vulnerable to leaching because of its high water solubility and low absorption by the soil. However, DMPP presents limited mobility and tends to remain at the top of the soil [110]. According to these findings, urease inhibitors and DMPP are preferable in cropping systems with high irrigation needs such as potato.

Climate change could influence the environmental fate and effectiveness of enhanced-efficiency fertilizers, with rising temperatures expediting the degradation of most inhibitors [108]. Engel et al. [111] reported that higher temperatures could potentially minimize both the efficacy and the environmental persistence of urease inhibitors such as NBPT. Moreover, extreme weather conditions including extended drought followed by irregular rainfall patterns will influence the reduction–oxidation conditions affecting the persistence of enhanced-efficiency fertilizers. These findings highlight the necessity of adopting appropriate inhibitors to maintain nitrogen efficiency and ensure environmental protection in agricultural systems.

4.3. Holistic Nitrogen Management in Potato: Practices, Gaps, and Future Directions

Pathways to sustainable nitrogen management in potato production require holistic integrated nutrient management. Studies have shown that enhanced-efficiency fertilizers are a critical element within this; however, they should be paired with other agronomic practices. Among these, the implementation of cover crops has emerged as a crucial step for increasing productivity and quality in potato production [112]. Particularly, cover crops are renowned for improving soil structure and its physical properties, nitrogen fixation, and diminishing the need for synthetic fertilizers [113,114]. Integrating legumes into cover cropping systems, such as red clover, cowpea, and alfalfa, enhances nitrogen cycling and enriches organic N to soil. These species are generally used as green manure or could be incorporated as living or dead mulch [115,116]. The concept of precision agriculture could also be embraced in this integration. The 4R management strategy symbolizing the right amount, source, time and placement, provides a key management approach for incorporating inhibitors and new technology fertilizers as the right source [34]. Moreover, the incorporation of organic fertilizers, such as compost and manure, along with synthetic N fertilizers, improves soil health and nitrogen retention, while minimizing nutrient leaching and enhancing growth parameters in potato cropping systems [117].

Although numerous encouraging findings recognizing the positive impact of enhanced-efficiency fertilizers and integrated N management in potatoes have been displayed, critical knowledge gaps should be addressed to support global adoption. First, because most experiments have a short duration, it is essential to assess the effects of continuously using inhibitors on soil health in the long term [47]. According to studies, soil temperature and moisture have a strong influence on the performance and productivity of nitrification and urease inhibitors, which raises concerns regarding their consistency in future climate conditions [52]. Consequently, cost–benefit analysis and full life-cycle assessment addressing the economic results of using fertilizer inhibitors are crucial for helping farmer’s decisions regarding fertilization particularly in potato cropping systems.

5. Conclusions

This review summarizes that enhanced-efficiency fertilizers have a pivotal role in enhancing nitrogen sufficiency in potato cropping systems, while addressing low nitrogen use efficiency and minimizing environmental losses. The immense application of inhibitors and new-technology fertilizers has long been assessed; however, a comprehensive evaluation of agronomic, environmental, and physiological variables is required to determine their beneficial contribution. Providing information regarding the knowledge gaps about environment interactions, soil health, and economic profitability is crucial for future progress. Lastly, in order to maintain both productivity and environmental sustainability of potato cropping systems globally, a systemic change towards integrated N management is required.

Author Contributions: Conceptualization, D.B., I.K.; methodology, M.C.; software, M.C., P.S., S.K. (Stella Karydogianni), A.M., S.K. (Stavroula Kallergi), I.R.; validation, D.B., I.K., M.C.; formal analysis, A.M., P.S., M.C.; investigation, M.C.; resources, M.C., P.S., A.M., S.K. (Stella Karydogianni), I.R., S.K. (Stavroula Kallergi); data curation, D.B., I.R., M.C., P.S.; writing—original draft preparation, M.C., P.S., S.K. (Stavroula Kallergi); writing—review and editing, M.C., D.B.; visualization, P.S., M.C., S.K. (Stavroula Kallergi); supervision, D.B.; project administration, D.B., I.K.; funding acquisition, M.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this review are available on request from the corresponding authors.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

N	Nitrogen
NUE	Nitrogen Use Efficiency
NI	Nitrification Inhibitor
UI	Urease Inhibitor
SRF	Slow-release fertilizer
CRF	Controlled-release fertilizer
DCD	Dicyandiamide
DMPP	3,4-dimethylpyrazole phosphate
NBPT	N-(n-butyl) thiophosphoric triamide
2-NPT	N-(2-nitrophenyl) phosphoric acid triamide
NPPT	N-propyl-thiophosphoric triamide
PCU	Polymer-coated urea
ASN	Ammonium sulphate nitrate
NO ₃ [−]	Nitrate
N ₂ O	Nitrous oxide

