

On-Farm Estimation of Economical and Ecological Optimum Nitrogen Rates for Rice Production: A Field Study of Transplanted Lowland Rice in Central Hills, Nepal

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It is ecologically and economically important to determine the proper amount of nitrogen as required by lowland rice plant since it is a prime limitation to crop yield. The central mid-hills of Nepal is a productive domain of rice, but the sub optimal dose of N by farmers and moreover, the blanket recommendation of N fertilizer by governmental bodies for wider regions without time variation at specific growth stages do less coincide with the dynamic soil property for supply and demand of N in soil-crop system, resulting less synchronized application of N-fertilizer and subsequent loss of applied N with poor recovery efficiency. Thus, the present study was designed to estimate the economically and ecologically safe nitrogen doses for lowland rice by the principles of site specific nutrient management (SSNM) considering soil spatial variability by evaluating the productivity, profitability and N use efficiency of SSNM based nitrogen rate (as recommended by Nutrient Expert® Rice and Leaf Color Chart) over the farmer's fertilizer and other government recommended nitrogen management practices for that area. A field experiment was conducted in 2017 during monsoon in central mid-hills at Bhaktapur, Nepal for field validation of DSS tools like Nutrient Expert® Rice (NE) and other simple diagnostic kit like Leaf Color Chart (LCC) designed for optimal application of N. Different N levels based on farmers practices, government recommendation, NE based, LCC based and NARC recommended dose were analyzed to evaluate the optimum dose of N for lowland rice in RCBD having 6 replications. The statistical results showed that the productivity of rice could be raised by 14%, profitability up to 21% and N uptake by 29% using N diagnostic tool like LCC. N fertilization remarkably promoted the grain and total biomass yield to the optimum level with LCC- based N dose and started to suppress rice grain yield if N level was increased beyond the LCC recommendation. The rice grain N uptake increased with its application to the level of 114 kg N ha⁻¹, but started to decline at 120 kg N ha⁻¹. The higher internal efficiency of N was obtained for the farmers' fertilizer N practice, receiving comparatively lower dose of N, in which the total uptake of N was lesser than others. The partial factor productivity of N was recorded higher for farmers' practice and the lowest for NARC recommendation such that PEP-N decreased with increasing rate of N. Therefore, optimum level of N application should be promoted through the use of N friendly DSS tools to maximize yield along with environmental protection and cost effectiveness.

Keywords: Economical and Ecological Optimum Yield; Leaf Color Chart; Nitrogen use Efficiency; Nutrient Expert®; SSNM

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Rice (*oryza sativa*) is the principal food grain widely produced throughout the world followed by wheat. About 89% of world rice is produced in the Asian countries, with a leading producers China and India accounting for nearly 55 percent of the production (Ali, 2019). In Nepal where agriculture is the mainstay of country's economies, rice production alone is attributed for 53 per cent of total cereal production and 20 per cent contribution to the agricultural Gross Domestic Product (AGDP) (Tripathi *et al.*, 2018). Rice is a crop that is grown in different ecosystems like irrigated lowland rice production comprises 75 percent of the global rice production, rainfed lowland for 20% and rainfed upland for about 4% (Rao *et al.*, 2017).

Among the major nutrients, nitrogen (N) plays a crucial role in producing the maximum grain yield under lowland. In fact, for lowland rice production N is considered as the major yield limiting nutrient (Moro *et al.*, 2015). It has a major role in promoting growth and yield along with grain quality through excessive tiller development, foliar area expansion, protein synthesis, grain formation and its filling. Thus, the lower dose of N application may lead to poor grain yield. However, excessive N application cannot increase the crop yield sufficiently, given diminishing returns of crop yields to N input (Yousaf *et al.*, 2016). It is the most mobile element in soil-crop system (Anonymous, 1993). The over use of chemical N fertilizer is more common in the developed countries like China, while it is not recordable in developing countries like Nepal. The excess use of chemical N has counter effect on environment since it harms off site ecosystems, aquatic ecosystems and ground water quality, emission & accumulation of greenhouse gases in atmosphere and health hazards (Baron *et al.*, 2013). Most importantly, the blanket recommendation of N fertilizer for wider regions without time variation at specific growth stages do less coincide with the dynamic soil property for supply and demand of N in soil-crop system, resulting less synchronized application of N-fertilizer and subsequent loss of applied N with poor recovery efficiency (Thapa and Amgain., 2018).

