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# Efficient Nutrient Management Practices for Sustaining Soil Health and Improving Rice-Wheat Productivity: A Review

**Vineet Kumar, RK Naresh, Sumit Kumar, Sunil Kumar, Arvind Kumar, RK Gupta, RS Rathore, SP Singh, Ashish Dwivedi, Saurabh Tyagi and NC Mahajan**

## Abstract

The challenge that the world is facing has been to maximize food production to feed the increasing population. Further, agriculture at present encompasses many problems such as stagnating food-grain production, multi-nutrient deficiency, declining fertilizer response, reduction in land availability for cultivation, environmental pollution and land degradation. To manage long term soil fertility, productivity as well as environment quality, efficient nutrient management practices integration can be the most sustainable practices to adopt. Among plant nutrients, nitrogen (N) is the most important. Its importance as a growth- and yield-determining nutrient has led to large and rapid increases in N application rates, but often with poor use efficiency. Nitrogen management requires special attention in its use so that the large losses can be minimized and the efficiency maximized. Site-specific nutrient management (SSNM) has been found especially useful to achieve the goals of improved productivity and higher N use efficiency (NUE).

Leaf color charts and chlorophyll meters assist in the prediction of crop N needs for rice and wheat, leading to greater N-fertilizer efficiency at various yield levels. Remote sensing tools are also used to predict crop N demands precisely. At the same time, traditional techniques like balanced fertilization, integrated N management (INM), split application and nutrient budgeting, among others, are also used to supplement recent N management techniques to attain higher productivity and NUE, and reduce environmental pollution through the leakage of fertilizer N.This will definitely enhance the productivity of rice and wheat crops by improving soil fertility and ameliorating adverse soil physical conditions. This paper reviews the effect of efficient nutrient management practices on sustaining soil health improving the productivity of Rice-wheat cropping sequence.

**Keywords:** Nitrogen use efficiency, sustainability, productivity, cropping sequence

## Introduction

Currently, the world, including countries like India, is facing the unprecedented challenge of substantially increasing agricultural production to secure food for the 80 million individuals joining our population each year. According to FAO estimates, we need to double food production in the next 40 years to achieve food security. In other words, what agricultural production was achieved between the beginnings of agriculture 10,000 years ago and today, must be achieved again in the next 40 years (Wade 2009) [92]. To accomplish this gigantic task, special attention is required on nutrient management, water management, plant protection, and the development of new crop cultivars with greater yield potential, suited to specific agro-climatic conditions, and strengthening of the extension agencies. Rice, wheat, and maize are the major sources of calories for the rising human population in Asia. The production of these cereal staples must increase by 1.2% to 1.5% annually to meet rising demand and ensure food security. The closing of exploitable yield gaps through improved use of nutrient inputs is a key technology for helping achieve needed increases in cereal production.

Maintenance of native soil fertility in the intensively cultivated regions of the country is one of the preconditions of maintaining and improving the current crop yield levels. Intensive cropping systems remove substantial quantities of plant nutrients from soil during continued agricultural production round the year. The basic principle of maintaining the fertility status of a soil under high intensity crop production systems is to annually replenish those nutrients that are removed from the field. Indeed this becomes more relevant in the absence of the measures for adequate replenishment of the depleted nutrient pools through the removal of crop residues from agricultural fields (Sanyal 2014) [67].

Integrated plant nutrient management (INM) is the combined use of mineral fertilizers with organic resources such as cattle manures, crop residues, urban/rural wastes, composts, green manures and bio-fertilizers (Antil, 2012) [2]. Its basic concept is sustaining soil and crop productivity through optimization of all possible sources of plant nutrients in an integrated manner. In this system, all aspects of mineral and organic plant nutrient sources are integrated into the crop production system FAO, 2006 and are utilized in an efficient and judicious manner for sustainable crop production Singh *et al* (2012) [77, 79]. It contributes in attaining agronomical feasible, economically viable, environmentally sound and sustainable high crop yields in cropping systems by enhancing nutrient use efficiency and soil fertility, reducing nitrogen losses due to nitrate leaching and emission of greenhouse gases (Milkha and Aulakh, 2013; FAO,2006).

The development and widespread rapid uptake by cereal producers of best practices for managing fertilizers is consequently crucial for producing sufficient rice, wheat, and maize at affordable prices for consumers of these cereals and profitability for producers without damaging the environment. Nitrogen is most essential nutrient element from crop production point of view. Major cereal crops like rice, wheat and maize consume around more than half of total fertilizer N in the world; however, demand for fertilizer N will increase in future at higher magnitude if fertilizer N recovery is not improved (Varinderpal-Singh *et al*., 2011) [91]. Poor synchronization between demand and supply of N leads to its poor use efficiency. Nitrogen use efficiency for most of the crops is lower and ranges from 30-50% (Ladha *et al*., 2005) [50]. Large portion of applied N escape soil-plant system to reach water bodies and the atmosphere thus creating pollution problems (Varinder-Pal Singh *et al*., 2010). Excessive application of fertilizer intended to avoid deficiency further reduces use efficiency, makes plant disease-pest susceptible increasing cost of production (Fageria and Baligar, 2005). That is why successful nitrogen management requires better synchronization between crop N demand and N supply from all sources throughout crop growing season (Cui *et al*., 2008) [21, 38] and plant need–based application of N to achieve high yield and higher N use efficiency.

Visual leaf color is often used as an indicator of N in leaves by farmers (Furaya, 1987) [30]. Keeping plant leaves dark green using such approximate and undefined visual indicator by farmers leads to over application of N (Varinderpal-Singh *et al*., 2012) [90]. Destructive and time consuming plant tissue analysis is not a pragmatic approach to recommend fertilizer N in standing crop. To cope up the problems associated with low nitrogen use efficiency and over application, one of the viable options for efficient N management in wheat is site-specific nutrient management (SSNM). Site-Specific Nutrient Management (SSNM) techniques increase the fertilizer-N use efficiency in different crops (Dobermann *et al*., 2002; Huang *et al*., 2008) [25, 38]. One of the key features of site specific nutrient management is dynamic adjustment of fertilizer N using tools like leaf color chart (LCC) and chlorophyll meters which (Bijay-Singh *et al*., 2012) [13] which takes into account spectral reflectance properties of leaves rationally.

## Material and Methods

The material related with the present study was collected from different journals, reports and review papers of national and international status. Besides this, websites were consulted / visited for relevant literature to be incorporated in the study. The material so collected has been reviewed and categorized into different sections i.e. Site Specific Nitrogen Management (SSNM), chlorophyll meter (SPAD), leaf colour chart (LCC), soil test crop response (STCR) approach, nutrient expert based N management, integrated nitrogen management (INIM), remote sensing and geographical information system (GIS), balanced fertilization, controlled/slow-release fertilizers (CRF/SRFs) and integrated management of organic and inorganic sources. Major findings emerged from the review have been discussed to bring out the present manuscript.

## Results and Discussion

### Site Specific Nitrogen Management (SSNM)

SSNM is a concept which involves field specific N management strategies that includes quantitative knowledge of field specific variability in crop N requirement and expected soil N supplying power. The fundamental underlying assumption of this concept is to establish an optimum synchronization between supply and demand of N for plant growth (Giller *et al*., 2004) [33]. On the basis of when and what type of decisions are made, SSNM can be grouped in two categories, A) prescriptive SSNM, (2) corrective SSNM (Dobermann *et al*., 2004) [24]. In former approach of N management, the amount and its application time are analysed prior to sowing based on N supplying power of the soil, expected crop N requirement for assumed yield target, expected N efficiency of fertilizer products in use. Contrast to this, corrective nitrogen management strategy involves use of diagnostic tools to assess nitrogen status of standing crop. The interpretation of these recorded data is serving as the basis for decisions about timing and quantity of N applications (Schroeder *et al*., 2000) [71]. Chlorophyll meters (SPAD), nutrient expert and leaf color charts (LCC) are the promising and gaining importance in recent years for corrective N management in cereals.

