

# Improved Nutrient Use Efficiency: A Review of Precision Fertilizer Methods in Corn Production

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**Abstract** Corn (*Zea mays* L.) is one of the most sensitive cereal crops in the world and in order to achieve high level of productivity, it is more reliant on the input of nitrogen (N). Conventional ways of applying uniformly the fertilizers lack consideration of the spatial and time variations and hence loss of nitrogen and the environment. Site-specific management of nutrients is made possible by precision agriculture technologies such as variable rate application (VRA), sensor-based nutrient monitoring, unmanned aerial vehicles (UAVs), and GPS/GIS-guided systems. This is a review of recent research on precision fertilizer technologies in production of corn. Results of various studies show that using precision methods can decrease nitrogen inputs by about 1530% and still retain the same or even higher yields and nitrogen use efficiency (NUE) [3], [4], [10], [17]. However, the adoption remains low because of high initial expenses, technicalities, and the lack of long-term validation [23], [25]. The cost-effective technologies and integrated decision support systems should be the subject of future research.

**Index Terms**—corn production, precision agriculture, nitrogen management, nutrient use efficiency, variable-rate application, UAV remote sensing.

## I. INTRODUCTION

Corn (*Zea mays* L.) is a very important crop in the world food systems as it is a food, feed, and industrial crop. Modern corn production is dependent on synthetic fertilizers because of its high nitrogen requirement. Nevertheless, traditional uniform application of fertilizers fails to take into account spatial differences in soil characteristics or temporal crop nutrient demands, resulting in inefficient utilization of nitrogen and losses through leaching, volatilization, runoff, and denitrification [24]. Precision agriculture has become a viable solution to the inefficiencies in farming through the application of modern technologies like GPS, GIS, remote sensing, UAVs, and sensor-based systems [1], [16]. These tools assist farmers to control nutrients more precisely in particular parts of their fields. Farmers can make more efficient decisions and enhance the overall efficiency by matching the fertilizer application with the real needs of crops and changes in the field. The purpose of this review is to assess the effectiveness of precision fertilizer technologies in enhancing nitrogen use efficiency in corn production and to determine the research gaps and future research directions.

### I. REVIEW OF RELATED LITERATURE

#### A. Precision Agriculture and Nutrient Management

Precision agriculture is a combination of geospatial and sensing technologies that are used to control variability in agricultural systems. Global Positioning Systems (GPS) and Geographic Information Systems (GIS) are common tools that are used to create spatial maps of soil properties, crop performance, and topography, which are the foundation of site-specific fertilizer management [1], [16]. Satellite imagery and unmanned aerial vehicles (UAVs) are remote sensing technologies that can be used to measure vegetation indices, including the Normalized Difference Vegetation Index (NDVI) and Green NDVI (GNDVI), which are highly correlated with crop nitrogen status [12], [17]. These technologies can be used together with ground-based instruments like SPAD chlorophyll meters to monitor the nutrient status of crops in real-time [6], [18]. A number of studies have indicated an increase in nitrogen use efficiency (NUE) and crop yield when precision agriculture methods are used [5], [11]. However, these improvements don't always apply in every situation, since their effectiveness depends on factors like soil conditions, climate, and how accurate the data is. This implies that precision agriculture must be tailored to the conditions of a particular field instead of being used in a uniform manner.

#### B. Development of Precision Fertilizer Technologies

The more recent changes in the precision fertilizer technologies have enhanced the collection, processing and use of the data. UAVs have multispectral and hyperspectral sensors allowing high-resolution images that aid in detecting nutrient deficiencies and crop stress at an early stage [2], [8]. Such systems help farmers to identify differences in fields and take action. Ground sensors, such as active canopy sensors and handheld chlorophyll meters are fast and accurate in determining the level of nitrogen in plants. Moreover, machine learning models have been created to enhance nitrogen recommendation systems by incorporating multi-source data, such as soil properties, weather, and crop development patterns [10], [11]. Although they are used in decision-making, their use can be costly in terms of technical knowledge and sound information that can prove a setback in low resource agricultural systems.

#### C. Variable-Rate Application (VRA) in Corn

A key feature of accuracy fertilizer management is Variable Rate Application (VRA) which enables the use of fertilizers which are spatially stratified within the fields. There are two methods, map-based VRA, and sensor-based VRA. Map-based systems apply the information gathered previously like soil tests and yield maps and sensor-based systems will modify the quantity of fertilizer applied to the crops in real-time in accordance with the data of the crops [9], [14]. It has already been demonstrated that VRA can decrease the rate of nitrogen application by up to 30 percent with no impact on crop yields or even crop yields increase [3], [4], [17]. But field variability is one of the determinants of VRA effectiveness. In low-variability industries, the economic values of implementing VRA can be low, and homogenous implementation can already be working. This underscores the need to conduct site-specific assessment prior to implementing precision technologies.

