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REVIEW ARTICLE

Advanced strategies for optimization of primary nutrients requirement in rice - A review

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Abstract

The Green Revolution led to India's food independence mostly through the inclusion of supply-driven technologies, such as the introduction of high-yielding cultivars, improved access to water, agrochemicals, and mechanization. The present and future needs target agricultural sustainability without endangering the ecosystem. In this regard, the adoption of precision agriculture is required to meet this expected objective. In developed nations, precision farming has already experienced tremendous growth. However, precision farming methods have taken a while for emerging nations in Asia to comprehend, create, and embrace. Moreover, precision farming is frequently misunderstood as a sophisticated technological intervention intended for extensive agricultural fields. However, it is essentially a science that involves using the "right input" in the "right quantity," at the "right time" and in the "right place" to improve input use efficiency. In the case of primary nutrients such as nitrogen, phosphorus, and potassium, so-called recommendations for nutrient management based on soil tests have improved food grain output which increased the nutrient use efficiency up to a certain extent. Moreover, the recommendations are made for a given agroclimatic region and crops irrespective of site-specific soil fertility, cultivars, and agronomic management levels resulting in excess or scanty use to crop needs. At this juncture, assessing the nutritional requirements of plants proves to be a superior method, as it takes into account the cumulative impact of nutrient availability from various sources on plant growth at any specific stage, making it a reliable indicator of nutrient accessibility. Rice, the most important food crop, is grown in diverse agroclimatic regions at different management levels. Hence, there is an urgent need to adopt a precision nutrient management strategy to optimize the yield output. The article offers an overview of several precision instruments available for managing nutrients at specific sites and aids in choosing the most appropriate one for each circumstances.

Keywords

Rice; optical sensors; nutrient expert; site-specific nutrient management; rice crop manager

Introduction

More than half of the world's population relies mostly on rice as a primary food crop. The main reason for the substantial increase in rice production during the Green Revolution is the implementation of high-yielding and fertilizer-responsive crops, coupled with the provision of necessary resources, which contributed to establishing global food security (1). By 2050, the population of the world is predicted to grow by 33% and reach 9 billion. In order to address the challenges posed by a rapidly growing population and diminishing land resources, it is believed to be crucial to enhance rice production to maintain food security. Although there are various factors that can potentially influence rice production, enhancing soil fertility through efficient fertilizer management is considered to be a critical factor that can substantially narrow the yield gap (2).

Early years were often linked with a quick increase in agricultural yields in places that significantly increased fertilizer usage during the Green Revolution, followed by slower relative yield growth in later decades (3, 4). A healthy supply of nutrients is essential for the management of soil and crops. The productivity of rice crops experiences a notable boost with an increase in the application of fertilizers. Fertilizer N is often administered by farmers in a series of split applications, however, the quantity of N used in each split as well as the timing of the splits can differ significantly. In general, farmers use too much nitrogen and too little phosphate and potassium fertilizer that causes a significant increase in the prevalence of pests, diseases, and lodging (5).

The blanket fertilizer recommendations don't take into consideration the significant differences in soil fertility that are prevalent in agricultural systems (6). Hence, with general fertilizer recommendations, nutrients may be applied too much or insufficiently for diverse sites, limiting the effect of the treated nutrients. Nutrient leakages into the environment as a result of excessive fertilizer application can have negative effects on the ecosystem, including the contamination of surface and ground waters (7, 8).

At this peak time to replenish depleted soils and maintain the sustainability of the environment and agricultural production over the long run, adopting precision nutrient management in rice has become imperative (9). The key benefit of this strategy is the synchronisation of fertilizer application to crop needs. Many smart instruments, such as the leaf colour chart (LCC), chlorophyll meter, green seeker etc. are frequently used to help with this, and information and communication technology (ICT) based decision support systems, such as the nutrient expert (NE), rice crop manager (RCM), and rice advise, are also rapidly gaining popularity (10). This review clearly highlights the ability of all the prominent smart tools in administering the need-based application of fertilizer to rice and help in evaluating their potential to improve nutrient use efficiency.

Role of primary nutrients in rice

In general, the primary nutrients *viz.,* nitrogen, phosphorus and potassium are needed in large quantities to fulfil the plant growth demands conferring marked enhancement in rice yield. Nitrogen being the structural component of several metabolically active substances like amino acids, nucleotides, nucleic acids, chlorophyll etc. conferred its role in dry matter production by regulating various metabolic processes in plant *viz.,* photosynthesis and respiration (11-13). Moreover, many studies indicated that top dressing of nitrogen at the panicle initiation stage was noted to minimize spikelet sterility, increase spikelet number and ultimately the panicle weight (14, 15). This was mainly due to the role of absorbed nitrogen during panicle initiation in keeping the leaves green after heading, contributing towards active photosynthesis and indeed, grain yield (16).

Phosphorus is the second most important nutrient after nitrogen that determines the root development and tiller performance and is thereby responsible for the early establishment of seedlings (17). Moreover, studies indicated that grain fertility was reported to be reduced significantly under phosphorus deficiency which might be attributed to prolongation in days to panicle emergence (18, 19). Although, prolongation in days to heading and maturity could be beneficial for increased dry matter accumulation it concomitantly increases susceptibility to various biotic and abiotic stresses. In an investigation conducted in the central highlands, Madagascar it was observed that under optimal temperatures the biomass production and grain yield of rice were improved with phosphorus deficiency while on the other hand, a contrasting response was realized in terms of biomass production and grain yield under low-temperature stress (20).

