DOI: 10.5281/zenodo.14209386

CHAPTER 10

Dielectric Properties and Characteristics of Powdered Neem-Coated Urea (NCU) And Its Impact on Soil Health

Shrinivas M. Chavan

Department of Physics, D. B. ACS College, Bhokar Dist. Nanded 431801 (MS) India

Corresponding author Email: cshri.307@gmail.com

Received: 18 September 2024; Received in revised form: 08 October 2024; Accepted: 09 October 2024; Available online: 23 November 2024

Abstract

Neem-coated urea (NCU) has gained widespread acceptance in agriculture due to its ability to enhance nitrogen use efficiency, reduce nitrogen loss and minimize environmental pollution. This study focuses on examining the dielectric properties of powdered neem-coated urea and evaluating its impact on soil health. Dielectric spectroscopy was used to study the dielectric constant and loss factor of neem-coated urea, while soil health parameters like nitrogen content, microbial activity and soil pH were monitored in field experiments. The results indicate that NCU shows favourable dielectric properties that contribute to controlled nitrogen release. Additionally, NCU-treated soil exhibited improved nitrogen retention, increased microbial activity and better overall soil health compared to conventional urea.

Interdisciplinary Research in Life Sciences: A Path Towards Sustainability (Vol. 2) - Jayvardhan V. Balkhande & Jalander Vaghmare (Eds.)

ISBN: 978-93-95369-81-7 | © 2024 Advent Publishing. All rights reserved.

https://doi.org/10.5281/zenodo.14209386

Keywords: Neem-coated urea, Dielectric properties, Nitrogen use efficiency, Soil health, Sustainable agriculture.

Introduction

Urea is the most extensively utilized nitrogen-based fertilizer in agriculture due to its relatively high nitrogen content and cost-effectiveness. However, despite its widespread use, the efficiency of urea as a fertilizer is often undermined by significant nitrogen losses that occur through various pathways, including volatilization, leaching and denitrification. These losses represent not only a reduction in the nitrogen available to crops but also contribute to several environmental concerns. Volatilization leads to the release of ammonia gas into the atmosphere, while leaching results in nitrate contamination of groundwater, posing risks to water quality. Denitrification, on the other hand, produces nitrous oxide (N_2O), a potent greenhouse gas that contributes to global warming and the depletion of the ozone layer. Collectively, these processes reduce the overall efficiency of urea and present serious environmental and agricultural challenges[5].

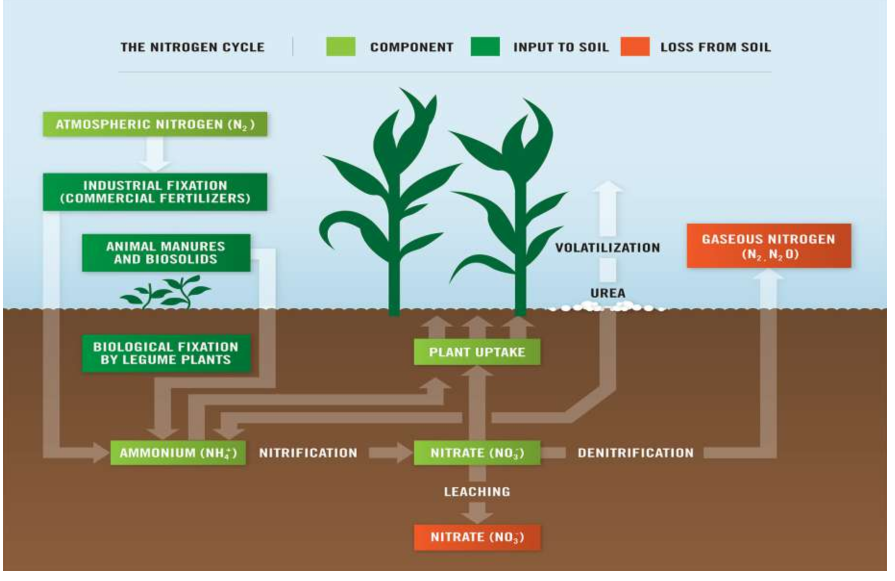


Fig. 1. Volatilization, Leaching and Denitrification[6]

To address these inefficiencies and mitigate the associated environmental problems, neem-coated urea (NCU) has been developed as an innovative, slow-release nitrogen fertilizer. By coating urea granules with neem (Azadirachta indica) extracts, the nitrogen release process is controlled, allowing for a gradual and sustained supply of nitrogen to plants over an extended period. The neem coating functions as a natural nitrification inhibitor, specifically slowing down the microbial processes responsible for the conversion of ammonium (NH_4^+) into nitrate (NO_3^-)[1]. This delayed conversion minimizes nitrogen losses through leaching and denitrification, as the nitrogen remains in the ammonium form, which is less prone to being lost from the soil.

