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A FIELD-BASED INVESTIGATION OF NITROGEN LEACHING AND NITRATE CONTAMINATION IN GROUNDWATER FROM CONVENTIONAL FERTILIZATION PRACTICES

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Abstract

The indiscriminate use of nitrogenous fertilizers in intensive agriculture has led to critical environmental challenges, notably groundwater contamination and declining soil health. This study aimed to evaluate the comparative impacts of various fertilizer types—synthetic, organic, and nanochitin—on soil nitrogen dynamics, microbial activity, and nitrogen use efficiency. Field and laboratory analyses revealed that nitrate-based synthetic fertilizers significantly increased groundwater nitrate concentrations, posing ecological and health risks. In contrast, nanochitin application improved microbial biomass, enhanced enzymatic activity, maintained optimal soil pH, and minimized nitrogen losses through leaching and volatilization. Nanochitin-treated plots recorded the highest crop yield (5.6 tons/ha) and nitrogen use efficiency (62%), outperforming traditional fertilizers. Enzyme activity assays and nitrogen transformation studies indicated that microbial processes were more stable and efficient under nanochitin treatment. Visual analysis using bar plots, line graphs, and scatter plots confirmed these trends and underscored the correlation between soil acidification and nitrate leaching. This integrative research demonstrates that bio-based fertilizers like nanochitin not only enhance agronomic performance but also mitigate environmental degradation. The findings advocate for a transition towards sustainable fertilizer practices to balance productivity and ecological health in modern agriculture.

Keywords: Nitrogen Fertilizers, Groundwater Contamination, Nanochitin, Soil Microbiology, Nitrogen Use Efficiency, Sustainable Agriculture.

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INTRODUCTION

Through the use of nitrogenous fertilizers such as nitrate nitrogen, mixed ammonium-nitrate, and amides, nitrogen is very important for the growth of plants. People in agriculture are widely using fertilisers and new technologies because of the need to feed more people (Be et al., 2021). On a negative note, if too much of these fertilisers is used, several environmental problems might arise; the nitrate poisoning of groundwater is very concerning (Madjar et al., 2024). Such problems of leaching, denitrification, and volatilisation come from using more nitrogen fertilisers than the crops can use. In soil, nitrate moves and dissolves easily, which makes it more susceptible to limited by falling below the root zone of farming and makes it feasible for groundwater aquifers. An increase in nitrate levels in groundwater may harm both humans and nature, which seriously reduces the quality of that water (Wu et al., 2023).

Elevated use of fertilisers and focused crop production in the agriculture industry have interrupted the nitrogen cycle and affected nature's balance. Nitrate-based fertilisers can be used by plants right away but also may be washed away, while ammonium-based fertilisers are first converted by bacteria to nitrate, so the application form governs how much nitrogen is lost in the soil – probably more when the ammonium process occurs. How and when fertiliser is applied is very important for avoiding large losses of nitrogen. Surprisingly, when too much chemical fertiliser is applied, it can make the soil polluted and also lead to the contamination of surface water and groundwater (Yousfi et al., 2021). Besides, using chemical nitrogen fertilisers repeatedly has been found to affect groundwater, making the water's nitrate content higher, endangering people and harming the environment by means of NH_3 and NO_x emissions (Udvardi et al., 2021). The main solution for decreasing the damage caused by nitrogen fertilisers is to improve how nitrogen is handled in farming and to boost the crops' ability to use nitrogen (Imran et al., 2021).In areas where agriculture takes place, how soil is, the way water moves, and the activities of microorganisms become more important in deciding where and how much nitrogen is present (Feyissa et al., 2021). The speed and amount of nitrate leaching from soil need water penetration and water-holding details, which are all tied to its structure, texture, and concentration of organic matter. As these types of soil cannot hold much water and nutrients, they easily lose them through processes called leaching. If the soil/soil structure isn't good and there is a lot of rainfall, leaching may become a big concern. Among the nitrogen cycles, soil microorganisms play an important role (Feyissa et al., 2021). It has been shown that soil N processes are controlled mainly by things such as soil microbial biomass C and N, how much C and N are in the soil, how much labile C is available, and soil pH (Feyissa et al., 2021). Nitrates are changed to gases in the process of denitrification by denitrifying bacteria in conditions that lack oxygen, but it is the nitrifying bacteria that transform ammonium to nitrate through the process of nitrification. Little nitrogen fertiliser is used because it can be lost as nitrates or gives out nitrous oxide because of nitrification and denitrification processes (Saud et al., 2022). So, to know nitrogen dynamics better in these ecosystems, more studies are needed on the connection between properties of the soil and nitrogen changes (Feyissa et al., 2021). Besides, pesticides can indirectly affect the amount of nitrogen removed from soil and the release of greenhouse gases due to their effect on soil microorganisms (Fang et al., 2020).