The ecological and economical optimal yield can be determined by rationalizing the amount of N application as required by lowland rice

(Buri and Roland, 2019). The optimum dose of N refers not only the rate of application, but also the proper timing of its application in combination with balanced dose (Sultana *et al.*, 2015). In lowland rice ecosystem, nitrogen use efficiency (NUE) of fertilizer N is proportionately less because of rapid fate of N by denitrification, volatilization and leaching in the flooded soil. When we consider fertilizer and product prices, the excess application of fertilizer N beyond the optimal eventually results the considerable reduction in yield and economic loss due to additional cost of excess fertilizer (Sultana *et al.*, 2015). Therefore, a Decision Support System (DSS) tool based on principle of site specific nutrient management (SSNM), named as Nutrient Expert® for rice, has been developed by IPNI to avoid under- and over- N fertilization, and the Leaf Color Chart (LCC)- non-destructive N diagnostic tool, optimize N use by synchronizing it with crop demand (Qureshi *et al.*, 2016). The central mid-hills of Nepal is a productive domain of rice, but the sub optimal dose of N and less synchronization between its application and crop demand has created the lower productivity and profitability. Thus, the present study was designed to estimate the economically and ecologically safe nitrogen doses for lowland rice by the principles of site specific nutrient management (SSNM) considering soil spatial variability by evaluating the productivity, profitability and N use efficiency of SSNM based nitrogen rate (as recommended by Nutrient Expert® Rice and Leaf Color Chart) over the farmer's fertilizer and other government bodies recommended nitrogen management practices for that area. A field experiment was conducted in 2017 during monsoon in central mid-hills at Bhaktapur, Nepal for field validation of DSS tools like Nutrient Expert® Rice (NE) and other simple diagnostic kit like Leaf Color Chart (LCC) designed for optimal application of N.

MATERIALS AND METHODS

A field experimentation was undertaken for puddled transplanting rice in 2017 June-October, under on farm condition at Bhaktapur, Central mid-hills, Nepal. The soil of this site was clay loam in texture with average pH 5.16, organic matter 3.03%, soil available N of 0.18%, soil available P₂O₅ of 34.0 kg ha⁻¹ and K₂O of

294.2 kg ha⁻¹. The nutrient content of Farm Yard Manure (FYM) used during land preparation was 1.74% N, 1.22% P₂O₅, 1.34% K₂O with 6.7 pH. The area received 1030.6 mm average rainfall with average temperature 21.75°C during the period of experiment. A preliminary survey was done among the selected farmers to assess the farmers' practice of rice cultivation as well as to run the Nutrient Expert® Rice model. The following five different doses of N were analyzed at six different farmers' field. The treatments allotted were: Farmers' fertilizer practice N (FP-N): on an average 87.62 kg N ha⁻¹ (preliminary survey data), Government recommendation on N (GR-N): 100 kg N ha⁻¹ (CDD and ASoN, 2017), Nutrient Expert formulated SSNM based N (NE-N): 102.3 kg N ha⁻¹ (Nutrient Expert® Rice model formulated N dose), Leaf color chart recommended SSNM based N (LCC-N): 114 kg N ha⁻¹, and Nepal Agricultural Research Council preferred dose of N (NARC-N): 120 kg N ha⁻¹.

