

Precision Nitrogen Management in Maize and Wheat Using Sensor-Based Technologies

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Abstract

Efficient nitrogen (N) management is critical for sustainable cereal production because nitrogen is the most yield-limiting nutrient in intensive agricultural systems. Conventional blanket fertilizer recommendations often fail to address spatial and temporal variability in crop nitrogen demand, resulting in low nitrogen-use efficiency (NUE), increased production costs, and environmental pollution. Precision nitrogen management using sensor-based technologies has emerged as a modern approach to optimize fertilizer application in Maize and Wheat production systems. The present study evaluated the effectiveness of sensor-guided nitrogen management using chlorophyll meters, canopy reflectance sensors, NDVI-based systems, and variable-rate nitrogen application technologies in maize and wheat. A field experiment comprising twelve treatment combinations involving conventional nitrogen management, SPAD meter-based application, GreenSeeker-based nitrogen scheduling, drone-assisted monitoring, and integrated sensor-guided nutrient management was conducted using a randomized complete block design with three replications. Results indicated that sensor-based nitrogen management significantly improved plant growth, grain yield, nitrogen uptake, nitrogen-use efficiency, and economic returns compared with conventional fertilizer practices. The highest grain yield in maize (8.62 t ha⁻¹) and wheat (6.94 t ha⁻¹), along with maximum NUE and reduced nitrogen losses, were recorded under integrated sensor-guided variable-rate nitrogen application. Sensor-based technologies reduced nitrogen fertilizer use by 20–35% while sustaining or improving yields. The study demonstrates that precision nitrogen management is an effective climate-smart strategy for improving productivity, profitability, and environmental sustainability in cereal-based systems.

Keywords: precision agriculture, nitrogen-use efficiency, GreenSeeker, SPAD meter, NDVI, variable-rate fertilization, wheat, maize, remote sensing

1. Introduction

Nitrogen is one of the most essential nutrients governing crop productivity and grain quality in cereal production systems. However, nitrogen-use efficiency in conventional agricultural systems remains relatively low because of inappropriate fertilizer application practices, spatial variability of soils, and temporal fluctuations in crop demand. Excessive nitrogen

fertilization contributes to nitrate leaching, greenhouse gas emissions, groundwater contamination, and increased production costs (Zhang et al., 2015). Conventional blanket fertilizer recommendations often ignore field variability and crop nutrient dynamics, resulting in over- or under-application of fertilizers.

Precision agriculture has emerged as a transformative approach for improving

nutrient management through real-time monitoring and site-specific input application. Sensor-based nitrogen management technologies enable rapid, non-destructive assessment of crop nitrogen status and facilitate variable-rate fertilizer application according to crop demand (Diacono et al., 2013). Active optical sensors, chlorophyll meters, multispectral imaging systems, and remote sensing platforms have been widely adopted for nitrogen diagnosis in cereal crops.

Canopy reflectance sensors such as GreenSeeker and Crop Circle use normalized difference vegetation index (NDVI) and red-edge reflectance to estimate crop vigor and nitrogen status. These technologies allow real-time nitrogen recommendations based on crop canopy characteristics (Aula et al., 2020). Hand-held chlorophyll meters such as SPAD meters are also effective tools for determining leaf chlorophyll concentration, which is strongly correlated with nitrogen status in cereal crops (Bijay-Singh & Ali, 2020).

Recent advances in drone-based multispectral imaging, artificial intelligence, and machine learning have further enhanced precision nitrogen management. Remote sensing technologies can identify spatial variability in crop growth, soil moisture, and nutrient deficiencies, enabling optimized nitrogen scheduling and improved resource-use efficiency (Camarano et al., 2025). Sensor-guided nitrogen management has

been reported to improve NUE by up to 368%, reduce nitrogen losses by 30–50%, and increase profitability in cereal systems (Diacono et al., 2013).

