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

Dissertation presented to ICAR-Indian Agricultural Research Institute, New Delhi, India

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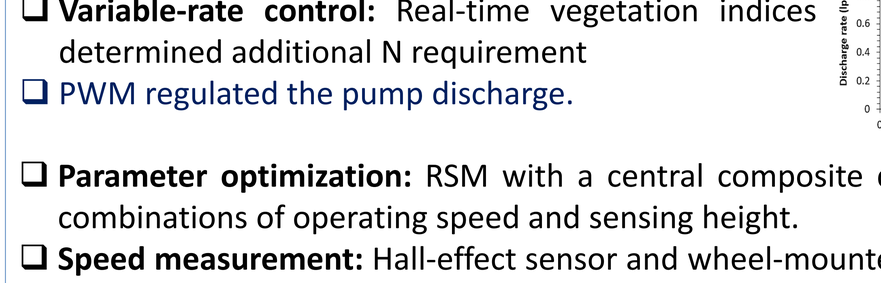
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1 RESEARCH NEED & INNOVATION

- ❑ Conventional nitrogen (N) management often overlooks crop-to-crop variability in N requirement, resulting in inefficient fertilizer use, higher input costs and environmental N losses.
- ❑ Existing canopy-sensing technologies can assess crop N status, but their cost and limited integration with real-time fertilizer application restrict field-level adoption.
- ❑ **Research objective**
- ✓ To develop and evaluate a **crop-canopy reflectance based real-time variable-rate fertilizer application system** for site-specific nitrogen management in direct seeded rice (DSR).
- ❑ **Approach**

SENSE (Crop canopy reflectance) → **ASSESS** (Crop nitrogen status) → **PRESCRIBE** (Additional nitrogen requirement) → **APPLY** (Variable-rate fertilizer application)

- ❑ An **affordable, integrated system** was developed to Assess crop N level, prescribe additional dose and real-time variable rate N fertilizer application.



2 SPECTRAL CHARACTERIZATION, N ASSESSMENT & DEVICE DEVELOPMENT

❑ CANOPY SPECTRAL CHARACTERIZATION

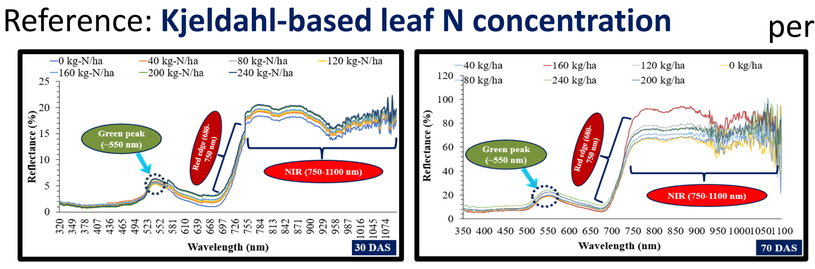
Experimental assessment

Nitrogen levels: **0–240 kg N ha^{-1}**

8 growth stages | Spectral range: **320–1100 nm**

Indices: **NDVI • NDRE • RVI**

Reference: **Kjeldahl-based leaf N concentration**

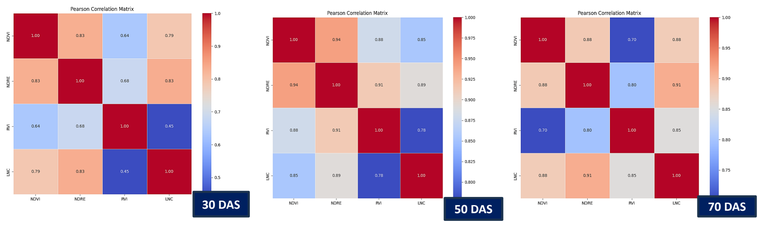


❑ VEGETATION INDICES vs. LEAF NITROGEN

Correlation with leaf nitrogen concentration (r)



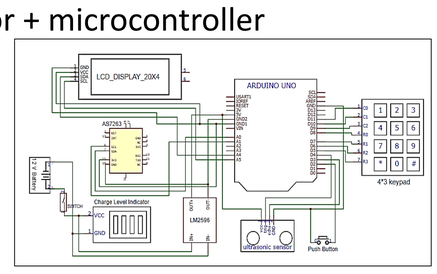
✓ NDRE showed the strongest overall relationship; RVI performed better at later growth stages.



