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LEAF COLOR CHART FOR CROP NEED BASED N MANAGEMENT IN RICE FROM RESEARCH TO ON FARM TESTING TO FARMERS VALIDATION AND ADOPTION

V. T. BALASUBRAMANIAN
IRRI, The Philippines

International Rice Research Institute (IRRI), DAPO Box 7777
Metro Manila, The Philippines
Email: v.balasubramanian@cgiar.org

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Leaf color chart for crop need-based N management in rice: from research to on-farm testing to farmer validation and adoption[1].

Paper by V. T. Balasubramanian
International Rice Research Institute (IRRI)

INTRODUCTION

Rice yields in Asia must increase by about 14% from 2000 to 2010, and by even 25% from 2000 to 2020 as recent estimates suggest (Dobermann et al., 2003c). These modified IMPACT model projections assume a moderate decline in rice area of about – 0.12% annually and yield growth rates of rice that are similar in irrigated and rainfed systems. Average yields of irrigated rice must then rise from about 5.3 t ha^{-1} in 1998 to 6.1 t ha^{-1} in 2010 and further to 6.7 t ha^{-1} in 2020 in order to meet the production demand which will increase from 599 million t in 2000 to 729 million t in 2020. This means that irrigated rice yields in tropical areas must increase to about 7.7 t ha^{-1} in dry season (DS) and 5.7 ha^{-1} in wet season (WS) by 2020. About 30% of all farmers must achieve yields of >8 t ha^{-1} and 15% >9 t ha^{-1} in at least one crop per year (Dobermann 2000). To achieve the projected increase in rice yield in 2020, it is assumed that the potential yield of rice varieties can be raised to 12 t ha^{-1} in DS and 8 to 9 t ha^{-1} in WS. Simultaneously, farmers must improve their nutrient and crop management practices to reach 70% of the potential yield in their fields.

POTENTIAL PROBLEMS AT HIGH YIELD LEVEL

Increasing amounts of inputs are needed to attain high rice yields. In high-input-intensive rice farming, farmers face certain potential problems (Balasubramanian et al., 2002):

- Higher production cost and lower profit at high yield levels;
- Decreasing factor productivity with increasing input use beyond certain level;
- Higher incidence of pests and diseases and higher pesticide use to maintain high yields;
- More lodging and deterioration of grain quality in lodged crop; and,
- Higher risk of pesticide-related human health and environmental problems.

Farmers require innovative technologies to tackle these problems in intensive rice farming and to secure high yields consistent with high profit. These technologies must be specifically developed for small rice farms of Asia that are managed by millions of less literate and less endowed farmers. We must look for a win-win situation for farmers as well as for input producers and distributors to maintain the profitability for all players in the food sector. As an example, let us look at N management in rice.

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NITROGEN, AN ESSENTIAL INPUT FOR RICE PRODUCTION

The efficiency of the rice plant's use of N is central to its overall yield potential. Therefore, breeding efforts to improve varietal potential must be guided by a thorough understanding of the processes that govern N-use efficiency (Ladha et al., 1998). In addition, crop management practices should aim at efficient use of N inputs. In the tropics, lowland rice yields 2.0 to 3.5 t ha^{-1} when using only naturally available N derived from the mineralization of soil N (Bouldin, 1986; Kundu and Ladha, 1997) and biological N fixation (BNF) by free-living and plant-associated diazotrophs (Watanabe and Roger, 1984; Ladha et al., 1993). To increase grain yields further, additional N must be applied as fertilizer (Cassman et al., 1998) and it must be applied as efficiently as possible to minimize the cost and maximize profit to farmers.

Nitrogen requirement for high rice yields

Crop response to applied N is almost universal, because most soils are deficient in N. Currently, irrigated rice farmers in India, Indonesia, Philippines, Thailand, and Vietnam apply an average of 111 kg N ha^{-1} to produce a mean yield of 5.1 t ha^{-1} (Dobermann et al., 2002); however, in China, farmers apply too much N (167 kg N ha^{-1}) to produce rice yields of 5.9 t ha^{-1} at an agronomic efficiency of only 6.4 kg grain per kg fertilizer N (Wang et al., 2001). The fertilizer N recovery efficiency was only 18%. Improved and efficient fertilizer N use is of fundamental importance for increasing yields and profit, and can avoid the excessive use of fertilizer N. For example, for a projected increase in irrigated rice yield from 5.1 to 6.7 t ha^{-1} in 2020, it would be theoretically necessary to apply 242 kg N ha^{-1} at a fertilizer N recovery efficiency of only 33%, while only 161 kg N ha^{-1} would be required at a recovery efficiency of 50%. This implies that in 2020 the current annual N fertilizer use of 10 million tons on rice (IFA-IFDC-FAO, 1992; IRRI, 1993) must be increased to 16.1 and 24.2 million tons, respectively, with 50% and 33% N recovery efficiency. Manufacturing the fertilizer for today's needs already requires 544 x 10^9 MJ of fossil fuel energy annually (Mudahar, 1987a, b). The projected annual fossil fuel energy need will be about two and a half times for manufacturing N fertilizers in 2020, if we do not improve the efficiency of N fertilizer use.