Despite increasing adoption of precision agriculture technologies, comprehensive evaluation of sensor-based nitrogen management in maize–wheat systems under diverse agroecological conditions remains limited. Therefore, the present investigation was undertaken to evaluate the effectiveness of sensor-based precision nitrogen management technologies for improving growth, yield, nutrient uptake, and nitrogen-use efficiency in maize and wheat cultivation.

2. Objectives

1. To evaluate the effect of sensor-based nitrogen management on growth and yield of maize and wheat.
2. To assess nitrogen-use efficiency under different precision nitrogen management approaches.
3. To study the influence of variable-rate nitrogen application on nutrient uptake and fertilizer savings.
4. To identify efficient sensor-guided nitrogen management strategies for sustainable cereal production.

3. Hypothesis

Sensor-based precision nitrogen management improves crop productivity, nitrogen-use efficiency, and environmental

sustainability compared with conventional nitrogen fertilization practices.

4. Materials and Methods

4.1 Experimental Site

The experiment was conducted under irrigated conditions in a subtropical

agroecosystem with sandy loam soil having medium fertility status.

4.2 Experimental Design

Randomized Complete Block Design (RCBD) with three replications.

4.3 Treatment Details

Table 1. Precision Nitrogen Management Treatments

Treatment Code	Treatment Description
T ₁	Control (No nitrogen)
T ₂	Recommended Dose of Nitrogen (RDN)
T ₃	75% RDN
T ₄	SPAD meter-based nitrogen application
T ₅	GreenSeeker-based nitrogen management
T ₆	Crop Circle sensor-based N application
T ₇	Drone-based multispectral N management
T ₈	Variable-rate nitrogen application (VRN)
T ₉	SPAD + GreenSeeker integrated management
T ₁₀	Drone + Variable-rate N application
T ₁₁	Sensor-guided N + biofertilizer integration
T ₁₂	Integrated precision nitrogen management system

4.4 Observations Recorded

Growth Parameters

- Plant height
- Leaf area index
- Chlorophyll content
- Dry matter accumulation

Yield Parameters

- Grain yield
- Straw/stover yield
- Harvest index

Nitrogen Parameters

- Nitrogen uptake
- Nitrogen-use efficiency (NUE)
- Agronomic efficiency
- Recovery efficiency