Gill (2006) [31] reported that SSNM approach in hybrid rice PHB-71 along with balanced supply of nutrients in combination with micro nutrients enables the breaking of yield barrier from 13 to 17 tha$^{-1}$, a remarkable increase in productivity of rice- wheat by 4 tha$^{-1}$ per annum which is mainly, because of paddy yield (10 tha$^{-1}$). The yield contributing characters were improved with notable margin under SSNM. The results of SSNM experiment further advocated that this approach can only help to achieve the climatic yield potential of 18 tha$^{-1}$ annum$^{-1}$ under Punjab conditions. The main micro nutrients applied were B, Cu, Mn, and Zn, while secondary nutrient applied was S to rice only. The corresponding rates of application were 5, 10, 20, and 25 kgha$^{-1}$, respectively of micro nutrient and 40 kgha$^{-1}$ of S. Khurana *et al*., (2008) [46] concluded that significant increases in N use efficiency were achieved in rice and wheat through the field-specific N management practiced in the SSNM treatment (*Figure* 1). In general, compared with the FFP, less fertilizer N was applied and AEN, REN, and PEN were significantly increased with SSNM. On average, AEN was increased by 7.3 kg kg$^{-1}$ (83%) and 5.3 kg kg$^{-1}$ (63%), REN by 0.10 kg kg$^{-1}$ (50%) and 0.10 kg kg$^{-1}$ (59%), and PEN by 9.5 kg kg$^{-1}$ (27%) and 7.7 kg kg$^{-1}$ (26%) in rice and wheat crops, respectively. This increase was attributed to more uniform N applications among sites under SSNM as compared to under FFP. Also, the N applications were spread more evenly through the growing season and avoided heavy single applications at early growth stages of rice and wheat crops when compared with FFP.

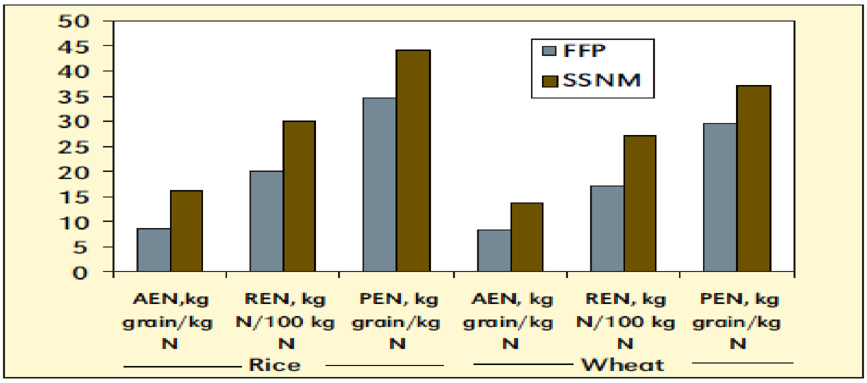

**Fig 1:** Fertilizer N use efficiencies in rice and wheat crops in FFP and SSNM averaged for 2 years.

Witt *et al*., (1999) [94] revealed that the SSNM approach, fertilizer P and K are applied in sufficient amounts to overcome deficiencies and ensure profitable rice farming. Total P and K taken up by the crop are determined from the target yield and an established optimal reciprocal internal efficiency (kg nutrient in above-ground dry matter per tonne grain) for each crop. Gill *et al*., (2009) [32] reported that maximum N, P and K accumulation by crop was registered in SSNM, followed by improved state recommendations (ISR), and it was lowest in the farmers' fertilization practice (FFP). NPK use efficiency was much higher in SSNM compared with FFP. Bruulselma *et al*., (2012) [14] reported that Site-Specific Nutrient Management (SSNM) aims to optimize the supply of soil nutrients over time and space to match the requirements of crops through four key principles (Table 1). The principles, called the "4 Rs".

**Table 1:** Examples of key scientific principles and associated practices of 4R nutrient stewardship

| SSNM principle | Scientific basis | Associated practices |
|---|---|---|
| Product | Ensure balanced supply of nutrients Suit soil properties | Commercial fertilizer, Livestock manure Compost, Crop residue |
| Rate | Assess nutrient supply from all sources Assess plant demand | Test soil for nutrients, Balance crop removal |
| Time | Assess dynamics of crop uptake and soil supply Determine timing of loss risk | Apply nutrients: Pre-planting, At planting, At flowering, At fruiting |
| Place | Recognize crop rooting patterns Manage spatial variability | Broadcast, Band/drill/inject Variable-rate application |

Wang *et al*., (2001) [93] found significant increases in NUE through the field- and season-specific N management practiced in the SSNM treatments. In general, compared with the FFP, less fertilizer N was applied, and agronomic N use efficiency (AEN), recovery efficiency of fertilizer N (REN) and physiological efficiency of N (PEN) were significantly increased with SSNM. On average, AEN was increased by 7.3 kg $kg^{-1}$ (83%) and 5.3 kg $kg^{-1}$ (63%), REN by 0.10 kg $kg^{-1}$ (50%) and 0.10 kg $kg^{-1}$ (59%), and PEN by 9.5 kg $kg^{-1}$ (27%) and 7.7 kg $kg^{-1}$ (26%) in rice and wheat crops, respectively. This increase was attributed to more uniform N applications among sites under the SSNM compared with FFP. Shukla *et al*., (2004) [76] on the productivity and profitability of hybrid rice–wheat cropping system under site-specific nutrient management practices, indicated that the SSNM package resulted in significant yield advantages in both rice and wheat compared with soil testing laboratory recommendation (STLR), local adhoc recommendation (LAR) and farmers' fertilizer practice.

**Table 2:** Yield and yield attributes of hybrid rice and wheat as influenced by site-specific nutrient management

| **Treatment** | **Rice** | | | | | **Wheat** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Yield attributes** | | | | **Grain yield tha$^{-1}$** | **Yield attributes** | | | **Grain yield tha$^{-1}$** |
| | **No. of panicles m$^{-2}$** | **No. of grains panicle$^{-1}$** | **Grain wt Panicle$^{-1}$, g** | **No. of unfilled grains panicle$^{-1}$** | | **No. of ears m$^{-1}$** | **No. of grains m$^{-1}$** | **Grain wt ear$^{-1}$** | |
| SSNM$_1$ | 198 | 180 | 5.30 | 29 | 9.86 | 249 | 40 | 1.78 | 5.71 |
| SSNM$_2$ | 215 | 176 | 5.34 | 32 | 9.95 | 254 | 49 | 1.96 | 5.94 |
| SSNM$_3$ | 201 | 182 | 5.22 | 29 | 9.72 | 255 | 48 | 1.90 | 5.78 |
| SSNM$_4$ | 210 | 167 | 5.09 | 31 | 9.18 | 248 | 45 | 1.62 | 5.34 |
| SSNM$_5$ | 210 | 147 | 4.66 | 37 | 9.75 | 248 | 40 | 1.48 | 5.06 |
| SSNM$_6$ | 206 | 171 | 4.92 | 42 | 9.47 | 252 | 42 | 1.60 | 5.36 |
| SSNM$_7$ | 190 | 165 | 4.89 | 42 | 9.00 | 255 | 42 | 1.68 | 5.28 |
| SSNM$_8$ | 193 | 156 | 4.76 | 47 | 8.71 | 238 | 38 | 1.68 | 4.98 |
| SSNM$_9$ | 196 | 142 | 4.52 | 47 | 7.92 | 217 | 34 | 1.65 | 4.59 |
| LAR | 190 | 133 | 4.12 | 40 | 8.03 | 205 | 36 | 1.56 | 4.86 |
| STLR | 188 | 138 | 4.30 | 42 | 7.94 | 216 | 38 | 1.52 | 4.62 |
| FP | 193 | 128 | 4.08 | 49 | 7.29 | 218 | 39 | 1.44 | 4.53 |
| CD ($p<0.05$) | 11 | 8 | 0.17 | 5 | 0.51 | 29 | 4 | 0.22 | 0.31 |