#### D. Sensor-Based Nutrient Management

Nutrient management based on sensors relies on optical signals like NDVI, NDRE and SPAD indices to approximate the crop nitrogen status throughout the growing period. Through these tools, they can make real-time modifications in the application of fertilizers so that the application of nitrogen is made at the most crucial growth stages when crops need it the most [6], [18]. Even though sensor-based systems can be effective in enhancing nitrogen use efficiency, the accuracy of sensor based system may be affected by the environment conditions including lighting conditions, canopy structure, and soil background reflectance [22]. The ground sensors are more likely to give more precise point measurements, whereas the UAV-based system can be used to cover a larger area, but they can be influenced by atmospheric factors. A combination of the

two methods is likely to enhance the overall accuracy and reliability.

#### E. GPS/GIS-Guided Fertilizer Application

The combination of UAV data and GIS platform allows farmers and researchers to learn more about how their fields are spread with nutrients. Such combination simplifies the process of analyzing patterns and controlling the use of fertilizers more accurately and efficiently. Multiplication of multiple layers of data, including soil properties, crop performance data, and topography data, is made possible by GIS to create a precise fertilizer application [8], [21]. This multi-layered method enhances the quality of decision-making in that it takes into account many factors which affect crop growth and nutrient requirement. However, the quality and resolution of input data determine the quality of the GPS/GIS-guided systems. Poor recommendations can be made due to incomplete and inaccurate data and hence reducing the returns of precision application of fertilizers. Irrespective of these constraints, research findings suggest that integrated systems can greatly help in improving the efficiency of nitrogen use, as well as environmental impacts in case they are well adopted [19], [24].

A summary of major precision fertilizer technologies, including their functions, advantages, and limitations, is presented in Table 1.

Technology	Function	Advantages	Limitations
<b>Variable Rate Application (VRA)</b>	Spatially adjusts the fertilizer rate	Lessens nitrogen application; enhances efficiency	Requires field variability
<b>UAV Remote Sensing</b>	Aerial crop monitoring	High-resolution data; early detection High cost	High cost
<b>SPAD/NDVI Sensors</b>	Determine the status of nitrogen	Real-time measurement	Poor coverage.
<b>GPS/GIS Systems</b>	Mapping and analysis	Site-specific decisions	Data complexity

Table 1. Summary of Precision Fertilizer Technologies in Corn Production

### F. Benefits of Precision Fertilizer Application

Accurate fertilizer technologies have several advantages when it comes to corn production. These practices have an agronomic fit in that they match the level of applied in fertilizer with the real crop demand, enhancing nutrient absorption and decreasing yield differences among fields. The economic advantages include lower costs of fertilizer inputs and better stability in yield that boosts profitability to the producers. Precision fertilizer practices have environmental benefits of reducing N losses (leaching and gaseous emissions), reducing nutrient runoff into water bodies, and reducing the risk of soil and groundwater contamination. Empirical research in a wide variety of agricultural environments has documented N application reductions of 15-30% and equal or greater yields than conventional methods [1], [4], [8], [17]. When summed up on a world scale, these advantages have significant consequences to sustainable intensification of agriculture.

## II. RESEARCH GAPS

Despite all the progress made, there are several gaps in research. Most of the studies are carried out on short-term experiments and there is a deficiency of long-term validation of studies in different agroecological settings. This is because it is



expensive and technical therefore limiting its usage especially among the small holder farmers [23]. The other problem is the challenge in integrating multi-source data into convenient decision support systems. There is also a lack of in-depth socio-economic research that explores the challenges to adoption and the policies needed to support it [25].

## III. METHODOLOGY

The review is based on the results of many peer-reviewed articles published since 2010. Data on literature were gathered through databases like Google Scholar, Scopus, and Web of Science with keywords like precision agriculture, nitrogen use efficiency, variable rate application and corn production. The selection of the studies was done in terms of relevance, empirical validation and added value to agronomic, environmental, and technological information.

Figure 4. Methodology flowchart for literature selection and review.

## IV. RESULTS

The literature that is reviewed shows that precision fertilizer technologies tend to enhance the efficiency of nitrogen use in producing corn. Research has continuously shown a decrease in nitrogen usage of about 15-30 percent without considerable yield loss [3], [4], [10], [17]. Sensor-based systems can give precise real-time nitrogen measurements [6], whereas UAV-based surveillance can enhance spatial targeting of fertilizer application [8], [21]. Economic advantages are less input costs [19], environmental advantages are less nitrogen losses and greenhouse gas emissions [24]. However, adoption is hindered by economic and technical barriers [23].

