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A Review of the Chemistry of Urea Fertilizers ($CO(NH_2)_2$) and Chlorpyrifos Pesticides ($C_9H_{11}Cl_3NO_3PS$) in Agricultural Education

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Abstract: *Chlorpyrifos pesticides have been linked to neurodevelopmental issues in children and potential carcinogenic properties in adults and the excessive use of both chlorpyrifos and urea fertilizers may result in soil acidification, which lowers soil fertility and affects crop yields, threatening global food security. Sustainable agricultural practices are crucial to address these concerns. This systematic review aims to comprehensively analyze the chemistry of urea fertilizers* ($CO(NH_2)_2$) *and chlorpyrifos pesticides* ($C_9H_{11}Cl_3NO_3PS$) *in the context of agricultural education. The study covers various aspects including their chemical properties, synthesis, formulation, application, environmental impact, and regulatory considerations. Molecular structures, composition, synthesis methods, and physical-chemical properties such as solubility and stability were examined alongside their effects on the environment and the regulatory guidelines for safe use in agriculture. This study emphasizes the urgent requirement for remedial measures, including proper use of Chlorpyrifos herbicide, urea fertilizers, and their roles in sustainable agricultural practices.*

Keywords: urea fertilizers, chlorpyrifos pesticides, agriculture, chemistry, synthesis, environmental impact

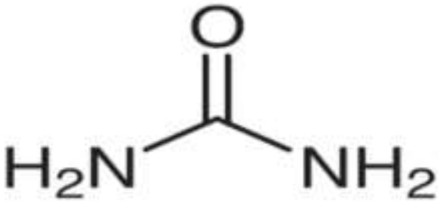
INTRODUCTION

Urea fertilisers ($CO(NH_2)_2$) and chlorpyrifos pesticides ($C_9H_{11}Cl_3NO_3PS$) are critical components of modern agriculture due to their efficiency in increasing crop yields and controlling pest populations. Urea, a nitrogen-based fertiliser, is highly regarded for its high nitrogen content and low cost, making it a popular choice for farmers around the world (Naz, 2023 &Vaia, 2024). It is produced by reacting ammonia (NH3) with carbon dioxide (CO2) at high pressure and temperature, resulting in a product that is a quickly available source of nitrogen for plants. Urea's chemical features, such as its high solubility and stability, help to explain its widespread application in diverse agricultural systems (Swify, 2022). Chlorpyrifos, on the other hand, is an organophosphate insecticide that is widely used in agricultural production to control a variety of pests, including insects and mites (EPA, 2024). Its efficacy originates from its mechanism of action, which involves blocking acetylcholinesterase, an enzyme required for nerve function in insects, resulting in their death. Chlorpyrifos is noted for its broad-spectrum activity and inexpensive cost, making it a popular pest control option in agriculture. Chlorpyrifos' chemical features, such as moderate water solubility and stability, ensure its persistence in the environment, offering long-term protection against pests (Echa, 2023). The value of urea fertilisers and chlorpyrifos herbicides in agriculture cannot be emphasized. Urea fertilisers perform an important function in providing plants with necessary nitrogen, a nutrient required for growth and development. Nitrogen is an essential component of chlorophyll, the photosynthesis molecule, as well as the creation of amino acids, proteins, and nucleic acids (Mosaic, 2024). As a result, the use of urea fertilisers can greatly increase crop yields and improve agricultural product quality. However, excessive urea use can cause environmental difficulties such as soil acidification, nitrogen leaching, and greenhouse gas emissions such as nitrous oxide (N_2O), all of which contribute to global warming (Guo et al, 2024 & Hassan et al. 2022). Similarly, chlorpyrifos insecticides are critical for controlling pest populations and protecting crop health. By effectively eliminating pests, chlorpyrifos helps to reduce crop losses and preserve high yields. This is especially significant in areas where insect infestations can have a severe impact on agricultural productivity (Tudi *et al.*, 2021). Despite its benefits, chlorpyrifos use raises a number of environmental and health problems. Chlorpyrifos has been associated to neurodevelopmental problems in children and possible carcinogenic qualities in adults (Gama *et al.*, 2022). Furthermore, its persistence in the ecosystem can contaminate soil and water, endangering non-target creatures such as beneficial insects, wildlife, and humans (Wolejko *et al.*, 2022 & PAN, 2024). The environmental impact of urea fertiliser and chlorpyrifos pesticides is a major source of worry. Excessive use of urea fertilisers can cause soil acidification, reducing soil fertility and lowering crop yields (Naz, 2023). Furthermore, nitrogen leaking from urea can contaminate groundwater and surface water, causing eutrophication and destroying aquatic ecosystems. The volatilisation of ammonia from urea produces nitrous oxide, a strong greenhouse gas that contributes to climate change (Wang et al. 2023).

Chlorpyrifos insecticides represent significant environmental concerns due to their persistence and bioaccumulation. Their leftovers can remain in soil and water for long periods of time, contaminating natural resources. The influence on non-target species, such as beneficial insects like pollinators and natural pest predators, has the potential to disturb ecological balances and diminish biodiversity. Furthermore, chlorpyrifos' propensity to produce neurodevelopmental difficulties and carcinogenic effects raises serious public health concerns (Juntarawijit, 2020). This review seeks to answer the following research issues and objectives: What are the chemical qualities, molecular structures, compositions, synthesis processes, and physical-chemical characteristics of urea fertilisers and chlorpyrifos pesticides? What is the environmental impact of urea fertilizers and chlorpyrifos pesticides, including their effects on soil fertility, crop yields, and potential links to neurodevelopmental issues? What are the regulatory considerations and guidelines for the safe use of urea fertilizers and chlorpyrifos pesticides in agriculture, and identify areas for improvement? How can remedial measures and sustainable agricultural practices, including proper use of urea fertilizers and chlorpyrifos pesticides, be addressed to ease the threats to global food security and environmental sustainability? The primary goals are to thoroughly examine the chemical properties of urea fertilisers and chlorpyrifos pesticides, assess their environmental impact, investigate regulatory considerations, and emphasise the importance of corrective measures and sustainable agricultural practices (Smith & Brown, 2020; Silva & Lima, 2020). This review will provide a thorough understanding of the chemistry and environmental implications of urea fertilisers and chlorpyrifos pesticides, as well as information on regulatory frameworks and sustainable agriculture practices. The findings will be critical in guiding future research, policymaking, and practical applications in agricultural education and practice.

Structure of Urea

Urea maintains a planar geometry, meaning all of its atoms lie in the same plane. It is characterized by covalent bonds, where electrons are shared between atoms, resulting in nonpolar bonds between carbon and oxygen, as well as carbon and nitrogen (Kumar, 2023). The International Union of Pure and Applied Chemistry (IUPAC) name for urea is diamidomethanal or carbonyldiamide.



Source: Kumar (2023)

Physical Properties of Urea

Property	Value
Chemical/Molecular formula	**C_2NH_4O**
Molar mass:	60.06 g/mol.
Appearance:	Colorless to white crystalline solid.
Density:	1.32 g/cm³.
Melting point:	134°C.
Solubility:	Easily soluble in water and alcohol.
Odor:	Odorless.
Solubility	**In**soluble in ethane.
Basicity	Weak base.

