

Precision Nutrient Management: Innovative Technological Approaches

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Precision Nutrient Management, Nutrient Use Efficiency, Variable Rate Technology, Remote Sensing, Environmental Sustainability

How to cite this article:

Mehta, T., Singh, D., Kavita. and Rana, M. 2025. Precision Nutrient Management: Innovative Technological Approaches. *Vigyan Varta* 6 (5): 233-237.

ABSTRACT

The human population worldwide is growing at an alarming rate over the last several decades, growing at an unprecedented rate that has never been observed in the history of mankind with great demand for food, therefore, food security has become a matter of great concern to the world. Higher food production from small land area with natural resource preservation requires precise and efficient farming. The issue of biased nutrient utilization, environmental damage and cost of production due to blanket application of fertilizers under conventional farming practice have been widely reported. Therefore, precision nutrient management is a promising approach in which new technologies are included to fit the nutrient management strategy.

Precision nutrient management implies the use of advanced technology specifically adapted to a site-specific condition to influence spatial and temporal variations in soil nutrient supply, with the objectives of enhancing production and reducing environmental contamination. It consists of modern techniques such as Geographic Information System (GIS), Global Positioning System (GPS), Remote Sensing, Variable Rate Technology (VRT), Sensor and Nutrient Expert for soil fertility and crop requirement. Adoption of these new technologies into nutrient management is essential in achieving sustainable agricultural intensification in a manner that meets world food demand while maintaining environmental integrity.



Vol. 6, Issue 5

INTRODUCTION

utrient management is a crucial component of sustainable agriculture that directly influences our crop yields, soil health and environmental quality. Conventional blanket fertilizer application often results in high cultivation costs, poor nutrient use efficiency, soil health and environmental degradation (Pedersen and Lind 2017). Imbalanced nutrient application can adversely affect crop yields, increase insect pest and disease incidence and promote environmental issues like nutrient runoff and water pollution. Nutrient management ensures that plants receive all the nutrients at the right time. Proper nutrient management ensures crops receive an optimal balance of essential nutrients, which promotes healthy growth, maximizes yields, and enhances nutritional quality, thereby increasing their value for human consumption. It also maintains soil fertility, preventing nutrient depletion and degradation supports beneficial and microorganisms crucial for soil health and nutrient cycling (Wolfert et al. 2017). Precision nutrient management has emerged as an innovative approach to optimize nutrient input based on site-specific requirements, thereby enhancing nutrient use efficiency (NUE) and sustainability.

Precision Nutrient Management

Precision nutrient management is an advanced agriculture practice that optimizes nutrients through technology and data-driven methods. The primary goal of precision nutrient management is to enhance the crop yield and quality while minimizing environmental impact and resource use (Nayak *et al.* 2024). The nutritional needs of the plant change at each stage of plant's growth, therefore it is important to provide plants with exactly what they need and when they need it.

5R's of precision nutrient management

The 5R's of precision nutrient management are developed by International Plant Nutrition Institute (IPNI) which includes the right source, right rate, right timing, right place and right method (Bruulsema 2018).

Right source

The fertilizer should be selected according to crop needs as well as the physical and chemical properties of the soil. The interactions between different nutrients or fertilizer sources should also be considered when selecting or blending the fertilizer products.

Right rate

Fertilizers should be applied at appropriate rates to meet the crop needs and avoid over or under application. The right rate should be determined by finding the available nutrients in the soil and then fulfilling the deficit nutrients.

Right place

Fertilizer should be applied at right place to benefit the crop and reduce the nutrient losses. The fertilizer should be applied according to the spatial variability in nutrient supply and crop demand from field to field and within field.

Right timing

Plants require nutrients at critical growth stages. Thus, it is important to provide nutrients to plants at right time to increase yields and reduce losses.

Right method

Fertilizer should be applied using the best method to improve nutrient us efficiency and reduce nutrient losses. The application



methods include broadcasting, band placement, top dress and foliar application etc.

Innovative technological approaches

1. GPS and GIS technologies

Global positioning system and geographic information system play important role in precision nutrient management. GIS allows the precise mapping of the field. GPS is a set of 24 satellites in the Earth's orbit which sends out radio signals that can be processed by a ground receiver to determine the geographic position on earth.



The field is divided into small grids and soil samples are collected from each grid. Each sample location is tagged with GPS coordinates so that future sampling is done from same locations. The soil samples are collected and tested for nutrient levels and other soil properties. The analyzed data is displayed using GIS software emphasizing nutrient distribution patterns throughout the field. Soil maps are used to direct variable rate applications, enabling precise and efficient fertilizer placement (Fig.1).

GPS and GIS help in precise nutrient application and prevent over or under nutrient application.

2. Variable rate technology (VRT)

Variable rate technology enables the application of fertilizers at variable rates across a field, based on specific soil and crop requirements. Utilizing data from sensors and GIS maps, VRT systems adjust fertilizer application rates in real-time, enhancing nutrient use efficiency and reducing input costs.