FIXED TIME NITROGEN MANAGEMENT STRATEGIES FOR RICE

Over the past 50 years, many strategies have been developed to increase N-use efficiency in flooded rice through proper timing, rate, placement, modified forms of fertilizer, and use of nitrification and urease inhibitors (De Datta and Pattrick, 1986; Fillery and Vlek, 1986; Mohanty et al., 1989; Mahapatra et al., 1990; Kumar et al., 1995). In addition, the potential of biological sources of N (such as *Azolla* and legume green manures to replace/supplement fertilizer-N) in crop N economy has been demonstrated, but farmer adoption has been poor (Ladha et al., 1998). Despite these efforts, about 70% of applied N is currently lost from the soil-water-plant system in irrigated rice fields (Zhu et al., 1989; Singh and Buresh, 1994; Mohanty et al., 1999; Bijay-Singh et al., 2001; Dobermann et al., 2002). Apart from inadequate splitting and timing of fertilizer N applications, possible other reasons include that crop response to added N varies markedly because of differences in weather, soil N supply, genotype, water regime, and other crop and pest management factors. Such dynamic changes in soil N supply and crop N demand under different growing conditions were not given adequate attention in earlier research. As such, most farmers continue to be inefficient in N management for rice. The insufficient, excessive and/or improper use of N fertilizers will likely damage the crops and the environment (FFTC 1994).

TACKLING VARIABILITY IN SOIL N SUPPLY AND CROP N DEMAND

Supply of N and other nutrients varies widely among rice fields in Asia (Dobermann and White, 1999; Olk et al., 1999; Dobermann et al., 2003 a, b). In addition, crop growth and demand for nutrients, including N, also vary widely among locations and seasons (Witt et al., 1999, 2002; Dobermann et al 2002, 2003c). Rice crops thus require different amounts of N in different fields, depending on native N supply and crop-growing conditions during a particular season. However, it is impossible to make N recommendations for individual rice fields or farms. What we need are simple strategies and tools that farmers can easily understand and use effectively to develop their own fertilizer N rates for individual fields based on indigenous N supply and crop's need for N. Synchronizing N application with actual crop demand will also improve N-use efficiency. This paper elaborates on the development, testing, and promotion of the leaf color chart (LCC) for crop need-based N management in rice.

TOOLS FOR CROP NEED-BASED N MANAGEMENT IN RICE

Crop need-based N management strategies aim at matching fertilizer N supply with actual crop demand, thus maximizing crop N uptake and minimizing N losses to the environment. These strategies should be robust enough to overcome the high field-to-field variability in soil N supply and crop-growing conditions. Two precision N management tools are available to monitor crop N status *in-situ* in the field and to determine the right time N topdressing in rice: (1) chlorophyll meter and (2) LCC (Figure 1) (Peng et al 1996, Balasubramanian et al 1999; 2000a).

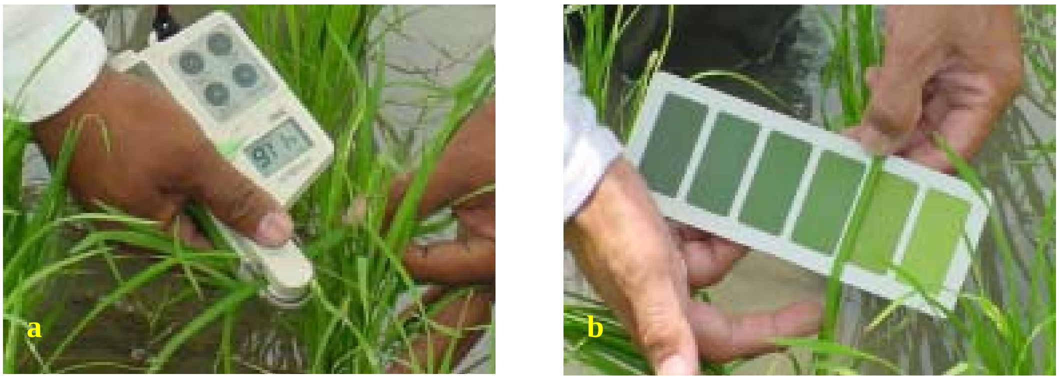

Figure 1:. (a) Chlorophyll meter and (b) leaf color chart (LCC) for monitoring crop N status *in situ* in the field and applying N as per actual crop demand.