***Source***: Shukla *et al*., (2004) [76] Dwivedi *et al.*, (2009) [26] comparing soil test-based SSNM with other fertilizer practices in pearl millet-wheat and pearl millet-mustard cropping systems revealed large yield and economic advantages with the adoption of SSNM. Similarly, Srivastava *et al.*, (2009) reported that SSNM increased the yield and improved the quality of sweet orange when compared with state nutrient recommendations and farmer fertilizer practice.

## Chlorophyll meter

Nitrogen status of crops can be estimated through chlorophyll meter since most of plant nitrogen is found in chloroplasts hence, it is closely related to leaf chlorophyll content (Olesen *et al.*, 2004) [58]. Bijay-Singh *et al.*, (2002) [11] reported that using the criteria of applying 30 kg N ha$^{-1}$ each time the SPAD value falls below 37.5 always resulted in a rice grain yield equivalent to that obtained with 120 kg N ha$^{-1}$ in three fixed-time splits. In treatments receiving all N doses beginning 14 days after transplanting (DAT) at a critical SPAD value of 37.5, rice grain yields equivalent to those produced by applying 120 kg N ha$^{-1}$ were obtained with 90 kg N ha$^{-1}$. As expected, the AE was greater when less N fertilizer was used, but this was achieved with the use of the chlorophyll meter without sacrificing yield. The threshold SPAD value of 35 for semi-dwarf indica rice varieties in transplanted rice systems during the dry season in the Philippines, has to be reduced to 32 during the wet season when solar radiation is relatively low (Balasubramanian *et al.* 1999) [7].

Hach and Tan (2007) [35] reported that fertilizer recommendations based on SSNM and LCC techniques are more flexible and meet the crop demand, resulting in a crop yield increment of up to 0.3–0.5 t ha$^{-1}$ and a saving of up to 20–30% fertilizer application. To quantify N status of crops the Soil Plant Analysis Development (SPAD) differently known as chlorophyll meter offers relative measurements of leaf chlorophyll content. Chlorophyll meters are able to self calibrate for different soils, seasons, and varieties. It is also recommended to assess the effectiveness of late applied nitrogen in standing crops to increase grain yield and protein content (Singh *et al.*, 2012) [77, 79]. Prost and Jeuffory (2007) [62] suggested that the SPAD chlorophyll meter can be used as an alternative to nitrogen nutrition index (NNI) to measure N status in wheat. Therefore, SPAD values have been successfully used for N fertilizer management in rice and wheat (Singh *et al*., 2002) [78]. Singh *et al*., (2010) [82] reported that the chlorophyll meter readings have been positively correlated with destructive chlorophyll measurements in many crop species and considered as a useful indicator of the need of N top-dressing during the crop growth. Wheat is very sensitive to insufficient nitrogen and very responsive to N fertilization. The chlorophyll meter is faster than tissue testing for N and allows "fine tuning" of N management to field conditions, and consequently reduces risk of under- or over fertilizing the wheat crop (Francis and Piekielek, 2012) [29]. SPAD meter based SSNM approach has been extensively demonstrated in Southwest Asia (China, India and Bangladesh). Author reported that compared with traditional local nitrogen management practices, SPAD meter based SSNM in rice crop can increases yield, REN, and net return to the tune of 7, 30, and 12% respectively (Dobermann *et al*., 2004) [24] (Table 3).

**Table 3:** Impact of SPAD meter based nitrogen management on rice performance and nitrogen recovery (Singh *et al*., 2012) [77, 79].

| Treatment | N rate (kg/ha) | Yield (t/ha) | PFP$_N$ |
|---|---|---|---|
| FFP | 120.0 | 5.6 | 46 |
| SPAD based SSNM | 60.0 | 5.7 | 62 |

El-Habbal *et al.*, (2010) [27] also observed that the higher rate of nitrogen fertilizer maintained higher SPAD values showing mean value of 48.8 between tillering to grain filling stage (46-130 DAS). Irrespective of fertilizer treatments, SPAD values increased from 67 DAS onwards and reached its maximum at 74 DAS (*Figure* 2). This point has been termed as photosynthetic maturity and does not necessarily correspond to maximum leaf size (Sestak and Catsky, 1962) [73]. Wuest and Cassman,(1992) [95] observed that the treatment of one-third at planting and two-thirds at Z31 was able to reach close to full light interception by the onset of rapid spike growth, thanks to the nitrogen applied at planting. In addition, this treatment was able to accumulate higher levels of chlorophyll in the leaves compared to the treatment of all nitrogen applied at planting, presumably increasing the radiation-use efficiency. The challenge seems to be to identify the optimum rate of N to be applied at planting and later at Z31 that will result in the ideal combination of light interception (LAI) and chlorophyll content in the leaves.

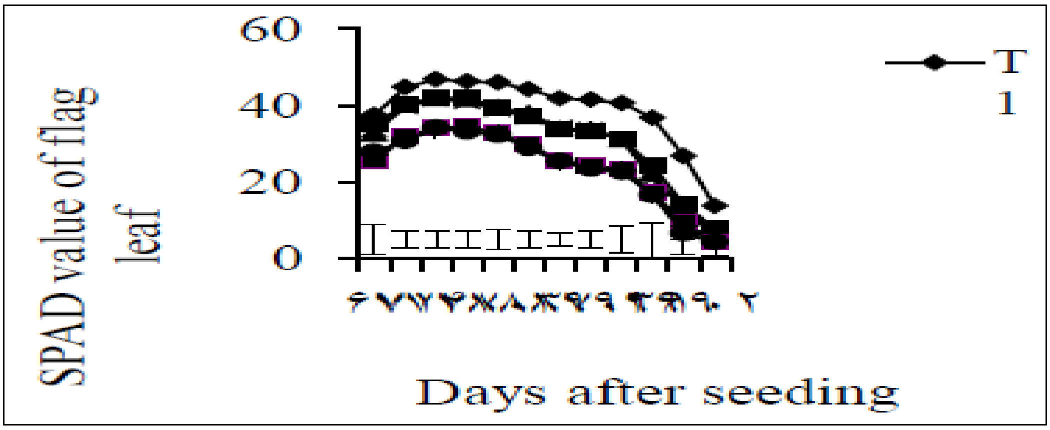

**Fig 2:** SPAD chlorophyll meter readings over the course of the plant growth in wheat

Chlorophyll meter-based N management saved 12.5–25% on the existing fertilizer N recommendation (Bijay-Singh *et al.* 2002) [11]. Many farmers also apply a dose of N approximately 1 week after transplanting, in lieu of basal application. Because rice seedlings take *7 days to recover from the transplanting shock (Meelu and Gupta 1980) [55], it is very likely that most N applied around 7 DAT is not used by plants and is lost. Based on chlorophyll-guided studies, Bijay-Singh *et al.* (2002) [11] suggested that: (1) a basal dose of 30 kg N ha$^{-1}$ was not efficiently used by the crop and was possibly prone to loss or immobilization; and (2) N applied starting at 14 DAT based on the crop need determined by the chlorophyll meter, was used more efficiently. A critical SPAD value of 37 resulted in high rice yield with less fertilizer application than blanket recommendation of 150 kg N ha$^{-1}$ (Maiti *et al.*, 2004) [54]. A threshold SPAD of 38 to prescribe top dressing of fertilizer N in rice grown under alternate wet and dry condition consistently gave similar result that by blanket application of 180 kg N ha$^{-1}$ with saving of water and fertilizer N; however, threshold SPAD value of 35 can be adopted by farmers where water and fertilizers commodities are scarce and costly (Cobangon *et al.*, 2011).

