

**[F] PhD Extended Abstract Form** *[Please, to fill out use Calibri 10 typeface]*

**DESIGN AND DEVELOPMENT OF CROP CANOPY REFLECTANCE BASED REAL-TIME VARIABLE RATE FERTILIZER APPLICATION SYSTEM**

by

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**Extended Abstract**

*[12000 characters max, spaces included . It is possible to include photographs, tables, and graphs]*

**1. Chapter 1: Introduction**

Rice is a staple crop for a large Indian population and its productivity largely depends on nitrogen (N) fertilization. However, nitrogen use efficiency (NUE) in conventional systems remains low (20–40 kg yield per kg N applied), leading to economic losses and environmental issues such as leaching, volatilization and greenhouse gas emissions. Farmers often compensate by applying excess N, increasing costs and environmental risks.

Efficient N management requires timely, site-specific application based on crop demand. Crop canopy reflectance sensing has emerged as a promising non-destructive approach for real-time N assessment. Vegetation indices such as Normalized Difference Vegetation Index (NDVI) are widely used due to their simplicity; however, NDVI suffers from chlorophyll saturation at higher N levels and is influenced by soil background, illumination and canopy structure.

To overcome these limitations, multiple vegetation indices such as NDVI, Normalized Difference Red Edge (NDRE) and Ratio Vegetation Index (RVI) have been proposed, providing improved sensitivity and reliability across varying N conditions. Despite this, commercial sensors like GreenSeeker, SPAD meter and Crop Circle remain expensive and complex, limiting their adoption. In addition, most existing systems lack integration with real-time fertilizer application.

Therefore, there is a need to develop an affordable, integrated system for real-time N assessment and on-the-go variable rate fertilizer application. Based on this, the present study aimed to:

- (i) determine spectral reflectance characteristics of rice under varying N levels and growth stages
- (ii) develop a portable canopy reflectance-based N assessment device using multiple vegetation indices
- (iii) integrate the device with a real-time variable rate aqueous fertilizer application system
- (iv) evaluate system performance in terms of accuracy, response time, and agronomic effectiveness under field conditions

**2. Chapter 2: Review of Literature**

Crop canopy reflectance-based sensing has been widely used for estimating plant N status, with vegetation indices showing strong relationships with leaf N concentration and crop growth. However, the performance of single index (NDVI) varies across growth stages and environmental conditions. Recent studies highlight that combining multiple vegetation indices improves the accuracy and reliability of N estimation. Although commercial devices provide accurate measurements, their high cost and complexity limit field-level adoption. Variable rate fertilizer application technologies have shown potential for improving input use efficiency, but most systems rely on pre-defined prescription maps and lack real-time integration with crop sensing. These limitations indicate the need for an affordable, integrated system capable of real-time N assessment and on-the-go variable rate fertilizer application.

**Published article:** Chowdhury, M., Kumar Khura, T., Ahmad Parray, R., Kushwaha, H. L., Upadhyay, P. K., Jha, A., ... & Kumar Prajapati, V. (2024). The use of destructive and nondestructive techniques in concrete nitrogen assessment in plants. *Journal of Plant Nutrition*, 47(14), 2271-2294. [Impact Factor: 1.7]

**3. Chapter 3: Materials and Methods**

The study was carried out to achieve the defined objectives through a systematic approach involving spectral characterization, device development, system integration and field evaluation. Initially, field experiments were conducted

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under varying N levels (0–240 kg N ha<sup>-1</sup>) in direct seeded rice to generate variability in crop N status across different growth stages. Canopy spectral reflectance was recorded using a spectroradiometer in the wavelength range of 320–1100 nm, and vegetation indices such as NDVI, NDRE and RVI were computed. Simultaneously, plant samples were analyzed for leaf N concentration using the Kjeldahl method to establish relationships between spectral indices and crop N status.