The role of potassium in osmotic adjustment and regulating the cell turgor influenced cell enlargement, conferring plant growth and development. Besides, additional application of inorganic potassium reported an increase in both the production and translocation of photo-assimilates from source to sink entailing heavier grains (21). The positive role of potassium in osmo-regulation might have rendered facile uptake of nitrogen and phosphorus from the soil which was held responsible for influencing the rice growth and productivity. However, in many regions of India the soils are saturated with potassium and therefore the response obtained through potassium application was low. However, in saline conditions, the response of potassium to productivity was observed to be more significant than under optimum conditions (22).

The importance of fertilizers in increasing rice yield was recognised in light of the aforementioned facts. Yet, using too much fertilizer to get the desired output was bad for the environment (23). To maintain food security and reduce the flow of unwanted fertilizers into the environment, it will be necessary to provide sufficient amounts of reactive nutrients.

Fertilizer consumption and cereal production in developed and developing nations

According to the data available in world bank database on cereal production and fertilizer consumption from 1960 to 2020 the following illustrations were depicted in Fig. 1 and Fig. 2 for both developed and developing nations (24). As seen in Fig. 1, both developed and developing nations have shown an increase in cereal production from

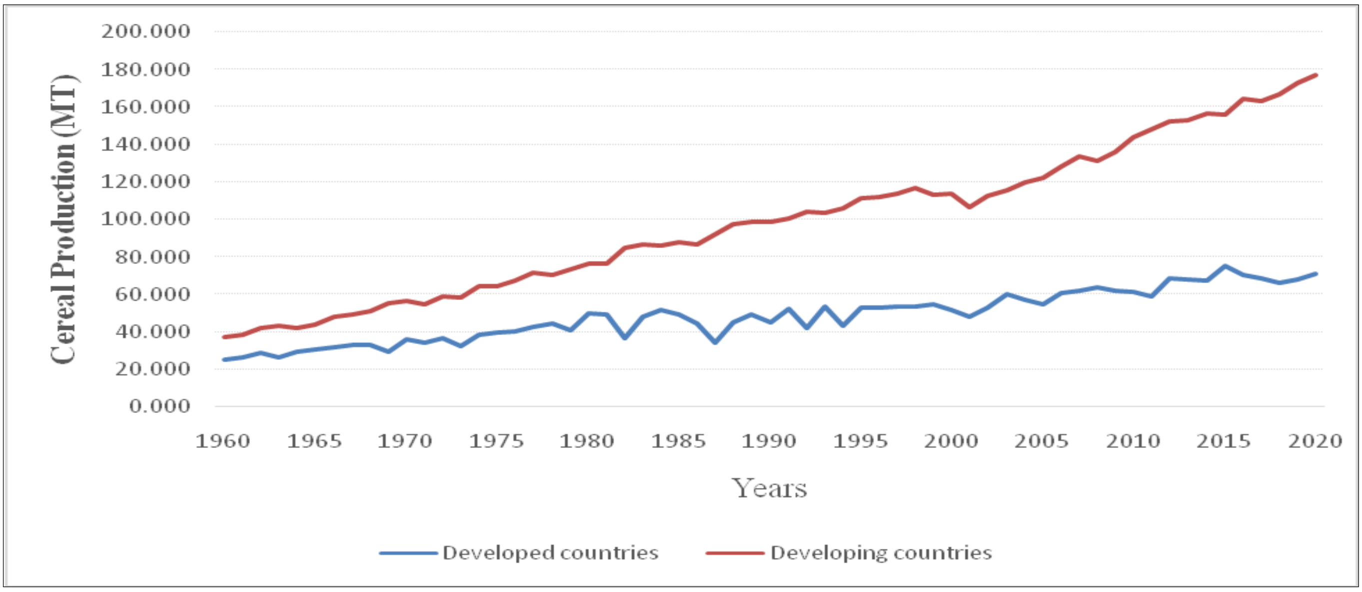

Fig. 1. Trend of cereal production in developed and developing nations from 1960 to 2020.