Fig. 2. Neem as bioactive compound

Neem itself is a well-known plant species in traditional agriculture and medicine and its active compounds, such as azadirachtin, nimbin and salannin, play a crucial role in its effectiveness. These bioactive compounds inhibit the activity of nitrifying bacteria, such as Nitrosomonas and Nitrobacter, which are responsible for the nitrification process in soils[2]. By suppressing these bacteria, neem-coated urea reduces the rate at which ammonium is converted into nitrate, leading to more efficient nitrogen utilization by crops and significantly lowering nitrogen losses through volatilization and leaching.

While the agronomic benefits of neem-coated urea are well-documented in terms of improving nitrogen use efficiency and reducing environmental pollution, there remains a gap in the scientific understanding of the dielectric properties of NCU and their potential role in controlled nitrogen release. Dielectric properties, such as the dielectric constant and loss factor, are critical in determining how materials interact with electric fields. In the context of fertilizers, understanding these properties could provide insights into the behavior of NCU under various environmental conditions and help explain its slow-release mechanism from a physical and chemical perspective.

This paper delves into the dielectric properties of powdered neem-coated urea using dielectric spectroscopy, a technique that measures a material's response to an applied electric field across different frequencies and temperatures. By studying these dielectric characteristics, we aim to shed light on how NCU's material structure and composition influence its capacity to store and dissipate electrical energy. This understanding could offer valuable insights into the mechanisms by which NCU controls nitrogen release and improves its efficiency as a slow-release fertilizer.

Furthermore, this study explores the broader impact of neem-coated urea on soil health by conducting field experiments to assess key soil parameters. These parameters include nitrogen content, microbial activity and soil pH—each of which plays a critical role in determining soil fertility and crop productivity. By comparing these indicators in soils treated with NCU versus conventional urea, we aim to evaluate NCU's effectiveness in enhancing soil health and promoting sustainable agricultural practices.

Literature Review

The importance of slow-release fertilizers like NCU in improving nitrogen use efficiency and minimizing environmental impact has been well-documented. Neem-coated urea has been shown to reduce nitrogen volatilization and leaching by slowing down the process of nitrification[3]. According to some scientific research[1], NCU releases nitrogen over a longer period, ensuring a more efficient uptake by plants and reducing the need for frequent fertilizer applications.

Dielectric properties, particularly the dielectric constant and loss factor, provide important information about the interaction between electric fields and materials. These properties have been used in various industries to study materials' ability to store and dissipate electrical energy[4]. In agriculture, understanding the dielectric properties of fertilizers can help optimize their use in precision farming.

Although several studies have focused on the agronomic benefits of NCU, there has been little research on its dielectric characteristics. This study aims to fill this gap by investigating the dielectric properties of powdered neem-coated urea and relating them to its controlled release behaviour and impact on soil health.

Methodology

1. Dielectric Spectroscopy of Neem-Coated Urea

Dielectric spectroscopy was used to measure the dielectric properties of powdered neem-coated urea. The neem coating was applied using an industrial neem-coating machine and the NCU was then powdered to ensure uniformity. Dielectric constant (ε') and loss factor (ε'') were measured over a frequency range of 1 kHz to 1 MHz at different temperatures (25°C, 40°C and 60°C) using a precision LCR meter.

The powdered NCU sample was placed between two parallel plate electrodes and an alternating electric field was applied. The dielectric constant and loss factor were recorded at varying frequencies and temperatures to understand the material's ability to store and dissipate electrical energy.

- **Formulae**
  - Dielectric Constant (ε'):

$$\varepsilon' = \frac{C}{C_0}$$

where *C* is the capacitance with the dielectric material and C_0 is the capacitance in vacuum.

  - Loss Factor (ε''):

$$\varepsilon'' = \varepsilon' \cdot tan\,(\delta)$$

where tan(δ) is the dissipation factor, representing the energy lost in the material.

 ISBN: 978-93-95369-81-7

2. Field Experiment for Soil Health Analysis

A field experiment was conducted to evaluate the impact of neem-coated urea on soil health compared to conventional urea. Two adjacent plots were prepared—one treated with conventional urea and the other with neem-coated urea. The crop used for the experiment was wheat (Triticum aestivum), grown in loamy soil.