**Published articles:** [Chowdhury, M., Khura, T. K., Upadhyay, P. K., Parray, R. A., Kushwaha, H. L., Singh, C., ... & Mani, I. (2024). Assessing vegetation indices and productivity across nitrogen gradients: a comparative study under transplanted and direct-seeded rice. *Frontiers in Sustainable Food Systems*, 8, 1351414. [Impact Factor: 3.1]

**Chowdhury, M., Khura, T. K., Parray, R. A., Upadhyay, P. K., Kushwaha, H. L., Lama, A., ... & Ansh, A. K. (2025). Impact of Nitrogen Variability on Yield Dynamics and Economics Viability of Transplanted and Direct Seeded Rice. *Journal of Experimental Agriculture International*, 47, 207-217.]**

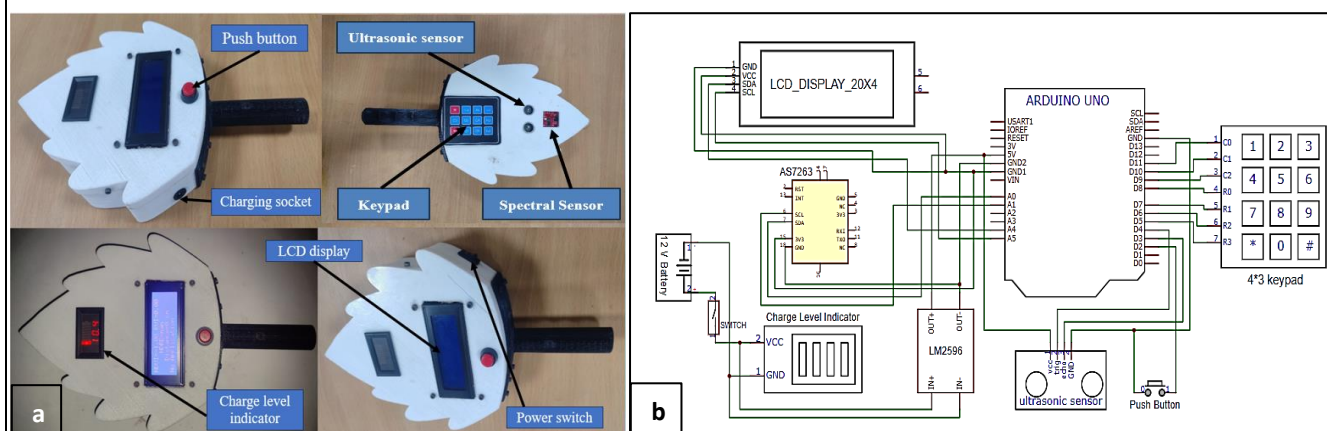
Based on the spectral analysis, a portable crop canopy reflectance-based nitrogen assessment and prescription (NAP) device was developed using a multispectral sensor (AS7263) integrated with a microcontroller-based system (Fig. 1) with the developmental cost of around Rs. 6000 (≈\$64). The device was programmed to compute multiple vegetation indices (NDVI, NDRE and RVI) and estimate additional N requirement using a multiple regression model incorporating vegetation indices and crop growth stage. The system was designed for real-time operation with an integrated display and optimized for sensing height and field of view.

**Published article:** [Chowdhury, M., Khura, T. K., Parray, R. A., Upadhyay, P. K., Kushwaha, H. L., Lama, A., & Kushwah, A. (2025). Multi-vegetation indices based handheld device for precise nitrogen assessment and prescription in direct seeded rice. *Computers and Electronics in Agriculture*, 229, 109886. [Impact Factor: 8.9]]