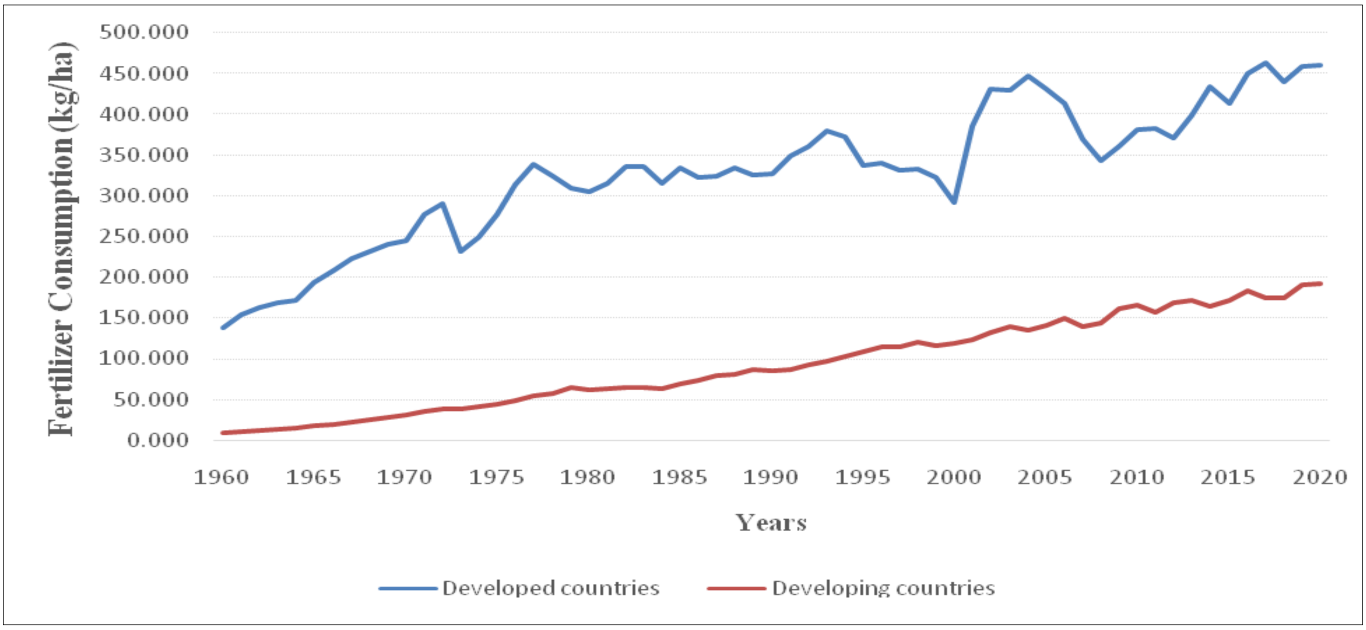

Fig. 2. Trend of fertilizer consumption in developed and developing nations from 1960 to 2020.

25 to 70 million tonnes and 35 to 175 million tonnes, respectively as observed with the advancement in years. Also, it was stated that, on an average, developing countries produce more cereal than developed ones. Similarly, when fertilizer use was assessed, it was found that developing countries consume more fertilizer over time than developed countries.

Present scenario of fertilizer consumption in India

The fertilizer consumption was burgeoning since the introduction of high-yielding and fertilizer responsive varieties in the country. According to the fertilizer association of India (FAI), nitrogenous fertilizers (20.40 million tonnes) rank first in consumption followed by phosphorus and potassium fertilizers in the tune of 8.97 million tonnes and 3.15 million tonnes, respectively (25). This was mainly ascribed due to an increase in budget allocation of government subsidy from Rs 21,535 to Rs 90,539 crores on nitrogenous fertilizers in the last 10 years (2010 to 2020). Among those nitrogenous fertilizers, urea occupies 50% of the total fertilizers consumed which is followed by diammonium phosphate (DAP).

Strategies for primary nutrient optimization in rice

The use of optical sensors and the adoption of decision supporting system (DSS) guided nutrition management are the two main methods used to optimise primary nutrients (26) (Fig. 3). Here, some of the most popular tools are discussed, including the leaf colour chart (LCC), chlorophyll meter, green seeker, and decision support systems.

Leaf colour chart

The leaf colour chart is a plastic reference strip with a series of panels based on the brightness of green produced by nitrogen application, which ranges from excessive to deficient amounts (27). It was first commercialised by Fuji Film Co. in 1980 and named as "Standard rice leaf colour scale". This scale consisted of seven panels, with light green representing panel 1 and dark green representing panel 7.

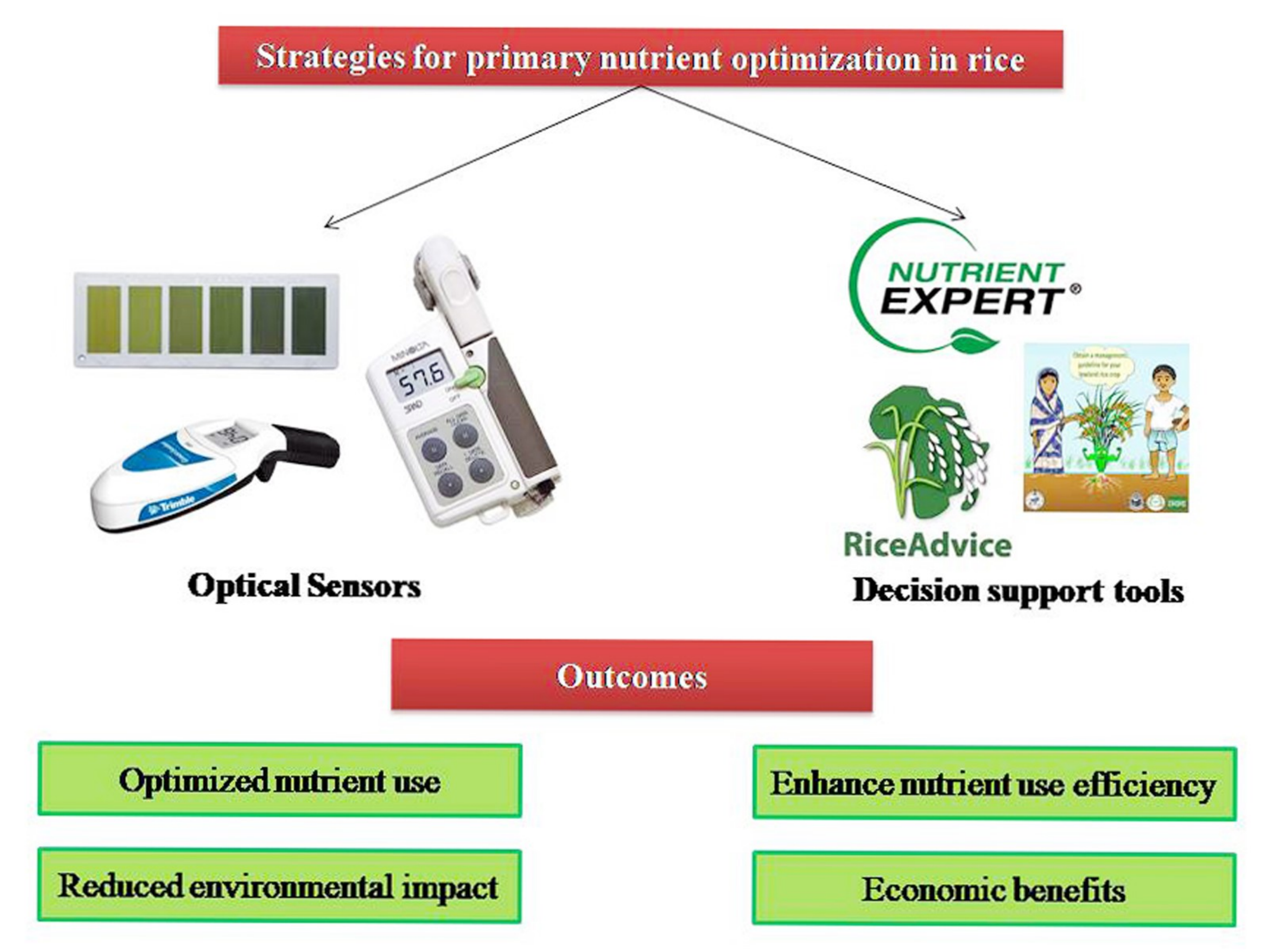

Fig. 3. Beneficial influence of different strategies of primary nutrient optimization on rice.