❑ NAP DEVICE DEVELOPMENT & VALIDATION

AS7263 multispectral sensor + microcontroller



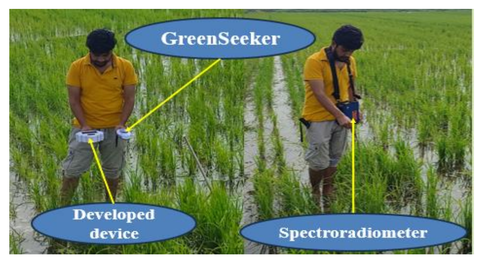


- 96–100% Precision in vegetation-index measurement
- 90–98% Measurement accuracy

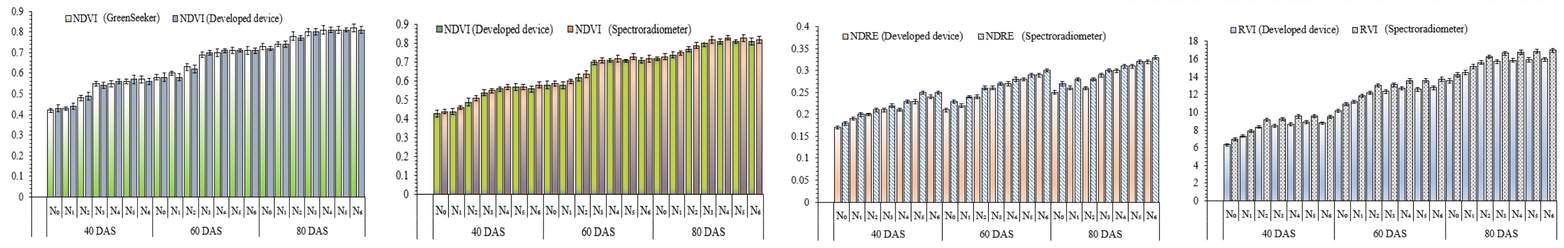
✓ $\mathbf{NDVI} = \frac{R_{760}-R_{680}}{R_{760}+R_{680}}$

✓ $\mathbf{NDRE} = \frac{R_{760}-R_{730}}{R_{760}+R_{730}}$

✓ $\mathbf{RVI} = \frac{R_{760}}{R_{680}}$



- ➢ Estimates additional N requirements using vegetation indices and crop growth stage.
- ➢ Validated against GreenSeeker and spectroradiometer measurements; no significant differences reported.