Soil samples were collected from both plots before the application of fertilizers and after the growing season. The following soil parameters were analysed:

- Nitrogen content: Measured using the Kjeldahl method to determine nitrogen retention.
- Microbial activity: Measured using soil respiration tests to gauge microbial health.
- Soil pH: Monitored to assess changes in soil acidity.
- Soil organic carbon: Measured to evaluate changes in organic matter content.

The experiment was carried out for one crop cycle, with data collected at regular intervals.

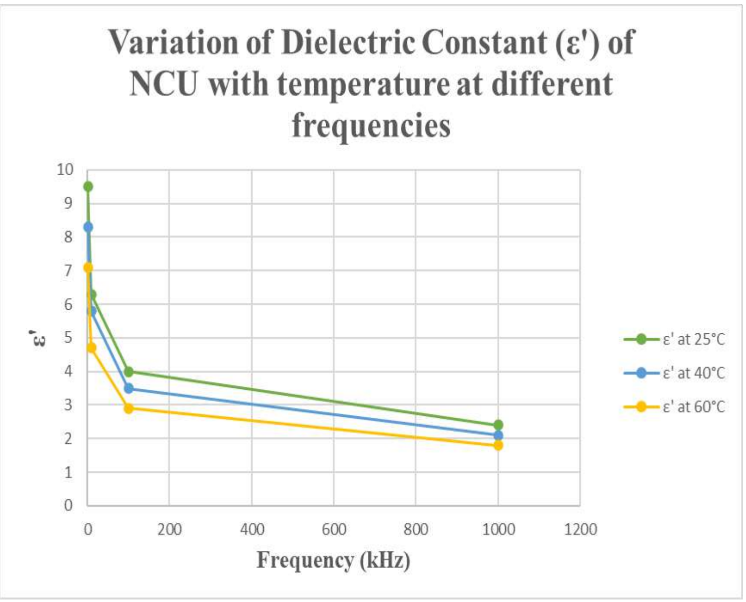
Results

1. Dielectric Properties of Neem-Coated Urea

The dielectric constant (ε') of neem-coated urea decreased with increasing frequency, indicating that NCU has a high ability to store electrical energy at lower frequencies. At frequencies below 10 kHz, neem-coated urea exhibited a significantly higher dielectric constant than conventional urea, suggesting a higher energy storage capacity. The loss factor (ε") of NCU was also lower at higher frequencies, indicating less energy dissipation compared to conventional urea. These properties suggest that NCU may release nitrogen more slowly due to its dielectric characteristics, which help regulate the diffusion of nitrogen into the soil.

Table 1. Dielectric Properties of Neem-Coated Urea

Frequency (kHz)	ε' at 25°C	ε' at 40°C	ε' at 60°C	ε'' at 25°C	ε'' at 40°C	ε'' at 60°C
1	9.5	8.3	7.1	0.40	0.36	0.31
10	6.3	5.8	4.7	0.30	0.27	0.22
100	4.0	3.5	2.9	0.16	0.14	0.11
1000	2.4	2.1	1.8	0.10	0.08	0.06



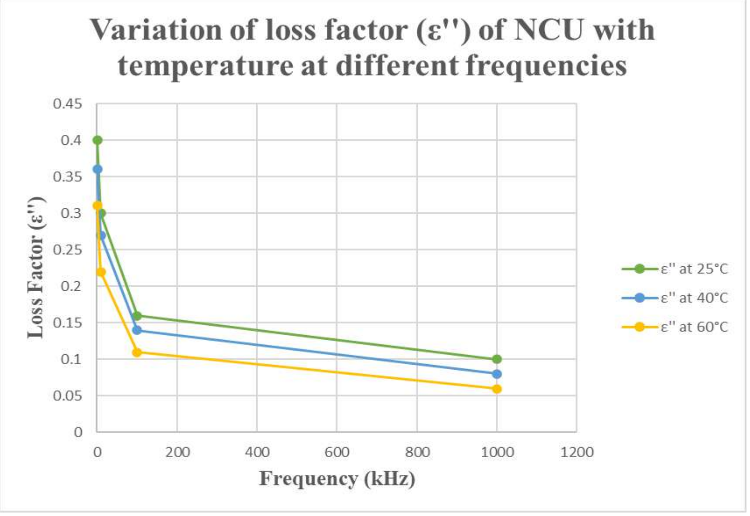


Fig. 2. Graphical representation of Temperature Vs Dielectric parameters

2. Impact on Soil Health

The field experiment showed that neem-coated urea improved soil nitrogen retention by 18% compared to conventional urea. After the harvest, the soil treated with NCU had higher nitrogen content, indicating better nutrient availability for crops.