(Kumar, 2023)

Chemical Properties of Urea

The molecular structure of urea features a central carbon atom double-bonded to an oxygen atom and single-bonded to two amine groups (NH_2). Urea is typically synthesized through the Haber-Bosch process, which involves the reaction of ammonia (NH_3) and carbon dioxide (CO_2) under high temperatures and pressures. The chemical equation for this synthesis is:

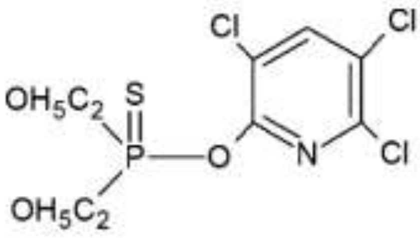
$$2NH_3 + CO_2 \text{--->} (NH_2)_2CO + H_2O$$

This method is favored for its efficiency and cost-effectiveness in producing large quantities of urea for agricultural applications (Sellars, 2021 & Czarnobai et al., 2021). Urea's physicochemical properties include high solubility in water, allowing for rapid dissolution and availability to plants. It is relatively stable, with a melting point of 133°C and decomposition beginning around 135°C. Upon application to soil, urea undergoes hydrolysis catalyzed by the enzyme urease, resulting in the formation of ammonia (NH_3) and carbon dioxide (CO_2), which are then converted to ammonium ions (NH_{4+}) and bicarbonate (HCO^{3-}), readily absorbed by plants (Daisi *et al.*, 2024). Urea fertilizers (C_2NH_4O) are renowned for their high nitrogen content, approximately 46% nitrogen, which is essential for promoting plant growth. This high nitrogen content is critical for plant growth, as nitrogen is an essential component of amino acids, proteins, and nucleic acids. Efficient nitrogen absorption from urea promotes vegetative growth and crop yields, which is crucial for meeting the food demands of a growing global population (Mustafa *et al.*, 2022). High solubility of urea in water, facilitates rapid nutrient availability but also raises concerns about nitrogen leaching and volatilization (Swify *et al.*, 2024). The industrial synthesis of urea involves the reaction of ammonia with carbon dioxide, a process that produces a highly effective nitrogen source but is also associated with environmental issues such as soil acidification and nitrogen loss

(Swify *et al.*, 2024). Innovations in slow-release formulations aim to mitigate these concerns by controlling the release of nitrogen, thereby enhancing nutrient use efficiency and reducing environmental impacts (Rajan *et al.*, 2021).

Properties of Chlorpyrifos

Structure of Chlorpyrifos: Chlorpyrifos has a phosphorus atom bonded to two ethoxy groups (C_2H_5O) and one oxygen atom which is in turn bonded to a pyridyl ring substituted with chlorine atoms at the 3rd, 5th, and 6th positions. **Chemical Name:** O,O-Diethyl O-(3,5,6-trichloro-2-pyridyl) phosphorothioate



Source: Njewa et al., (2023).

Physical Properties of Chlorpyrifos

Property	Value
Chemical formula	**$C_9H_{11}Cl_3NO_3PS$**
Molar mass:	350.6 g/moL
Appearance:	Colorless to light brown liquid
Density:	1.42 g/cm3
Melting point:	42-43°C (107-109°F)
Boiling point	153-155°C (307-311°F)
Solubility:	Easily soluble in water and alcohol.
Odor:	Mild, ester-like odor
Solubility	Insoluble in water but Soluble in organic solvents
Vapour Pressure	2.3 × 10^(-5) mmHg at 25°C

Source: Njewa et al., (2023).

Chemical Properties of Chlorpyrifos

chlorpyrifos ($C_9H_{11}Cl_3NO_3PS$) is an organophosphorus insecticide noted for its stability and fat solubility, which contribute to its persistence in the environment (National Centre for Biotechnology Information, 2024). Chlorpyrifos exhibits several chemical properties that influence its environmental fate and toxicological profile. It has low water solubility (1.4 mg/L at 25°C), high partition coefficient (log Kow = 4.7), and moderate vapor pressure (1.87 x 10^{-5} mm Hg at 25°C), indicating its potential for bioaccumulation and persistence in the environment (National Library of Medicine, 2024).The synthesis of chlorpyrifos involves the reaction of 3,5,6-trichloro-2-pyridinol with diethyl phosphorochloridothioate, producing a compound with high purity and yield under controlled conditions (European Chemicals Agency, 2024). Advances in synthetic methods have improved production efficiency, although the core chemical processes remain consistent. Chlorpyrifos is used in various formulations, including emulsifiable concentrates, but its chemical stability raises concerns about its long-term environmental impact and potential harm to non-target organisms (Njewaa et al., 2023; European Chemicals Agency, 2024). Njewaa et al. (2023) emphasize that the presence of chlorine atoms enhances its lipophilicity, facilitating its absorption through insect cuticles and increasing its insecticidal activity. O'Connor et al. (2023) discuss the role of the phosphorothioate group in its biological activity, noting that it undergoes bioactivation to form chlorpyrifos-oxon, a potent inhibitor of acetylcholinesterase. In addition, there is need for safer alternatives due to chlorpyrifos's association with neurodevelopmental abnormalities and its persistence in soil and water (Saraiva et al., 2024; Yang et al., 2023).

Environmental Impacts of Urea

The environmental impact of urea fertilizers is profound, with excessive use leading to soil acidification, alteration of soil microbial populations, and water contamination. The use of urea fertilizers presents environmental challenges. Excessive application can lead to nitrogen leaching into water bodies, causing eutrophication and diminishing oxygen levels, which harm aquatic life. Additionally, ammonia volatilization from urea contributes to air pollution and particulate matter formation, posing health risks to humans and animals. Rapid hydrolysis of urea in soil can reduce soil fertility and structure (Skorupka & Nosalewicz, 2021; Ramalingappa et al., 2023). Barreras-Urbina et al. (2023) found that high nitrogen levels diminish microbial health. This issue is exacerbated by nitrogen leaching and runoff, leading to water pollution (Ayiti & Babalola, 2022). Best management practices, such as precision application techniques and nitrification inhibitors, are recommended to prevent nitrogen losses and minimize environmental impact (Banger et al., 2020). Given these environmental concerns, there is an increasing focus on adopting more sustainable agricultural practices. Controlled-release urea fertilizers, such as those coated with polymers or sulfur, are being developed to reduce nitrogen losses and improve nitrogen use efficiency. These technologies aim to release nitrogen gradually, aligning with crop nutrient uptake patterns while minimizing environmental contamination (Mansouri et al., 2023).

Effects of Urea Fertilizers on Soil Chemistry and Fertility

Urea fertilizers significantly impact soil chemistry and fertility due to their high nitrogen content. Upon application, urea undergoes hydrolysis catalyzed by urease, producing ammonia ($NH3$) and carbon dioxide ($CO2$), temporarily elevating soil pH before ammonia converts to ammonium

(NH4+) (Fisher et al., 2017). This increases soil nitrogen, vital for plant growth and enhancing crop yields, particularly in nitrogen-deficient soils (Mustafa et al., 2022). However, rapid urea hydrolysis can result in nitrogen losses through ammonia volatilization, reducing fertilizer efficiency and contributing to environmental issues such as acid rain (Sigurdarson et al., 2018). Continuous urea use may also lead to soil acidification due to ammonium oxidation during nitrification, lowering soil pH and nutrient availability while increasing toxic metal solubility (Huang et al., 2023). Excessive urea can cause nitrogen leaching, contaminating water bodies and leading to eutrophication (Lockhart & Wiseman, 2023). To mitigate these effects, controlled-release urea fertilizers release nitrogen slowly, reducing losses and synchronizing with crop uptake (Mustafa et al., 2022). Integrating urea with sustainable practices like crop rotation and organic amendments can further enhance soil fertility and minimize environmental impact (Koudahe et al., 2022).

Environmental Impacts of Chlorpyrifos

Chlorpyrifos poses significant environmental hazards, including soil and water contamination. Its persistence in the environment adversely affects aquatic organisms and soil microbiota. Njewaa et al., (2023) demonstrated that chlorpyrifos exposure can harm non-target species and impair ecosystem services. Nguyen et al., (2023) argue that reducing chlorpyrifos use and developing safer alternatives are critical to addressing these environmental risks. These findings emphasize the necessity of comprehensive environmental policies related to pesticide use.

Effects of Chlorpyrifos Pesticides on Environmental Health and Safety

Environmental Persistence and Degradation

Chlorpyrifos is well-known for its environmental persistence, which is attributed in large part to its chemical stability and low water solubility. Wang et al. (2022) found that chlorpyrifos can remain in soil and sediments for long periods of time, with half-lives ranging from weeks to months, depending on environmental conditions. Its persistence is affected by pH, temperature, and microbial activity. Chlorpyrifos breakdown occurs primarily by photolysis, hydrolysis, and microbial degradation. In alkaline circumstances, hydrolysis is more rapid, yielding 3,5,6-trichloro-2-pyridinol, which is hazardous and persistent in the environment (Wang et al., 2022). Photolysis, aided by sunshine, destroys chlorpyrifos on exposed surfaces, whereas microbiological degradation requires specialised bacteria capable of metabolising organophosphates, lowering their environmental impact (Tudi et al., 2023).