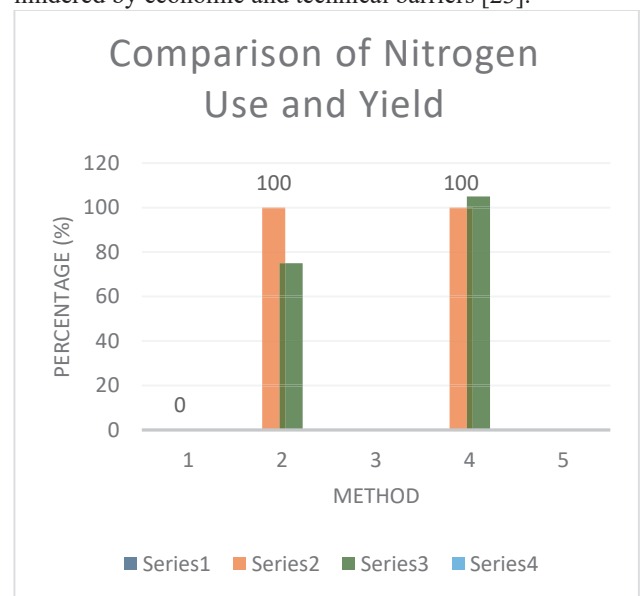


Figure 1. Comparison of nitrogen use and yield between conventional and precision fertilizer methods.

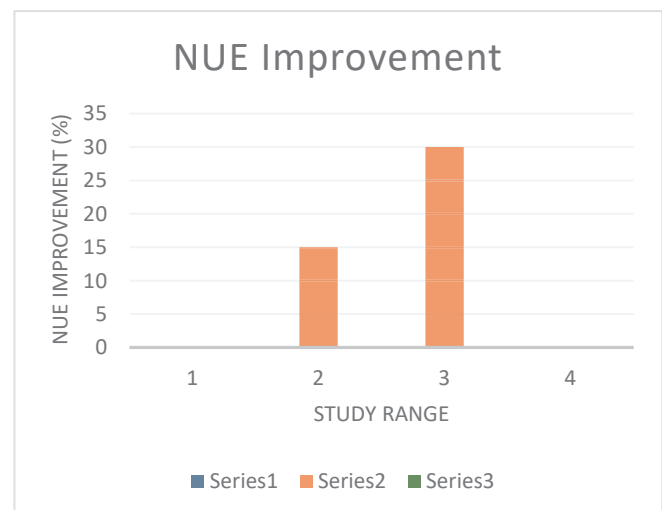


Figure 2. Reported improvement in nitrogen use efficiency (NUE) using precision agriculture techniques.

## V. DISCUSSION

The results indicate that precision fertilizer technologies have substantial benefits compared to traditional approaches because they match the spatial variability and crop nutrient demand with the application of fertilizers. Their performance, however, is sensitive to aspects like variability of the field, accuracy of data and the expertise of the users. In other instances, the costs of implementation can be higher than economic gains in the short term especially to small scale farmers [23]. Moreover, the discrepancy in the results of studies suggests that no precision technologies can be universal and should be adjusted to the local conditions. To achieve broader adoption, it is important to increase accessibility, lower costs, and create user-friendly decision support systems. The long-term research is also needed to assess the sustainability and economic viability.

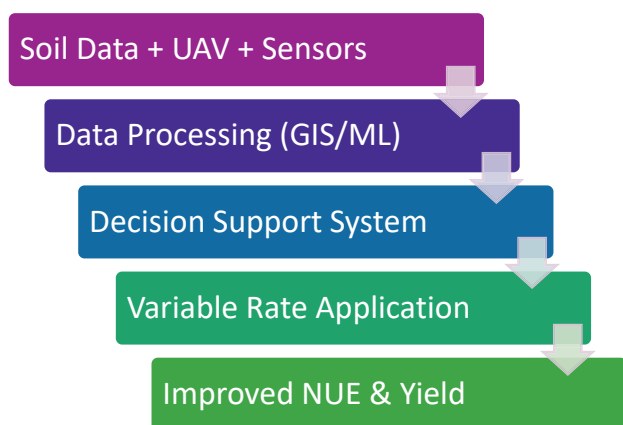


Figure 3. Conceptual framework of precision fertilizer management system

## VI. CONCLUSION

The use of precision fertilizer technologies is a hopeful method to enhance the efficiency of nitrogen in crop production of corn. These technologies will allow site-specific nutrient management, minimize fertilizer inputs, sustain yields, and minimize environmental impacts. Nevertheless, any issues concerning cost, complexity, and long-term validation need to be overcome. Further in-depth studies are needed to come up with affordable technologies and comprehensive systems to facilitate sustainable agriculture.

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