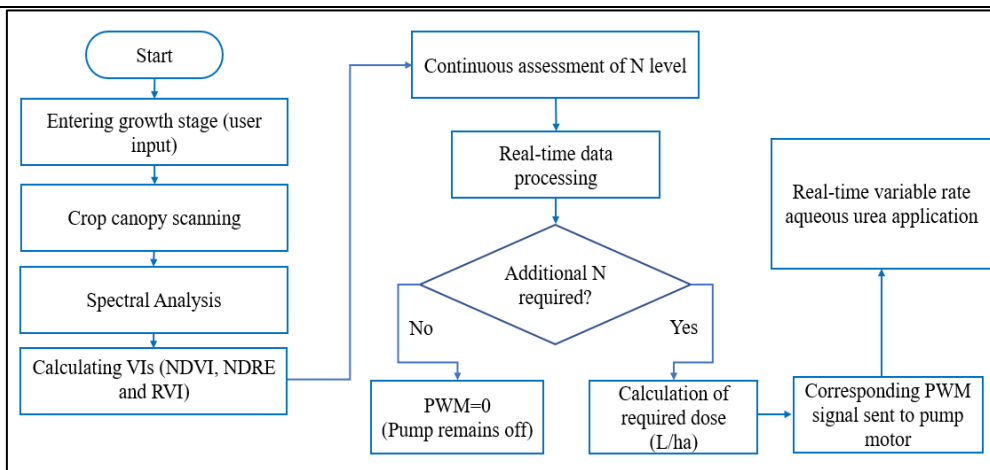
To enable real-time fertilizer application, the developed NAP device was integrated with an on-the-go variable rate aqueous fertilizer application system mounted on a high-clearance vehicle. Aqueous urea with 10% N concentration was used as the fertilizer medium. The discharge rate was controlled using pulse width modulation (PWM) and a calibration relationship between PWM signal and discharge rate was established to ensure precise flow control (Fig. 2). The fertilizer was applied through an inverted T-type tine for subsurface placement to enhance nutrient use efficiency and reduce losses.

The system was calibrated and evaluated under laboratory and field conditions. Performance parameters such as sensing accuracy, response time, and discharge characteristics were assessed, and optimization of operational variables including sensing height and operating speed was carried out. Field evaluation (Fig. 3) was conducted in direct seeded rice to assess the effectiveness of the system in real-time N management, considering parameters such as crop growth, yield attributes and system performance in comparison with conventional fertilizer application practices.

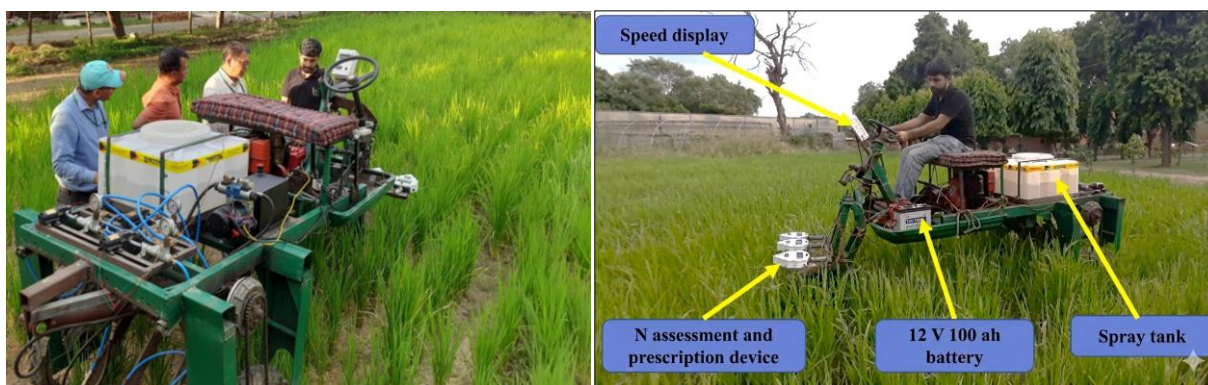
**Published article:** [Chowdhury, M., Khura, T. K., Parray, R. A., Upadhyay, P. K., Kushwaha, H. L., Lama, A., Kushwah, A., Malkani, P., Madhusudan B. S. & Chaudhary, S. (2026). Development of an on-field system for rapid detection and mitigation of nitrogen stress in direct seeded rice. *Results in Engineering*, 108758. [Impact Factor: 7.9]]