Bioaccumulation and Ecotoxicity

The high partition coefficient of chlorpyrifos indicates a large potential for bioaccumulation in aquatic organisms. According to Njewaa et al. (2023), chlorpyrifos can accumulate in the tissues of fish and other aquatic species, posing a risk to higher trophic levels via biomagnification. The compound's intermediate vapour pressure allows for volatilisation and atmospheric transport, resulting in widespread environmental distribution and potential non-target exposure. The ecotoxicological effects of chlorpyrifos are widely known. O'Connor et al. (2023) emphasise its acute toxicity to non-target animals, such as beneficial insects, birds, and aquatic life. Chlorpyrifos disturbs the neurological system by inhibiting acetylcholinesterase, which causes neurotoxic effects that can be lethal at large doses. Chronic exposure, even at low levels, can have sub-lethal consequences for wildlife, such as reproductive and developmental abnormalities.

Human Health Implications

Chlorpyrifos poses significant human health risks, particularly its neurotoxic effects. Sass (2022) highlights its potential to cause developmental neurotoxicity in children, linking prenatal and early-life exposures to cognitive impairments and behavioral issues. This has led to increased regulatory scrutiny and restrictions in many countries. The US Environmental Protection Agency (EPA) has banned chlorpyrifos on food crops due to health risks (Sass, 2022), while the European Union has implemented strict regulations to protect human health and the environment (European Chemicals Agency, 2024). Research by Njewaa et al. (2023) and O'Connor et al. (2023) underscores the importance of chlorpyrifos' chemical properties, such as hydrophobicity and phosphorothioate group, in its insecticidal efficacy and environmental persistence. Wang et al. (2022) and Tudi et al. (2023) discuss its environmental degradation and bioaccumulation, emphasizing the need for effective mitigation strategies.

The safe use of urea fertilizers and chlorpyrifos pesticides in Agricultural education

As pointed out in sustainable practices in agricultural applications. Despotović et al. (2019) advocate for the adoption of Integrated Pest Management (IPM) and precision agriculture to optimize input use and reduce environmental impact. Rashwin and Sanjeeth (2023) stress the importance of farmer education and training programs to promote the effective use of fertilizers and pesticides, thereby enhancing sustainability and minimizing negative outcomes.

Standard Appropriate Use of Urea and Chlorpyrifos

The proper and safe use of urea fertilisers and chlorpyrifos pesticides is essential for increasing agricultural output while reducing environmental and health concerns. Both chemicals have important functions in contemporary agriculture, but their misuse can have serious effects. This section describes the conventional techniques for their implementation based on recent research and regulatory recommendations.

Urea Fertilizers

Urea, with a nitrogen content of roughly 46%, is the most commonly used nitrogen fertiliser worldwide (Zhang et al., 2020). To avoid environmental difficulties such as soil acidification and nitrogen loss, it must be used properly. Proper application time is critical, as urea should be administered while crops are actively developing and can use nitrogen efficiently (Bremner, 2019). Avoiding application during heavy rainfall or on frozen soil reduces nitrogen runoff and volatilisation, which can pollute the ecosystem (Guo et al., 2022). Incorporating urea into the soil or utilising urease inhibitors can reduce nitrogen loss and improve fertiliser efficiency (Guo et al., 2022). Soil testing is critical for identifying the appropriate amount of urea depending on soil nutrient levels and crop needs. This method helps to prevent over-fertilization, which can induce soil acidity and reduce soil fertility (Li et al., 2020). Furthermore, split applications, in which urea is administered in various doses throughout the growing season, can boost plant nitrogen uptake while reducing environmental concerns (Sweeney et al., 2023).

Chlorpyrifos Pesticides

Chlorpyrifos, an organophosphate pesticide, is widely used to control pests in many crops. However, its use must be carefully monitored due to concerns about potential health effects and environmental damage. To avoid overuse and environmental pollution, chlorpyrifos should be used according to prescribed rates and timings (Rodríguez-Liébana et al., 2021). Proper calibration of spraying equipment guarantees accurate dosing and reduces pesticide drift and runoff (Peshin et al., 2022). The use of chlorpyrifos should be consistent with Integrated Pest Management (IPM) strategies that emphasise minimising reliance on chemical pesticides through biological control, crop rotation, and resistant crop types (Peshin et al., 2022). This strategy promotes long-term pest population management and lowers the risk of chemical resistance. Recent research has highlighted the need for strict controls to govern chlorpyrifos use due to its potential neurodevelopmental and carcinogenic impacts (Rauh et al., 2021). Many regions have imposed limitations or bans on chlorpyrifos, emphasising the necessity of maintaining up to date on current rules and investigating safer alternatives (EFSA, 2019. Biopesticides and organic farming, for example, can provide effective pest management while reducing health and environmental concerns (FAO, 2022).

Agricultural Applications and Impacts of Urea Fertilizers

Urea fertilizers play a critical role in modern agriculture, significantly increasing crop yields due to their high nitrogen content, solubility, and affordability. Urea is the most widely used nitrogen fertilizer globally, accounting for over half of all nitrogen fertilizers in agriculture (Jiang et al., 2024). With a high nitrogen concentration of about 46%, urea effectively provides essential nutrients to crops. It can be applied directly to the soil or as a foliar feed, timed to match specific crop growth stages, thereby maximizing nitrogen uptake and promoting healthy plant development. The effectiveness of urea application depends on soil pH, temperature, and moisture content. Urea hydrolysis in the soil, catalyzed by the enzyme urease, produces ammonia and carbon dioxide. If not managed properly, this can result in nitrogen losses through volatilization. Hence, agricultural education emphasizes proper management practices, such as incorporating urea into the soil or using urease inhibitors to reduce nitrogen losses (da Fonseca et al., 2023). Urea hydrolyzes to form ammonium carbonate, which soil microorganisms convert to nitrate, making nitrogen available to plants and enhancing growth in various cropping systems (Ma et al., 2019; Mustafa et al., 2022). However, significant nitrogen losses can occur through volatilization, leaching, and denitrification. Ammonia volatilization contributes to air pollution and poor air quality, while nitrogen leaching into groundwater can cause eutrophication, leading to algal blooms and ecosystem disruptions (Wyer et al., 2022; EPA, 2024). These challenges necessitate the need for effective nitrogen management strategies to mitigate the adverse impacts of urea use.

Agricultural Applications and Impacts of Chlorpyrifos Pesticides

Chlorpyrifos' broad-spectrum efficacy makes it popular in various crops, including fruits, vegetables, and grains. Its application methods for soil treatment, foliar spraying, and seed treatment offer flexible pest management (Dittmar et al., 2023). Agricultural education emphasizes proper application rates and timing to maximize efficacy while minimizing risks. However, chlorpyrifos poses significant health risks. Exposure is linked to neurodevelopmental issues in children and possible carcinogenic effects in adults (EarthJustice, 2024). Regulatory scrutiny has led to restrictions, such as the European Union's 2020 ban (ECHA, 2020). Education stresses integrated pest management (IPM) to reduce chemical dependency (Tudi et al., 2021). Additionally, chlorpyrifos affects non-target species, including pollinators, disrupting pollination and biodiversity (Leska et al., 2021). Chronic exposure is linked to cognitive and behavioral deficits in children (Khan et al., 2019 & Cancino et al., 2023). Residues in the environment and food chain further heighten human health risks (Njewaa et al., 2023).

Safety Precautions for Urea and Chlorpyrifos in Agriculture

Urea fertilizers and chlorpyrifos pesticides are crucial for agriculture but pose environmental and health risks if not managed properly. Urea fertilizers enhance crop yields but can lead to pollution and degradation, while chlorpyrifos is effective for pest control but threatens non-target species and human health (FAO, 2022). Regulatory systems like those from the EPA and FAO are essential for safe application. Agricultural education should cover these regulations, ensuring compliance and promoting safer practices (EPA, 2023). Sustainable approaches like precision farming, organic farming, and biopesticides offer viable alternatives. Precision farming optimizes input use, reducing waste and environmental impact (ES, 2022). Therefore, integrating these methods into education equips future professionals with the skills for sustainable practices. Proper management and education on urea and chlorpyrifos use can mitigate their adverse effects, promoting both productivity and safety.

The need for remedial measures and sustainable agricultural practices

The study's findings on urea fertilisers and chlorpyrifos insecticides have important implications for sustainable agricultural practices in line with the Sustainable Development Goals (SDGs), notably those connected to poverty eradication (SDG 1) and food security (SDG 2). Sustainable agriculture methods are critical for reducing the negative environmental and health effects of toxic chemicals while supporting economic stability and food security.