'Taichung' cultivar of rice with yield capacity of 7.9 ton ha⁻¹ was transplanted. A preliminary survey was followed out among the farmers of the study area to make foundation for operating Nutrient Expert Model, and the NE was run to get the estimated yield and fertilizer-N recommendation. Farmers N application was applied twice at basal and at 30 DAT. Nutrient Expert- Rice Model recommended 3 times application of N: one third at basal, remaining two equally at equal splits at active tillering (45 DAT) and panicle initiation (70 DAT). The Government and NARC-N recommended doses were applied at basal and at 45 DAT. The basal application of 30 kg N ha⁻¹ at transplanting followed by additional top-dressings after 14 DAT up to flowering as indicated by Leaf Color Chart rules were used in the LCC-based N (Subedi *et al.*, 2017). The NE based N and LCC based N were actually soil-plant based N or SSNM based N. The yield parameters (grain and straw yield, yield parameters like no. of effective tillers, filled grains, sterility percentage), economic parameters (total cost, revenue and B:C ratio) and nitrogen use efficiency in terms of Internal efficiency (IE-N) and Partial Factor Productivity (PEP-N) of N fertilizers were evaluated by using following formulae (Ladha *et al.*, 2005):

$$\text{N uptake in grain (kg kg}^{-1}\text{)} = (\text{N concentration in grain} * \text{Oven dried weight of grain}) / 100$$

$$\text{N uptake in Straw (kg kg}^{-1}\text{)} = (\text{N concentration in straw} * \text{Oven dried weight of straw}) / 100$$

where grain and straw were dried in oven at 70°C for 2-3 days until constant weight was gained and the N concentration was obtained by Kjeldahl method of N digestion.

$$\text{IE-N} = (\text{Grain yield (kg per ha)}) / (\text{TNU (kg per ha)})$$

where, TNU is total N uptake (sum of N uptake by grain and straw).

$$\text{PEP-N} = (\text{Grain yield (kg per ha)}) / (\text{Fertilizer N applied (kg per ha)})$$

The recorded data were subjected to analyses of variance using statistical package GenStat® 15th edition. The treatments were compared by Duncan's Multiple Range Test, at probability level of 0.05. MS-Excel was used for data recording, and making charts and figures.

RESULTS AND DISCUSSION

Rice Culture Characteristics of SSNM Based N

The rice total biomass went on increasing with increased N application. It increased from 13.4 ton ha⁻¹ at 87.62 kg N ha⁻¹ (FP-N) to as much as 15.5 ton ha⁻¹ at 120 kg N ha⁻¹ (NARC-N) (Table 1). The grain yield was maximum at 114 kg N ha⁻¹ (LCC-N plot) yielding 6.9 ton ha⁻¹ and started to decline to 6.6 ton ha⁻¹ (3.03 % lower than maximum grain yield) at 120 kg N ha⁻¹. The SSNM based on LCC-N were productive by 14% over farmers' practice. While the total biomass increased upto 120 kg N ha⁻¹ application, the grain yield, on the other hand, not increased after 114 kg N ha⁻¹. The additional N applied after 114 kg ha⁻¹ might be useful for more straw yield at the expense of grain yield, as evident by Moro *et al.*, (2015). The grain yield reached maximum in LCC-N plot by optimizing the dose of N in response to its application rate, timing along with other primary

nutrients. Rice grain yield is determined by its yield components- number of panicles per unit area, number of spikelet per panicle, weight of spikelet and spikelet sterility (Fageria, 2007). The increased yield might be attributed to the maximum counts of effective tillers coupled with less sterility and more filled grains in the LCC-N plots than others. N fertilization contributes to promote the number of tillers, nevertheless, all the tillers are not productive especially those developed at late emerging phase do produce less productive panicles (Wang *et al.*, 2007). Because of this reason, the grain yield of NARC-N plot was lower than that of LCC-N plot, in spite of having the highest number of effective tillers in former one than the later one. The filled grains panicle⁻¹ was superior by 13% in LCC-N plot compare to farmer's plot. The similar finding of greatest number of filled grains and low sterility percentage in LCC-N plot was evident by Marahatta (2017). This increment might be attributed to the real N management by sufficient application of N fertilizer at split-based. Despite the enough dose of N application, the filled grains panicle⁻¹ was lower in NARC- N plot than SSNM based N management (NE-N and LCC-N), because of plant lodging due to excess N fertilization than optimal that makes the plant soft, succulent, such that it was lodged even by fairly occurred rainfall during grain filling period. The pre-heading lodging results in suppression of grain formation because of failure in flower opening and fertilization of the inflorescence coupled with interruption in photosynthesis and