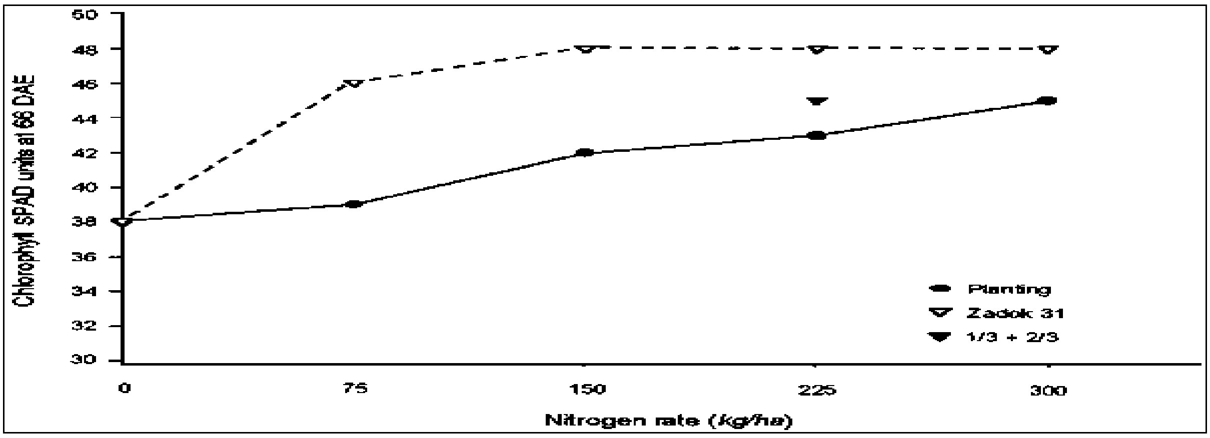

**Fig 3:** Chlorophyll SPAD units in a wheat crop at 66 days after emergence (DAE) with different timings and rates of nitrogen application

## Leaf Color Chart

LCC is a diagnostic tool which can help farmers for making appropriate decisions regarding the need for nitrogen fertilizer applications in standing crops. Conventionally farmers use eye observations to know the crop nutrient status particularly nitrogen. The LCC can act as a plant health indicator diagnostic tool particularly to optimize the nitrogen supply of rice based cropping systems. The LCC is economical and easy to use diagnostic tool for precise N management especially in rice-wheat cropping system. Conceptually it is based on the measurement of relative greenness of plant leaves which directly co-related with its chlorophyll content. Nitrogen is a principle component of leaf chlorophyll so its measurement over various phenological stages serves as the indirect basis for nitrogen management. Sen *et al.* (2011) [72] noticed that critical or threshold values of LCC are variety specific. They recommended a critical value of ≤ 5 for rice genotypes NDR 359 and Sarju 52 and ≤4 for HUBR 2-1 for real time N management of N. Use of leaf colour shade 4 were reasonably consistent with SPAD meter and helped to avoid over application of fertilization to rice crop (Bijay-Singh *et al.*, 2002) [11]. A study on LCC based real time N management to synchronize crop N demand and application revealed a critical value of ≤ 3 for'Basmati-370', ≤ 4 for 'Saket-4' and ≤ 5 for 'Hybrid6111/PHB71' to produce higher grain yield and N use efficiency than the recommended split application (Shukla *et al.*, 2004) [76].

Varinderpal Singh *et al.* (2012) [90] proposed a fertilizer N management strategy based on application of 25 kg N ha$^{-1}$ prescriptive dose at planting, 45 kg N ha$^{-1}$ at 1st irrigation or crown root initiation (CRI) and then a dose of 30 or 45 N ha$^{-1}$ at 2nd irrigation stage depending on colour of the leaf to be ≤ LCC4 or ≥ LCC4 resulted in high yield levels with improved agronomic and recovery efficiencies of fertilizer N. They reported that at 1st irrigation (crown root initiation) quantification of N using leaf colour greenness was not best possible; however, leaf colour at 2nd irrigation (maximum tillering stage) appeared to be the best indicator of leaf N status.In China, LCC guided nitrogen management in hybrid rice by a group of 107 farmers has been resulted in 25% saving of N fertilizer without compromising crop yield (Singh *et al.*, 2012) [77, 79] (Table 4).

**Table 4:** Leaf color chart guided nitrogen management and its impact of nitrogen recovery efficiency (Singh *et al.*, 2012) [77, 79].

| Treatments | N applied (kg N/ha) DAT* | | | | Yield (t/ ha) | N uptake(kg/ ha) | $AE_N$ |
|---|---|---|---|---|---|---|---|
| | Basal | 21 | 42 | Total | | | |
| **T** | 0 | 0 | 0 | 0 | 4.95 | - | - |
| **$T_1$** | 0 | 40 | 45 | 85 | 7.70 | 110.8 | 30.4 |
| **$T_2$** | 30 | 40 | 45 | 115 | 8.43 | 131.7 | 32.2 |
| **LSD (0.05)** | | | | | 0.20 | 4.930 | 1.97 |

* Days after Transplanting

Bijay-Singh, (2008) [12] revealed that because shade 4 on the LCC represents greenness equivalent to a SPAD value between 35 and 37, it was found to be the threshold value for inbred rice varieties prevalent in the Indo-Gangetic plains in India. Singh *et al.*, (2005) [83] on rice ('PB-1') grain yield and N-use efficiency under different N management practices indicated a significant improvement in yield and agronomic efficiency of N with LCC-based N application compared with fixed time N application. Application of 30 kg N ha$^{-1}$ at LCC 4 resulted in a total N application of 90 kg N ha$^{-1}$ and a grain yield statistically similar to that obtained with 120 kg N ha$^{-1}$ applied in recommended splits Table 5.

**Table 5:** Rice (‘PB-1’) grain yield and N-use efficiency under different N management practices

| N management practice | Total N applied (kg ha$^{-1}$) | Grain yield (t ha$^{-1}$) | Agronomic efficiency (kg kg$^{-1}$ N) |
|---|---|---|---|
| No- N (control) | 0 | 2.75 | – |
| Recommended N management | 80 | 3.86 | 13.9 |
| LCC < 3 (No basal N) | 80 | 4.18 | 17.9 |
| 80% basal + LCC < 3 | 104 | 3.62 | 8.4 |
| Farmers’ practice (three splits) | 100 | 3.74 | 9.9 |

**Note:** The results presented are the means of trials on 20 farmers’ fields. LCC, leaf color chart
**Source**: Singh *et al*. (2005).