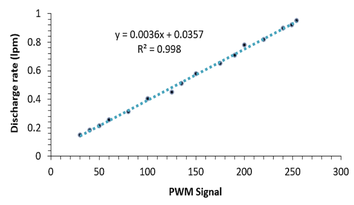


3 SYSTEM INTEGRATION & OPTIMIZATION

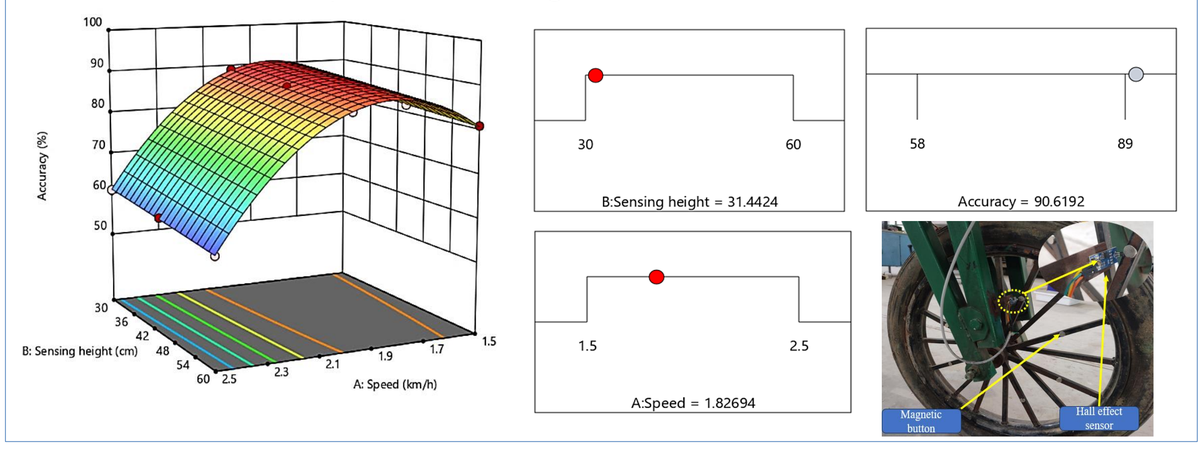
- ❑ **Vehicle integration:** Three NAP devices mounted at the front for sensing three rice rows.
- ❑ **Fertilizer application:** Aqueous urea delivered between rows through inverted T-type tines.



- ❑ **Variable-rate control:** Real-time vegetation indices determined additional N requirement
- ❑ PWM regulated the pump discharge.



- ❑ **Parameter optimization:** RSM with a central composite design evaluated 13 combinations of operating speed and sensing height.
- ❑ **Speed measurement:** Hall-effect sensor and wheel-mounted magnetic buttons enabled real-time speed monitoring.



4 FIELD VALIDATION & AGRONOMIC IMPACT

- ❑ The integrated variable-rate fertilizer application system was evaluated under field conditions in direct seeded rice (DSR) using **10% N aqueous urea**.
- ❑ The system sensed crop nitrogen status in real time and adjusted fertilizer application according to crop demand.
- ❑ Performance was compared with conventional fixed-rate nitrogen application.



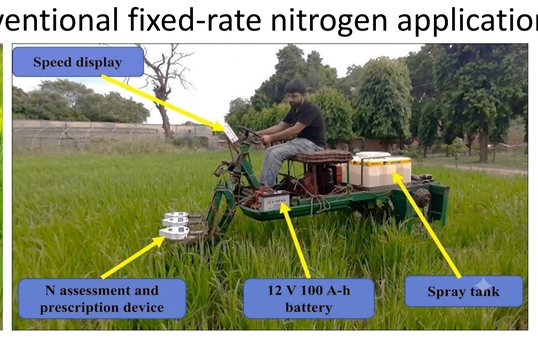


Table: Performance of the variable rate fertilizer application system in DSR

Parameter		Fixed rate N application	Variable rate N application
1st top dressing (45 DAS)	Application rate (l/ha)	750	586
	Fertilizer saving as compared to fixed rate application (%)	Nil	**21.87%**
	Field capacity (ha/h)	0.068	0.072
	Field efficiency (%)	84.33	91.13
2nd top dressing (65 DAS)	Application rate (l/ha)	750	518
	Fertilizer saving as compared to fixed rate application (%)	Nil	**30.93%**
	Field capacity (ha/h)	0.065	0.076
	Field efficiency (%)	83.25	93.82
Yield (t ha^{-1})		4.56	5.12
Nitrogen use efficiency (kg grain/kg N)		25.31	**38.89**
Cost of fertilizer (₹ ha^{-1}) @₹5.35/kg Urea		1719.09	1281.68
Depth of fertilizer application (cm)		5.4 ± 0.3	5.4 ± 0.3
Increment in NUE as compared to conventional method (%)		**53.69**	
Increment in yield as compared to fixed rate N application (%)		**12.28**	
Cost saving as compared to fixed rate N application (%)		**25.44**	

n Final Remark(s)

- ❑ 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** with **five high-quality international journal articles published from the research**.
- ❑ 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), IAUA Award for Outstanding Ph.D. Thesis Research 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.