Chlorophyll meter as a diagnostic tool for assessing leaf N status of rice crops

The chlorophyll meter or SPAD meter (Figure 1a) method is a reliable and nondestructive method to determine the right time of N topdressing for rice (Turner and Jund, 1994; Peng et al., 1996; Balasubramanian et al., 1999, 2000a). What the chlorophyll meter measures is the leaf color intensity or leaf chlorophyll content that is closely related to leaf N status. The threshold or critical SPAD value indicates the leaf area-based critical N concentration in rice leaves. For example, a SPAD threshold value of 35-36 is equal to 1.4–1.5 g N m^{-2} of leaf area in semi dwarf indica varieties (Peng et al., 1996). Whenever SPAD readings fall below the critical SPAD value, the crop will suffer from N deficiency and yields will decline if N fertilizer is not applied immediately. Different SPAD threshold values are needed to optimize rice yields under different conditions (Balasubramanian et al., 2000a). SPAD critical values can be refined by 1–2 seasons of testing for locally important rice varieties and the crop's environmental, nutritional, and cultural conditions. Chlorophyll meter is often used more as a research tool than as a farmers' device because of its high cost (>US$1000 per unit). An alternative simple tool was sought for farmers to measure crop N status *in situ* in the field and give rice crops N fertilizers as and when needed.

Leaf color chart (LCC) for crop need-based N management in rice

Because the SPAD meter measures leaf color as a proxy for leaf N status, a simplification of this is to use the intensity of leaf color as an indicator of crop N status. In fact, farmers use the leaf color as a visual and subjective indicator of the rice crop's nitrogen status. Using this principle, a farmer-affordable LCC (Figure 1b) was developed to measure leaf color intensity that is related to leaf N status (IRRI-CREMNET, 1998; Balasubramanian et al., 2000b). The LCC is simple, easy to use and inexpensive ($ 1 per chart). It is an ideal tool for individual farmers to optimize N use in rice at medium to high yield levels, irrespective of the source of N applied, that is, organic manure, biologically fixed N, or chemical fertilizers. It is also ecologically friendly.

LCC as an important component of site-specific nutrient management (SSNM)
Small-farm based SSNM is a precision farming approach that takes into account the variability in plant nutrient need as affected by site, year and season (climate) while making soil and crop management decisions (Dobermann et al., 1996, 2003c; Dobermann and White, 1999; Olk et al., 1999). SSNM promotes the efficient use of nutrients from all indigenous sources, including soil, irrigation water, biological fixation, organic matter, and crop residues (Buresh et al., 2003). In this approach, fertilizers are applied at the right time and in right amounts to satisfy crop's need for nutrients over and above that provided by indigenous sources. The LCC forms an important component of SSNM for crop need-based N management. Other techniques are used for managing P, K, and other nutrients (Dobermann and Fairhurst, 2000; Fairhurst and Witt, 2002; Balasubramanian et al., 2003; Buresh et al., 2003; Ladha et al., 2003).

DEVELOPMENT, TESTING, AND FIELD EVALUATION OF LCC

Development of LCC

Initially, the International Rice Research Institute (IRRI) developed a leaf color chart on a photographic paper and laminated it. Farmers faced difficulties using the photographic chart because of reflection of light even under the shade. Later, IRRI and the Philippine Rice Research Institute (PhilRice) jointly developed the plastic LCC from a Japanese prototype (Furuya, 1987). The IRRI-produced LCC is about 20 cm long and 7 cm wide and is made of high impact plastic. It consists of six panels to depict six shades of green from yellowish green (# 1) to dark green (# 6) (Figure 1b). The color panels are designed with veins resembling rice leaves. The holder is gray. The color shades were standardized with the chlorophyll meter. A simple instruction sheet in local language pasted at the back of the chart explains to farmers how to use the LCC.

Scientific principles of LCC

The LCC was developed based on the scientific principle that leaf color intensity is directly related to leaf chlorophyll content, which in turn relates to leaf N status. Thus, in this research, leaf color was used as a proxy for crop N status. Both the chlorophyll meter and LCC can measure leaf color intensity. They are related to leaf N status as follows: a leaf color reading of SPAD 35-36 or LCC 3.5-4.0 is equivalent to 1.4-1.5 g N per square meter of leaf area. Below this critical level, rice crops suffer from N deficiency and N fertilizer must be applied immediately to prevent yield loss.