## Soil test crop response (STCR) approach

Soil test based fertilizer recommendation means „Fertilizing the soil‟ versus „Fertilizing the crop‟ ensuring for real balance (not apparent balance) between the applied fertilizer nutrients among themselves and with the soil available nutrients. In order to sustain the yield and reduce the cost of fertilizers and in turn cost of cultivation, the STCR approach is very important (Saxena *et al*., 2008; Chatterjee *et al*., 2010) [70, 19]. Long-term fertilizer experiments provide best possible means to study changes in soil properties, dynamics of nutrient processes and future strategies for maintaining soil health (Swarup, 2010) [86]. Rajput *et al*., (2016) [63] revealed that, balanced fertilization based on soil test recorded higher yield of rice over general recommended dose of fertilizers. Similarly, soil organic carbon, available NPK and microbial activity in terms of FDA, DHA and Phosphates enzyme were also significantly enhanced under the treatments receiving STCR based recommended dose of fertilizers along with FYM. Field specific balanced amounts of N, P and K were prescribed based on crop based estimates of the indigenous supply of N, P and K and by modelling the expected yield response as a function of nutrient interaction (Dobermann and White 1998 ; Witt *et al*., 1999. Khosa *et al*. (2012) [23, 94, 45] also reported the superiority of the target yield concept over other practices for different crops as it gave higher yields and optimal economic returns. The specific yield equation based on soil health besides ensuring sustainable crop production also steers the farmers towards economic use of costly fertilizer inputs depending on their financial status and prevailing market price of the crop under consideration (Bera *et al*., 2006) [10].

## Nutrient expert based N management

Proper nutrient management in exhaustive maize and wheat based systems should aim to supply adequate fertilizers based on the demand of the component crops and apply in ways that minimize loss and maximize the use efficiency (Basso *et al*., 2011). In this regard nutrient expert is an emerging N management diagnostic tool wherein the input variables such as fertilizers are applied in the right amount, at the right place and at right time (variable rate application) as per demand of the crop-plants (Pampolino *et al*., 2012) [59]. It helps to improve the input use efficiency, economy of fertilizer use and ensures sustainable use of natural resources. The steps involved in smart N management using nutrient expert are as follows A) ensuring an optimal density of crops, B) Evaluate ongoing nitrogen management practices, C) establishment of meaningful yield goal, D) determine quantum of indigenous soil N, E) Required N fertilizer rates for above selected yield goal, F)Translate fertilizer N rates into fertilizer sources, G) Develop an efficient application strategy for N fertilizers, H) compare the expected or actual benefit of ongoing and improved N management practices (Majumdar *et al*., 2013) [53].

## Integrated nitrogen management (INIM)

Integrated nitrogen management (INIM) refers to the combined use of fertilizer N and organic N, which includes N fixed by legumes and other organisms (Azotobacter, Azospirillum, blue–green algae, Azolla etc.) and N supplied by organic manures such as farmyard manure, compost, vermin- compost, crop residues and animal refuse. INIM has received considerable attention in recent years for sustaining soil productivity. The use of bio-fertilizers is particularly important from the eco-safety point of view and to reduce the cost of cultivation. Avasthe (2009) [6] reported that agronomic efficiency and production efficiency decreased with increase in N level from 80 to 160 kg N ha$^{-1}$, and the efficiency was higher when mineral N use was integrated with farmyard manure. The highest values of agronomic efficiency and production efficiency were observed when 80 kg N ha71 was applied along with 2.5 t farmyard manure ha$^{-1}$. Conjunctive application of urea + farmyard manure increased the agronomic efficiency by 5.4–14.8%. Dadarwal *et al*., (2009) [22] reported that the application of 75% recommended dose of fertilizers (RDF) + 2.5 t ha$^{-1}$ vermicompost + bio fertilizers to maize significantly improved plant height, dry matter accumulation, dehusked cob yield, green fodder yield and available NPK in the soil after the harvest of crop over the 150% RDF (RDF values were 120: 40: 30 kg ha$^{-1}$ of NPK). A ~29.0% increase in dehusked cob yield was recorded with 75% NPK + 2.5 t vermin-compost ha$^{-1}$ + bio-fertilizers over 150% NPK through mineral fertilizers.

Top-dressing of N at later stage of the wheat crop proved most effective in increasing grain protein concentration, yield and fertilizer use efficiency (Krishna Kumari *et al*., 2000) [47]. Kaur *et al*., (2010), N applied in four splits (foliar spray) increased N recovery under all dates of sowing over the treatment in which N was soil applied in two or three splits in wheat. To get the highest NUE, N may be applied in three splits (68 kg N ha$^{-1}$ at sowing + 75 kg N ha$^{-1}$ at first irrigation + 7 kg N ha$^{-1}$ (3% urea spray) at the anthesis growth stage of wheat. An adequate supply of N during the later crop growth stages delays the synthesis of abscisic acid, promotes cytokinin activity and causes higher chlorophyll retention and thereby higher photosynthesis activity in leaves for the supply of photosynthates to grains (Sarkar *et al*. 2007) [69]. Maximum recovery efficiency and agronomic efficiency were observed in rice for ¼ N at 10 days after transplanting + ¼ at maximum tillering + ½ at panicle initiation, which was 11.1–97.1% and 9.0 – 180.1% higher than under other schedules (Avasthe 2009) [6].

## Use of remote sensing and geographical information system (GIS)

The agriculture industry is adopting information technology as a new tool to cope up lower input use efficiency (Pimstein *et al*., 2011) [61]. Remote sensing has a potential to predict the foliar biochemical concentration of nutrients in plants, thereby reduces time and energy to be spend on tedious detailed sampling and expensive laboratory analysis (Basayigit *et al.*, 2009) [9]. Use of remote sensing devices in agriculture until recent times was limited to development of vegetation indices based on reflectance in red and near infra red bands; one of the widely used and accepted vegetation index is Normalized Difference Vegetation Index (NDVI) (Hatfield *et al.*, 2008) [36]. An appreciable improvement over spectral band remote sensing is hyperspectral remote sensing, which helps in retrieving number of plant and soil related information in quantitative terms precisely. But, the major fact associated with this is, limited use of (hyperspectral) remote sensing in prediction of nitrogen and biomass development (Hermann *et al.*, 2010; Samborski *et al.,* 2009) [37, 66]. Exploration of nutritional monitoring in plants other than nitrogen using remote sensing still remains a matter of quest.

Recently, methods based on measurements of reflectance in the red (defined by chlorophyll content) and near infrared (defined by living vegetation) region of the electromagnetic spectrum for estimating the N requirement of crops using early season estimates of N uptake and potential yield have been developed. Normalized difference vegetative index (NDVI) based on the in-season sensor reading can predict biomass, plant N concentration and plant N uptake (Gupta 2006) [34]. The NDVI increases with increasing leaf greenness and green leaf area, and can be used as a guide for in season N applications. Spatial and temporal variability in the nutrient supply are the major reasons for variations in crop yield, which can be managed by dividing a heterogeneous field into supposedly uniform management zones. Management zones are created on the basis of information on crop yield, soil data or crop conditions by adopting remote sensing techniques.