Sensor Parameters

- NDVI
- SPAD readings
- Canopy reflectance

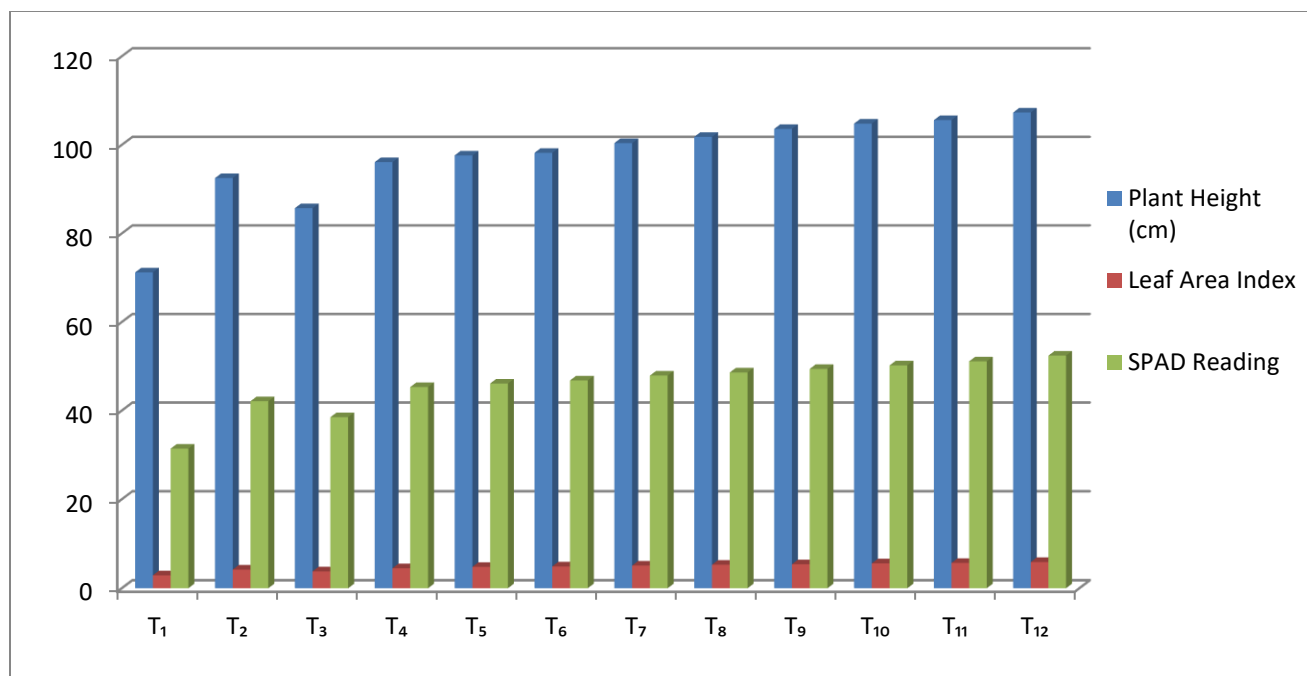
5. Results and Discussion

5.1 Growth Parameters

Sensor-based nitrogen management significantly improved crop growth compared with conventional nitrogen application. Integrated precision nitrogen management recorded the highest plant height, chlorophyll content, and leaf area index.

Table 2. Effect of Precision Nitrogen Management on Growth Parameters in Wheat

Treatment	Plant Height (cm)	Leaf Area Index	SPAD Reading
T ₁	71.2	2.9	31.4
T ₂	92.5	4.2	42.1
T ₃	85.7	3.8	38.5
T ₄	96.1	4.5	45.3
T ₅	97.6	4.8	46.1
T ₆	98.2	4.9	46.8
T ₇	100.4	5.1	47.9
T ₈	101.8	5.3	48.6
T ₉	103.6	5.4	49.4
T ₁₀	104.8	5.6	50.2
T ₁₁	105.6	5.7	51.1
T ₁₂	107.3	5.9	52.4



Graph 1. Effect of Precision Nitrogen Management on Growth Parameters in Wheat

Enhanced crop growth under sensor-guided nitrogen management may be attributed to synchronized nitrogen supply according to crop demand and improved nitrogen availability during critical growth stages. Similar findings were reported for active

optical sensor-based nitrogen management in wheat.