The LCC color shades were standardized with the chlorophyll meter. When we compare the chlorophyll meter or SPAD readings with LCC shades, the difference between two LCC shades is about 7 SPAD units (Yang et al., 2003). Thus, the LCC cannot measure the greenness of rice leaves as accurately as the chlorophyll meter. However, field tests show that for all practical purposes, the LCC is as good as or even better than the chlorophyll meter to determine the right time of N fertilizer application for rice crops (IRRI-CREMNET, 1998, 2000).

Using the LCC

1. Start LCC readings from 14 days after transplanting (DAT) for transplanted rice or 21 days after seeding (DAS) for direct wet-seeded rice. The last reading is taken when the crop just starts heading.
2. Randomly select at least 10 disease-free rice plants or hills in a field with uniform plant population.
3. Select the topmost fully expanded leaf from each hill or plant.
4. Place the middle part of the leaf on top of the chart and compare the leaf color with the LCC shades. When the leaf color falls between two shades, the mean value is taken as the reading, e.g. 2.5 for color between 2 & 3. *Do not detach or destroy the leaf.*
5. Measure the leaf color under the shade of your body (Figure 2), because direct sunlight affects leaf color readings. If possible, the same person should take LCC readings at the same time of the day every time.
6. Repeat the process every 7 to 10 days intervals (see below) or at critical growth stages (early tillering, active tillering, panicle initiation, and first heading) and apply N as needed (see step 7).

Parameters	**Short-duration varieties** (100-110 days)	**Medium-/long-duration varieties** (130-150 days)
Measurement (Intervals, days)	**7**	**10**
Measurement Period	**14-49** (DAT) **21-56** (DAS)	**15-65** (DAT) **20-70** (DAS)

DAT: days after transplanting; DAS: days after seeding

7. If more than 5 out of 10 leaves read below a set critical value, apply
   - 23-30 kg N (50 to 65 kg urea) per ha for wet season or low-yielding rice
   - 30-35 kg N (65 to 76 kg urea) per ha for dry season or high-yielding rice

Figure 2: Shading the leaf being measured while taking LCC readings in the field

Critical LCC values for N topdressing

The critical LCC value is the guiding point that helps farmers make decisions on fertilizer N application. Farmers do not apply N fertilizer when the measured LCC reading is above the critical LCC value and apply N fertilizer when it is below the critical value (Figure 3). The critical LCC values vary by rice varietal groups or crop establishment methods. The suggested critical values given below can be validated and/or refined for locally important rice varieties and crop growing conditions by testing for 1-2 seasons.

Variety/Crop Establishment Method	Critical Value
Semi dwarf indica varieties, *direct seeded*	**3**
Scented or aromatic varieties, *transplanted*	**3**
Semi dwarf indica varieties, *transplanted*	**3.5 – 4.0**
Hybrid rice varieties, *transplanted*	**3.5 – 4.0**

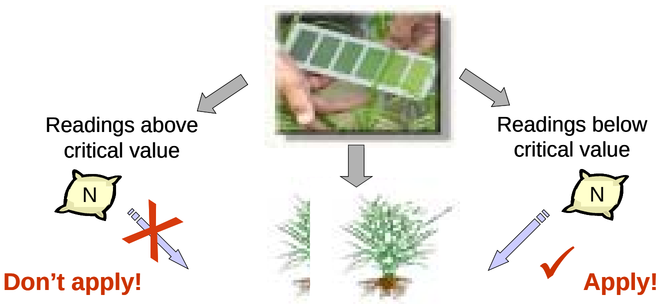

Fig. 3. Leaf color is monitored with a LCC, and N fertilizer is applied when leaf color falls below a critical value.

How long to use the LCC?

After using the LCC for 2-3 seasons, many farmers would have fixed in their mind the right leaf or canopy color that produces healthy plants and high yields. They can then apply N fertilizer by visual observations and use the LCC only when they are in doubt or when need to confirm their observation.

Factors affecting the use of LCC

Three factors affect leaf color measurement by the LCC: (i) a subjective decision on color comparison by the field person, (ii) the difference in color between panels for facilitating leaf color measurement perceived by the field evaluator, and (iii) the quality of the LCC in terms of maintaining the color shades for different panels (Balasubramanian et al., 2003).

Subjective measurement: We recommend that the same person take the LCC readings at the same time of the day to minimize variations in readings (subjective decisions) and reduce reading errors. We also recommend that the national research and extension personnel and lead farmers fix the critical LCC value for locally important rice varieties and growing conditions by testing for 1–2 seasons.

Perceptible differences in color between LCC panels: In the IRRI standard LCC, the important color panels 3, 4, and 5 are easily distinguishable by farmers when they measure leaf color in the field to determine the timing of N application.