Types of variable rate technology in fertilizer application

- a) Map-based VRT: Map-based VRT is more effective for fields exhibiting high nutrient variability. It utilizes GPS-guided prescription maps derived from soil sampling data. Fertilizer spreaders automatically adjust application rates according to predefined recommendations.
- **b) Sensor-based VRT:** Sensor-based VRT is well suited for environments with variable nutrient conditions. It employs real-time sensors to monitor soil nutrient levels and crop health. Fertilizer application rates are adjusted instantly based on sensor readings.
- 3. Remote Sensing (Satellites and Drones): A breakthrough in precision nutrient management is the use of drones and satellite imagery for real-time monitoring of crop health and soil nutrient status. These tools deliver high-resolution images and spectral data, allowing farmers to detect nutrient deficiencies early before they impact crop yields. Multispectral and hyper spectral imaging capture different wavelengths of light to assess chlorophyll levels, plant stress and nitrogen content. It helps to detect early signs of nutrient deficiencies, allowing farmers to apply fertilizers at the right time (Bhamini et al. 2025). Drones equipped with sprayers can apply fertilizers precisely in nutrientdeficient areas.



- 4. Green Seeker: Green seeker is a handheld optical sensor used to measure and analyze crop health and nutrient levels. It calculates the NDVI (Normalized difference vegetation index) value. It offers more efficient and precise way to manage fertilizers. By using green seeker, farmers can avoid blanket applications of nitrogen, instead applying nutrients only where needed and in appropriate amounts. This not only enhances nutrient use efficiency but also reduces environmental impacts and input costs.
- **5. SPAD Chlorophyll meter:** Soil plant analysis development meter was released in 1984. SPAD meter is a lightweight handheld diagnostic tool used to measure the chlorophyll content of leaves. The chlorophyll content thus serves as an indirect indicator of nitrogen content in plants. SPAD meter supports more efficient nutrient management by preventing over or under application of fertilizers.
- 6. Leaf Color Chart: Leaf Color chart (LCC) has been jointly developed by IRRI and Philippine rice research institute. LCC is an affordable and user-friendly tool which assess the relative greenness of green leaves. The intensity of the leaf color is the indicative of the amount of nitrogen in leaves. More intensity of color indicates efficient N management and less intensity indicates poor nitrogen use efficiency.
- 7. Soil based sensors: Soil based sensors help in determining the available NPK nutrients in the soil. These sensors use arduino and NPK sensors to measure soil nutrients in real-time. The sensor is placed in the soil and Sensor is connected to arduino. NPK Sensor measures the soil nutrients and sends the data to the arduino. Then the data is displayed on the OLED Display. Deficient nutrients are supplied to plants.

8. Decision Support Systems: Decision support system (DSS) integrates data from various sources to provide actionable insights for nutrient management. Nutreint expert (NE) is a computer or mobile based DSS for site specific fertilizer recommendation (Gorai et al. 2021). It reviews nutrient management practices and plant population. It provides site specific nutrient recommendation and suggest fertilizer types and timings. It also calculates profits.

Benefits of precision nutrient management

- a) **Improved nutrient use efficiency:** Precision nutrient applications reduce nutrient losses and improve crop uptake.
- **b) Improved crop yields:** Precision tools help in improving crop yields by reducing nutrient losses and maximizing crop uptake.
- c) Economic gains: Efficient fertilizer use lowers input costs and improves crop yields.
- d) Data-driven decision making: Real-time data facilitates informed management practices, improving overall farm productivity.
- e) Reduced environmental impact: Precision nutrient management minimizes environmental degradation by reducing excess fertilizer runoff, thereby preventing soil and water pollution.

Challenges and limitations

- a) **High initial costs:** Investment in advanced equipment and technologies can be prohibitive for smallholder farmers.
- **b) Technical expertise:** Effective use of precision tools require knowledge and training. Limited local technical expertise can hinder the effective use of these tools.



- c) Data management: Handling and interpreting large volumes of data necessitates robust data management systems.
- **d) Infrastructure limitations:** Inadequate internet connectivity in rural areas can hinder the functionality of IoT and cloudbased systems.

CONCLUSION

Nutrient management is transforming with the rise of advanced digital and technological tools. Precision nutrient management ensures optimal use of fertilizers by applying the right nutrients at the right time and place, improving crop yields and reducing input costs. Through the integration of advanced technologies such as GIS, remote sensing, soil sensors and datadriven decision support systems, precision nutrient management enhances nutrient use efficiency, minimizes nutrient losses. maintains soil health and ensures long-term agricultural productivity, contributing to sustainable and profitable farming systems. Unlike conventional blanket fertilizer applications, precision methods tailor nutrient supply to actual field conditions, addressing and temporal variability spatial more effectively. Precision nutrient management stands out as a critical tool to meet future food security goals while maintaining ecological balance. The successful implementation of precision nutrient management will play a pivotal role in shaping resilient and environmentally responsible farming systems.

FUTURE THRUSTS

Government subsidies and financial incentives can play a crucial role in reducing the initial investment burden, thus, encouraging farmers to adopt innovative technologies for precision nutrient management. Research and extension agencies can provide information on costeffective technologies and their long-term benefits to the farmers. Farmers should be trained and provided with technical support to help them adopt these technologies. Adopting precision nutrient management technologies will be essential to tackle global food security issues and support sustainable farming practices in the years ahead.

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