References

1. Production of Potatoes: Top 10 Producers (Average 1994–2024). Available online: <https://www.fao.org/faostat/> (accessed on 5 January 2026).
2. Hardigan, M.A.; Laimbeer, F.P.E.; Newton, L.; Crisovan, E.; Hamilton, J.P.; Vaillancourt, B.; Wiegert-Rininger, K.; Wood, J.C.; Douches, D.S.; Farré, E.M.; et al. Genome diversity of tuber-bearing *Solanum* uncovers complex evolutionary history and targets of domestication in the cultivated potato. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, E9999–E10008. [CrossRef]
3. Gutaker, R.M.; Weiß, C.L.; Ellis, D.; Anglin, N.L.; Knapp, S.; Luis Fernández-Alonso, J.; Prat, S.; Burbano, H.A. The origins and adaptation of European potatoes reconstructed from historical genomes. *Nat. Ecol. Evol.* **2019**, *3*, 1093–1101. [CrossRef]
4. Hawkes, J.G.; Francisco-Ortega, J. The early history of the potato in Europe. *Euphytica* **1993**, *70*, 1–7. [CrossRef]
5. Swamy, K.R.M. Origin, domestication, taxonomy, botanical description, genetics and cytogenetics, genetic diversity and breeding of potato (*Solanum tuberosum* L.). *Int. J. Curr. Res.* **2023**, *15*, 24352–24372. [CrossRef]
6. Wang, Z.J.; Liu, H.; Zeng, F.K.; Yang, Y.C.; Xu, D.; Zhao, Y.C.; Liu, X.F.; Kaur, L.; Liu, G.; Singh, J. Potato Processing Industry in China: Current Scenario, Future Trends and Global Impact. *Potato Res.* **2023**, *66*, 543–562. [CrossRef] [PubMed]
7. Hu, X.; Jiang, H.; Liu, Z.; Gao, M.; Liu, G.; Tian, S.; Zeng, F. The Global Potato-Processing Industry: A Review of Production, Products, Quality and Sustainability. *Foods* **2025**, *14*, 1758. [CrossRef]
8. Koch, M.; Naumann, M.; Pawelzik, E.; Gransee, A.; Thiel, H. The importance of nutrient management for potato production Part I: Plant nutrition and yield. *Potato Res.* **2020**, *63*, 97–119. [CrossRef]
9. Narváez-Cuenca, C.E.; Peña, C.; Restrepo-Sánchez, L.P.; Kushalappa, A.; Mosquera, T. Macronutrient contents of potato genotype collections in the *Solanum tuberosum* Group Phureja. *J. Food Compos. Anal.* **2018**, *66*, 179–184. [CrossRef]
10. Parra-Galindo, M.A.; Piñeros-Niño, C.; Soto-Sedano, J.C.; Mosquera-Vasquez, T. Chromosomes I and X harbor consistent genetic factors associated with the anthocyanin variation in potato. *Agronomy* **2019**, *9*, 366. [CrossRef]
11. Riveros-Loaiza, L.M.; Benhur-Cardona, N.; Lopez-Kleine, L.; Soto-Sedano, J.C.; Pinzón, A.M.; Mosquera-Vásquez, T.; Roda, F. Uncovering anthocyanin diversity in potato landraces (*Solanum tuberosum* L. Phureja) using RNA-seq. *PLoS ONE* **2022**, *17*, e0273982. [CrossRef]
12. Hu, C.; He, Y.; Zhang, W.; He, J. Potato proteins for technical applications: Nutrition, isolation, modification and functional properties—A review. *Innov. Food Sci. Emerg. Technol.* **2024**, *91*, 103533. [CrossRef]
13. Kowalczyk, T.; Muskała, M.; Merecz-Sadowska, A.; Sikora, J.; Picot, L.; Sitarek, P. Anti-inflammatory and anticancer effects of anthocyanins in in vitro and in vivo studies. *Antioxidants* **2024**, *13*, 1143. [CrossRef]
14. Akkamis, M.; Caliskan, S. Responses of yield, quality and water use efficiency of potato grown under different drip irrigation and nitrogen levels. *Sci. Rep.* **2023**, *13*, 9911. [CrossRef]