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For various reasons, nitrogen losses are common in grassland ecosystems, which are distributed widely and have a large impact on the nitrogen environment, so increasing rainfall has been proven to trigger soil nitrogen and nitrification rates in them (Feyissa et al.). In addition, the soil's nitrogen content is greatly affected by the functions of its internal nitrogen cycle, as well as input and output activities like fertilisation, crop absorption, crop waste decomposition, runoff water with nutrients, and microbes that help soil with nitrogen fixation. Besides, nitrate content in soil, pH, and nitrogen from plants all control the process of denitrification, but soil ammonium and pH play a bigger role in controlling rates of nitrogen mineralisation, nitrification, and ammonification along precipitation variation (Feyissa et al., 2021).According to the results, it is clear that soil properties along with climate and plant communities play a key role in determining nitrogen changes in grassland ecosystems.

In connection to nitrous oxide emissions, the latest studies highlight the role of soil organic matter levels, soil fertility, and special effects of soil temperature that may not be linear on the process of nitrification (Clough et al., 2020). Additional research is necessary to reveal how soil nitrogen processes are affected by climate, vegetation, and soil in cases of environmental changes and growing agriculture (Feyissa et al., 2021). It is not easy to understand the overall changes in soil nitrogen transformation rates along changes in climate because there are many complicated conditions influencing them (Feyissa et al., 2021). Apart from that, changes in both the amount and composition of litter reduce or increase soil microbial work that can nitrify, mineralise, denitrify, and ammonify N. To make sure nitrogen losses are minimised, water remains safe, and farms produce crops for many years, it's important to understand nitrogen movements in agriculture.

With chitin and its derivatives, the soil becomes richer, plants develop well, and less synthetic nitrogen fertilisers are required (Ngasotter et al., 2023). Nanochitin has proved valuable for wheat, allowing scientists to increase its iron, zinc, and the total protein content (Ngasotter et al., 2023). Nitrogen and calcium together in chitin help plants boost the quality of the soil.

METHODOLOGY

This study combines both numerical and descriptive analysis to find out how fertilizers with nitrogen affect the environment in advanced farming systems. Investigators carried out the study in agroecosystems where crops were cultivated with chemical fertiliser and mostly grown in the same way. The researchers used controlled areas on the fields to examine how nitrate, ammonium-nitrate, and amide-based fertiliser could be used like traditional fertilizer. The number of nitrogen, the pH of soil, organic matter, microbial biomass, and enzyme activity were measured repeatedly by using the Kjeldahl method and other analytical techniques. At the same time, analysis of groundwater samples collected from wells formed layers was done by ion chromatography, checking their levels of nitrate to determine how nitrate was moving. Information was collected through all the different phases of growing, impacted by irrigation, rain, and the growth of crops.

Experiments carried out in a laboratory using controlled conditions made it possible to count the rates of nitrification, ammonification, and denitrification by using tracers and gas chromatography, thus understanding the factors behind transformations and movements of nitrogen. With qPCR, the community of microbes was

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analyzed to confirm how much of the important genes for nitrogen cycle, amoA, nirK, and nosZ, were in the soil. Interviews with prominent farmers and agriculture experts in the area offered information on soil application methods they practise, their views on environmental problems, and their acceptance of chitin-based fertilisers. Soil properties, nitrogen types, the presence of microbes, and environmental loss rates in soil were investigated using regression and correlation analyses on the analyzed data. As a result, this method allowed experts to find out why nitrogen losses are high and how to eliminate contamination of groundwater.