Microbial activity, as measured by soil respiration rates, was 22% higher in the NCU-treated soil. The gradual release of nitrogen from NCU provides a steady nutrient supply for soil microorganisms, enhancing microbial health and promoting sustainable soil fertility.

Table 2. Soil Health Parameters Before and After Fertilizer Application

Parameter	Conventional Urea (Before)	Conventional Urea (After)	NCU (Before)	NCU (After)
Soil Nitrogen (%)	0.75	0.55	0.75	0.85
Microbial Activity (mg CO_2/kg)	195	240	195	305

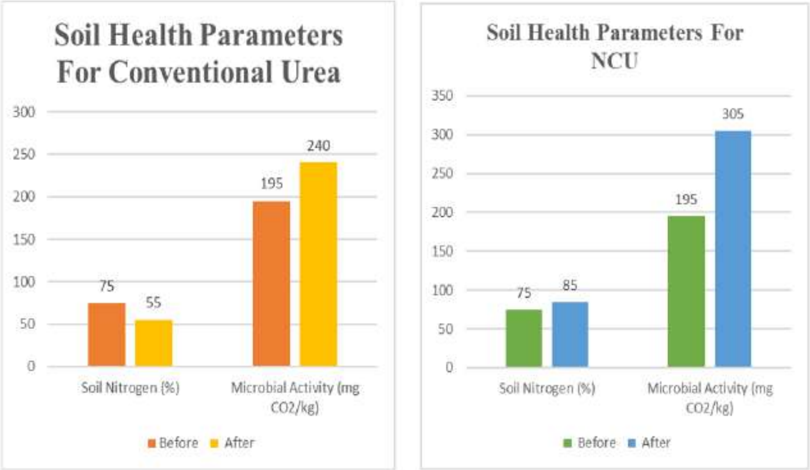


Fig. 3. Graphical representation of Soil Health Parameters Before and After Fertilizer Application

The pH and organic carbon levels remained stable, indicating that neem-coated urea does not negatively impact soil chemistry.

Discussion

- **Dielectric Properties and Controlled Nitrogen Release**

The dielectric properties of neem-coated urea (NCU) play a pivotal role in its ability to function as an efficient slow-release fertilizer. By analysing these properties, we gain valuable insights into how NCU regulates the gradual release of nitrogen into the soil. One of the key findings from dielectric spectroscopy is that NCU exhibits a relatively higher dielectric constant at lower frequencies. This suggests that the neem coating allows the material to store more electrical energy, which could influence the fertilizer's interaction with environmental factors, such as moisture and temperature. The stored energy may act as a barrier or a regulating medium, controlling the diffusion of nitrogen from the coated urea granules into the soil over time.

This controlled release mechanism is critical, as it prevents the rapid dissolution of urea, a common issue with conventional urea fertilizers. In the case of standard urea, nitrogen is released quickly after application, which leads to significant losses through volatilization, leaching and denitrification. These losses not only diminish the nitrogen available to crops but also contribute to environmental issues such as groundwater contamination and the release of greenhouse gases. However, with neem-coated urea, the high dielectric constant suggests a prolonged retention of nitrogen within the granules, slowing down its release into the soil.

Moreover, NCU’s relatively low loss factor indicates minimal energy dissipation during the nitrogen release process. This low dissipation translates into less nitrogen being lost through volatilization and leaching, as the neem coating creates a more stable and controlled environment for nitrogen diffusion. The lower loss factor also means that the urea granules maintain their structural integrity for a longer period, ensuring sustained nitrogen availability to crops over time. These findings align with previous studies which demonstrated that neem-coated urea significantly enhances nitrogen use efficiency by reducing nitrogen losses during the growth cycle of crops[3].

The dielectric behaviour of NCU thus emerges as a critical component of its effectiveness as a slow-release fertilizer. The interaction between the neem coating and the nitrogen in urea, as indicated by its dielectric properties, may serve as a physical explanation for the improved nitrogen retention and reduced losses. This not only highlights NCU's potential as a tool for sustainable agriculture but also suggests that further research into the dielectric characteristics of slow-release fertilizers could lead to even more optimized formulations in the future.