Quality of panel color shades: We recommend to private companies that manufacture the LCC to maintain quality among different batches of LCC by standardizing the factors that affect the panel color (e.g. quality of plastic, quality and composition of colorant, temperature of panel molding, etc.).

Field evaluation of the LCC method

The purpose of using the LCC is to improve the overall efficiency of farmers' N fertilizer use by optimizing N rates and improving the time of application. For farmers applying too much N to their rice crops, LCC will help them reduce N rates to optimum levels and still maintain high grain yield with good grain quality. In other areas where farmers apply less than required amount of fertilizer N to realize the potential yield of rice varieties (e.g. parts of Bangladesh, Cambodia, Laos, Madagascar, Myanmar, many countries in Africa), use of the LCC indicates the need for additional fertilizer N application to realize high yields and profit. Thus, the use of the LCC is expected to correct both under- and over-application of N by rice farmers.

Comparison of LCC and chlorophyll meter methods

Under practical on-farm situations, the LCC has proved as good as or even better than the chlorophyll meter in terms of improving N use efficiency and maintaining or increasing grain yield (IRRI-CREMNET, 1998). In a set of 17 on-farm trials conducted in the Philippines during the 1996 wet season, the LCC method produced grain yield similar to that of the chlorophyll meter method, but with less N (Table 1). In another set of 20 on-farm evaluation trials conducted in the new Cauvery Delta Zone of Tamil Nadu, India, during the 1998 dry season, the LCC compared very well with the chlorophyll meter method in terms of grain yield, N-use efficiency, and savings in N fertilizer use (Table 2) (Balasubramanian et al., 2003). Another study by Buresh et al. (2001) reported that, among the N management methods evaluated during 2001, the LCC method produced high total grain yield and N-use efficiency over two seasons (Table 2).

Table 1: Comparison of chlorophyll meter (SPAD) and leaf color chart methods in on-farm trials in the Philippines (1996) and India (1998).

Treatment	N used (kg ha^{-1})	Grain yield (Mg or t ha^{-1})	AEN[a]	PFP-N[b]	N saved (kg ha^{-1})
Philippines – Maligaya: TPR[c] 1996 WS[d] (17 farms)					
Control	0	3.16c[e]	–	–	–
Farmers' practice	101	4.16a	10c	41	–
SPAD-32 N[f]	73	4.17a	14b	57	28
LCC-4[g]	48	4.18a	21a	87	53
India: New Cauvery Delta, TPR 1998 DS[h] (Kuruvai) (20 farms)					
Control	0	3.57b	–	–	–
Soil test recommendation	142	5.03a	10b	35	–
SPAD-35[i]	110	4.99a	13a	45	32
LCC-4[g]	108	4.93a	13a	46	34

[a] AEN: Agronomic efficiency of applied N = kg additional grain yield over control per kg N applied.
[b] PFP-N: Partial factor productivity for applied N = grain yield divided by applied N.
[c] TPR: Transplanted rice.
[d] WS: Wet season.
[e] Values followed by the same letters within a column and a set are not significantly different at $P > 0.05$ by Duncan's Multiple Range Test.
[f] SPAD-32: Chlorophyll meter or SPAD critical value set at 32.
[g] LCC-4: Leaf color chart critical value set at 4.
[h] DS: Dry season.
[i] SPAD-35: Chlorophyll meter or SPAD critical value set at 35.

Table 2: Effect of N management practices on rice yield for the dry plus wet seasons, 2001 (Source: Buresh et al., 2001).

Treatment	Grain yield (Mg or t ha^{-1})	AEN[a]
Fixed split[b]	12.8 b	23 b
LCC-3[c]	13.4 a	27 a
SPAD-35[d]	12.9 b	29 a
SSNM-40[e]	12.2 c	16 c
SSNM-50[f]	13.1 ab	24 b

[a] AEN: Agronomic efficiency of applied N = kg additional grain yield over control per kg N applied.
[b] Fixed split: Total amount of N fixed in 3 to 4 splits
[c] LCC-3: LCC critical value fixed at 3
[d] SPAD-35: Chlorophyll meter critical value fixed at 35
[e] SSNM-40: N rate based on predetermined N response and 40% recovery of added N
[f] SSNM-50: N rate based on predetermined N response and 50% recovery of added N

Comparative efficiency of the LCC method

Three efficiency criteria were used to evaluate the LCC method in relation to other N management practices: (a) the grain yield at 14% moisture content (MC); (b) the agronomic efficiency of applied N (AEN) defined as the increase in grain yield over control per unit of N applied, and (c) the partial factor productivity of N (PFP-N) defined as the grain yield per unit of N applied. The AEN is calculated from the difference in grain yield between the zero N control and N-fertilized plots, so the magnitude of grain yield of the control plot would affect the AEN values. The PFP-N integrates the grain yields of both control and fertilized plots. It is considered as a better indicator of N-use efficiency, especially when N levels are compared under different crop management methods having different zero-N control yields (Peng et al., 1996).