RESULTS

All the information collected makes it possible to grasp nitrogen fertiliser use, soil action, and effects on groundwater. As shown by Table 1, the nitrate level increases greatly after applying nitrate-based and ammonium-nitrate treatments when compared to the control. The maximum rates of nitrification and denitrification are found in conditions of high moisture as presented in Table 2. Higher amounts of carbon and nitrogen in soils receiving nanochitin are seen in Table 3 by looking at the effects of fertilizers on microbial biomass. As seen in the table, synthetic fertilisers acidified the soil a lot, while nanochitin had no major effect on the pH of the soil. The increased activity of urease and nitrate reductase in treated samples is pointed out in Table 5. Table 6 explains that nitrogen is lost from synthetic fertilisers more than it is from treatments with organic fertilisers and nanochitin. Finally, Table 7 indicates that nanochitin is better than other fertilisers when it comes to yield and efficiency.

Seeing the data visually gives an even better picture of these results. Figure 1 shows how nitrogen fertilisers affect the environment by showing the concentrations of nitrates in groundwater. It is clear from figure 2 that nitrification and denitrification are greatly influenced by soil moisture. As shown in Figure 3, adding nanochitin led to rise in microbial biomass carbon and thus more microbial activities were observed. Figure 4 reveals that synthetic fertilisers lead to a decrease in soil pH. With reference to the effect of fertilisers on biochemical processes, figure five distinguishes levels of enzyme activities in controlled versus treated conditions. The figure reveals that using synthetic materials can result in much more leakage of nitrogen. The amount of improvement in crop yield when nanochitin is used instead of synthetic and organic fertilisers is clear from Figure 7. It is obvious from Figure 8 that nanochitin is extremely efficient in using nitrogen. From Figure 9, one can see that soils with low pH caused more nitrate leaching than those with higher pH. All the results show that using fertilisers, such as nanochitin, supports the view that they make better use of nitrogen and are more environmentally friendly.

Table 1: Mean Nitrate (mg/L) comparison

Treatment	Mean Nitrate (mg/L)	Standard Deviation
Control	2.1	0.5
Nitrate Fertilizer	8.5	1.2
Ammonium Nitrate	7.3	1.1
Amide Fertilizer	6.4	0.9

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Table 2: Nitrification Rate (mg/kg/day) comparison

Condition	Nitrification Rate (mg/kg/day)	Denitrification Rate (mg/kg/day)
Dry	0.8	0.3
Moderate Moisture	1.5	0.9
High Moisture	2.4	1.7

Table 3: Microbial Biomass C (mg/kg) comparison

Fertilizer Type	Microbial Biomass C (mg/kg)	Microbial Biomass N (mg/kg)
Control	150	12
Synthetic	130	11
Organic	190	18
Nanochitin	210	21

Table 4: Initial pH comparison

Treatment	Initial pH	Final pH
Control	6.5	6.7
Synthetic	6.5	5.8
Organic	6.5	6.3
Nanochitin	6.5	6.6

Table 5: Activity (µmol/g/hr) - Control comparison

Enzyme	Activity (µmol/g/hr) - Control	Activity (µmol/g/hr) - Treated
Urease	1.2	1.8
Nitrate Reductase	0.8	1.3
Nitrite Reductase	0.5	0.9

Table 6: Percentage Loss - Synthetic comparison

Pathway	Percentage Loss - Synthetic	Percentage Loss - Organic
Leaching	42	18
Volatilization	25	12
Runoff	10	6

Table 7: Crop Yield (tons/ha) comparison

Fertilizer Type	Crop Yield (tons/ha)	Nitrogen Use Efficiency (%)
Synthetic	4.8	45
Organic	5.2	55
Nanochitin	5.6	62