metabolism in grain development process (Setter *et al.*, 1997). The higher number of partially filled grain was counted under this plot which eventually lower the weight of the panicle. Thus, LCC-N out-yielded rest of the other N management. The extent of greenish color of rice leaf is closely correlated to its foliar N status so as to indicate the crop N demand during the growing season. These green leaves maintain the photosynthetic process and accumulates the assimilates for grain development. N-fertilizer application based on LCC was effectual to retain demand driven N to the crop that produced maximum crop growth and higher grain yield.

The rice grain and straw yield boosted up with increase in N rates (Fig. 1 and 2). The yield of grain yield was found significantly correlated with amount of N applied (correlation coefficient = 0.5592) at 0.005 levels of probability (Figure 1). Similarly, the straw yield was strongly correlated with the N application rate at 0.005 levels of probability (correlation coefficient = 0.5219).

Nitrogen use Efficiency

The nitrogen use efficiency was determined on the basis of its uptake by the plants under different N rates at physiological maturity along with its internal efficiency (IE-N) and partial factor productivity of fertilizer-N (PEP-N), which is presented in Table 2.

The total N-uptake by plant dry matter obtained as high as 125.2 kg ha⁻¹ in NE-N plot as amount of N increased from 87.62 kg N ha⁻¹ to 102.3 kg N ha⁻¹ and got diminished instead of

Table 1. Effect of improved N management on characteristics of rice culture in field experiment at Bhaktapur, Nepal, 2017

Treatments	N- applied (kg ha ⁻¹)	Grain yield at 14% moisture (t ha ⁻¹)	Straw yield (t ha ⁻¹)	No. of tillers per meter square	Filled grain per panicle	Sterility percentage
Farmers' practice N	87.62	6.0 ^d	7.4 ^b	293.8	90.1 ^b	18.1 ^{ab}
GR-N	100	6.3 ^{bed}	7.8 ^b	311.6	92.6 ^b	15.5 ^{ab}
NE-N	102.3	6.4 ^{bc}	8.1 ^{ab}	337.6	99.4 ^a	11.6 ^b
LCC-N	114	6.9 ^a	8.3 ^{ab}	324	101.9 ^a	13.2 ^b
NARC-N	120	6.6 ^{ab}	8.9 ^a	350.5	91.8 ^b	22.6 ^a
GM		6.4	8.0	323.5	95.7	16.5
LSD (5%)		0.3	0.9	65.8	5.3	6.7
CV%		2.3	4.4	8.2	1.7	15.6

Different lowercase letters within a column indicates significant differences between treatments at P<0.05. GR-N: Government recommended doses of N (100 kg ha⁻¹); NE- N: Nutrient Expert recommended doses of N; LCC-N- Leaf Color Chart recommended dose of N, NARC-N: Nepal Agricultural Research Council preferred dose of N (120 N kg ha⁻¹)

increasing N rates afterwards. However, the highest N uptake in grain was recorded for LCC-N plot of 58 kg ha⁻¹. The IE-N was statistically at par among the treatments except treatment NE based SSNM. The highest IE-N was experienced in NARC-N and the lowest for NE-N plot. Higher the yield response to N, greater the N use efficiency (NUE). Therefore, NUE is generally higher for lower rates of N and is diminished for increased N application rates (Haile *et al.*, 2012). PEP-N is the measure of grain yielded by unit application of N fertilizer and it was recorded highest for farmers' plot receiving 87.6 kg N ha⁻¹ accounting the value of 60.1 kg kg⁻¹. Contrast to this, PEP decreased by 21.8 per cent for NARC-N plot receiving highest N rate-120 kg ha⁻¹ accounting the value of 47 kg kg⁻¹. With increasing N rate, the partial factor productivity decreased, as evident by Amanullah and Almas (2009).