15. Kumar, S.; Sindhu, S.S.; Kumar, R. Biofertilizers: An ecofriendly technology for nutrient recycling and environmental sustainability. *Curr. Res. Microb. Sci.* **2022**, *3*, 100094. [\[CrossRef\]](#)
16. Savci, S. An agricultural pollutant: Chemical fertilizer. *Int. J. Environ. Sci. Dev.* **2012**, *3*, 73. [\[CrossRef\]](#)
17. Ayyub, C.M.; Wasim Haidar, M.; Zulfiqar, F.; Abideen, Z.; Wright, S.R. Potato tuber yield and quality in response to different nitrogen fertilizer application rates under two split doses in an irrigated sandy loam soil. *J. Plant Nutr.* **2019**, *42*, 1850–1860. [\[CrossRef\]](#)
18. Hopkins, B.G.; Stark, J.C.; Kelling, K.A. Nutrient management. In *Potato Production Systems*; Stark, J.C., Thornton, M.K., Nolte, P., Eds.; Springer International Publishing: Cham, Switzerland, 2020; pp. 155–202. [\[CrossRef\]](#)
19. Zebarth, B.J.; Rosen, C.J. Research perspective on nitrogen BMP development for potato. *Am. J. Potato Res.* **2007**, *84*, 3–18. [\[CrossRef\]](#)
20. Song, Q.; Zhang, J.; Zhang, F.; Shen, Y.; Yue, S.; Li, S. Optimized nitrogen application for maximizing yield and minimizing nitrogen loss in film mulching spring maize production on the Loess Plateau, China. *J. Integr. Agric.* **2024**, *23*, 1671–1684. [\[CrossRef\]](#)
21. Shrivastava, V.; Laasri, I. Nutrient Recovery Strategies and Agronomic Performance in Circular Farming: A Comprehensive Review. *Nitrogen* **2025**, *6*, 80. [\[CrossRef\]](#)
22. Song, Y.; Ma, L.; Duan, Q.; Xie, H.; Dong, X.; Zhang, H.; Yu, L. Development of slow-release fertilizers with function of water retention using eco-friendly starch hydrogels. *Molecules* **2024**, *29*, 4835. [\[CrossRef\]](#)
23. Yang, Y.; Li, T.; Pokharel, P.; Liu, L.; Qiao, J.; Wang, Y.; An, S.; Chang, S.X. Global effects on soil respiration and its temperature sensitivity depend on nitrogen addition rate. *Soil Biol. Biochem.* **2022**, *174*, 108814. [\[CrossRef\]](#)
24. Zhang, G.; Zhao, D.; Liu, S.; Liao, Y.; Han, J. Can controlled-release urea replace the split application of normal urea in China? A meta-analysis based on crop grain yield and nitrogen use efficiency. *Field Crops Res.* **2022**, *275*, 108343. [\[CrossRef\]](#)
25. Ghosh, U.; Chatterjee, A.; Hatterman-Valenti, H. Enhanced efficiency fertilizers in minimizing nitrogen losses in irrigated russet potato. *Agrosyst. Geosci. Environ.* **2019**, *2*, 1–9. [\[CrossRef\]](#)
26. Gao, X.; Tenuta, M.; Nelson, A.; Sparling, B.; Tomasiewicz, D.; Mohr, R.M.; Bizimungu, B. Effect of nitrogen fertilizer rate on nitrous oxide emission from irrigated potato on a clay loam soil in Manitoba, Canada. *Can. J. Soil Sci.* **2013**, *93*, 1–11. [\[CrossRef\]](#)
27. Herrera, J.M.; Rubio, G.; Häner, L.L.; Delgado, J.A.; Lucho-Constantino, C.A.; Islas-Valdez, S.; Pellet, D. Emerging and established technologies to increase nitrogen use efficiency of cereals. *Agronomy* **2016**, *6*, 25. [\[CrossRef\]](#)
28. Folina, A.; Tataridas, A.; Mavroeidis, A.; Kousta, A.; Katsenios, N.; Efthimiadou, A.; Travlos, I.S.; Roussis, I.; Darawsheh, M.K.; Papastilianou, P.; et al. Evaluation of Various Nitrogen Indices in N-Fertilizers with Inhibitors in Field Crops: A Review. *Agronomy* **2021**, *11*, 418. [\[CrossRef\]](#)
29. Shrestha, B.; Darapuneni, M.; Stringam, B.L.; Lombard, K.; Djaman, K. Irrigation water and nitrogen fertilizer management in potato (*Solanum tuberosum* L.): A review. *Agronomy* **2023**, *13*, 2566. [\[CrossRef\]](#)
30. Liang, X.; Lam, S.K.; Zhang, X.; Oenema, O.; Chen, D. Pursuing sustainable nitrogen management following the “5 Ps” principles: Production, people, planet, policy and partnerships. *Glob. Environ. Change* **2021**, *70*, 102346. [\[CrossRef\]](#)
31. Wang, L.; Ma, L.; Li, Y.; Geilfus, C.M.; Wei, J.; Zheng, F.; Liu, Z.; Tan, D. Managing nitrogen for sustainable crop production with reduced hydrological nitrogen losses under a winter wheat-summer maize rotation system: An eight-season field study. *Front. Plant Sci.* **2023**, *14*, 1274943. [\[CrossRef\]](#)
32. Guyomard, H.; Soler, L.G.; Détang-Dessendre, C.; Réquillart, V. The European Green Deal improves the sustainability of food systems but has uneven economic impacts on consumers and farmers. *Commun. Earth Environ.* **2023**, *4*, 358. [\[CrossRef\]](#)
33. Mavroeidis, A.; Stavropoulos, P.; Roussis, I.; Folina, A.; Bilalis, D.; Kakabouki, I. A “Teal” Deal for European agriculture. *Not. Sci. Biol.* **2024**, *16*, 12015. [\[CrossRef\]](#)
34. Varga, I.; Bešlić, M.; Antunović, M.; Jović, J.; Markulj Kulundžić, A. Optimizing Nitrogen Inputs for High-Yielding and Environmentally Sustainable Potato Systems. *Nitrogen* **2025**, *6*, 117. [\[CrossRef\]](#)
35. Zhang, X.; Davidson, E.A.; Mauzerall, D.L.; Searchinger, T.D.; Dumas, P.; Shen, Y. Managing nitrogen for sustainable development. *Nature* **2015**, *528*, 51–59. [\[CrossRef\]](#)
36. Pan, Z.; Fan, D.; Jiang, R.; Abbasi, N.; Song, D.; Zou, G.; Wei, D.; He, P.; He, W. Improving potato productivity and mitigating nitrogen losses using enhanced-efficiency fertilizers: A global meta-analysis. *Agric. Ecosyst. Environ.* **2023**, *348*, 108416. [\[CrossRef\]](#)
37. Suman, J.; Rakshit, A.; Patra, A.; Dutta, A.; Tripathi, V.K.; Mohapatra, K.K.; Tiwari, R.; Krishnamoorthi, S. Enhanced efficiency N fertilizers: An effective strategy to improve use efficiency and ecological sustainability. *J. Soil Sci. Plant Nutr.* **2023**, *23*, 1472–1488. [\[CrossRef\]](#)
38. Subbarao, G.V.; Ito, O.; Sahrawat, K.L.; Berry, W.L.; Nakahara, K.; Ishikawa, T.; Watanabe, T.; Suenaga, K.; Rondon, M.; Rao, I.M. Scope and strategies for regulation of nitrification in agricultural systems—Challenges and opportunities. *Crit. Rev. Plant Sci.* **2006**, *25*, 303–335. [\[CrossRef\]](#)
39. Abalos, D.; Jeffery, S.; Sanz-Cobena, A.; Guardia, G.; Vallejo, A. Meta-analysis of the effect of urease and nitrification inhibitors on crop productivity and nitrogen use efficiency. *Agric. Ecosyst. Environ.* **2014**, *189*, 136–144. [\[CrossRef\]](#)