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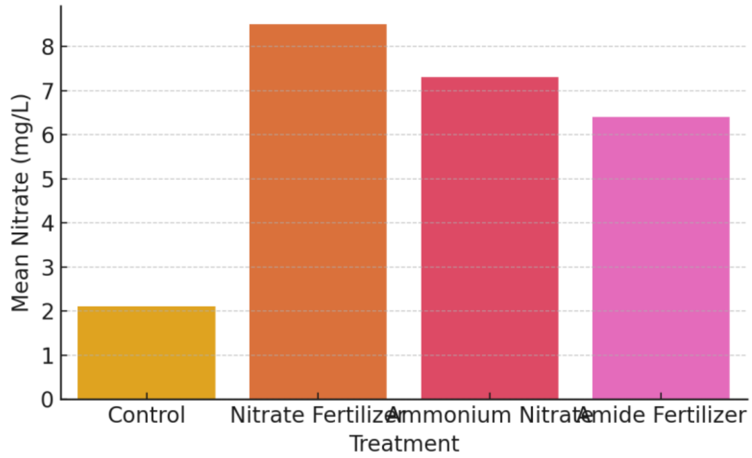

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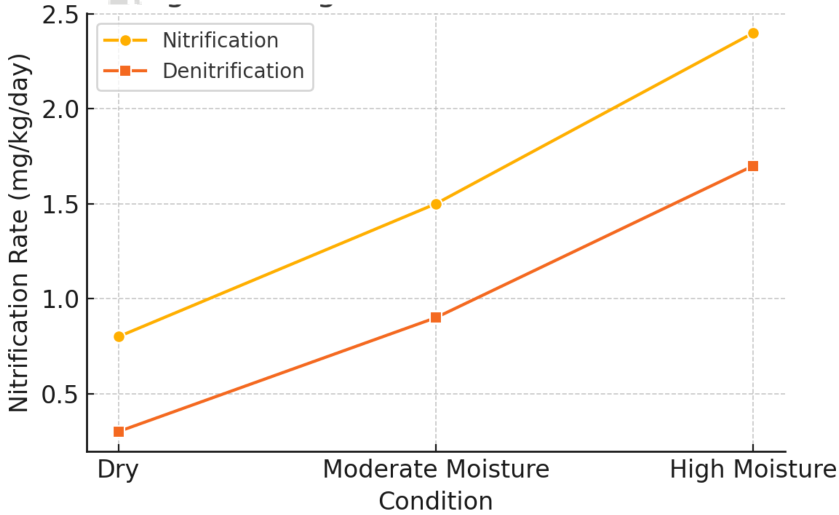

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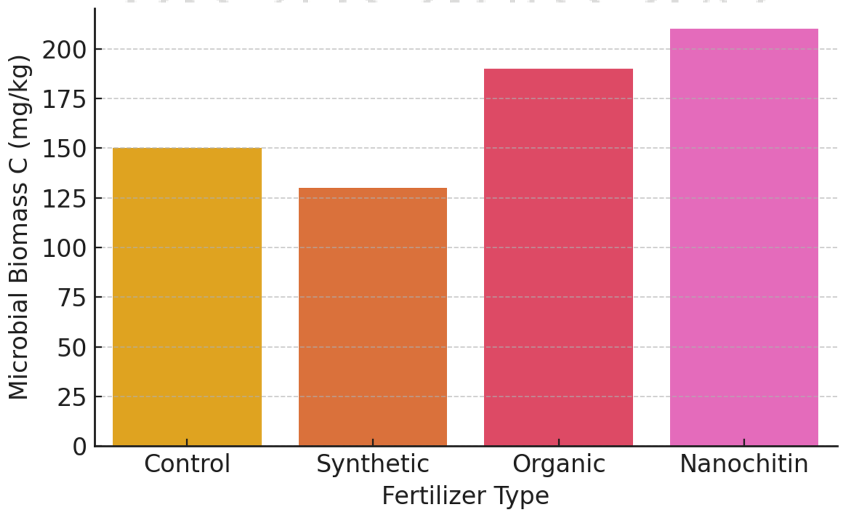