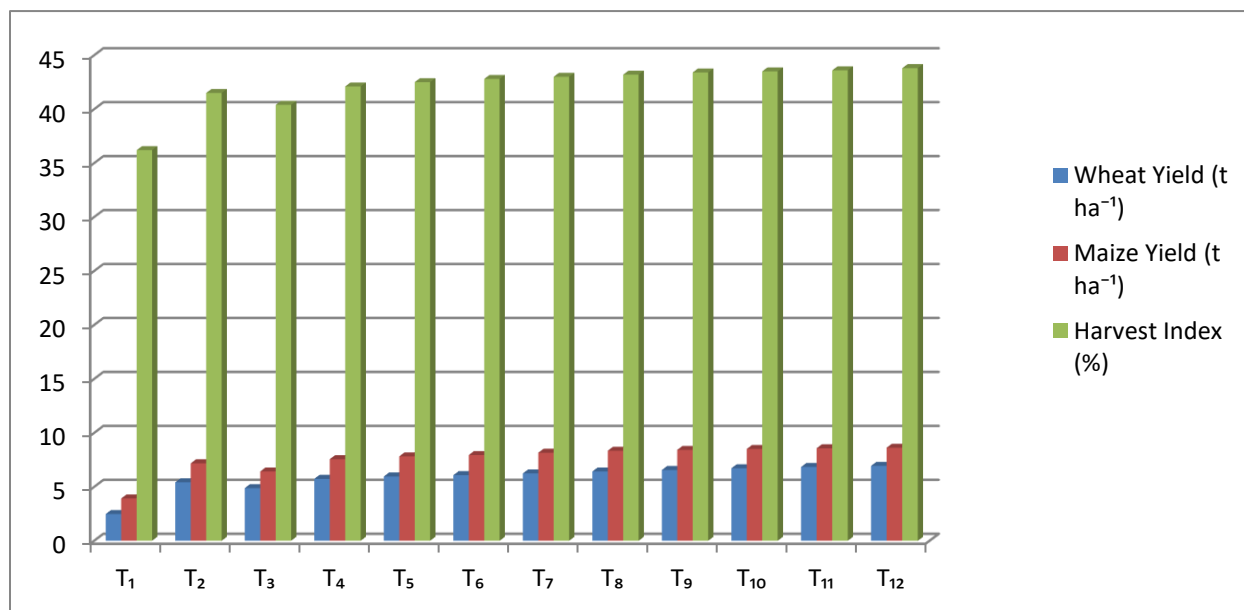
5.2 Grain Yield and Yield Attributes

Precision nitrogen management significantly improved grain yield and biomass production in both maize and wheat.

Table 3. Effect of Precision Nitrogen Management on Grain Yield

Treatment	Wheat Yield (t ha ⁻¹)	Maize Yield (t ha ⁻¹)	Harvest Index (%)
T ₁	2.48	3.92	36.2
T ₂	5.42	7.18	41.5
T ₃	4.88	6.42	40.4
T ₄	5.74	7.56	42.1
T ₅	5.96	7.82	42.5
T ₆	6.08	7.94	42.8
T ₇	6.24	8.16	43.0
T ₈	6.42	8.34	43.2
T ₉	6.56	8.42	43.4
T ₁₀	6.72	8.51	43.5
T ₁₁	6.84	8.57	43.6

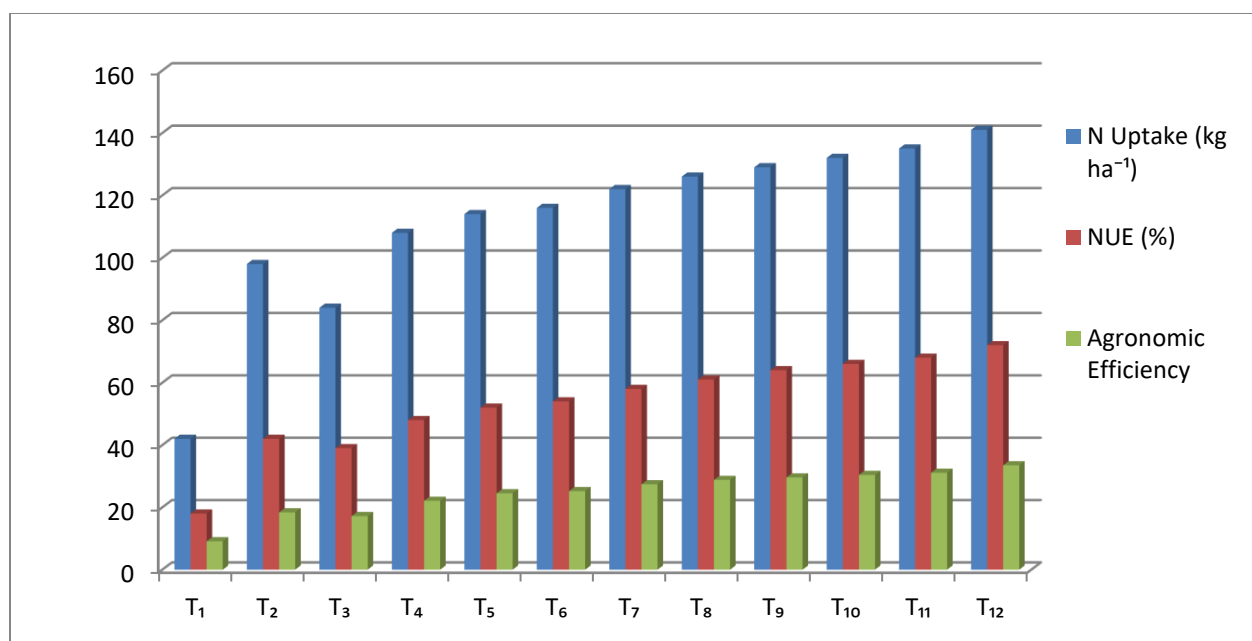
T ₁₂	6.94	8.62	43.8
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Graph 2. Grain Yield under Different Treatments