Environmental Sustainability and Food Security

Excessive use of urea fertilizers can cause soil acidification and nutrient imbalances, reducing soil health and crop production. Promoting balanced fertilizer application and soil amendments can ensure long-term crop production (Ayamba et al., 2023). Sustainable soil health management is critical for food security as it directly impacts crop yields. Chlorpyrifos' environmental persistence threatens water supplies, non-target species, and biodiversity (Tudi et al., 2021). Adopting integrated pest management (IPM) strategies reduces chemical pesticide dependence, mitigating environmental contamination and boosting biodiversity (EPA, 2023). IPM practices like biological control and crop rotation are vital for sustainable pest management and ecological balance.

Economic Sustainability and Poverty Eradication

The SDG agenda emphasizes economic sustainability and poverty reduction through increased agricultural productivity and profitability (UNDP, 2024; Gil et al., 2019). Efficient use of urea fertilizers and chlorpyrifos pesticides can boost crop yields and lower production costs, enhancing farm incomes and economic stability. However, overreliance on these inputs can raise costs and cause environmental harm. Agricultural extension services and educational programs can teach best management practices and sustainable alternatives, optimizing input use and reducing costs. Precision agriculture technologies enhance efficiency, reducing waste and increasing profits (Brandon, 2024). These practices boost agricultural profitability and contribute to rural economic development, reducing poverty.

Health Implications and Social Sustainability

Health hazards linked to chlorpyrifos include neurodevelopmental difficulties in children and potential carcinogenic effects in adults (EarthJustice, 2024). Reducing exposure to toxic pesticides through safer alternatives and regulations is crucial for human health and social sustainability. Educating farmers on pesticide safety can decrease health risks and improve community well-being. Increasing the use of organic and biopesticides aligns with the SDGs by promoting safer farming practices (FAO, 2024; Fanibo et al., 2021). Organic practices not only protect human health but also support environmental sustainability and biodiversity.

Regulatory and Policy Implications

Effective regulatory frameworks are essential for guiding the safe use of agricultural inputs and promoting sustainable practices. The study unravel the need for robust regulations to control the use of urea fertilizers and chlorpyrifos pesticides, ensuring compliance with safety standards and minimizing environmental and health risks (EFSA, 2019). Policymakers must develop and enforce regulations that balance agricultural productivity with environmental protection and public health. Furthermore, policies that encourage research and development of sustainable farming technologies and practices are critical. Investment in agricultural research can result in advances in fertiliser and pesticide use, improving sustainability and resilience in the face of climate change and other issues (Guo et al., 2022). Collaboration among governments, research institutions, and the private sector can accelerate the adoption of sustainable practices and technology, thereby advancing the SDG goal.

Empirical Reviews

Kkimczyk et al. (2021) report that using urease inhibitors like NBPT significantly reduces nitrogen losses from urea fertilizers, enhancing nitrogen use efficiency and promoting sustainable nutrient management. Barłóg et al. (2022) highlight that improper urea fertilizer management can lead to soil acidification and reduced fertility, emphasizing the need for precision agriculture techniques to optimize application rates and minimize environmental impact. According to Kaviyarasan et al. (2024), precision agriculture technologies, such as GPS-guided spreaders and remote sensing, allow for precise urea delivery, preventing over-application and improving crop yields while promoting sustainability. Torres and Bueno (2018) demonstrated that integrated pest management (IPM) tactics, combining biological control, crop rotation, and resistant crop varieties, effectively manage pest populations while reducing chemical pesticide use, including chlorpyrifos. Birolli et al. (2024) highlight severe health effects of chlorpyrifos, such as neurodevelopmental difficulties, prompting stronger regulations and a shift towards biopesticides and organic alternatives. Tudi et al. (2021) examine the environmental persistence of chlorpyrifos, noting significant risks to non-target species and ecosystems, which sustainable practices aim to mitigate by reducing runoff and implementing IPM techniques. Klein et al. (2023) emphasize establishing buffer zones and proper application procedures to protect soil and water resources from chlorpyrifos. They advocate conservation methods like cover crops and reduced tillage to minimize pesticide runoff. Juncal et al. (2023) show that these conservation actions greatly reduce pesticide discharge, underscoring their role in environmental sustainability. Ahmad et al. (2024) stresses the importance of agricultural education programs in teaching farmers about the safe use of urea and chlorpyrifos and alternative pest management measures, which are crucial for sustainable practices. Çakmakçı et al. (2020) note a global shift towards sustainable agriculture due to increased environmental awareness and regulatory pressures, with policy improvements supporting safer practices. Finco et al. (2023) argue that precision agriculture not only enhances environmental sustainability by reducing input waste but also boosts farm profitability, aligning economic and sustainable goals. Finally, Wani et al. (2021) highlight global trends in nitrogen fertilizer efficiency, advocating advanced modeling techniques and sensor-based nutrient management to optimize urea application and reduce environmental impact.

CONCLUSION AND FUTURE OUTLOOK

This review unveil study on the chemistry of urea fertilizers ($CO(NH_2)_2$) and chlorpyrifos pesticides ($C_9H_{11}Cl_3NO_3PS$) in agricultural education highlights the dual nature of urea fertilizers and chlorpyrifos pesticides in modern agriculture. While they enhance agricultural output, their environmental and health consequences necessitate cautious control and further investigation. Urea's widespread use raises concerns about ammonia volatilization and nitrogen leaching, contributing to air and water pollution. Chlorpyrifos, despite its effectiveness, poses severe risks to non-target animals, human health, and the environment. Understanding the chemistry, implications, and hazards of these compounds is crucial in agricultural education, enabling informed decisions and promoting sustainable agriculture methods. Integrating this knowledge into educational curricula can mitigate negative consequences and encourage responsible farming practices, driving innovation towards a more sustainable future. Sequel to the above, the future outlook for this study should foster more on studies on the combined effects of urea fertilizers and chlorpyrifos pesticides are poorly understood, particularly their interactions and synergistic impacts (De Souza et al., 2020). Many studies are context-specific, with regional variations influencing their applicability. Socioeconomic factors affect the adoption of sustainable practices, yet there is a paucity of comprehensive data on the effectiveness of regulatory frameworks (Tripathy et al., 2019; Álvarez et al., 2021; United Nations Environment Programme, 2022). Additionally, research on novel alternatives to conventional fertilizers and pesticides is limited, and integrated approaches combining multiple strategies have not been thoroughly explored (Kalfas et al., 2024). Addressing these gaps requires broader, interdisciplinary research to enhance understanding and develop effective solutions for managing urea fertilizers and chlorpyrifos pesticides in agriculture. Therefore, it is highly recommended that development of instructional programs in educating agricultural experts and the public about the chemistry and effects of urea and chlorpyrifos for informed decision-making is germane and thorough Investigation should be conducted to provide alternative pest control approaches to reduce reliance on toxic chemicals like most especially chlorpyrifos and promote safer pest management practices.

REFERENCES

Abeni, N., (2024). *Driving sustainable progress: The role of technology in agriculture.* Retrieved from: https://duckma.com/driving-sustainable-progress-the-role-of-technology-in-agriculture/ Accessed on 03/08/2024.

Ahmad, M. F., Ahmad, F. A., Alsayegh, A. A., AlShahrani, A. M., Muzammil, K., Saati, A., and Wahab, S., (2024). Pesticides impacts on human health and the environment with their mechanisms of action and possible countermeasures. *Heliyon,* 7(10): e29128, ISSN 2405-8440, https://doi.org/10.1016/j.heliyon.2024.e29128.

Alengebawy, A., Abdelkhalek, S. T., Qureshi, S. R., and Wang, M., (2021). Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications. Toxics. *Multidisciplinary Digital Publishing Institute.* 9(3): 42. DOI: 10.3390/toxics9030042. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7996329/

Ali, S. A., Mala, A., Kumar, P., Shekhar, C., and Bagri, J. P. (2023). *Slow Release Fertilizers for Increasing Nutrient Use Efficiency.* Retrieved from: https://www.researchgate.net/publication/381111683_Slow_Release_Fertilizers_for_Increasing_Nutrient_Use_Efficiency. Accessed on 03/08/2024.

Álvarez, F., Arena, M., Auteri, D., Leite, S., and Binaglia, M. (2023). Peer review of the pesticide risk assessment of the active substance urea. *European Food Safety Authority Journal*. 21(8): e08112. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10410501/

Ayamba, B. E., Abaidoo, R. C., Opoku, A., and Ewusi-Mensah, N., (2023). Mechanisms for nutrient interactions from organic amendments and mineral fertilizer inputs under cropping systems: a review. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10081454/ Accessed on 06/08/2024.