The data obtained are superimposed on a base map to create management zones using GIS. These management zone maps can be used for site specific input management rather than applying a uniform dose of fertilizer N over the entire field. The use of green seeker, which is also a hand-held instrument for measuring the NDVI at various critical growth stages, generates data for crop conditions (Gupta 2006; Singh *et al.* 2006) [34]. These NDVI data from a standard plot, which has been sufficiently fertilized with N, can be compared with a reference plot for which the N requirement is to be determined. The use of green seeker helps in applying adequate N at specific crop growth stages in various management zones. Jat *et al*., (2012) [39] revealed that the INSEY [in season estimation of yield) – GY (grain yield)] relationship used for calculating the N fertilizer dose in rice was: y = 90.97x INSEY – 0.602 at 54–57 days and y = 315.35 x INSEY – 0.958 at 41–43 days. The same relationship for calculating N fertilizer dose in wheat was: y = 1978 x INSEY –1.926 for Feekes 5/6 and y = 6192.7 x INSEY – 1.605 for Feekes 7/8. The INSEY (calculated as: NDVI/days from planting to sensing or emergence to sensing) is an excellent predictor of the yield potential or yield (grain or forage depending on the system) that is likely to result with no added input. Using such relationship, the maximum yield of rice (9.06 $tha^{-1}$) and wheat (5.60 $t\ ha^{-1}$ ) can be achieved in the schedule for N application in rice with 143 $kg\ N\ ha^{-1}$ applied at 7 (40 $kg\ ha^{-1}$), 28 (40 $kg\ ha^{-1}$) and 49 (63 $kg\ ha^{-1}$) DAT and wheat with 130 $kg\ ha^{-1}$ applied at basal (60 $kg\ ha^{-1}$), crown root initiation (60 $kg\ ha^{-1}$) and Feekes 7/8 days (10 $kg\ ha^{-1}$).

Sen *et al.*, (2008) revealed that IPNI has successfully tried the GIS based fertility mapping to measure the spatial variability in nutrient status and used such maps as a site specific fertilizer recommendation tool to positively impact rice yields in farmer fields. GIS based decision support tool helps in delineating the fertility management zones within the study area and the maps generated through this approach can give a clear visual indication of changing fertility scenario with time, which is important for nutrient management planning (Sen *et al*. 2008).

## Balanced fertilization

Attention to NPK is desirable because 89% of Indian soils are low to medium in available N, 80% are low to medium in available P and 50% are low to medium in available K (Motsara 2002) [57]. Therefore, it is essential to apply NPK and other secondary and micronutrients in adequate and balanced amounts. Focus has been given on N as the main yield-controlling nutrient at the expense of P, K, S and micronutrients (Aulakh and Malhi 2004) [4]. The efficient use of any nutrient depends on the balanced supply of other nutrients, i.e. all nutrients should be available in the right amount and at the right time. The ‘Law of the Minimum’ emphasizes balanced nutrition (Claupein 1993; Lægrid *et al*. 1999) [20, 51], a good example of which was presented by Johnston *et al*. (2001) [40] and the results are presented in Table 6. Ramachandrappa *et al*., (2013) [65] found that soil nitrogen balance increased with balanced nutrition and there was a net gain of 103.94 kg N/ha in the plots under recommended dose of N and $K_2O$ + lime @ 300 kg/ha + $MgCO_3$ @ 150 kg/ha + borax @ 10 kg/ha. Higher nutrient balance was noticed in recommended dose of N and $K_2O$ + lime @ 300 kg/ha + $MgCO_3$ @ 150 kg/ha + borax @ 10 kg/ha while lowest nutrient balance was noticed in control. The actual nutrient balance in the soil followed the same trend as that of net nutrient balance.

A continuous mismatch between nutrient removal and replenishment, even at the recommended levels of fertilizer application, was evident in the long-term studies on rice-wheat systems in the IGP reveals that in general, additions of N and P in different locations were greater than their removal by the crops. As a result, the apparent balances of N or P were positive (Table 7). On the other hand, negative K balances were noted in all the treatments at all the locations studied. The magnitude of nutrient balance varies with crop production in a given location or among the locations. However, the effect of negative K balance may not be visible on available K content of soil, owing to high K supplying capacity of the illitic minerals-dominated soils of the IGP. As these soils are moderate to high in non-exchangeable K (Sanyal *et al*. 2009b) [68] and contribution of this pool to the crop uptake is often greater than the available pool, the available K content may not be related to the decline in productivity, caused by the mining of K by the crop uptake (Tiwari and Nigam 1985) [87]. However, continued excessive depletion of K from the interlayer space of the illitic clays may lead to an irreversible structural collapse of these minerals, thereby severely restricting the release of K from such micaceous minerals (Sarkar *et al*. 2013). This would go a long way to impair the long-term soil fertility in respect of soil K, and is thus thoroughly unwarranted. The estimates of apparent N balance, which is positive at all the locations, may not also mean a sustainable input-output relation. In rice soils, the inclusion of N losses from rhizosphere by leaching, volatilization and denitrification in the nutrient balance calculation may render the N balances negative at all the locations. This suggests that the current practices of cropping and nutrient management are exhaustive in terms of N and K withdrawals leading to depletion of these nutrients from the native soil reserves.

**Table 6**: Yield of winter wheat (t ha$^{-1}$) under four rates of applied N in soils at four levels of available P (measured by Olsen's method) in the soil.

| Available P (mg kg$^{-1}$) | N applied (kg ha$^{-1}$) | | | |
|---|---|---|---|---|
| | 80 | 120 | 160 | 200 |
| 30.4 | 9.32 | 9.64 | 10.12 | 10.25 |
| 19.0 | 9.37 | 9.83 | 10.25 | 10.30 |
| 10.3 | 8.46 | 9.14 | 9.10 | 9.34 |
| 5.0 | 7.75 | 7.88 | 7.85 | 8.08 |

***Note:*** Values underlined are the optimum N rates. Adapted from Johnston *et al*., (2001) [40]

**Table 7:** Apparent nutrient balance (NPK) in rice-wheat system under long-term experiments conducted in IGP (5 year average)