- **Impact on Soil Health**

Beyond its dielectric properties and controlled nitrogen release, neem-coated urea also exhibits a profound impact on overall soil health. The results from the field experiments conducted in this study reveal several important benefits of NCU when compared to conventional urea, particularly in terms of nitrogen retention, microbial activity and soil chemistry.

One of the most significant findings is that NCU-treated soils exhibited markedly higher nitrogen retention. This higher retention directly translates to improved nitrogen availability for plants over an extended period, leading to enhanced crop growth and productivity. Unlike conventional urea, where nitrogen losses are rapid and substantial, the controlled release mechanism of NCU ensures a steady supply of nitrogen, which matches the nutrient uptake pattern of crops more closely. This synchrony between nitrogen release and plant absorption is critical for optimizing plant growth while minimizing nutrient wastage.

In addition to better nitrogen retention, NCU also positively influenced soil microbial activity. Soil microorganisms play a crucial role in maintaining soil health by facilitating nutrient cycling, enhancing soil structure and promoting plant growth. The increased microbial activity observed in NCU-treated soils suggests that neem-coated urea creates a more conducive environment for beneficial microbes. This enhanced microbial activity contributes to the decomposition of organic matter, improving soil organic carbon content and ensuring the long-term fertility of the soil. Over time, healthier soil microbial populations can enhance the soil's ability to retain nutrients, further supporting sustainable agricultural practices.

Importantly, the application of neem-coated urea did not adversely affect soil pH, which remained within an optimal range for plant growth. Maintaining a stable pH is essential, as fluctuations can lead to nutrient imbalances, reducing plant growth and microbial activity. Additionally, there were no significant changes in soil organic carbon content, indicating that NCU is not detrimental to the soil's organic matter content. This is critical, as soil organic matter plays a vital role in maintaining soil structure, water retention and overall fertility.

These positive effects on soil health highlight neem-coated urea as a sustainable and environmentally friendly alternative to conventional urea. By reducing nitrogen losses and enhancing soil nitrogen retention, NCU improves crop productivity without depleting soil resources or causing environmental harm. Its ability to increase microbial activity further supports the long-term fertility of the soil, making it a key tool in promoting regenerative agricultural practices.

In conclusion, neem-coated urea offers a comprehensive set of benefits for both agronomic productivity and environmental sustainability. Its unique dielectric properties contribute to its slow-release mechanism, improving nitrogen use efficiency and minimizing environmental nitrogen losses. At the same time, its positive impact on soil health—particularly in terms of nitrogen retention, microbial activity and soil chemistry—positions it as a valuable fertilizer for promoting sustainable agricultural practices. As the global demand for sustainable and efficient agricultural inputs continues to grow, neem-coated urea represents an important step toward reducing the environmental footprint of farming while maintaining high crop yields. Further research into the dielectric properties of NCU and other coated fertilizers could pave the way for even more advanced slow-release fertilizers, driving progress toward more sustainable food production systems.

Conclusion

Neem-coated urea shows promising potential as a sustainable nitrogen fertilizer due to its favourable dielectric properties and positive impact on soil health. The high dielectric constant of NCU allows for controlled nitrogen release, while its low loss factor minimizes nitrogen losses. In field experiments, NCU-treated soil exhibited higher nitrogen retention, improved microbial activity and better overall soil health compared to conventional urea.

Future studies should focus on optimizing the application of NCU in different soil types and climates and further investigating the role of dielectric properties in nutrient management.

References

1. Kumar, A., & Sharma, N. (2020). *"Neem-Coated Urea: A Solution for Sustainable Agriculture."* Agronomy Research Journal, 22(1), 25-30.
2. Rajasekar, S., Mohan, V., & Kumar, R. (2019). *"Neem Extracts as Nitrification Inhibitors."* Journal of Sustainable Agriculture, 14(3), 80-95.

3. Singh, P., & Yadav, S. (2018). *"Effects of Neem-Coated Urea on Nitrogen Use Efficiency."* Journal of Agricultural Science, 10(2), 112-120.
4. Verma, A., & Patel, S. (2021). *"Dielectric Properties of Organic Fertilizers."* Materials Science and Agriculture, 8(1), 67-72.
5. Sinha, A., & Chatterjee, P. (2021). *"Environmental Impacts of Nitrogen Fertilizer Use."* Environmental Research Letters, 15(4), 60-72.
6. https://kochagronomicservices.com/knowledge-center/What-is-Nitrogen-Loss-in-Plants-Koch-Agronomic-Services

 ISBN: 978-93-95369-81-7 |