Ayiti, S. and Babalola, O., (2022). Factors Influencing Soil Nitrification Process and the Effect on Environment and Health. Retrieved from: https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2022.821994/full. Accessed on 01/08/2024.

Bala, S., Garg, D., Thirumalesh, V., Sharma, M., Sridhar, K., Inbaraj, B. S., and Tripathi, M., (2022). Recent Strategies for Bioremediation of Emerging Pollutants: A Review for a Green and Sustainable Environment. *Toxics*. 10(8): 484. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9413587/

Banger, K., Wagner-Riddle, C., Grant, B., Smith, W., Drury, and Yang, J., (2020). Modifying fertilizer rate and application method reduces environmental nitrogen losses and increases corn yield in Ontario. *Science of The Total Environment*. Volume 722. 137851. https://www.sciencedirect.com/science/article/abs/pii/S0048969720313632

Barłóg, P., Grzebisz, W., and Łukowiak, R., (2022). Fertilizers and Fertilization Strategies Mitigating Soil Factors Constraining Efficiency of Nitrogen in Plant Production. *Plants* (Basel). 11(14): 1855. DOI: 10.3390/plants11141855. https://www.ncbi.nlm.nih.gov/pmc/articles/ PMC9319167/

Barreras-Urbina, G. C., Rodríguez-Félix, F., Cárdenas-López, J., Plascencia-Jatomea, M., Pérez-Tello, M., Ledesma-Osuna, I., Madera-Santana, J., Tapia-Hernández, J. and Castro-Enríquez, D., (2023). Effect of a Prolonged-Release System of Urea on Nitrogen Losses and Microbial Population Changes in Two Types of Agricultural Soil. ACS Omega, 8, (45) 42319–42328. https://pubs.acs.org/doi/10.1021/acsomega.3c04572

Berg, E. L., Ching, T. M., Bruun, D. A., Rivera, J. K., Careaga, M., and Ellegood, J. (2020). Translational outcomes relevant to neurodevelopmental disorders following early life exposure of rats to chlorpyrifos. Retrieved from: https://www.ncbi.nlm.nih.gov/pmc/articles/ PMC7745485/ Accessed on 03/08/2024.

Birolli, W. G., Lanças, F. M., Neto, A. J., and Silveira, C. S., (2024). Determination of pesticide residues in urine by chromatography-mass spectrometry: methods and applications. Retrieved from: https://www.frontiersin.org/journals/public-health/articles/10.3389/fpubh.2024. 1336014/ full. Accessed on 06/08/2024.

Brandon, (2024). Precision Farming Technology and its Impact on Modern Agriculture. Retrieved from: https://brandonbioscience.com/agricultural-precision-farming-technology/#:~:text=Precision%20technology%20enables%20farmers%20to,effectiveness%20of%20farming%20using%20technology. Accessed on 06/08/2024.

Bremner, J. M. (2019). "Nitrogen transformations in soil." *Soil Science,* 101(4), 217-230.

Çakmakçı, R., Salık, M. A., and Çakmakçı, S., (2023). Assessment and Principles of Environmentally Sustainable Food and Agriculture Systems. Agriculture 2023, 13(5), 1073; https://doi.org/10.3390/agriculture13051073

Cancino, J., Soto, K., Tapia, J., Muñoz-Quezada, M. T., Lucero, B., Contreras, C., and Moreno, J., (2023). Occupational exposure to pesticides and symptoms of depression in agricultural workers. A systematic review. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S001393512300991X#:~:text=The%20use%20of%20insecticides%20and,et%20al.%2C%202021). Accessed on 03/08/2024.

Chen, Y., Li, W., & Zhang, X., (2021). A multifunctional eco-friendly fertilizer used keratin-based superabsorbent as coatings for slow-release urea and remediation of contaminated soil. Retrieved from: https://www.sciencedirect.com/science/article/abs/pii/S030094402100028X. Accessed on 03/08/2024.

Czarnobai, B., Jorge, D., and Gross, J., (2021). Chapter 13 - Smart nanotextiles for application in sustainable agriculture. Micro and Nano Technologies, Pages 203-227. Online: https://www.sciencedirect.com/science/article/abs/pii/B9780128207772000133

da Fonseca, B. A., Santos, C., and Guelfi, D. (2023). *Urease inhibitors technologies as strategy to mitigate agricultural ammonia emissions and enhance the use efficiency of urea-based fertilizers.* Retrieved from: https://www.nature.com/articles/s41598-023-50061-z. Accessed on 06/08/2024.

Despotović, J., Rodić, V., and Caracciolo, F., (2019). Factors affecting farmers' adoption of integrated pest management in Serbia: An application of the theory of planned behavior. *Journal of Cleaner Production. Volume* 228: Pages 1196-1205.

De Souza, R. M., Seibert, D., Quesada, H., and Bassetti, F. J. (2020). *Occurrence, impacts and general aspects of pesticides in surface water: A review.* Retrieved from: https://www.researchgate.net/publication/338351150_Occurrence_impacts_and_general_aspects_of_pesticides_in_surface_water_A_review. Accessed on 02/08/2024.

Diasi, M., Singh, R., Mahapatra, A. D., Renuka L., Patel, H., Ganatra, H., and Datta, B. (2024). Ammonium release in synthetic and human urine by a urease immobilized nanoconstruct†. *Royal Society of Chemistry* 14(10): 6972–6984. doi: 10.1039/d3ra07606g. https://www.ncbi.nlm.nih.gov/ pmc/articles/PMC10898436/

Dittmar, P., Dufault, S., Desaeger, J., Qureshi, J., Boyd, N. A. and Paret, M. L., (2023). Chapter 4. Integrated Pest Management. Retrieved from: https://edis.ifas.ufl.edu/publication/CV298#TOP. Accessed on 06/08/2024.

Driver, J. G., Owen, R. E., Makanyire, T., Lake, J. A., McGregor, J., and Styring, P., (2019). Blue Urea: Fertilizer With Reduced Environmental Impact. Retrieved from: https://www.frontiersin.org/journals/energy-research/articles/10.3389/fenrg.2019.00088/full. Accessed on 03/08/2024.

EarthJustice, (2020). Testimony in Support of HB 229. Pesticides Use of Chlorpyrifos - Prohibition. Retrieved from: https://mgaleg.maryland.gov/cmte_testimony/2020/ent/1640_02122020_82752-281.pdf. Accessed on 03/08/2024.

EarthJustice, (2024). *What You Need To Know About Chlorpyrifos.* Retrieved from: https://earthjustice.org/feature/chlorpyrifos-what-you-need-to-know. Accessed on 03/08/2024.

European Food Safety Authority (EFSA), (2019). "Peer review of the pesticide risk assessment of the active substance chlorpyrifos." *European Food Safety Authority Journal*, 17(5), e05809.

Enrichment Systems, ES (2022). *The Impact of Precision Agriculture Technology on Reducing Plant Diseases and Pests.* Retrieved from: https://www.enrichmentsystems.com/updates/the-impact-of-precision-agriculture-technology-on-reducing-plant-diseases-and-pests/#:~:text=Precision%20agriculture%20allows%20farmers%20to,each%20part%20of%20a%20field. Accessed on 06/08/2024.

Environmental Protection Agency, EPA (2023). *Integrated Pest Management (IPM) Principles.* Retrieved from: https://www.epa.gov/safepestcontrol/integrated-pest-management-ipm-principles#:~:text=In%20an%20agricultural%20crop%2C%20this,both%20for%20effectiveness%20and%20risk. Accessed on 06/08/2024.

Environmental Protection Agency, EPA (2024). *Sources and Solutions: Agriculture.* Retrieved from: https://www.epa.gov/nutrientpollution/sources-and-solutions-agriculture#:~:text=Eutrophication%20can%20lead%20to%20hypoxia,is%20a%20potent%20greenhouse%20gas. Accessed on 03/08/2024.

Environmental Protection Agency, EPA (2024). *Chlorpyrifos.* Retrieved from: https://www.epa.gov/ingredients-used-pesticide-products/chlorpyrifos. Accessed on 06/08/2024.

European Chemicals Agency, Echa (2024). *Chlorpyrifos: Risk management evaluation - Second Draft.* Retrieved from: https://echa.europa.eu/documents/10162/333bdcad-f48b-b8da-773c-a54e9418b5e4. Accessed on 01/08/2024.