Based on this prototype, the International Rice Research Institute (IRRI) and the Philippines Rice Research Institute (PRRI) developed a leaf colour chart (LCC) in 1996. It consists of six colour panels arranged in ascending order of rice leaf greenness (28). Furthermore, IRRI researchers worked to establish a link between spectral reflectance from leaves and chlorophyll content, reducing the number of panels to four. Nonetheless, Zheijiang Agriculture University (ZAU) in China and the University of California, Davis (UCD) in the United States developed an eight-panelled ZAU-LCC and UCD-LCC, respectively.

Initially, the four and six-colour panel IRRI-LCCs were used in India in the first decade of the twenty-first century to create LCC usage guidelines that were tailored to the country's circumstances. Later, customised LCCs were introduced in various regions of India. LCC-based fertilizer nitrogen management protocols were standardised for various crops like rice, maize and wheat (29). In the interim, Punjab Agricultural University (PAU) introduced an LCC with six coloured panels that was specifically designed for north-western India. Due to the use of shades that correspond to 3.5 and 4.5 in place of the first two panels of the IRRI-LCC, the PAU-LCC provides a higher level of precision when assessing the level of greenness in leaves. Similarly, for irrigated rice ecologies a five-coloured panel known as IIRR-LCC was developed by the Indian Institute of Rice Research (IIRR) located at Hyderabad and a five-coloured panel *viz.,* NRRI-LCC with a similar pattern was created by NRRI Cuttack and is ideal for rice varieties grown in eastern India.

The basic idea behind all LCCs is same, despite the visual differences in the range of green colours, a user can estimate the amount of nitrogen supplied to the crop in real time by comparing a leaf to the reference panel on LCC (30). Although the LCC may not be as precise as a chlorophyll meter in determining the leaf N status in field crops, it offers a straightforward, affordable, quick, and non-destructive method for measuring changes in the level of leaf greenness (22). The LCC readings were typically taken at intervals of 7 to 10 days following the most recent fully expanded leaves on crop plants in order to synchronise the nitrogen application to the crop demand (31). The recommended amount of fertilizer nitrogen, which is typically between 20 and 45 kg N per hectare (kg N/ha), is applied when the leaf colour falls below a specific threshold of greenness on the LCC (32). The threshold LCC score is determined by a series of preliminary experiments for a varietal group in a particular area.

Chlorophyll meter

A chlorophyll meter is a simple and portable equipment used to assess the relative chlorophyll content of leaves. In 1983, Minolta Co. released the first chlorophyll meter for use on a commercial scale. The meter readings were specified as SPAD values, which show the relative quantities of chlorophyll contained in plant leaves. The SPAD meter is commonly used to assess the chlorophyll content in a leaf by comparing the transmission of red (650 nm) and infrared (940 nm) light, resulting in a SPAD value (33). Moreover, due to the strong and linear relationship between leaf N concentration and chlorophyll content, SPAD values were also used to evaluate the real-time greenness index in rice fields and decide whether nitrogen top dressing is necessary (34). Nevertheless, the correlation between the weight-based leaf nitrogen concentration and chlorophyll meter readings is subject to variation based on the growth stage and variety of the crop, primarily due to differences in leaf thickness. In order to address this issue, Peng and his co-workers carried out an experiment on rice and found that to mitigate the influence of leaf thickness on chlorophyll meter values, one can overcome this issue by representing foliar nitrogen concentration on a leaf area basis rather than a weight basis (35).

Using the correlation between leaf area-based nitrogen concentration and chlorophyll meter (SPAD) measurements, the SPAD threshold was calculated. Below this level, the crop would experience N deficit, which will reduce production. The requirement for nitrogen top dressing was determined by Peng and his co-workers using a single SPAD threshold of 35, which corresponds to a foliar nitrogen concentration of 1.4 g N/m^2 of leaf area (36). Under well-controlled experimental circumstances, this particular threshold proves to be adequate in attaining the highest possible yield potential in the IR72 rice variety (37).

In relation to fertilizer N, soil N contributes more to rice production. So, the effectiveness of applied N can be improved if N fertilizer application is adapted to the soil's capacity to deliver N (38). Due to the great geographical and temporal diversity of lowland rice soils, it is challenging to establish the indigenous N supply. Based on the findings of Peng *et al.*, (36) utilizing SPAD-guided nitrogen management enhances the synchronization between crop nitrogen requirements and supply, resulting in elevated grain yields, enhanced efficiency in fertilizer usage, and improved harvest indices (39).

Moreover, they hypothesise that rice plants that are more productive as a consequence of SPAD-based N control will be less likely to lodge and are more resistant to ailments like sheath blight and blast (40). The SPAD reading is influenced by specific situations, just like any other diagnostic tool. These include the kind of variety, plant density, environmental factors, the presence of other nutrients than nitrogen in the soil and plants, and biotic and abiotic plant stressors that lead to leaf chlorosis (41). Indeed, rice plants that are deficient in phosphorus (P) often exhibit dark green leaves, which can lead to elevated SPAD measurements. However, when other nutrients in the soil and plants are adequately supplied, the SPAD method proves to be effective. It serves as a valuable tool for fine-tuning nitrogen fertilization, provided that SPAD values are appropriately calibrated for a specific situation and varietal group (42).