NUE is basically grain production per unit of available N harvested by the plant biomass during its growing season and this availability highly depends soil N previously present in that soil, externally added N as a fertilizer and efficiency of mineralization of existing N to plant acceptable form (Cui *et al.*, 2010). Since the farmers were using under doses of N fertilizers as per the FFP, the uptake of N was also low in respective plots than the SSNM based treatment plots. The N uptake was 16 to 29% higher in SSNM treatments (NE-N and LCC-N) than farmers' fertilizer practice, respectively. The increased uptake could be attributed to the well synchronization between crop N need and making its availability on soil through right time application. The SSNM based on NE received the higher N uptake in rice, similar to the findings of Zhang *et al.*, 2018. N application

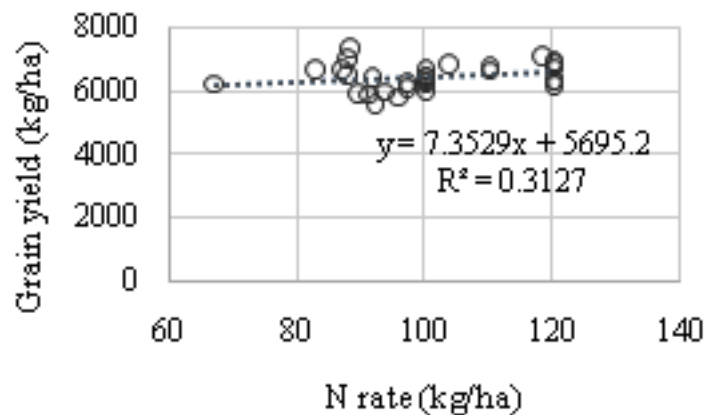


Fig. 1. Relationship between N application rate and rice grain yield

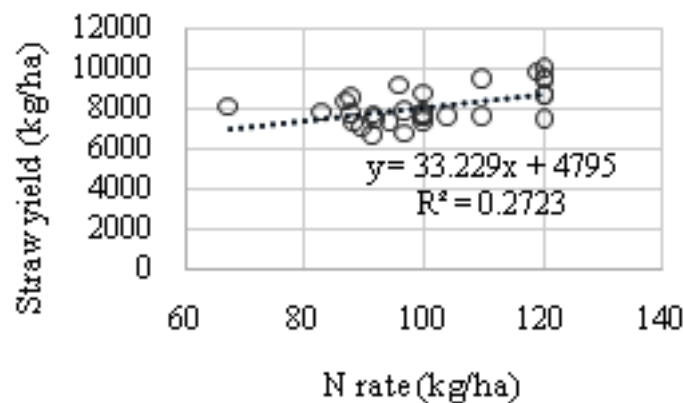


Fig. 2. Relationship between straw yield and N application rate

during the reproductive phase is also absorbed by the crop and hence boost up for grain yield (Singh and Singh, 2017).

Profitability of SSNM Based N

The economic analysis revealed that SSNM based on LCC-N recorded the best economic performance (Table 3). Although the total cost for LCC-N was higher (NRs. 1.9 lakhs ha⁻¹) than other treatments it provided the maximum gross returns (NRs. 3.97 lakhs ha⁻¹), and net returns (NRs. 2.06 lakhs ha⁻¹), with maximum B: C ratio (2.8). The farmers' fertilizer practice recorded the minimum cost (NRs. 1.79 lakhs ha⁻¹), minimum net revenue (NRs. 1.69 lakhs ha⁻¹) with minimum B: C ratio (1.94). The total cost of NE-N and FP-N was although comparable, the net revenue and B:

C ratio were far more in NE-N than FP-N. Though the total cost in LCC-N management was 6.5 % higher than FP-N management the net revenue was nearly 21% higher than that of farmers' fertilizer plot. The NE-N plot recorded the cost nearly 0.6% than FP-N, but the net revenue was almost 12% higher than FP-N. Thus, SSNM based on either NE-N or LCC-N based or both were profitable than farmers current fertilizer management practice. The research result inferred that the current profitability of rice cultivation can be enhanced adopting the principles of SSNM. The total amount of fertilizers applied by farmers should be raised from sub optimal to optimal to obtain the attainable yield of that variety under the favorable rainfed environment.