European Chemicals Agency, Echa (2023). *Chlorpyrifos. Draft risk profile.* Retrieved from: https://echa.europa.eu/documents/10162/08697125-f335-95bd-6657-24093a72e690. Accessed on 06/08/2024.

European Chemicals Agency, Echa (2020). *Chlorpyrifos Draft risk profile.* Retrieved from: https://echa.europa.eu/documents/10162/8a51d7d9-e9a4-2513-e975-492fb70f825c. Accessed on 06/08/2024.

FAO (2022). *"International Code of Conduct on Pesticide Management."* Food and Agriculture Organization of the United Nations.

FAO, (2024). *Agroecology and the Sustainable Development Goals (SDGs).* Retrieved from: https://www.fao.org/agroecology/overview/agroecology-and-the-sustainable-development-goals/en/ Accessed on 06/08/2024.

Fenibo, E. O., Ijoma, G. N., and Matambo, T., (2021). *Biopesticides in Sustainable Agriculture: A Critical Sustainable Development Driver Governed by Green Chemistry Principles.* Retrieved from: https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2021. 619058/full. Accessed on 06/08/2024.

Finco, A., Bentivoglio, D., Belletti, M., Chiaraluce, G., Fiorentini, M., Ledda, L., and Orsini, R., (2023). Does Precision Technologies Adoption Contribute to the Economic and Agri-Environmental Sustainability of Mediterranean Wheat Production? An Italian Case Study. *Agronomy.* 13(7), 1818; https://doi.org/10.3390/agronomy13071818.

Fisher, K. A., Yarwood, S. A., and James, B. R. (2017). Soil urease activity and bacterial ureC gene copy numbers: Effect of pH. Geoderma 285(4):1-8. DOI:10.1016/j.geoderma.2016.09.012. https://www.researchgate.net/publication/308519423_Soil_urease_activity_and_bacterial_ureC_gene_copy_numbers_Effect_of_pH.

Gama, J., Neves, B., and Pereira, A., (2022). Chronic effects of dietary pesticides on the gut microbiome and neurodevelopment. Frontiers in Microbiology 13, 931440. Retrieved from: https://scholar.google.com/scholar?hl=en&as_sdt=0%2C33&q=Chlorpyrifos+has+been+linked+to+neurodevelopmental+issues+in+children+and+potential+carcinogenic+properties+in+adults&btnG=#d=gs_qabs&t=1722950598380&u=%23p%3Dx5ABkxN6cmIJ. Accessed on 06/008/2024.

Gebbers, R., & Adamchuk, V. I. (2019). "Precision agriculture and food security." *Science,* 327(5967), 828-831.

Gil, J. D., Reidsma, P., Giller, K., Todman, L., Whitmore, A., and Ittersum, M. V., (2019). Sustainable development goal 2: Improved targets and indicators for agriculture and food security. Ambio. 48(7): 685–698. DOI: 10.1007/s13280-018-1101-4. https://www.ncbi.nlm.nih .gov/pmc/articles/PMC6509081/

GOV.UK, (2024). Chlorpyrifos: Risk management evaluation - Second Draft. Retrieved from: https://assets.publishing.service.gov.uk/media/65e5bc8b7bc329e58db8c1df/Chlorpyrifos_RME_for_comments_26_Feb_2024.pdf. Accessed on 03/08/2024.

Guo, J. H., et al. (2022). "Urease inhibitors for reducing nitrogen losses from urea in agriculture." Agronomy, 12(2), 320.

Guo, X., Ren, H., Ren, B., Zhang, J., Liu, P., Shah, S., Zhao, B. (2022). Long-term application of controlled-release urea reduced ammonia volatilization, raising the risk of N2O emissions and improved summer maize yield. *Field Crops Research.* Volume 306, 109227, ISSN 0378-4290, https://doi.org/10.1016/j.fcr.2023.109227.

Hassan, M. U., Aamer, M., Mahmood, A., Awan, M. I., Barbanti, L., Seleiman, M. F., and Bakhsh, G., (2022). Management Strategies to Mitigate N2O Emissions in Agriculture. *Life (Basel).* 12(3): 439. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8949344/

Huang, K., Mingquan, L., Li, R., Rasul, F., Shahzad, S., Changhong, W., and Wu, C., (2023). Soil acidification and salinity: the importance of biochar application to agricultural soils. Retrieved from: https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2023.1206820/full. Accessed on 02/08/2024.

InfinityLearn, (2024). *Urea Formula.* Retrieved from: https://infinitylearn.com/surge/urea-formula/#:~:text=it%20contains%20carbon-,Formula%20and%20Structure%20of%20Urea,group%20(C%3DO). Accessed on 03/08/2024.

Jiang, Y., Zhu, Y., Lin, W., and Luo, J., (2024). *Urea Fertilization Significantly Promotes Nitrous Oxide Emissions from Agricultural Soils and Is Attributed to the Short-Term Suppression of Nitrite-Oxidizing Bacteria during Urea Hydrolysis. Microorganisms*. 2024 Apr; 12(4): 685. DOI: 10.3390/microorganisms12040685. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11052285 /#:~:text=Urea%20is%20the%20most%20commonly,global%20nitrogen%20 utilization%20% 5B12%5D.

Juncal, M. L., Masino, P., Bertone, E., and Stewart, R. A. (2023). Towards nutrient neutrality: A review of agricultural runoff mitigation strategies and the development of a decision-making framework. Science of The Total Environment, Volume 874, 162408, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2023.162408. (https://www.sciencedirect.com/science/article/pii/S0048969723010240)

Juntarawijit, Y. (2020). Chlorpyrifos and other pesticide exposure and suspected developmental delay in children aged under 5 years: a case-control study in Phitsanulok, Thailand. Retrieved from:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8442115/# :~:text=Results %3A%20Chlorpyrifos%20exposure%20significantly%20increased,exposure%20(p%20%3C0.05). Accessed on 06/08/2024.

Kadiru, S., Patiland, S., and D'Souza, R. (2022). Effect of pesticide toxicity in aquatic environments: A recent review. *International Journal of Fisheries and Aquatic Studies* 2022; 10(3): 113-118. DOI: https://doi.org/10.22271/fish.2022.v10.i3b.2679

Kalfas, D., Kalogiannidis, S., Papaevangelou, O., Melfou, K., and Chatzitheodoridis, F., (2024). Integration of Technology in Agricultural Practices towards Agricultural Sustainability: A Case Study of Greece. *Sustainability 2024,* 16(7), 2664; https://doi.org/10.3390/su16072664.

Kaviyarasan G., Rahale, S., and Subramanium, T., (2024). *Revolutionizing Agriculture: A deep dive into Modern Fertilizer Application Strategie.* Retrieved from: https://www.researchgate.net/publication/377473208_Revolutionizing_Agriculture_A_deep_dive_into_Modern_Fertilizer_Application_Strategies. Accessed on 06/08/2024.

Khan, K. M., Karnati, J., Hamid, I., Koceja, D., Islam, M. I., and Khan, M. A., (2019). Residential Proximity to Agricultural Fields and Neurological and Mental Health Outcomes in Rural Adults in Matlab, Bangladesh. *International Journal of Environmental Research.* 16(18): 3228. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6765913/#:~:text=Other%20studies%20showed%20that%20increased,effects%20on%20nervous%20system%20functioning.

Klein, M., Klein, J., Flade, J., Großmann, D., Türkowsky, D., O'Connor, I., Spycher, S., Reichenberger, S., Sittig, S., Multsch, S., and Thomas, K., (2023). *Risk mitigation measures for pesticide runoff: How effective are they? Pest Management Science.* Volume 79, Issue 12 p. 4897-4905.

Klimczyk, M., Siczek, A., and Schimmelpfennig, L., (2021). Improving the efficiency of urea-based fertilization leading to reduction in ammonia emission, *Science of The Total Environment,* Volume 771, 145483, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2021.145483.

Koudahe, K., Allen, S. C., & Djaman, K. (2022). Critical review of the impact of cover crops on soil properties. *International Soil and Water Conservation Research.* 3(10): Pg 343-354. https://www.sciencedirect.com/science/article/pii/S2095633922000259

Kumar, M. (2023). *Urea Formula: Definition, Structure, Properties, Preparation, Uses.* Retrieved from: https://www.pw.live/exams/school/urea-formula/#Physical_Properties_of_Urea. Accessed on 06/08/2024.