Thousands of rice farmers using the LCC report substantial improvements in N use efficiency compared to their own N management practice. In farmer participatory evaluations, three types of crop response emerge for the comparison of the LCC method and farmers' practice or local recommendation (Balasubramanian et al., 2000b; Balasubramanian and Buresh, 2002):

- Inadequate N application: We got an increase in grain yield but with higher fertilizer N use in the LCC plot. The efficiency values were similar for both farmers' and LCC methods (Table 3A). This case confirms the local farmers' efficient use of N fertilizers, but at a level lower than the amount of N fertilizer needed to reach full potential yields of rice varieties. The LCC method shows that yields can be further increased without compromising on N-use efficiency.

- Over-application of N: Here, grain yields were similar for both farmers' and LCC methods. However, the amount of N used was much lower and N-use efficiency much higher for the LCC technique (Table 3B). In this case, the LCC method helps farmers to save on N fertilizer cost without any penalty on the yield, that is, to prevent the wastage of N fertilizer.
- Excessive and improper N use: We obtained an increase in grain yield and a reduction in N fertilizer use in the LCC method in contrast to farmers' practice. As such, N-use efficiency was much higher for the LCC method than for the farmers' practice (Table 3C). Here, much more improvement is needed in farmers' N management practice to optimize grain yield and N-use efficiency.

Thus, the farmer-participatory on-farm evaluation has demonstrated the advantage of using the LCC technique to promote crop need-based N application in rice. The increase in N-use efficiency values (AEN and PFP-N) were due to (a) higher grain yield in the LCC plots at the same N rate as that of the farmers' practice or (b) the same grain yield as that of the farmers' practice, but with lower levels of N application for the LCC method.

Table 3: Comparison of leaf color chart (LCC) method with farmers' practice or local recommendation for N management in rice in Asian countries (Source: Balasubramanian et al 2000b).

A. An increase in grain yield but with higher fertilizer N use in the LCC method.

Treatment	N used (kg ha^{-1})	Grain yield (Mg or t ha^{-1})	AEN[a]	PFP-N[b]	N saved (kg ha^{-1})
Philippines – Maligaya: TPR[c], 1998 DS[d] (14 farms)					
Control	0	3.84b[e]	–	–	–
Farmers' practice	116	5.75a	19a	49	–
LCC-4[f]	130	6.05a	19a	46	-14
Philippines – Maligaya: TPR, 1999 DS (9 farms)					
Control	0	3.33b	–	–	–
Farmers' practice	121	5.10a	15a	42	–
LCC-4	135	5.30a	16a	39	-14

B. Same grain yield, but with less N fertilizer use in the LCC method.

Treatment	N used (kg ha^{-1})	Grain yield (Mg or t ha^{-1})	AEN†	PFP-N‡	N saved (kg ha^{-1})
Philippines – Maligaya: TPR, 1998 WS[g] (11 farms)					
Control	0	3.43b	–	–	–
Farmers' practice	78	3.97a	9b	51	–
LCC-4	33	3.87a	20a	117	45
Philippines – Maligaya: TPR, 1999 WS (11farms)					
Control	0	3.71b	–	–	–
Farmers' practice	74	4.49a	12b	61	–
LCC-4	46	4.68a	19a	102	28
Vietnam – Cai Lay District: B-WSR[h], 1998 DS (28 farms)					
Farmers' practice	120	5.24a	–	44	–
LCC-3[f]	82	5.26a	–	64	38
Vietnam – Cai Lay District: B-WSR, 1999 DS (7 farms)					
Farmers' practice	99	6.34a	–	64	–
LCC-3	70	6.31a	–	90	29
India – Haryana State: Random TPR, 2001 WS (165 farms)					
Farmers' practice	149	6.36a	–	43	–
LCC-4	124	6.37a	–	51	25

C. Increase in grain yield and a reduction in N fertilizer use in the LCC method.

Treatment	N used (kg ha^{-1})	Grain yield (Mg or t ha^{-1})	AEN†	PFP-N‡	N saved (kg ha^{-1})
Philippines – Maligaya: B-WSR, 1998 DS (6 farms)					
Control	0	3.62c	–	–	–
Farmers' practice	151	4.53b	6b	30	–
LCC-3	125	5.15a	14a	41	26
Vietnam – Huyen District: B-WSR, 1999 DS (18 farms)					
Farmers' practice	98	4.63b	–	47	–
LCC-3	80	4.92a	–	62	18