Table 4. Nitrogen Uptake and Nitrogen-Use Efficiency

Treatment	N Uptake (kg ha ⁻¹)	NUE (%)	Agronomic Efficiency
T ₁	42	18	9.1
T ₂	98	42	18.4
T ₃	84	39	17.2
T ₄	108	48	22.1
T ₅	114	52	24.5
T ₆	116	54	25.2
T ₇	122	58	27.4
T ₈	126	61	28.8
T ₉	129	64	29.6
T ₁₀	132	66	30.4
T ₁₁	135	68	31.1
T ₁₂	141	72	33.5



Graph 3. Nitrogen-Use Efficiency under Different Treatments

Sensor-based nitrogen scheduling improved nitrogen synchronization and minimized nutrient stress, thereby increasing grain yield. Precision technologies also reduced nitrogen wastage and lodging risks.

5.3 Nitrogen Uptake and Nitrogen-Use Efficiency

Integrated precision nitrogen management significantly enhanced nitrogen uptake and NUE.

Precision nitrogen technologies enhanced fertilizer-use efficiency by matching nitrogen application with crop demand and reducing nitrogen losses through leaching and volatilization.

5.4 Environmental and Economic Benefits

Precision nitrogen management reduced excessive fertilizer application and environmental pollution. Sensor-based treatments saved 20–35% nitrogen fertilizer while maintaining higher productivity. Reduced nitrogen losses lowered nitrate

contamination and greenhouse gas emissions.

Economic analysis revealed higher net returns and benefit–cost ratios under integrated precision nitrogen management due to improved fertilizer efficiency and reduced input costs.

6. Mechanisms of Sensor-Based Nitrogen Management

The improved performance of precision nitrogen management may be attributed to:

- Real-time assessment of crop nitrogen demand
- Site-specific nitrogen application
- Reduced nitrogen losses through leaching and volatilization
- Improved chlorophyll synthesis and photosynthetic efficiency
- Enhanced root growth and nutrient uptake
- Better synchronization between nitrogen supply and crop demand

- Increased nitrogen recovery efficiency
- Reduced environmental pollution

Remote sensing and canopy reflectance technologies enabled rapid and accurate estimation of crop nitrogen status using NDVI, chlorophyll concentration, and spectral reflectance indices.

7. Conclusion

Precision nitrogen management using sensor-based technologies significantly improved growth, grain yield, nitrogen uptake, nitrogen-use efficiency, and economic returns in maize and wheat cultivation. Integrated precision nitrogen management involving SPAD meters, GreenSeeker sensors, drone-based monitoring, and variable-rate fertilizer application recorded the highest productivity and NUE. Sensor-guided nitrogen management reduced fertilizer consumption by 20–35% while sustaining or enhancing crop yields. The study demonstrates that precision agriculture technologies are effective climate-smart tools for sustainable nitrogen management and environmental protection in cereal-based systems.

8. Future Research Perspectives

1. Integration of artificial intelligence and machine learning for automated nitrogen recommendation systems.
2. Development of low-cost sensor technologies for smallholder farmers.

3. Use of satellite-based hyperspectral imaging for real-time nitrogen diagnosis.
4. Integration of drone-based nutrient mapping with robotic fertilizer application.
5. Long-term studies on environmental impacts of precision nitrogen management.

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