In practical applications, when the greenness of rice leaves falls below a certain threshold, nitrogen fertilizer doses are commonly applied. However, it is important to note that the growth stage of the plant and recent environmental conditions such as temperature, moisture stress, and sunlight exposure can influence the level of leaf greenness (43). For instance, if the sky is persistently cloudy for a week or longer, rice leaves tend to lose some of their green colour from lack of sunlight. Hence, occasionally adopting the incorrect threshold for leaf greenness may result in poor fertilizer management decisions that result in yield loss and/or inefficient fertilizer N usage. To assist with in-season nitrogen fertilizer applications for rice under such conditions, utilizing the concept of dynamic threshold greenness or sufficiency index method may prove to be more effective compared to relying on a fixed threshold level of leaf greenness (35). The concept of dynamic threshold greenness emerged due to the need for individual calibration of SPAD meters for each field, soil type, cultivar, and environmental conditions. This calibration is necessary because SPAD meter readings alone do not carry any inherent meaning (44). The most effective method to calibrate the SPAD meter involves establishing reference strips within each field that are over-fertilized or nitrogen-rich. By utilizing the readings from these reference strips as a benchmark, the threshold leaf greenness for a specific crop growth stage and season in a given field can be defined precisely (45). Dynamic threshold greenness is determined through the utilization of a SPAD meter, where it is expressed as a percentage of the SPAD value observed in the nitrogen-rich strip. This measurement is commonly referred to as a sufficiency index (46). When the sufficiency index value drops below a specific threshold, such as 90%, it indicates the need for nitrogen fertilizer recommendation to the crop (49) (Table 1).

Table 1. Types of chlorophyll meter manufactured by various companies (47, 48).

Chlorophyll meter	Manufacturer	Wavelengths used
SPAD 502	Konica Minolta	650,940
atLeaf Plus	FT Green LLC	640,940
CCM 200 plus	Opti-Sciences	653,931
MultispeQ	PhotosynQ	655,950

Green seeker

Green seeker is a comprehensive optical sensing and application system that provides a more effective and precise method for promptly applying fertilizer. Although the Green seeker technology was developed around the same period as the N-Sensor, its commercial viability has only emerged recently (50). In 2001, N Tech Industries Inc. obtained a license from Oklahoma State University in the United States to utilize the technology that had been developed by the university.

Based on predictions of early-season N uptake and potential yield, green seeker evaluates crop N demands using reflectance measurements. The ratio of energy that is reflected from an item in relation to the energy that strikes is known as reflectance (51). A crop's spectral reflectance varies significantly between the visible red range and the near-infrared area of the electromagnetic spectrum. Plants frequently reflect less red and blue light than green, giving the impression that they are green to the human eye because chlorophyll absorbs these colors (52). The quantity of near-infrared radiant radiation that is significantly reflected off the plant surface depends on the characteristics of the leaf tissues, their cellular composition, and the interfaces between the protoplasm, chloroplast, cell wall, and air. Consequently, spectral reflectance data may be utilized to compute a variety of vegetative indices that have good correlations with plant agronomic and biophysical factors linked to photosynthetic activity and plant productivity (53).

Since the NDVI calculation takes into account both red and near-infrared light, it aids in the assessment of photosynthetic activity. Nevertheless, rather than only reflecting the impact of one component, NDVI must be understood as a measurement of aggregated plant development that takes into account a number of plant growth characteristics. Physical factors picked up by the index are probably connected to leaf area or total biomass (54).

It measures spectral reflectance from the crop canopy using an active light source to generate the non-normalized difference vegetative index (NDVI), which is then used to quantify the amount of nitrogen (N) applied to the crop by comparing it with a nitrogen-rich strip within the field (32). Both the red (650 nm) and near-infrared (770 nm) portions of the spectrum are emitted from the inbuilt light source in the sensor unit. The gadget measures the amount of emitted light that is reflected to the sensor from the perceived region (55).

Decision support tools

A strategy for feeding crops with nutrients as and when necessary is called site-specific nutrient management (SSNM) (56, 57). Using SSNM principles has increased agricultural output, nutrient usage efficiency (NUE), and farmer income, according to a number of studies. Using SSNM concepts in various circumstances is made easier by the 4 R Nutrient Stewardship concept proposed by International Plant Nutrient Institute (IPNI), which emphasises using the right amount of fertilizer at the right time from the right sources using the right ways (58). In order to aid with decision-making for scheduling nutrients in accordance with SSNM principles, two software applications, such as nutrition expert and rice crop manager, were developed.

Nutrient expert

The Nutrient expert (NE) is an intuitive computer-based decision support tool developed by IPNI that makes it easier to decide how much fertilizer is needed to a farm (59). It was initially developed in Microsoft Access to direct the delivery of fertilizer to hybrid maize in southern Asia, but over time it changed into a web-based system and spread to other geographical areas and crops like rice, wheat etc. As a result, there is less possibility of over- or under-fertilizing the crop (60). This tool assists in estimating the rates of nutrient application at the field level, taking into account predicted yield, influence of climate, soil type, and crop management practices adopted by the farmer (58). In nutrient omission studies set out in farmers' fields, which call for at least one crop season, the parameters required for nutrient expertise are often assessed. Crop advisers can create fertilizer recommendations for a place using NE even without data from field trials since parameters can be inferred using proxy information such as growing environment, indicators of soil fertility, the farmer's cropping patterns, use of fertilizer inputs and crop residue management, and current yields of farmers (61). In this tool, the projected increase in yield resulting from the application of specific fertilizer nutrients nitrogen (N), phosphorous (P), and potassium (K) are utilized to determine the precise quantity of fertilizer required for a crop in a particular location. This is achieved by assessing the disparity between the potential yield achievable with sufficient nutrients and the yield limited by nutrient deficiencies (62).