[a] AEN: Agronomic efficiency of applied N = kg additional grain yield over control per kg N applied.
[b] PFP-N: Partial factor productivity for applied N = grain yield divided by applied N.
[c] TPR: Transplanted rice; B-WSR, Broadcast wet-seeded rice.
[d] DS: Dry season; WS, Wet season.
[e] Values followed by the same letters within a column and a set are not significantly different at $P < 0.05$ by Duncan's Multiple Range Test.
[f] LCC-4: Leaf color chart critical value set at 4; LCC-3: Leaf color chart critical value set at 3.
[g] WS: wet season
[h] B-WSR: Broadcast wet-seeded rice

Potential savings in N fertilizer by using the LCC method

When averaged over 518 on-farm evaluation plots conducted in four countries during1998-2000, farmers using the LCC could save 8 to 22 kg N per ha per season and increase grain yield by 2% to 8% in four Asian countries (Table 4). In Karnal District of India in 2001, 165 farmers evaluated the LCC method. Average saving in N was 25 kg ha^{-1} by using the LCC method, without any reduction in yield (mean yield 6.37 t ha^{-1}) (Figure 4). In such areas, the use of LCC will prevent farmers' over application of N to their rice crops. With savings in N fertilizer cost, farmers are encouraged to apply more P and K (and micronutrients, if necessary) to enhance balanced nutrient use in rice and to maintain soil health and productivity over time.

Table 4: Average kg N saved and grain yield increase with the use of LCC method over the local farmers' practice for N management in rice in farmers' field in different countries, 1998-2000 (Source: Balasubramanian and Buresh 2002).

Country	Year	Number of farms	N saved, Kg ha^{-1}	Grain yield Increase, %
Philippines	1998-2000	74	7.8	3.7
Vietnam	1998-2000	96	19.8	3.4
Indonesia	1998-1999	120	19.5	1.8
India	1999	228	21.8	8.0

Treatment	N applied kg ha-1	Gr. Yield, kg ha-1	PFP-N	N saved, kg ha-1
FFP	149	6359	42.7	-
LCC-N	124	6371	51.4	25

Figure 4: Saving in N by using LCC in farmers' fields of Karnal, Haryana, India, 2001.

Farmers' feedback on the LCC method

Most farmers feel that the LCC method is simple and easy to learn and use. They often use the LCC to confirm the right time for N topdressing; it also prevents too much or too little application of N to their rice crops. Farmers observed that with proper N management using the LCC, rice plants remain healthy with reduced pest incidence and less need for pesticide use. It is necessary to quantify this nutrient x pest interaction effect in rice.

Farmers in Central Luzon of the Philippines believed that the LCC method was easy to use and that it could save N (Otai 1997) in some areas. Progressive farmers using the LCC were also aware of balanced fertilizer application to maintain soil fertility and to sustain high rice yields. Otai (1997) also observed that the spread of the improved knowledge from the progressive farmers to others was slow.

Farmers in the Mekong Delta of Vietnam extensively use the LCC for N management in rice. Some of them have adapted the LCC method to their own needs. They claim that, by using the LCC, they could save 10 to 35% N, observed less bacterial sheath blight and red stripe diseases, noted less or no lodging, and obtained the same or higher grain yields in direct-seeded rice. Mr. Vo Van Mau, a 72-year old farmer in Tien Giang Province of Vietnam, said that he had reduced his N rate from 92 kg ha^{-1} to 69 kg ha^{-1} and harvested 7 t ha^{-1} of grain using the LCC method and rice variety IR64. Farmer cooperators in Indonesia and India expressed similar views. Saving on fertilizer cost without compromising on grain yield appears to be the prime mover for the spread of the LCC method among farmers in these countries. Many farmers are proud to carry the LCC in their pockets and show others that they use it to manage N precisely in their rice fields. They emphasize that knowledge-based resource management is possible if simple methods and/or tools such as the LCC are made available to them.

INTEGRATING THE LCC METHOD WITH OTHER TECHNOLOGIES TO ENHANCE PROFIT TO FARMERS

The LCC method can be combined with improved crop establishment to secure optimum plant populations and better crop management to reduce cultivation cost, increase profit to farmers, and lessen the risk of fertilizers polluting the environment in farming areas and beyond. Integrating technologies that meet farmers' needs and enhance their profit is called integrated crop management (ICM). For example, in an ICM study conducted on direct-seeded rice (Figure 5) by the Plant protection Department of South Vietnam during 2001-02, farmer cooperators reported that they could reduce the seed rate by more than 50%, N input by 20% to 30%, number of pesticide applications by 30% to 50%, and crop lodging by 100% (Table 5) (Balasubramanian et al., 2002). In this study, synchronization of N application with actual crop demand by using the LCC has not only prevented crop lodging, but also improved the quality and market value of grains obtained from non-lodged crops. Farmers evaluating ICM in India and Indonesia have demonstrated similar benefits.