| Locations/ Treatments | Annual addition (kg ha$^{-1}$) | | | Annual removal (kg ha$^{-1}$ ) | | | Apparent balance (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|---|
| | N | P | K | N | P | K | N | P | K |
| Ludhiana (Trans-Gangetic Plain) | | | | | | | | | |
| Control | 0 | 0 | 0 | 49.2 | 9.2 | 58.9 | -49.2 | -9.2 | -58.9 |
| 50% NPK | 120 | 19.7 | 27.3 | 98.1 | 21.5 | 121.3 | +21.9 | -1.8 | -94.0 |
| 75% NPK | 180 | 29.5 | 40.1 | 135.3 | 29.9 | 146.7 | +44.7 | -0.4 | -106.6 |
| 100% NPK | 240 | 39.3 | 54.5 | 178.7 | 38.5 | 192.4 | +61.3 | +0.8 | -137.9 |
| Kanpur (Upper Gangetic Plain) | | | | | | | | | |
| Control | 0 | 0 | 0 | 50.1 | 8.3 | 50.2 | -50.1 | -8.3 | -50.2 |
| 50% NPK | 120 | 26.2 | 33.2 | 110.5 | 20.9 | 111.4 | +9.5 | +5.3 | -78.2 |
| 75% NPK | 180 | 39.2 | 49.8 | 132.8 | 24.3 | 141.6 | +47.2 | +14.9 | -91.8 |
| 100% NPK | 240 | 52.4 | 66.4 | 172.2 | 27.4 | 174.3 | +67.8 | +25 | -107.9 |
| Faizabad (Middle Gangetic Plain) | | | | | | | | | |
| Control | 0 | 0 | 0 | 30.2 | 7.8 | 48.6 | -30.2 | -7.8 | -48.6 |
| 50% NPK | 120 | 26.2 | 33.2 | 96.2 | 22.3 | 123.4 | +23.8 | +3.9 | -90.2 |
| 75% NPK | 180 | 39.2 | 49.2 | 116.6 | 28.4 | 145.4 | +63.4 | +10.8 | -96.2 |
| 100% NPK | 240 | 52.4 | 66.4 | 155.3 | 35.1 | 181.6 | +84.7 | +17.3 | -115.2 |
| Varanasi (Middle Gangetic Plain) | | | | | | | | | |
| Control | 0 | 0 | 0 | 26.2 | 3.8 | 44.3 | -26.2 | -3.8 | -44.3 |
| 50% NPK | 120 | 26.2 | 33.2 | 78.4 | 9.2 | 68.9 | +41.6 | +17 | -35.7 |
| 75% NPK | 180 | 39.3 | 49.2 | 130.1 | 15.1 | 128.8 | +49.9 | +24.2 | -79.6 |
| 100% NPK | 240 | 52.4 | 66.4 | 202.4 | 23.4 | 192.6 | +37.6 | +29 | -126.2 |
| Sabour (Middle Gangetic Plain) | | | | | | | | | |
| Control | 0 | 0 | 0 | 36.9 | 7.8 | 52.4 | -36.9 | -7.8 | -52.4 |
| 50% NPK | 80 | 19.7 | 20. 5 | 76.2 | 19.7 | 120.6 | +3.8 | 0 | -100.2 |
| 75% NPK | 120 | 29.5 | 30.7 | 132.3 | 24.2 | 142.2 | -12.3 | +5.3 | -111.5 |
| 100% NPK | 160 | 39.3 | 40.9 | 180.6 | 32.4 | 184.3 | -20.6 | +6.9 | -143.4 |

***Source:*** AICRP – IFS Reports (2006-2011)

Buresh *et al.*, (2010) [15] showed that when the yield gain to applied K is relatively small, fertilizer requirements can be determined with only a partial maintenance approach. When the yield gain is more pronounced, a partial maintenance plus yield gain approach can be considered for determining the fertilizer requirements. Singh *et al*. (2014a) [84] used the nutrient input-output balance to come up with nutrient recommendations for the targeted yield of rice-wheat cropping system (RWS) in the IGP. Chuan *et al*., (2013) [17] also estimated the balanced nutrient requirement for wheat in China as being essential to manage the nutrient application more effectively for increasing the crop yields with reduced negative environmental impact, by way of using the QUEFTS model. The optimum nutrient doses for the RWS in IGP were worked out based on the plant nutrient demand for a targeted yield and nutrient balance calculations. On-farm data were used to estimate the reciprocal internal efficiencies (RIE) of rice and wheat (Buresh *et al*., 2010) [15]. These values were subsequently combined with the indigenous nutrient supply (INS) and yield gains from the added nutrients to determine the nutrient requirements for rice and wheat for a predetermined yield target. The components of INS calculations included nutrient (N, P and K) contributions from soil available pool, irrigation water, and rainfall, and their availability (%, efficiency) to the crop. Singh *et al*., (2014a) [84] indicating a stress on soil K and S supplies. Further, these results (Table 8) become more interesting when nutrient uptake for P, K and S was furnished from the soil native reserves in the absence of their external input. The highest removal of the soil nutrients accompanied the highest productivity level (Table 8). For example, at Ludhiana, exclusively soil-derived maximum nutrient uptake led to the highest productivity, whereas the acid soils of Ranchi could support only 65% of the productivity of the Ludhiana, with the concomitant soil-derived nutrient removal being also much less (Table 8). These results bring out the possible depletion of a nutrient from the native soil reserves when its application is omitted and yet high grain yields are targeted. It is very likely that on a longer-term basis, these soil contributions will decrease due to continued soil mining. It is thus obvious that such management practices should not be allowed to continue endlessly, while planning for obtaining high yields of the crops in a sustainable agricultural production system.

**Table 8:** Nutrient depletion factor and nutrient uptake from soil reserve under rice-wheat system with BMPs* correcting all existing nutrient deficiencies except that of the indicated nutrients

| Location | Rice-wheat system yield (t ha$^{-1}$) | Nutrient depletion factor (output: input ratio) | | | Depletion of soil nutrients from soil reserve (kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| | | $P_2O_5$ | $K_2O$ | S | $P_2O_5$ | $K_2O$ | S |
| Sabour | 13.8 | 1.74 | 1.86 | 1.20 | 88 | 261 | 42 |
| Ranchi | 10.4 | 0.73 | 1.09 | 2.04 | 63 | 205 | 41 |
| Ludhiana | 16.1 | 1.36 | 2.29 | 2.07 | 126 | 354 | 58 |
| Palampur | 9.8 | 1.70 | 1.83 | 1.35 | 74 | 226 | 36 |
| R.S.Pura | 13.2 | 0.67 | 1.71 | 1.48 | 94 | 301 | 45 |
| Faizabad | 12.3 | 0.97 | 1.52 | 1.48 | 80 | 252 | 39 |
| Kanpur | 14.6 | 1.03 | 1.48 | 2.27 | 66 | 247 | 43 |
| Modipuram | 16.7 | 1.98 | 1.63 | 3.50 | 100 | 294 | 58 |
| Varansi | 12.1 | 1.35 | 1.50 | 1.60 | 65 | 221 | 38 |
| Pantnagar | 12.4 | 0.77 | 1.45 | 2.02 | 67 | 220 | 42 |

*Best management practices

***Source:*** Tiwari *et al*., (2006) [88]

**Controlled/slow-release fertilizers (CRF/SRFs)**

An important route for improving NUE is the use of mineral fertilizers, particularly N fertilizers, which release nutrients according to the plants' requirements, so-called 'intelligent fertilizers', i.e. by the application of slow and controlled-release, or by 'stabilized' N fertilizers, which preserve the nutrients until plants really require them (Trenkel 2007). Improving nutrient efficiency, and particularly NUE, while reducing environmental hazards by using controlled-release or slow-release fertilizers is an important option (Hauck 1985; Bockman and Olfs 1998; Shaviv 2001) [75]. Thind *et al*., (2010) [82]; Wu and Liu, (2008) reported that the use of slow-release fertilizers has become a new trend to save fertilizer consumption and minimize environmental pollution. Controlled or slow-release nitrogenous fertilizers (SRNFs) based on coating with hydrophobic organic polymers are perceived to provide the best control over nutrient release from applied fertilizers (Trenkel 1997). There are two types of SRNF, namely, coated fertilizers [e.g. sulfur-coated urea, polymer-coated urea, gypsum/rock phosphate coated urea, lac-coated urea, neem (*Azadirachta indica*) slurry-coated urea] and inherently slow release materials [e.g. isobutylidene di-urea (IBDU), urea form, urea Z].

Thind *et al*., (2010) [82] also noted that NCU gave 9.4, 5.6 and 2.5% higher grain yield over urea with application of 48, 96 and 120 kg N ha$^{-1}$, respectively, at Ludhiana, India. The corresponding increase was 3.2, 4.5 and 1.6% at Gurdaspur, India.