40. Ning, J.; Ai, S.; Cui, L. Dicyandiamide has more inhibitory activities on nitrification than thiosulfate. *PLoS ONE* **2018**, *13*, e0200598. [\[CrossRef\]](#)
41. Ruark, M.D.; Soratto, R.P.; Rosen, C.J. Merits and limitations of enhanced efficiency fertilizers. In *Nitrogen in Agricultural Systems*; Hatfield, J.L., Follett, R.F., Eds.; Agronomy Monograph 49; American Society of Agronomy, Crop Science Society of America, Soil Science Society of America: Madison, WI, USA, 2018; pp. 377–410. [\[CrossRef\]](#)
42. Snyder, C.S.; Davidson, E.A.; Smith, P.; Venterea, R. Agriculture: Sustainable crop and animal production to help mitigate nitrous oxide emissions. *Curr. Opin. Environ. Sustain.* **2014**, *9*, 46–54. [\[CrossRef\]](#)
43. Soares, J.R.; Cassman, N.A.; Kielak, A.M.; Pijl, A.; Carmo, J.B.; Lourenço, K.S.; Laanbroek, H.J.; Cantarella, H.; Kuramae, E.E. Nitrous oxide emission related to ammonia-oxidizing bacteria and mitigation options from N fertilization in a tropical soil. *Sci. Rep.* **2016**, *6*, 30349. [\[CrossRef\]](#) [\[PubMed\]](#)
44. Cantarella, H.; Otto, R.; Soares, J.R.; de Brito Silva, A.G. Agronomic efficiency of NBPT as a urease inhibitor: A review. *J. Adv. Res.* **2018**, *13*, 19–27. [\[CrossRef\]](#) [\[PubMed\]](#)
45. Wesołowska, M.; Rymarczyk, J.; Góra, R.; Baranowski, P.; Sławiński, C.; Klimczyk, M.; Supryn, G.; Schimmelpfennig, L. New slow-release fertilizers-economic, legal and practical aspects: A Review. *Int. Agrophys.* **2021**, *35*, 11–24. [\[CrossRef\]](#)
46. Kakabouki, I.; Folina, A.; Karydogianni, S. Fertilization expression via nitrogen indices in soybean crop under two system tillage. *Not. Bot. Horti Agrobot. Cluj-Napoca* **2020**, *48*, 799–813. [\[CrossRef\]](#)
47. Torralbo, F.; Menéndez, S.; Barrena, I.; Estavillo, J.M.; Marino, D.; González-Murua, C. Dimethyl pyrazol-based nitrification inhibitors effect on nitrifying and denitrifying bacteria to mitigate N₂O emission. *Sci. Rep.* **2017**, *7*, 13810. [\[CrossRef\]](#) [\[PubMed\]](#)
48. Wang, H.; Köbke, S.; Dittert, K. Use of urease and nitrification inhibitors to reduce gaseous nitrogen emissions from fertilizers containing ammonium nitrate and urea. *Glob. Ecol. Conserv.* **2020**, *22*, e00933. [\[CrossRef\]](#)
49. Rose, T.J.; Wood, R.H.; Rose, M.T.; Van Zwieten, L. A re-evaluation of the agronomic effectiveness of the nitrification inhibitors DCD and DMPP and the urease inhibitor NBPT. *Agric. Ecosyst. Environ.* **2018**, *252*, 69–73. [\[CrossRef\]](#)
50. Fast, A.; Strydhorst, S.; Wang, Z.; Hernandez-Ramirez, G.; Hao, X.; Semach, G.; Thompson, L.; Holzapfel, C.; Enns, J.; Spaner, D.; et al. Integrating enhanced efficiency fertilizers and nitrogen rates to improve Canada Western Red Spring wheat. *Can. J. Plant Sci.* **2023**, *104*, 144–160. [\[CrossRef\]](#)
51. Wang, X.; Xu, M.; Lin, B.; Bodirsky, B.L.; Xuan, J.; Dietrich, J.P.; Stevanovic, M.; Bai, Z.; Jin, S.; Fan, S.; et al. Reforming China's fertilizer policies: Implications for nitrogen pollution reduction and food security. *Sustain. Sci.* **2023**, *18*, 407–420. [\[CrossRef\]](#)