**Fig. 1: (a) Different views of the developed NAP Device (b) Circuit diagram**



**Fig. 2: Flowchart of the algorithm for variable rate aqueous urea application**



**Fig. 3: Performance evaluation of the developed variable rate fertilizer application system in direct seeded rice field**

#### 4. Chapter 4: Results and Discussion

The developed crop canopy reflectance-based real-time variable rate fertilizer application system was evaluated under laboratory and field conditions to assess its performance in N sensing, prescription and application. The NAP device demonstrated high accuracy and reliability, showing no significant difference ( $p < 0.05$ ) compared to GreenSeeker and Spectroradiometer for NDVI, NDRE and RVI measurements. The device achieved precision of 96–100% and accuracy of 90–98% in assessing the vegetation indices, indicating consistent and reliable performance. Strong correlations were observed between vegetation indices and leaf nitrogen concentration (LNC) at different growth stages, with NDRE showing the highest correlation ( $r = 0.79\text{--}0.93$ ), followed by NDVI ( $r = 0.79\text{--}0.91$ ). RVI showed lower correlation at early growth stage but improved significantly ( $r \approx 0.90$  at 80 DAS) at later growth stages. This confirms that multi-index integration improves N estimation accuracy and overcomes NDVI saturation limitations.

The system exhibited a rapid response time of 1.82 seconds, enabling real-time N assessment and application. The optimal sensing height was 30 cm, with a field of view of  $36.86^\circ$ , resulting in a target application accuracy of 91%. The PWM-controlled fertilizer application system showed a strong linear relationship between PWM signal and discharge rate ( $R^2 = 0.998$ ), ensuring precise flow regulation. The speed measurement system also demonstrated high accuracy ( $R^2 = 0.999$ ) with minimal error (0.2 m/s), supporting reliable field operation.

The study on aqueous urea concentration revealed that concentrations above 12% N were detrimental, whereas 10% N was optimal, achieving the highest benefit-cost ratio (BCR = 2.37). Field evaluation demonstrated significant improvements in N management, with fertilizer savings of 22.38% and 28.35% during first and second top dressings, respectively. This resulted in 25.44% reduction in cost, 53.69% increase in NUE and 12.28% increase in grain yield compared to conventional practice. The system performed optimally at a forward speed of  $1.8 \text{ km h}^{-1}$ .

#### 5. Chapter 5: Conclusions

The study successfully developed a crop canopy reflectance-based real-time variable rate fertilizer application system integrating multi-vegetation indices based N sensing and automated fertilizer delivery. The system demonstrated high accuracy, rapid response and reliable field performance, enabling precise N application based on crop demand. The use of multi-index sensing (NDVI, NDRE and RVI) improved N assessment accuracy, while PWM-controlled application ensured efficient fertilizer delivery. Field evaluation confirmed significant improvements in NUE, crop yield and input cost reduction, highlighting the effectiveness of the developed system over conventional practices. The technology offers a cost-effective, scalable and practical solution for precision N management in rice, contributing to sustainable and resource-efficient agriculture.

**Final remarks concerning benchmarks and strength points of the the Pellizzi Prize 2026**

*[compulsory chapter to fill with 1000 characters max, spaces included]*

This thesis falls within Agricultural Machines and Mechanization or Automation and Electronics topic, focusing on real-time precision nutrient management in rice. The research led to the development of an integrated crop canopy reflectance-based variable rate fertilizer application system, combining multi-vegetation index sensing with automated PWM-controlled aqueous fertilizer delivery for on-the-go N application.

The technology has been patented, registered for design and copyright, and successfully licensed for commercialization. The work has received significant recognition, including the FAI Award for Outstanding Doctoral Research in Fertilizer Usage, Dr. K. N. Synghal Memorial Gold Medal (ICAR-IARI), and the Ph.D. Thesis Competition Award by the Indian Society of Agricultural Engineers.

The system demonstrated substantial field benefits, improving NUE, yield and reducing fertilizer cost. It offers a practical and scalable solution for sustainable agricultural mechanization.