According to the research, applying nutrition experts produced grain yields that were substantially higher than those produced by using the recommended fertilizer dose. Consequently, using fertiliser recommendations based on the soil's capability for supplying nutrients, particularly with the help of nutrient experts, helped to achieve improved crop yields (63).

Rice crop manager

RCM is an online tool available at no cost, designed to assist farmers in making informed decisions regarding nutrient management in rice by providing valuable recommendations (64). In collaboration with national partners across Asia, the International Rice Research Institute (IRRI) developed the web-based decision support tool called nutrient manager for rice in 2008. The purpose of this tool is to facilitate the dissemination of fertilizer recommendations based on site-specific nutrient management (SSNM) to rice farmers. In 2013, nutrient manager for rice underwent a name change and became as rice crop manager (RCM). Alongside this update, enhancements were made to the tool, which was subsequently adopted and utilized by national programs in various Asian countries. Its primary function is to calculate site-specific crop and nutrient management strategies aimed at increasing yield and profitability for both irrigated and rainfed rice cultivation (65). The tool is accessible at http://cropmanager.irri.org.

In a field trial conducted in Philippines, revealed that the average amounts of N, P, and K applied per hectare were 82 kg, 10 kg, and 21 kg, respectively, using a decision support system called RCM. Comparatively, in a different practice called farmer's practice, the application rates were 93 kg, 11 kg, and 18 kg/ha, respectively. Grain yield in farmer's practice ranged from 1.82 to 6.49 t/ha, and it was observed that RCM increased the average yield by 6% (66).

Machine learning

Machine learning is a significant technological advancement that plays a crucial role in assisting with nutrient management decisions by leveraging existing data.

Machine learning can be categorized into three primary types: supervised learning, unsupervised learning, and reinforcement learning. In supervised learning, input data is linked to output through training datasets, while unsupervised learning identifies patterns in large datasets by grouping data into clusters based on certain features. Generally, when creating a machine learning model for nutrient management, decision tree-based algorithms are frequently employed. Among these, artificial neural networks (ANN), which rely on radial basis function networks, perceptron algorithms, and back propagation techniques, are highly popular for developing predictive models.

Nutrient omission

The omission plot approach is used to evaluate the amount of fertilizer needed to get a desired yield. With the exception of the nutrient of interest, which is the missing nutrient, all the main nutrients are used in this procedure (67). The method gives a rough assessment of the soil's natural nutrient supply. The amount of fertilizer needed is then determined by calculating the yield gap between the maximum yield that can be obtained and the yield obtained using the omission plot approach (68).

Impact of precision nutrient management on growth and productivity of rice

Over the past sixty years, the combination of fertilizer application and genetic advancements in cereal crops has played a significant role in enhancing crop productivity and improving global food security. However, in the case of rice, the use of fertilizers has surpassed the rate of yield improvement. However, overuse of fertilizers beyond crop needs is highly detrimental to the environment whereas, underuse may cause global food insecurity (69). In this situation, the precision nutrient management approach plays a major role in optimizing the nutrient requirement based on crop demand.

In *kharif* transplanted rice, it was shown that LCC-based nitrogen management with a threshold of 4 resulted in a significant improvement in grain production of 19.96% above its recommended nitrogen management and a save of 18 kg N/ha (70). While, it was discovered that in *rabi* transplanted rice, a leaf colour chart with a threshold of 5 produced grain yield increases of 158 and 10.44% relative to the absolute control and recommended dose of nitrogenous fertilizers, respectively (71). With the use of fertilizer N, hybrid rice's grain production improved, and a considerable rise was seen up to 120 kg N/ha. When compared to 120 kg N/ha, an additional increase in the N rate did not result in a discernible gain in rice output. Depending on the diversity of the soil and weather conditions, the utilization of LCC 4 (Leaf Color Chart 4) for nitrogen (N) management in hybrid rice led to the implementation of 80-110 kg N/ha, resulting in a reduction of 10-40 kg N/ha compared to the conventional practice of applying 120 kg N/ha in three equal portions at specific growth stages. In terms of nitrogen use efficiency, LCC 4's agronomic efficiency and recovery efficiency were better than LCC 5's observations (40). Moreover, for basmati rice Lone *et al*. (72) suggested using the threshold leaf colour value LCC 4 by administering 20 kg N/ha to maintain the critical greenness level and Subedi *et al*. (73) discovered that using LCC 4 as the threshold allowed for good yields and high fertilizer N usage efficiency for dry direct seeded rice. Some key case studies are presented in the Table 2.

Table 2. Effect of leaf colour chart (LCC) on grain yield of rice.

Threshold	Grain yield (kg/ha)			References
	Control	Recommended dose of fertilizer	LCC based N management	
LCC 3	3079	-NA-	4850	(74)
LCC 4	2474	5499	6533	(75)
LCC 5	2435	5696	6291	(70)
LCC5	-NA-	3803	4833	(76)

NA- Not Applicable

Chlorophyll meters are potential substitutes in estimating the greenness index, as LCC cannot detect subtle variations in leaf greenness. The influence of chlorophyll meters on the grain yield of rice is presented in Table 3.

Table 3. Effect of SPAD 502 on grain yield of rice.