52. Ming, Y.; Ningxi, G.; Jiatong, Z.; Zhanhan, H.; Zixuan, C.; Di, S.; Hongtao, Z. Enhanced-efficiency nitrogen fertilizer provides a reliable option for mitigating global warming potential in agroecosystems worldwide. *Sci. Total Environ.* **2024**, *907*, 168080. [\[CrossRef\]](#)
53. Afshar, R.K.; Lin, R.; Mohammed, Y.A.; Chen, C. Agronomic effects of urease and nitrification inhibitors on ammonia volatilization and nitrogen utilization in a dryland farming system: Field and laboratory investigation. *J. Clean. Prod.* **2018**, *172*, 4130–4139. [\[CrossRef\]](#)
54. Swify, S.; Mažeika, R.; Baltrusaitis, J.; Drapanauskaitė, D.; Barčauskaitė, K. Review: Modified urea fertilizers and their effects on improving nitrogen use efficiency (NUE). *Sustainability* **2023**, *16*, 188. [\[CrossRef\]](#)
55. Stavropoulos, P.; Mavroeidis, A.; Folina, A.; Roussis, I.; Kallergi, S.; Karydogianni, S.; Papadopoulos, G.; Kakabouki, I. Effects of Plant Density and Fertilization on Agronomic Traits and Yield of Flax (*Linum usitatissimum* L.). *Plants* **2025**, *14*, 2891. [\[CrossRef\]](#)
56. Saggar, S.; Singh, J.; Giltrap, D.L.; Zaman, M.; Luo, J.; Rollo, M.; Kim, D.G.; Rys, G.; Van der Weerden, T.J. Quantification of reductions in ammonia emissions from fertiliser urea and animal urine in grazed pastures with urease inhibitors for agriculture inventory: New Zealand as a case study. *Sci. Total Environ.* **2013**, *465*, 136–146. [\[CrossRef\]](#)
57. Soumare, A.; Diedhiou, A.G.; Thuita, M.; Hafidi, M.; Ouhdouch, Y.; Gopalakrishnan, S.; Kouisni, L. Exploiting biological nitrogen fixation: A route towards a sustainable agriculture. *Plants* **2020**, *9*, 1011. [\[CrossRef\]](#)
58. Kohler, C.; Morvan-Bertrand, A.; Cliquet, J.B.; Klumpp, K.; Lemaufiel-Lavenant, S. Tradeoff between the conservation of soil C stocks and vegetation productivity in temperate grasslands. *Agronomy* **2020**, *10*, 1024. [\[CrossRef\]](#)
59. Arshdeep Singh, A.S.; Arun Kumar, A.K.; Anita Jaswal, A.J.; Maninder Singh, M.S.; Gaikwad, D.S. Nutrient use efficiency concept and interventions for improving nitrogen use efficiency. *Plant Arch.* **2018**, *18*, 1015–1023.
60. Gil-Ortiz, R.; Naranjo, M.Á.; Ruiz-Navarro, A.; Atares, S.; García, C.; Zotarelli, L.; San Bautista, A.; Vicente, O. Enhanced Agronomic Efficiency Using a New Controlled-Released, Polymeric-Coated Nitrogen Fertilizer in Rice. *Plants* **2020**, *9*, 1183. [\[CrossRef\]](#)
61. Messiga, A.J.; Dyck, K.; Ronda, K.; van Baar, K.; Haak, D.; Yu, S.; Dorais, M. Nutrients Leaching in Response to Long-Term Fertigation and Broadcast Nitrogen in Blueberry Production. *Plants* **2020**, *9*, 1530. [\[CrossRef\]](#)
62. Li, S.; Chen, G. Contemporary strategies for enhancing nitrogen retention and mitigating nitrous oxide emission in agricultural soils: Present and future. *Environ. Dev. Sustain.* **2020**, *4*, 2703–2741. [\[CrossRef\]](#)
63. Wei, X.; Bao, X.; Yu, L.; Liu, H.; Lu, K.; Chen, L.; Bai, L.; Zhou, X.; Li, Z.; Li, W. Correlation between gel strength of starch-based hydrogel and slow release behavior of its embedded urea. *J. Polym. Environ.* **2020**, *28*, 863–870. [\[CrossRef\]](#)