**Integrated Management of Organic and Inorganic Sources in Rice- Wheat**

Integrated use of 75% NPK and FYM @ 5 t ha$^{-1}$ or poultry manure @ 1.5 mg ha$^{-1}$ or phosphor-compost @5 mg ha$^{-1}$ to rainy season crops and 75% NPK to wheat significantly improved the yield of wheat over application of 100% NPK in both the season (Bandyopadhyay *et al*., 2009) [8]. Yadav *et al*., 2009 [96] reported that Continuous rice-wheat cropping system had variable efforts on soil fertility depending on soil types, nutrient application and productivity levels. The improvement in mean grain yield of wheat (4.0 t ha$^{-1}$) and straw (6.3 t ha$^{-1}$) was recorded due to use of organic manure (FYM + Sesbania) to proceeding rice as compared to control (Singh *et al*., 2001) [81]. Application of wormi-compost at 3 t ha$^{-1}$ + RDF significantly recorded maximum plant height,at harvest,DM and LAI at 30,60 and 90 DAS total and effective tillers per plant,grain /ear,1000 grain weight, grain and straw yield, net monetary return and B:C ratio in wheat crop. Combined application of 100% NPK+FYM 15 tha$^{-1}$ increased significantly in grain and straw yield of wheat and bio-fertilizer,which sustained better growth produced better yield attributes and ultimately higher grain yield of wheat. Application of FYM (12 tha$^{-1}$) with 75% NPK improves the fertility status and also recorded higher grain and straw yield of wheat than 100% NPK (Ram *et al*., 2006) [64]. Application of 100% NPK + FYM (10 t ha$^{-1}$ ) recorded significant increase in biological parameters viz. soil microbial biomass carbon (SMBC),soil microbial biomass nitrogen (SMBN) and dehydrogenase activities (DHA) to the extent of 8.8, 9.8 and 9.0% compared to 150% NPK through chemical fertilizers without organics (Katkar *et al*.,2011) [42]. Application of NPK and FYM amended soil has higher microbial biomass in wheat (Majundar *et al.,* 2008) [52]. Application of 100% NPK + 50% N through FYM showed beneficial effect on plant height and dry matter accumulation at harvest in wheat. (Kumar *et al.,* 2005) [48].

Singh *et al.,* (2001) [81] indicated that FYM can substitute a part fertilizer N needs of monsoon crop without any adverse effect on the total productivity of cereal based cropping system. It was further noticed that fertilizer needs of the winter wheat could be reduced to the extent of 25% by substituting 25% needs of proceeding monsoon crop through FYM. Integrated use of 75% NPK and FYM @ 5 t ha$^{-1}$ or poultry manure @ 1.5 mg ha$^{-1}$ or phosphocompost @5 mg ha$^{-1}$ to rainy season crops and 75% NPK to wheat significantly improved the yield of wheat over application of 100% NPK in both the season (Bandyopadhyay *et al*., 2009) [8]. At maturity, wheat grain had highest Zn concentration under 100% NPK + Zn treatments (Peeyush *et al.,* 2009) [60]. Application of different levels of potassium and zinc significantly increased all the yield attributes and yield of wheat (Khare and Dixit, 2011) [44]. Higher seed yield (36.42 q ha$^{-1}$ ) of wheat was recorded when 120 kg N ha$^{-1}$ was applied to preceding rice crop and 120 kg N ha$^{-1}$ was applied to succeeding wheat crop. Application of N @120 kg N ha$^{-1}$ helps to increased uptake of N by wheat significantly (Kumar *et al*., 2011) [49]. Application of 100% N,100% NP and 100% NPK produced 2681,4431 and 4950 kg ha$^{-1}$ grain of wheat (Chauhan, *et al*,2011) [18]. The bio-fertilizer application significantly improved grain yield and straw yield of wheat over uninoculated plots and enhanced the concentration of micro nutrients like Fe, Zn, Cu and Mn (Malik *et al*., 2009). Katiyar *et al*., (2011) [43] revealed that there was significant increase in nitrogen content due to inoculation with Azotobacter (1.92 and 2.00%) with mixed strain as compared to uninoculated control (1.82 and 1.90%).

Aulakh (2010) [5, 56] reported the reduction of gaseous loss of

N under the conjunctive use of inorganic with organics i.e, green manure and crop residues. There was improvement of physical, chemical and biological properties of soil too under integrated nutrient management. Kharche *et al*., (2013) [41] have observed that the long-term effect of continuous integrated nutrient management and adoption of easily available options of practicing green manuring, addition of crop residues and organic manures in conjunction with chemical fertilizers in balanced form are efficient for building-up of the active carbon fractions in soil which is important for enhancing soil quality. The organic matter in soils enhanced under integrated nutrient management was found to be a key attribute of soil quality which has shown far-reaching effects on physical, chemical and biological properties of soil indicating necessity of addition of crop residues and organic manures in conjunction with chemical fertilizers for securing soil quality under intensified agriculture.

Shah *et al*., (2010) [74] reported that the maximum percent increase over control in rice and wheat was (95 and 111%, respectively) obtained where integration of chemical fertilizers and poultry manure (75:25) was used. This is due to better utilization of phosphorus in the presence of organic manures. Upadhyay and Vishwakarma (2014) [89] found that the application of 50% NPK + 50% N substituted through green leaf manuring (GLM) to rice resulted in the maximum grain yield, which was 148% higher over the control followed by 50% NPK + 50% N substituted through FYM (135%) and for rabi wheat the treatment receiving 50% NPK + 50% N substituted through GLM (2.98t/ha) and FYM (2.85tha$^{-1}$) enhanced the productivity of wheat by 282 and 259% respectively. This improvement in seed yield was owing to incorporation of GLM and FYM, attributed to its ability to proper nutrient supply throughout the growing season. Anwar *et al*., (2015) [3] also found that in rice-wheat cropping system maximum plant height, number of tillers, number of grains per spike/panicle, 1000 grains weight and paddy/grain yield was obtained in treatment where 75% N through chemical fertilizers and 25% N through poultry litter was applied. The highest soil organic carbon after the harvest of rice and wheat was obtained in treatment where 100% N was applied through farm manure while soil nitrate was maximum in treatment where 75% N through chemical fertilizers and 25% N through poultry litter was applied.

## Conclusion

Proficient nitrogen management is essential in modern crop production systems for improving the long term sustainability. N management using through SSNM, SPAD meter and LCC gives higher grain yield and NUE as compared to blanket N recommendation. Integrated N management and balance fertilization improve not only plant performance, but also NUE of production system. Significant linear response of leaf N indicators in the present study to N application levels at tillering, panicle initiation and flowering stage of hybrid rice crop and maximum tillering, booting and flowering stage of wheat crop is concordant with the findings by Bijay-Singh *et al*. (2012) [13], Swain and Sandip (2010) [85] and Varinderpal-Singh *et al*. (2011) [91]. Based on these observations three critical growth stages tillering, panicle initiation and flowering of rice and maximum tillering, booting and flowering stage of wheat were targeted for making N management decisions to obtain economic optimum grain yields. Efficient nutrient management is vital for sustaining food production. Use of organic and green manures along with fertilizers has been found effective in improving and maintaining soil fertility, increasing nutrient use efficiency so maximizing productivity in different cropping system. Therefore, an integrated approach for the management of most important natural resource base is extremely important which would ensure efficient use of on-farm generated organic manures along with mineral fertilizers, thereby ensuring sustainable crop production. Besides sustaining crop production, INM decreases the heavy use of inorganic fertilizers alone and improves efficiency of nutrients thereby reducing losses to the environment which ultimately checks environmental pollution. Efficient nutrient management can therefore be used as a part of global strategy to ensure food security and protect the environment.

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