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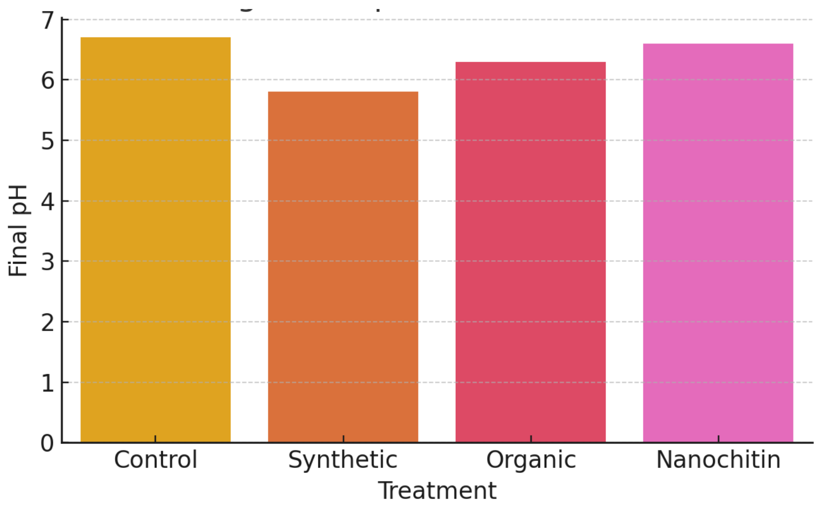

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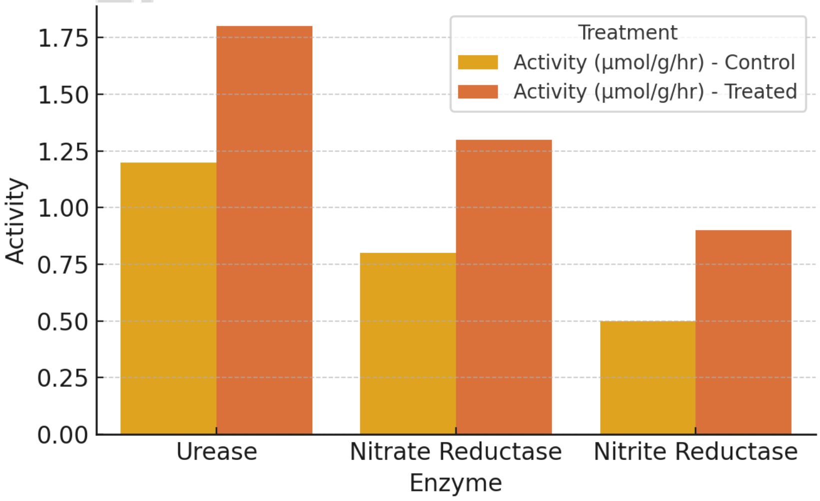

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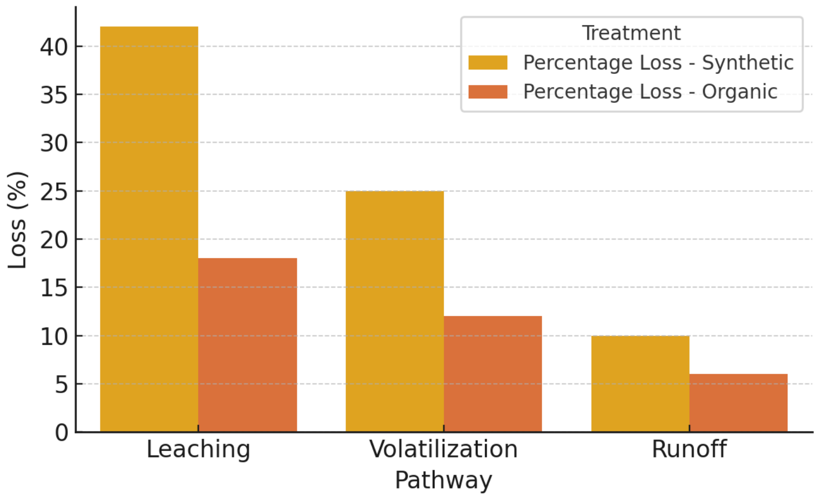