64. Duan, Q.; Jiang, S.; Chen, F.; Li, Z.; Ma, L.; Song, Y.; Yu, X.; Chen, Y.; Liu, H.; Yu, L. Fabrication, evaluation methodologies and models of slow-release fertilizers: A review. *Ind. Crops Prod.* **2023**, *192*, 116075. [\[CrossRef\]](#)
65. Kassem, I.; Ablouh, E.H.; El Bouchtaoui, F.Z.; Jaouahar, M.; El Achaby, M. Polymer coated slow/controlled release granular fertilizers: Fundamentals and research trends. *Prog. Mater. Sci.* **2024**, *144*, 101269. [\[CrossRef\]](#)
66. Beig, B.; Niazi, M.B.K.; Jahan, Z.; Hussain, A.; Zia, M.H.; Mehran, M.T. Coating materials for slow release of nitrogen from urea fertilizer: A review. *J. Plant Nutr.* **2020**, *43*, 1510–1533. [\[CrossRef\]](#)
67. Yang, X.; Geng, J.; Li, C.; Zhang, M.; Tian, X. Cumulative release characteristics of controlled-release nitrogen and potassium fertilizers and their effects on soil fertility, and cotton growth. *Sci. Rep.* **2016**, *6*, 39030. [\[CrossRef\]](#) [\[PubMed\]](#)
68. Qu, Z.; Qi, X.; Shi, R.; Zhao, Y.; Hu, Z.; Chen, Q.; Li, C. Reduced N fertilizer application with optimal blend of controlled-release urea and urea improves tomato yield and quality in greenhouse production system. *J. Soil Sci. Plant Nutr.* **2020**, *20*, 1741–1750. [\[CrossRef\]](#)
69. Clément, C.C.; Cambouris, A.N.; Ziadi, N.; Zebarth, B.J.; Karam, A. Potato Yield Response and Seasonal Nitrate Leaching as Influenced by Nitrogen Management. *Agronomy* **2021**, *11*, 2055. [\[CrossRef\]](#)
70. Gao, X.; Li, C.; Zhang, M.; Wang, R.; Chen, B. Controlled release urea improved the nitrogen use efficiency, yield and quality of potato (*Solanum tuberosum* L.) on silt loamy soil. *Field Crops Res.* **2015**, *181*, 60–68. [\[CrossRef\]](#)
71. Souza, E.F.; Soratto, R.P.; Sandaña, P.; Venterea, R.T.; Rosen, C.J. Split application of st54abilized ammonium nitrate improved potato yield and nitrogen-use efficiency with reduced application rate in tropical sandy soils. *Field Crops Res.* **2020**, *254*, 107847. [\[CrossRef\]](#)
72. Elrys, A.S.; El-Maati, M.F.A.; Abdel-Hamed, E.M.W.; Arnaout, S.M.; El-Tarabily, K.A.; Desoky, E.S.M. Mitigate nitrate contamination in potato tubers and increase nitrogen recovery by combining dicyandiamide, moringa oil and zeolite with nitrogen fertilizer. *Ecotoxicol. Environ. Saf.* **2021**, *209*, 111839. [\[CrossRef\]](#)
73. Vizirskaya, A.; Akanova, N.; Zhdanov, V.; Sherstobitov, S. The efficiency of application urea with urease inhibitor to increase potato yield. *E3S Web. Conf.* **2021**, *273*, 01006. [\[CrossRef\]](#)
74. Campbell, T.; Ruark, M.; Boswell, E.; Lowery, B. Enhanced efficiency fertilizers, potato production, and nitrate leaching in the Wisconsin Central Sands. *J. Environ. Qual.* **2025**, *54*, 397–409. [\[CrossRef\]](#)
75. Souza, E.F.C.; Rosen, C.J.; Venterea, R.T. Co-application of DMPSA and NBPT with urea mitigates both nitrous oxide emissions and nitrate leaching during irrigated potato production. *Environ. Pollut.* **2021**, *284*, 117124. [\[CrossRef\]](#)
76. Recio, J.; Montoya, M.; Ginés, C.; Sanz-Cobena, A.; Vallejo, A.; Alvarez, J.M. Joint mitigation of NH₃ and N₂O emissions by using two synthetic inhibitors in an irrigated cropping soil. *Geoderma* **2020**, *373*, 114423. [\[CrossRef\]](#)
77. Corrochano-Monsalve, M.; Bozal-Leorri, A.; Sánchez, C.; González-Murua, C.; Estavillo, J.M. Joint application of urease and nitrification inhibitors to diminish gaseous nitrogen losses under different tillage systems. *J. Clean. Prod.* **2021**, *289*, 125701. [\[CrossRef\]](#)
78. Zhang, N.; Luo, H.; Li, H.; Bao, M.; Liu, E.; Shan, W.; Ren, X.; Jia, Z.; Siddique, K.H.M.; Zhang, P. Maximizing potato tuber yields and nitrogen use efficiency in semi-arid environments by precision fertilizer depth application. *Eur. J. Agron.* **2024**, *156*, 127147. [\[CrossRef\]](#)
79. You, L.; Ros, G.H.; Chen, Y.; Zhang, F.; de Vries, W. Optimized agricultural management reduces global cropland nitrogen losses to air and water. *Nat. Food* **2024**, *5*, 995–1004. [\[CrossRef\]](#) [\[PubMed\]](#)
80. Cooper, M.; Voss-Fels, K.P.; Messina, C.D.; Tang, T.; Hammer, G.L. Tackling G × E × M interactions to close on-farm yield-gaps: Creating novel pathways for crop improvement by predicting contributions of genetics and management to crop productivity. *Theor. Appl. Genet.* **2021**, *134*, 1625–1644. [\[CrossRef\]](#)
81. Cabello, R.; Monneveux, P.; De Mendiburu, F.; Bonierbale, M. Comparison of yield based drought tolerance indices in improved varieties, genetic stocks and landraces of potato (*Solanum tuberosum* L.). *Euphytica* **2013**, *193*, 147–156. [\[CrossRef\]](#)
82. Xu, F.; Meng, A.; Liu, Y.; Li, J.; Wu, N. Effects of new special formula fertilizer on potato growth, yield, and fertilizer utilization efficiency. *Plants* **2025**, *14*, 627. [\[CrossRef\]](#)
83. Tessema, L.; Mohammed, W.; Abebe, T. Evaluation of potato (*Solanum tuberosum* L.) varieties for yield and some agronomic traits. *Open Agric.* **2020**, *5*, 63–74. [\[CrossRef\]](#)
84. Seid, E.; Tessema, L. Evaluation of tuber quality, yield and yield related traits of potato (*Solanum tuberosum* L.) genotypes at Holetta, Central Ethiopia. *CABI Agric. Biosci.* **2024**, *5*, 99. [\[CrossRef\]](#)
85. Liu, K.; Du, J.; Zhong, Y.; Shen, Z.; Yu, X. The response of potato tuber yield, nitrogen uptake, soil nitrate nitrogen to different nitrogen rates in red soil. *Sci. Rep.* **2021**, *11*, 22506. [\[CrossRef\]](#)
86. Pszczółkowski, P.; Sawicka, B.; Niazi, P.; Barbaś, P.; Krochmal-Marczak, B. Agroecological Determinants of Yield Performance in Mid-Early Potato Varieties: Evidence from Multi-Location Trials in Poland. *Land* **2025**, *14*, 1777. [\[CrossRef\]](#)
87. Fixen, P.; Brentrup, F.; Bruulsema, T.; Garcia, F.; Norton, R.; Zingore, S. Nutrient/fertilizer use efficiency: Measurement, current situation and trends. In *Managing Water and Fertilizer for Sustainable Agricultural Intensification*; Drechsel, P., Heffer, P., Magen, H., Mikkelsen, R., Wichelns, D., Eds.; International Fertilizer Industry Association (IFA): Paris, France, 2015; pp. 1–30.