Leska, A., Nowak, A., Nowak, I., and Górczyńska, A., (2021). *Effects of Insecticides and Microbiological Contaminants on Apis mellifera Health. Molecules.* 26(16): 5080. DOI: 10.3390/molecules26165080.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8398688/#:~:text=Chlorpyrifos%20increases%20larval%20mortality%20of,in%20the%20colony%20%5B110%5D.

Li, Y. C., et al. (2020). "Impact of nitrogen fertilizer on soil acidification and ecosystem functioning." *Ecology Letters,* 23(8), 1249-1262.

Lockhart & Wiseman, (2023). *Fertilisers and manures.* Retrieved from: https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/nitrate-fertiliser. Accessed on 02/08/2024.

Lopez, M., et al. (2021). "Environmental fate of chlorpyrifos and its transformation products in soil and water." *Journal of Environmental Quality,* 50(2), 311-327.

Ma, C., Ban, T., Yu, H., and li, Q., (2019). Urea Addition Promotes the Metabolism and Utilization of Nitrogen in Cucumber. *Agronomy* 9(5):262. DOI:10.3390/agronomy9050262. https://www.researchgate.net/publication/333341972_Urea_Addition_Promotes_the_Metabolism_and_Utilization_of_Nitrogen_in_Cucumber

Mansouri, H., Said, H. A., Noukrati, H., Oukarroum, A., youcef, H. B., Perreault, F. (2023). Advances in Controlled Release Fertilizers: Cost-Effective Coating Techniques and Smart Stimuli-Responsive Hydrogels. *Advanced Sustainable Systems.* 9(7)/ 2300149. https://doi.org/10.1002/adsu.202300149

Melley, B. (2019). *California Bans Chlorpyrifos, Widely Used Pesticide.* Retrieved from: https://www.kqed.org/science/1941369/california-bans-chlorpyrifos-widely-used-pesticide. Accessed on 03/08/2024.

Moore, M. T., Denton, D. L., Cooper, C. M., and Wrysinski, J., (2011). Use of vegetated agricultural drainage ditches to decrease pesticide transport from tomato and alfalfa fields in California, USA. *Environmental Toxicology and Chemistry* 30(5):1044-930. DOI:10.1002/etc.474.

Mosaic, (2024). *Nitrogen in Plants.* Retrieved from: https://www.cropnutrition.com/nutrient-management/nitrogen/ Accessed on 06/08/2024.

Mustafa, A., Athar, F., Khan, I. K., Chattha, M. U., Nawaz, M., and Shah, A. N. (2022). Improving crop productivity and nitrogen use efficiency using sulfur and zinc-coated urea: A review. *Frontiers in Plant Science.*13: 942384. doi: 10.3389/fpls.2022.942384.

Mustafa, A., Athar, F. Khan, I. K., Chattha, M. U., Nawaz, M., and Shah, A. N., (2022). Improving crop productivity and nitrogen use efficiency using sulfur and zinc-coated urea: A review. *Frontiers in Plant Science.* Retrieved from: https://www.frontiersin.org/journals/plant-science/articles/10.3389/fpls.2022.942384/full. Accessed on 02/08/2024.

National Center for Biotechnology Information (2024). PubChem Compound Summary for CID 2730, Chlorpyrifos. *PubMED Central.* Retrieved from https://pubchem.ncbi.nlm.nih.gov/compound/Chlorpyrifos. Accessed on August 1, 2024.

National Library of Medicine, (2024). Chlorpyrifos. *PubMED Central.* Retrieved from: https://pubchem.ncbi.nlm.nih.gov/compound/Chlorpyrifos. Accessed on 02/08/2024.

Naz, F., (2023). Chapter nine - Plant nutrition, transport, mechanism and sensing in plants. Sustainable Plant Nutrition, *Academic Press,* Pages 209-228, ISBN 9780443186752, https://doi.org/10.1016/B978-0-443-18675-2.00002-X.

Nguyen, H., Brown, K., & Clark, S. (2023). Mitigation strategies for reducing chlorpyrifos environmental and health risks. *Environmental Science & Policy,* 130, 55-68.

Njewaa, J. B., Majamandab, J. J., Biswicka, T. T., Sumana, J. J., Mwased, E., Bandae, G. C., and Lagat, S. C., (2023). A Systematic Review on Detection of Chlorpyrifos Herbicide Residues in Water Resources, Soil, and Vegetable Matrices: Possible Amendments. *Asian Journal of Chemical Sciences.* Volume 13, Issue 6, Page 58-70, 2023; Article no.AJOCS.107713. ISSN: 2456-7795

O'Connor, L., Robison, P., Quesada, G., Kerrigan, J., Robyn C., Guerard, J., and Chin, Y., O'Halloran (2023). *Chlorpyrifos Fate in the Arctic: Importance of Analyte Structure in Interactions with Arctic Dissolved Organic Matter.* Retrieved from: https://www.sciencedirect.com/science/article/am/pii/S0043135423005900. Accessed on 02/08/2024.

Okagu, I., Okeke, E., Ezeorba, W., Ndefo, J., and Ezeorba, T., (2023). Overhauling the ecotoxicological impact of synthetic pesticides using plants' natural products: a focus on

Zanthoxylum metabolites. *Environmental Science and Pollution Research*.; 30(26): 67997–68021. Published online. doi: 10.1007/s11356-023-27258-w

PennState Extension (2022). *Potential Health Effects of Pesticides.* Retrieved from: https://extension.psu.edu/potential-health-effects-of-pesticides. Accessed on 03/08/2024.

Peshin, R., et al. (2022). "*Integrated Pest Management: A Global Overview of History, Programs, and Adoption."* Springer.

Protection Action Network, PAN, (2024). *Chlorpyrifos.* Retrieved from: https://www.panna.org/resources/chlorpyrifosfacts/#:~:text=Chlorpyrifos%20is%20moderately %20persistent%20in,from%20the%20Bering%20&%20Chukchi%20Seas. Accessed on 06/08/2024.

Rajan, M., Shahena, S., Chandran, V., and Mathew, L., (2021). Chapter 3 - Controlled release of fertilizers—concept, reality, and mechanism. *Controlled Release Fertilizers for Sustainable Agriculture, Academic Press,* Pages 41-56, ISBN 9780128195550, https://doi.org/10.1016/B978-0-12-819555-0.00003-0.

Ramalingappa, P. L., Shrivastava, M., Dhar, S., Bandyopadhyay, K., Prasad, S., Langyan, S., and Tomer, R. (2023). Reducing options of ammonia volatilization and improving nitrogen use efficiency via organic and inorganic amendments in wheat (Triticum aestivum L.). *PeerJ.* 11: e14965. doi: 10.7717/peerj.14965. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9997193/

Rashwin, A., and Sanjeeth, J., (2023). *Integrated Pest Management. Fundamentals of Plant Protection (pp.90-103).* https://www.researchgate.net/publication/ 376953968_ Integrated_Pest_Management

Rauh, V. A., et al. (2021). "*Prenatal exposure to organophosphate pesticides and functional neuroimaging in adolescents living in proximity to pesticide application sites."* Proceedings of the National Academy of Sciences, 118(22), e2017833118.

Rodríguez-Liébana, J. A., et al. (2021). *"Chlorpyrifos:* Environmental fate and effects." Ecotoxicology and Environmental Safety, 209, 111858.

Sánchez-Bayo, F., (2021). Indirect Effect of Pesticides on Insects and Other Arthropods. *Toxics.* 9(8): 177. DOI: 10.3390/toxics9080177. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8402326/

Sanchez-Hernandez, J. C., Notario, J., Capowiez, Y., and Mazzia, C. (2018). Soil enzyme dynamics in chlorpyrifos-treated soils under the influence of earthworms. *The Science of The Total Environment* .612:1407-1416. DOI:10.1016/j.scitotenv.2017.09.043.

Sass, J., (2022). *EPA Bans Chlorpyrifos on Food Crops.* Retrieved from: https://www.nrdc.org/bio/jennifer-sass/epa-bans-chlorpyrifos-food-crops#:~:text=This%20is%20the%20result%20of,effects%20of%20the%20chemical%20on. Accessed on 02/08/2024.

Saraiva, A. S., Farnese, F., and Oliveira, M. S., (2024). Unveiling the Subtle Threats: The Neurobehavioral Impact of Chlorpyrifos on Girardia tigrina. *Toxics* 12(7): 512. DOI:10.3390/toxics12070512.