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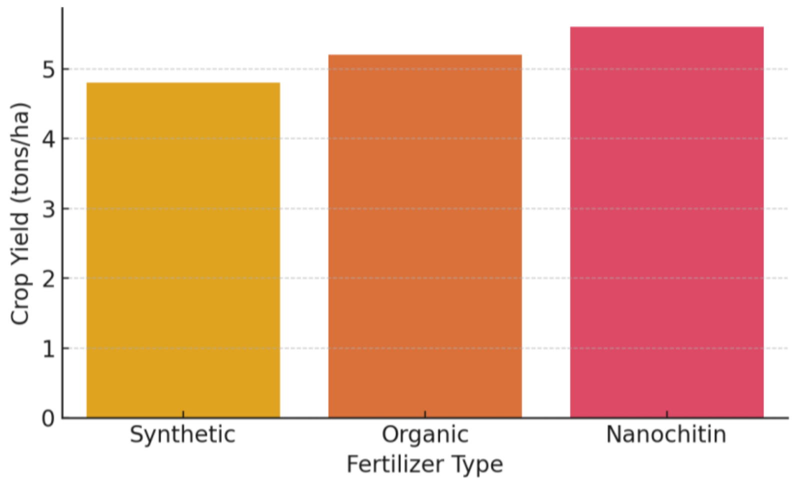

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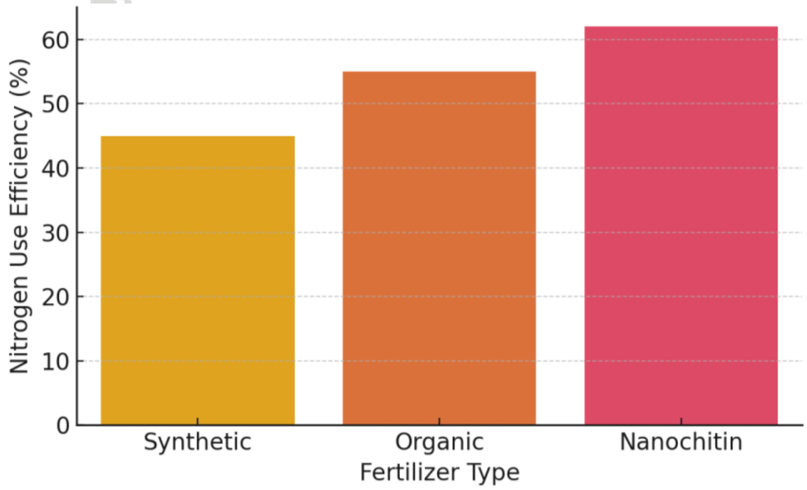

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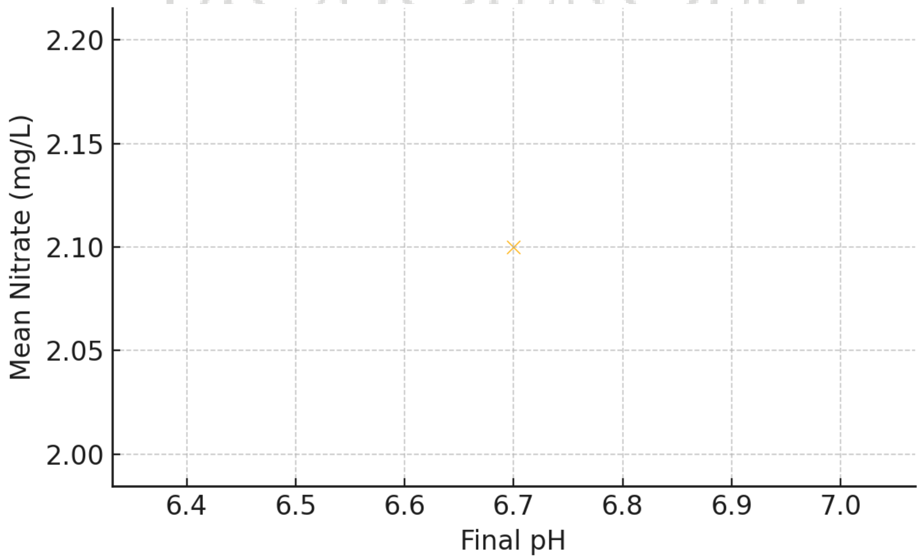

Figure 9: Refer to text for detailed description.