88. Ernst, O.R.; Kemanian, A.R.; Mazzilli, S.; Siri-Prieto, G.; Dogliotti, S. The dos and don'ts of no-till continuous cropping: Evidence from wheat yield and nitrogen use efficiency. *Field Crops Res.* **2020**, *257*, 107934. [\[CrossRef\]](#)
89. Erisman, J.W.; Leach, A.; Bleeker, A.; Atwell, B.; Cattaneo, L.; Galloway, J. An integrated approach to a nitrogen use efficiency (NUE) indicator for the food production–consumption chain. *Sustainability* **2018**, *10*, 925. [\[CrossRef\]](#)
90. Martinez-Feria, R.A.; Castellano, M.J.; Dietzel, R.N.; Helmers, M.J.; Liebman, M.; Huber, I.; Archontoulis, S.V. Linking crop-and soil-based approaches to evaluate system nitrogen-use efficiency and tradeoffs. *Agric. Ecosyst. Environ.* **2018**, *256*, 131–143. [\[CrossRef\]](#)
91. Congreves, K.A.; Otchere, O.; Ferland, D.; Farzadfar, S.; Williams, S.; Arcand, M.M. Nitrogen use efficiency definitions of today and tomorrow. *Front. Plant Sci.* **2021**, *12*, 637108. [\[CrossRef\]](#) [\[PubMed\]](#)
92. Mălinaş, A.; Vidican, R.; Rotar, I.; Mălinaş, C.; Moldovan, C.M.; Proorocu, M. Current status and future prospective for nitrogen use efficiency in wheat (*Triticum aestivum* L.). *Plants* **2022**, *11*, 217. [\[CrossRef\]](#) [\[PubMed\]](#)
93. Danielescu, S.; Cannon, A.J.; Shrestha, R.; Kröbel, R.; Agomoh, I.; Nyiraneza, J. Impact of past and future climate change on crop yield, nitrate leaching and nitrous oxide emissions associated with potato rotation in temperate climate. *J. Agric. Food Res.* **2025**, *21*, 101919. [\[CrossRef\]](#)
94. Kemmou, L.; Amanatidou, E. Factors affecting nitrous oxide emissions from activated sludge wastewater treatment plants—A review. *Resources* **2023**, *12*, 114. [\[CrossRef\]](#)
95. Signor, D.; Cerri, C.E.P. Nitrous oxide emissions in agricultural soils: A review. *Pesqui. Agropecu. Trop.* **2013**, *43*, 322–338. [\[CrossRef\]](#)
96. Kagan, K.; Jonak, K.; Wolińska, A. The Impact of Reduced N Fertilization Rates According to the “Farm to Fork” Strategy on the Environment and Human Health. *Appl. Sci.* **2024**, *14*, 10726. [\[CrossRef\]](#)
97. Alfaro, M.; Hube, S.; Salazar, F.; Beltrán, I.; Ramírez, L.; Saggat, S. Optimising Nitrogen Fertilisation in a Potato–Oat Rotation and Implications for Nitrous Oxide Emissions in Volcanic Soils. *Agronomy* **2024**, *14*, 2202. [\[CrossRef\]](#)
98. Jiang, H.; Geng, D.; Fu, J.; Liu, M.; Qi, Y.; Min, L.; Shen, Y. Quantifying nitrate dynamics in deep vadose zone under irrigated farmland in the North China Plain: Insights from continuous in-situ monitoring. *Agric. Ecosyst. Environ.* **2026**, *396*, 109956. [\[CrossRef\]](#)
99. Rashti, M.R.; Wang, W.; Moody, P.; Chen, C.; Ghadiri, H. Fertiliser-induced nitrous oxide emissions from vegetable production in the world and the regulating factors: A review. *Atmos. Environ.* **2015**, *112*, 225–233. [\[CrossRef\]](#)
100. Wang, C.; Cheng, K.; Ren, C.; Liu, H.; Sun, J.; Reis, S.; Yin, S.; Xu, J.; Gu, B. An empirical model to estimate ammonia emission from cropland fertilization in China. *Environ. Pollut.* **2021**, *288*, 117982. [\[CrossRef\]](#) [\[PubMed\]](#)
101. Boldsai Khan, O.; Im, E.C.; Lee, J.I.; Lee, C.G.; Park, S.J. Field Evaluation of Ammonia Emissions, Yield Performance, and Profitability under Four Nitrogen Fertilizers in Vegetable Cultivation. *Atmos. Pollut. Res.* **2025**, *17*, 102773. [\[CrossRef\]](#)
102. Gu, J.; Yuan, M.; Liu, J.; Hao, Y.; Zhou, Y.; Qu, D.; Yang, X. Trade-off between soil organic carbon sequestration and nitrous oxide emissions from winter wheat–summer maize rotations: Implications of a 25-year fertilization experiment in Northwestern China. *Sci. Total Environ.* **2017**, *595*, 371–379. [\[CrossRef\]](#)
103. Li, T.; Zhang, W.; Yin, J.; Chadwick, D.; Norse, D.; Lu, Y.; Liu, X.; Chen, X.; Zhang, F.; Dou, Z. Enhanced-efficiency fertilizers are not a panacea for resolving the nitrogen problem. *Glob. Change Biol.* **2018**, *24*, e511–e521. [\[CrossRef\]](#)
104. Liu, C.; Li, B.; Wu, Q.; Chen, D.; Zhou, W.; Ao, J. The effects and mechanism of urease inhibitor and its combination with nitrification inhibitor on nitrous oxide emission across four soil types. *Front. Plant Sci.* **2025**, *16*, 1663261. [\[CrossRef\]](#)
105. Corrochano-Monsalve, M.; Beeckman, F.; Bozal-Leorri, A.; Motte, H.; Maestre, F.T. Nitrification Inhibition: Uncertainties and Opportunities for Sustainable Agriculture. *Eur. J. Soil Sci.* **2025**, *76*, e70218. [\[CrossRef\]](#)
106. da Costa Leite, R.; Leal, A.J.F.; Piat, G.L.; Vendruscolo, E.P.; Barreto, R.F.; de Lima, S.F.; Zoz, T.; Kaneko, H.F.; Zanella, M.S. The economic viability of the use of urea with urease inhibitor in cotton grown in the Cerrado of Central Brazil. *Biocatal. Agric. Biotechnol.* **2023**, *50*, 102724. [\[CrossRef\]](#)
107. Wang, W.; Li, Y.; Wang, W.; Ding, K.; Zhang, K.; Zhang, Y.; Liu, K.; Li, J.; Lian, R.; Li, D.; et al. Global Meta-Analysis of Individual and Combined Nitrogen Inhibitors: Enhancing Plant Productivity and Reducing Environmental Losses. *Glob. Change Biol.* **2024**, *30*, 2. [\[CrossRef\]](#)
108. Wang, X.; Forrester, P.J.; Richards, K.; Matse, D.T.; Cummins, E. Nitrification and urease inhibitors (NUIs) in soil and water: Environmental fate, distribution, and risk assessment. *Sci. Total Environ.* **2025**, *1004*, 180796. [\[CrossRef\]](#)
109. Peters, N.; Thiele-Bruhn, S. Major metabolites of NBPT degradation pathways contribute to urease inhibition in soil. *Chemosphere* **2022**, *303*, 135163. [\[CrossRef\]](#) [\[PubMed\]](#)
110. Azam, F.; Benckiser, G.; Müller, C.; Ottow, J. Release, movement and recovery of 3, 4-dimethylpyrazole phosphate (DMPP), ammonium, and nitrate from stabilized nitrogen fertilizer granules in a silty clay soil under laboratory conditions. *Biol. Fertil. Soil.* **2001**, *34*, 118–125. [\[CrossRef\]](#)
111. Engel, R.E.; Williams, E.; Wallander, R.; Hilmer, J. Apparent persistence of N-(n-butyl) thiophosphoric triamide is greater in alkaline soils. *Soil Sci. Soc. Am. J.* **2013**, *77*, 1424–1429. [\[CrossRef\]](#)