Table 2. N uptake in dry matter of rice under improved N management at Bhaktapur, Nepal, 2017

Treatments	Grain N uptake (kg ha ⁻¹)	Straw N uptake (kg ha ⁻¹)	Total N uptake (kg ha ⁻¹)	IE-N	PFP-N
Farmers' practice-N	41.7 ^c	54.94 ^b	96.6 ^d	62.3 ^a	60.1 ^a
GR-N	56.2 ^{ab}	52.4 ^{bc}	108.6 ^{bc}	58.5 ^a	54.6 ^{ab}
NE-N	53.97 ^{ab}	71.3 ^a	125.2 ^a	50.9 ^b	53.8 ^{ab}
LCC-N	58 ^a	54.2 ^{bc}	112.3 ^b	61.1 ^a	50 ^{bc}
NARC-N	50.64 ^{bc}	50.8 ^{bc}	101.4 ^{cd}	64.6 ^a	47 ^c
LSD(5%)	5.3	5.7	8.7	5.7	2.5
CV%	5.3	2	3.8	2	2.4

Different lowercase letters within a column indicates significant differences between treatments at P < 0.05. GR-N: Government recommended doses of N (100 kg ha⁻¹); NE- N: Nutrient Expert recommended doses of N; LCC-N- Leaf Color Chart recommended dose of N, NARC-N: Nepal Agricultural Research Council preferred dose of N (120 N kg ha⁻¹)

Table 3. Effect of site specific N management on cost, revenue and B: C ratio at Bhaktapur, Nepal, 2017

Treatments	Gross Revenue (NRs. in lakhs ha ⁻¹)	Total Cost (NRs. in lakhs ha ⁻¹)	Net Revenue (NRs. in lakhs ha ⁻¹)	B:C ratio
Farmers' practice-N	3.49 ^d	1.79 ^c	1.69 ^b	1.90 ^b
GR-N	3.67 ^{bcd}	1.80 ^c	1.87 ^{ab}	2.04 ^{ab}
NE-N	3.70 ^{bc}	1.80 ^c	1.90 ^{ab}	2.05 ^{ab}
LCC-N	3.97 ^a	1.90 ^a	2.06 ^a	2.08 ^a
NARC-N	3.80 ^{ab}	1.85 ^b	1.95 ^a	2.05 ^{ab}
LSD(0.05)	0.01	0.02	0.2	0.11
CV%	2.3	2.3	5.5	2.2

Different lower caseletters within a column indicates significant differences between treatments at P < 0.05. GR-N: Government recommended doses of N (100 kg ha⁻¹); NE- N: Nutrient Expert recommended doses of N; LCC-N- Leaf Color Chart recommended dose of N, NARC-N: Nepal Agricultural Research Council preferred dose of N (120 N kg ha⁻¹)

CONCLUSION

Nitrogen management through optimum and timely application of need-based N fertilizer has a great potential in achieving the potential yield of rice. SSNM based on DSS tool like Nutrient Expert®-Rice and simple diagnostic tool as Leaf Color Chart have been identified as the best fertilizer management strategy over current suboptimal dose and less synchronized N fertilization practice of farmers of mid-hills. LCC N management was 14% more productive, 21% more profitable and 29% more efficient in N use than current farmers' N management. It was also concluded that increasing the N level beyond the optimum dose would not contribute in maximum grain yield and nutrient uptake, which rather starts to diminish that are ecologically and economically unworthy as well. Therefore, optimum level of N application should be promoted through the use of N friendly diagnostic tools to maximize yield along with environmental protection and cost effectiveness. Nepalese farmers would be benefitted by the rationalization in N use recommended by NE and LCC to enhance the rice productivity and profitability and, hence the concern authority should promote such approaches in the central mid-hills familiarizing these tools to make operation handy through the effective training to agriculture extension workers, lead farmers and custom hiring service.

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