Threshold	Grain yield (t/ha)			References
	Control	Recommended dose of fertilizer	SPAD-based N management	
SPAD 35	2.84	-NA-	4.67	(82)
SPAD 35	2.48	3.35	3.88	(83)
SPAD 36	3.62	5.70	5.83	(79)
SPAD 37.5	3.38	5.78	5.86	(78)

NA- Not Applicable

Hou *et al*. (77) demonstrated that leaf SPAD readings increases when N rates increases, and the SPAD-guided N management lowered N rates and enhanced N use efficiency without reducing grain production. Further, it was reported that the productivity of partial factors and N agronomic efficiency increases by 10.0% and 14.2%, respectively, over farmer practice. In comparison to fixed time nitrogen management and control, Singh *et al*. (78) observed a 5.76 and 44.58% increase in yield with a corresponding saving of 30 kg N/ha by adopting SPAD based 90% sufficiency index strategy. In another experiment, the top dressing of nitrogen at a SPAD threshold of 37 recorded a maximum grain production of 6098 kg/ha and further increasing the rate and quantity of N treatment at a higher SPAD threshold of 38, on the contrary lowered the grain yield. In addition, the adoption of real-time nitrogen management showed a significant reduction in N application rate by 27 to 54% of the current N fertilizer guideline without lowering rice grain yield (79). These results are supported by Ghosh *et al*. (80), indicating that the medium rate of N topdressing at SPAD 37 produced grain and straw yields equivalent to fixed time nitrogen management while saving 33.3% of fertilizer N. Interestingly, despite increasing total N rates and the quantity of N applications while employing a higher SPAD threshold to 38, no improvement in grain production was observed. Similarly, Shantappa *et al*. (81) found that application of N through SPAD 37.5 to 40.0 revealed saving of N by 90 to 100 kg/ha without considerable reduction in grain yield, and in terms of economics, rise in SPAD from 30 to 37.5 boosted the net returns significantly, but further increase to 40.0 reported loss in gross returns and benefit-cost ratio owing to greater cost of cultivation.

Moreover, since the SPAD 502 is so expensive, competing chlorophyll meters like the atLeaf plus, CCM 200 plus, Dualex, and MultispeQ are gaining popularity. Real leaf chlorophyll, in contrast, displayed a linear correlation coefficient with dualex-4 as opposed to SPAD 502 and CCM-200. According to which Dong *et al*. (84) claimed that Dualex-4 is a preferable option when compared to the SPAD-502 and the CCM-200 for collecting leaf chlorophyll data. Unfortunately, employing these chlorophyll meters to regulate nitrogen in rice is yet to be explored, thus opening up new avenues for investigation.

Although the LCC and chlorophyll meter have aided in the development of real-time N management techniques for rice, they do not account for photosynthetic rates, biomass production, or anticipated yields when determining the amount of fertilizer N needed. Recently, techniques for calculating the amount of nitrogen (N) that crops need have been developed utilising early-season predictions of N uptake and potential yield. These techniques are based on measurements of reflectance in the red and near-infrared regions of the electromagnetic spectrum. Spectral vegetation indices like the normalized difference vegetative index (NDVI) are generally used to express measured spectral reflectance. The NDVI is sensitive to the leaf area index, green biomass, and photosynthetic efficiency and hence has been demonstrated to offer an assessment of photosynthetic efficiency and potential productivity of crops (Table 4). According to Billa *et al.* (85), the maximum grain (5411 kg/ha) and straw production (6541 kg/ha) of rice was seen when N was administered at NDVI value 0.8, which was comparable to NDVI value 0.7. Both of these values were noticeably better than the other NDVI values of the green seeker tested. In another trial by Mohanta *et al*. (86), green seeker-based nitrogen management was claimed to have increased grain output by 16.55% in Chellakamarpada village, West Bengal. Similar to this, it has been reported that green seeker-based nitrogen management increased the grain and straw yield of *kharif* rice by 7.47% and 5.49%, respectively, beyond the recommended dose of nitrogen in sandy loam soils at Dharwad, Bengaluru.

Table 4. Influence of green seeker on grain yield of rice.

Region	Grain yield (t/ha)		References
	Control	Green seeker-based N management	
Hyderabad, India	2.73	4.33	(87)
Nepal	3.80	6.13	(88)
Ludhiana, India	3.85	6.48	(89)
Ludhiana, India	4.39	7.00	(90)

All of the sophisticated technologies that have been detailed up to this point are only capable of administering a precise nitrogen application. Yet, careful administration of all the primary nutrients can increase the effectiveness of nutrient usage. In this case, the use of ICT-based decision support systems was created to assist with fertilizer recommendations specific to the field. Nutrition expert (NE), rice crop manager (RCM), and rice advise (RA) are the three most widely utilized ICT-based decision support systems for rice. These systems enable dynamic nutrient management to meet crop conditions and demands. According to a study with 209 tests employing rice crop manager (RCM) for field-based fertilizer recommendations revealed an improvement in grain production ranging from 0.25 to 0.65% above farmer's fertilizer practise (FFP) for both seasons, *kharif* and *rabi* (91). The results of a study by Amgain and his co-workers showed that, in the Terai areas of Nepal, grain yields from NE-Rice recommendations were 54.4% and 24.3% greater than farmer's fertilizer practise (FFP) for hybrids and improved varieties, respectively. Also, nutrition experts in Terai regions do better than in Nepal's mid hills (92).

Impact of fertilizer use on the environment and climate change

Fertilizers are a vital component that fuels the production of food. Nevertheless, the increased usage of synthetic fertilizer has resulted in major direct and indirect environmental issues, with estimates placing the origin of more than 60% of the nitrogen pollution in agricultural production (93). According to recent assessments from the IPCC and FAO, synthetic fertilizers account for 13% of all agricultural GHG emissions globally, which accounts to around 0.7 Gt CO_2eq. The buildup or fall of SOM can be caused by the application of fertilizers, particularly N to crops. Fertilizer N encourages the formation of both above- and below -ground plant biomass, which raises SOM concentrations when administered in synchronization with the crop needs. However, excessive fertilizer N applications may hasten SOM loss by causing the organic C and plant litter already present in the soil to rot due to increased microbial activity.