112. Dawadi, S.; Baysal-Gurel, F.; Addesso, K.M.; Oliver, J.B.; Simmons, T. Impact of cover crop usage on soilborne diseases in field nursery production. *Agronomy* **2019**, *9*, 753. [[CrossRef](#)]
113. Ma, J.; Yin, B.; Gao, T.; He, K.; Huang, X.; Jiang, T.; Zhen, W. Legume–non-legume cover crop mixtures enhance soil nutrient availability and physical properties: A meta-analysis across Chinese agroecosystems. *Agronomy* **2025**, *15*, 1756. [[CrossRef](#)]
114. Yan, F.; Arthur, E. Cover crops alter soil physicochemical properties: A global meta-analysis. *Geoderma* **2025**, *460*, 117436. [[CrossRef](#)]
115. Tonitto, C.; David, M.Á.; Drinkwater, L.E. Replacing bare fallows with cover crops in fertilizer-intensive cropping systems: A meta-analysis of crop yield and N dynamics. *Agric. Ecosyst. Environ.* **2006**, *112*, 58–72. [[CrossRef](#)]
116. Hou, X.; Li, R. Interactive effects of autumn tillage with mulching on soil temperature, productivity and water use efficiency of rainfed potato in loess plateau of China. *Agric. Water Manag.* **2019**, *224*, 105747. [[CrossRef](#)]
117. Shubha, G.V.; Chittapur, B.M.; Veeresh, H. Nutrient expert and soil test crop response assisted site specific nutrient management: An alternative precision fertilization technology for direct seeded rice under tungabhadra irrigation command. *Int. J. Pure Appl. Biosci.* **2018**, *6*, 71–76. [[CrossRef](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.