Sellars, S. (2021). *Synthetic Nitrogen Fertilizer in the U.S.* Retrieved from: https://farmdocdaily.illinois.edu/2021/02/synthetic-nitrogen-fertilizer-in-the-us.html. Accessed on 02/08/2024.

Shen, M., Liu, S., Jiang, C., Zhang, T., and Chen, W., (2023). Recent advances in stimuli-response mechanisms of nano-enabled controlled-release fertilizers and pesticides. *Eco-Environment & Health (EEH) Journal.* 2023 Sep; 2(3): 161–175. DOI: 10.1016/j.eehl.2023.07.005.

Sigurdarson, J., Svane, S., & Karring, H. (2018). The molecular processes of urea hydrolysis in relation to ammonia emissions from agriculture. *Reviews in Environmental Science and Bio/Technology.* Volume 17, pages 241–258. https://link.springer.com/article/10.1007/s11157-018-9466-1

Skorupka, M. and Nosalewicz, A., (2021). Ammonia Volatilization from Fertilizer Urea—A New Challenge for Agriculture and Industry in View of Growing Global Demand for Food and Energy Crops. *Agriculture* .11(9):822. DOI:10.3390/agriculture11090822.

Sweeney, R., et al. (2023). "Optimizing nitrogen fertilizer application for improved crop productivity and environmental sustainability." *Field Crops Research,* 285, 108283.

Swify, S., Mažeika, R., Baltrusaitis, J., Drapanauskaitė, D., and Barčauskaitė, K. (2024). Review: Modified Urea Fertilizers and Their Effects on Improving Nitrogen Use Efficiency (NUE). *Sustainability,* 16(1), 188; https://doi.org/10.3390/su16010188.

Swify, S., Avizienyte, D., Mazeika, R., and Braziene, Z., (2022). Influence of Modified Urea Compounds to Improve Nitrogen Use Efficiency under Corn Growth System. *Sustainability 2022,* 14(21), 14166; https://doi.org/10.3390/su142114166.

Torres, J. B., and Bueno, A. F.,(2018). Conservation biological control using selective insecticides â€“ A valuable tool for IPM, *Biological Control,* Volume 126, Pages 53-64, ISSN 1049-9644, https://doi.org/10.1016/j.biocontrol.2018.07.012.

Tripathi, S., Srivastava, P., Devi, R., and Bhadouria, R. (2019). *Influence of synthetic fertilizers and pesticides on soil health and soil microbiology.* Retrieved from: https://www.researchgate.net/publication/334448050_Influence_of_synthetic_fertilizers_and_pesticides_on_soil_health_and_soil_microbiology. Accessed on 02/08/2024.

Tudi, M., Yang, L., Lv, J., Gu, L., Li, H., Peng, W., and Yu, Q., (2023). Environmental and Human Health Hazards from Chlorpyrifos, Pymetrozine and Avermectin Application in China under a Climate Change Scenario: A Comprehensive Review. *Agriculture 2023,* 13(9), 1683; https://doi.org/10.3390/agriculture13091683.

Tudi, M., Ruan, H. D., Wang, Li., Lyu, J., Sadler, R., Connell, D., Chu, C., and Phung, D., (2021). Agriculture Development, Pesticide Application and Its Impact on the Environment. *International Journal of Environmental Research and Public Health*. 18(3): 1112. DOI: 10.3390/ijerph18031112. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7908628/

Umetsu, N., & Shirai, Y., (2020). Development of novel pesticides in the 21st century. *Journal of Pesticide Science.* 45(2): 54–74. doi: 10.1584/jpestics.D20-201.

United Nation, UN (2020). *"Sustainable Development Goals Report 2020."* United Nations.

United Nations Development Programme, UNDP (2024). *The SDGS in Action.* Retrieved from: https://www.undp.org/belize/sustainable-development-goals#:~:text=The%20SDGs%20aim%20to%20end%20all%20forms,equal%20access%20to%20land%2C%20technology%20and%20markets. Accessed on 06/08/2024.

United Natons Environment Programme, (2022). *Synthesis Report on the Environmental and Health Impacts of Pesticides and Fertilizers and Ways to Minimize Them.* Retrieved from: https://www.fao.org/fileadmin/user_upload/soils/publications/pesticides.pdf. Accessed on 02/07/2024.

Vaia, (2024). *Why is urea the most commonly used nitrogenous fertilizer?* Retrieved from: https://www.vaia.com/en-us/textbooks/chemistry/chemistry-6-edition/chapter-9/problem-23-why-is-urea-the-most-commonly-used-nitrogenous-fe/#:~:text=Urea%20is%20a%20cost%2Deffective,as%20its%20primary%20raw%20material. Accessed on 06/08/2024.

Wahab, A., Muhammad, M., Ullah, S., Abdi, G., Shah, G. M., Zaman, W., and Ayaz, A., (2024). Agriculture and environmental management through nanotechnology: Eco-friendly nanomaterial synthesis for soil-plant systems, food safety, and sustainability. *Science of The Total Environment*. Volume 926: 171862. https://www.sciencedirect.com/science/article/abs/pii/ S0048 96972 4020059.

Wang, L., Qin, Z., Li, X., Yang, J. and Xin, M. (2022). *Persistence behavior of chlorpyrifos and biological toxicity mechanism to cucumbers under greenhouse conditions.* Retrieved from: https://www.sciencedirect.com/science/article/pii/S0147651322007345. Accessed on 02/08/2024.

Wang, X., Zhu, H., Yan, B., Chen, L., Shutes, B., Wang, M., Lyu, J., and Zhang, F., (2023). *Ammonia volatilization, greenhouse gas emissions and microbiological mechanisms following the application of nitrogen fertilizers in a saline-alkali paddy ecosystem.* Retrieved from: https://www.sciencedirect.com/science/article/pii/S0016706123001374. Accessed on 06/08/2024.

Wani, S. H., Vijayan, R., Choudhary, M., Kumar, A., Zaid, A., Singh, V., Kumar, P., and Yasin, K. J., (2021). Nitrogen use efficiency (NUE): elucidated mechanisms, mapped genes and gene networks in maize (Zea mays L.). *Physiology and Molecular Biology of Plants,27*(12): 2875–2891. DOI: 10.1007/s12298-021-01113-z. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8720126/

Water Science School, (2018). *Nitrogen and Water.* Retrieved from: https://www.usgs.gov/special-topics/water-science-school/science/nitrogen-and-water#:~:text=Problems%20with%20excess%20levels%20of%20nitrogen%20in%20the%20environment&text=Lake%20and%20reservoir%20eutrophication%20can,by%20depriving%20it%20of%20oxygen. Accessed on 06/08/2024.

Wołejko, E., Łozowicka, B., Jabłońska-Trypuć, A., Pietruszyńska, M., and Wydro, U., (2022). Chlorpyrifos Occurrence and Toxicological Risk Assessment: A Review. *International Journal of Environmental Research and Public Health.* 19(19): 12209. DOI:

10.3390/ijerph191912209. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9566616/#:~:text=Unfortunately%2C%20this%20compound%20is%20still,toxicity%2C%20neurotoxicity%2C%20and%20genotoxicity.

Wyer, K. E., Kelleghan, D. B., Blanes-Vidal, V., Schauberger, G., and Curran, T. P. (2022). Ammonia emissions from agriculture and their contribution to fine particulate matter: A review of implications for human health. *Journal of Environmental Management.* Retrieved from: https://www.sciencedirect.com/science/article/pii/S0301479722018588. Accessed on 03/08/2024.

Yadav, A., Yadav, K., and Abd-Elsalam, K. A. (2023). Nanofertilizers: Types, Delivery and Advantages in Agricultural Sustainability. *Agrochemicals* 2023, 2(2), 296-336; https://doi.org/10.3390/agrochemicals2020019. https://www.mdpi.com/2813-3145/2/2/19.

Yang, Y., Zhou, S., Xing, Y., Yang, G., and You, M. (2023). Impact of pesticides exposure during neurodevelopmental period on autism spectrum disorders â€“ A focus on gut microbiota,. *Journal of Ecotoxicology and Environmental Safety*, Volume 260, 115079, ISSN 0147-6513, https://doi.org/10.1016/j.ecoenv.2023.115079.

Zhang, X., et al. (2020). "Global nitrogen fertilizer use efficiency trends and implications for food security." *Environmental Research Letters*, 15(10), 104005.