Nitrous oxide (N_2O), a long-lived greenhouse gas that builds up in the atmosphere, contributes to climate change and stratospheric ozone depletion. Besides, nitrate pollution of freshwaters is increasingly becoming a prevalent worldwide concern with the growing reliance and usage of fertilizer nitrogen. The historical and ongoing uses of N fertilizers and manures are reflected in the current patterns of nitrate-N enrichment of groundwater. According to one of the most thorough analyses of N_2O emissions, human sources were responsible for 43% of worldwide emissions between 2007 and 2016 (7.3 Tg N/year) (94). Among which, 52% of emissions attributed to human activities were direct emissions from agricultural N applications.

Apart from that, even relatively little P losses from farmland to open waterways might have an impact on eutrophication. The excess P in the soil continues to be the major factor in its transfer to surface water bodies (95). Erosion of P-fertilized soil also contributes to the delivery of phosphorus to streams and lakes, even though applied P is tightly bound to soil components and the release of P to the soil solution or runoff water depends on the type of soil. Furthermore, the rising demand for phosphate fertilizers in the agricultural sector has led to the depletion of available phosphorus reserves in India, primarily concentrated in Rajasthan and Madhya Pradesh. This depletion may lead to a shortage of raw materials, affecting the manufacturing industries and, ultimately, farmers (96).

In South Asia, the effectiveness of fertilizer application is only 30–40%. (97). If we can cut N_2O emissions, lower production costs, and raise fertilizer usage efficiency by 5–10%, it will increase yield and boost farmer profitability. Contrary to popular belief, precision agriculture is a method that may be used to control inputs on smallholder farms in the tropics as well as large-scale mechanised farms. By making sure that nutrients are given in the proper form, quantity, timing, and location, precision nutrient management strives to increase the effectiveness of fertilizer usage (98).

Limitations and future scope of research

The main component of precision nutrition management systems is based on the measurement of leaf greenness utilizing optical sensors which is influenced by a variety of circumstances. These measurements can be impacted by a variety of factors like insufficient or excessive supply of water or nutrients, soil moisture, organic matter, and meteorological conditions, which might result in poor nutrient management decisions. The use of technology-based precision N management may also be affected by several stresses, such as the presence of excessive salts in the soil or water, irregular rain, etc. Nevertheless, P and K deficits are predicted to interfere with leaf greenness and impact the results obtained by optical sensors. Determining the stressful situations in which need-based N management is ineffective is necessary. The quantity of solar radiation that a location receives appears to have an impact on the threshold SPAD/LCC levels. For this problem to be solved, more information must be gathered.

Certain cultivars' leaves may have different spectral characteristics. As a result, several thresholds may need to be defined for various cultivars. In cases of uncertainty, the sufficiency index or dynamic threshold greenness technique, which maintains a N-rich strip or plot in each field where, precise N management is to be practised, may be used. The intensity of the green colour and NDVI of the plants are also altered by the insect-pest occurrence. It is best to stay away from such plants when collecting data. Although, precision management of nutrients necessitates regular inspections and may cost more labour for additional splits, but synchronising demand and supply for nitrogen is necessary to increase N usage efficiency. However, the energy used on greater crop monitoring is offset by the amount of fertilizer N saved, decline in the frequency of insect pests occurence, decline in the contamination of air and water resources, and in certain situations, increased yield. There is a need for well-designed research to evaluate the impact of real-time N control on weed ecology in cereals. Studying the effects of using SSNM techniques on grain quality is also necessary.

Winter crops may be more difficult to handle in real-time than rice. Since, during the early stages of growth, the leaves are small and the growth is sluggish to quantify the intensity of the leaf colour. The optimal decision support system in these circumstances is a fixed-time variable rate fertilizer-N management option with a predefined prescriptive fertilizer N application at the beginning growth stages. Prior to beginning need-based N applications, appropriate criteria for prescribing N dosages must be established. To discriminate between soil types, clear criteria must be created to decide where basal N application cannot be avoided. In areas where LCC or SPAD meter-based N management is being studied, more information has to be gathered on soil characteristics and/or N providing capacity in plots with no nitrogen application. Machine learning applications can be used to evaluate soil parameters, which make it easier to conduct non-destructive analyses of soil samples for mapping, but their accuracy and precision have not yet been developed for use in precise nutrient management. The various ICT-based decision support tools are intended to be prospective choice in balanced nutrient management, but its effectiveness in various cultivars of rice and under various agroclimatic circumstances should be validated.

Conclusion

The precise nutrient management options namely, optical sensors, leaf colour charts, omission plot method, and crop models can be adopted for enhancement of nutrient use efficiency and optimum productivity of rice. Optical sensors such as SPAD meter, LCC, and Green Seeker have emerged as rapid and reliable instruments to direct real-time need-based fertilizer-N treatments for effective nitrogen management. The fixed time variable rate method, which combines a prescribed time for applying basal fertilizer and N top dressing with LCC, SPAD, or optical sensor-guided corrective N management, appears to be more promising in places where the yield in the control plot is not less than 3 t/ha. The omission plot approach and decision support models are the best ways to control nutrients other than nitrogen. This review article demonstrated the effectiveness of the real-time N management technique in rice. In the modern era of ICT, the precision nutrient management may emerge as a key driver for boosting rice yields per unit area.

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Authors contributions

LS and SM have conceptualized and prepared the original draft. SS contributed to manuscript making and MS have contributed in the preparation of tables and figures. All authors read and approved the final manuscript.

Compliance with ethical standards

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