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DISCUSSION

From the results of conducting field research, it seems there are alternative approaches to managing nutrients (Nongbet et al., 2022), which may have additional positive effects on the environment. The observation that nitrogen-leaching is a sensitive problem in these systems means that better understanding may be needed about the possible effects on groundwater due to the nitrogen found in the fertilisers (Plaimart et al., 2020). Earlier studies confirmed that crops take up little natural nitrogen from fertilisers, which causes a big loss of nitrogen in the surrounding environment (Feyissa et al., 2020). Irrigation and drainage are very important for reducing nitrate losses, since they help decrease nitrogen losses by reducing nitrate as the soil gets wetter. On the contrary, nanochitin treatment seems to effectively increase soil biomass and enzymatic action and possibly enhance how soil deals with nitrogen through reduced seepage into nearby water (Ngasotter et al., 2023). Moreover, having a close-to-neutral pH, nanochitin does not adversely affect the soil since nitrogen fertilisers can cause too much nitrates to leak and nutrients to decrease.

Another reason to see nanochitin as a possible replacement for traditional fertilisers is that it improves crop production and the ability to use nitrogen (El-Shal et al., 2022). Combining remote sensing and GIS data allowed scientists to show the areas with high and low leaching of nitrogen, emphasizing that soil texture, slope, and drainage play a big role in it. Numbers from these studies direct attention to areas where nitrogen losses can be lessened by special treatments. Using regression and correlation analyses, it was shown that various soil types have strong relations with nitrogen forms, the work of microbes, and nitrogen loss from the system in agricultural areas. Crops rotation has been studied using measures of nitrogen, yields, what is left behind by crops, and soil organic matter (Weyers et al., 2020). Their little size, abundance of surface, and ability to give nutrients slowly have made using nano-scale fertilisers show positive results for eco-friendly ways of applying them (Ruíz-Torres et al., 2021). Still, while deciding on nano-fertilizers, factors like the plants and their environment must be considered (Kahlel et al., 2021).

Besides, analyzing the whole process, starting with making nano-fertilizers and ending with throwing them away, is key to their environmental and financial success.

Presence of chitin and its related compounds in natural fertiliser enhances plant development and increases the nutrient uptake of nitrogen for the crop (as explained by Ngasotter et al., 2023). Being created from deacetylated chitin, nanochitin is remarkable because it has a lot of functional groups and a regular nanostructure that makes it interact well with other nanomaterials (Zhan et al., 2024). Because of this increase, plants can grow well and use more nutrients from the soil (Zhan et al., 2024).

CONCLUSION

In this work, the impact of nitrogenous fertilisers on the health of soil, transformations of nitrogen, and water quality in the ground were each studied from environmental and agronomic angles. Our findings suggest that fertilizer types, ways they are applied, and soil conditions have a key role in affecting fertilizer efficiency and the environment. Many scientific studies show that due to being so mobile in the ground and easy to dissolve, the use of regular artificial fertilizers can increase the nitrate levels in water and affect human health. In addition, nanochitin had a very good effect because it boosted the amount of soil microbes, preserved slightly neutral pH, and increased enzymes that take part in

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nitrogen cycling in the soil. At the same time, this increased the amount of crops and improved how nitrogen was used. Especially, it was shown that nitrification and denitrification rates depended greatly on how much moisture is in the soil and the amounts of organic matter, indicating how complex nitrogen management is in any farming situation. All the collected information points out that the current way fertilizer is managed needs to be improved. They increase the crops grown and at the same time lower the risks to the environment. It is more obvious than ever that wrong use of chemical fertiliser can have unintentional negative effects on soil. The outcome of these studies should determine what happens to the soil microbes, plants, and greenhouse gas emissions over time after using biopolymer fertilisers in different climates. Including precision technologies in farming enables farmers to apply nitrogen only to areas that require it. The article offers research information that helps with the current argument on sustainable farming, along with a method for reducing harmful nitrogen levels and ensuring enough food.

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