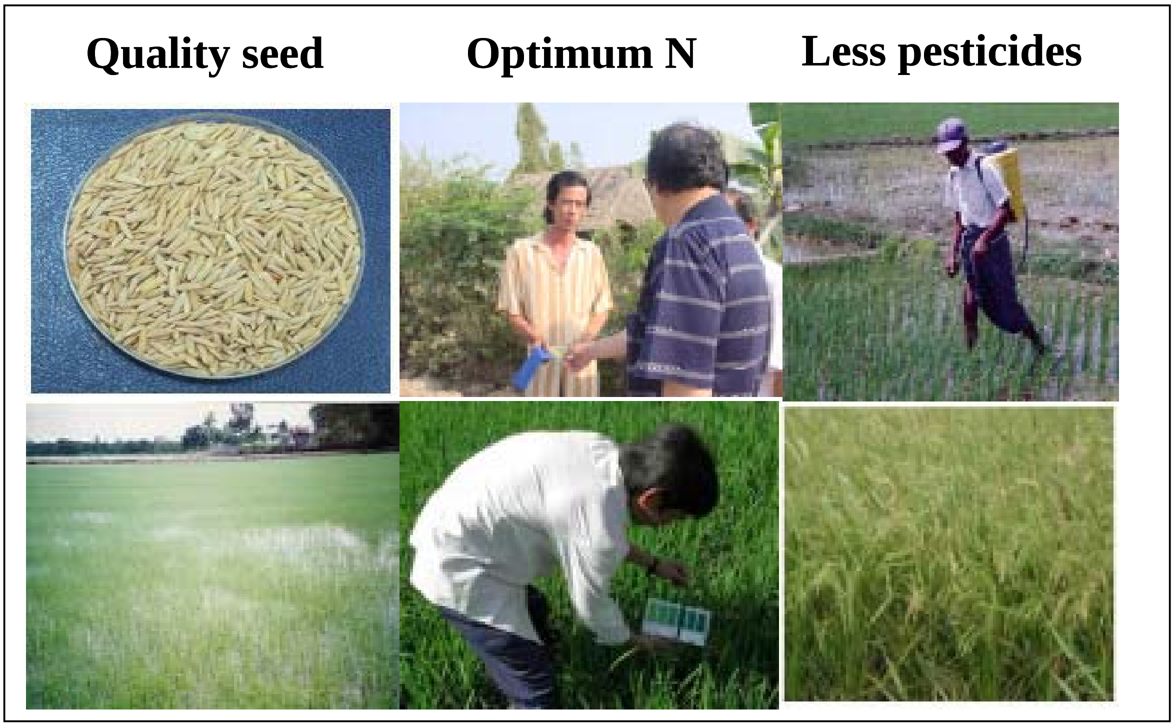

Figure 5: ICM study conducted on direct-seeded rice by the Plant protection Department of South Vietnam, 2001-02 (Source: Balasubramanian et al., 2002).

Table 5:Comparative results of applying ICM on contrast to the farmers' practice in the Mekong Delta of Vietnam, 2001-02 (Source: Balasubramanian et al., 2002).

	Farmer 1		Farmer 2	
Farmer's name/Province	Mr. Ni / Tien Giang		Mr. Ngo / Tra Vinh	
Evaluation plot	FP[a]	INPM	FP	INPM
Seed rate (kg ha^{-1})	250	100	250	100
No. of insecticide sprays/season	3-4	2	5	3
No. of fungicide sprays/season	3	2	3	2
N management	FP	LCC-based	FP	LCC-based
Yield (t ha^{-1})	7.0	6.9	4.9	6.5
Production cost per ha (US$)[b]	418	319	227	173
Savings in cost (US$ ha^{-1})	--	99	--	54
Gross income (US$ ha^{-1} assuming a rice price of \$0.10 kg^{-1})	696	690	490	650
Gross profit (US$ ha^{-1})	278	371	263	477
Additional gross profit due to INPM (US$ ha^{-1})	--	93	--	214

[a] FP = farmers' practice
[b] US$1.00 = VND15,000.

PROMOTION OF THE LCC TECHNOLOGY

A strong partnership has been developed with national agricultural research and extension systems (NARES) of different countries in Asia to evaluate and promote the LCC with the active participation of farmers. Our NARES partners come from public, NGO, voluntary and private sector agencies. Training and technical support of field researchers, extension personnel, and farmer cooperators are critical to sustain the promotion of the LCC method over time.

Developing partnership for evaluation and promotion of the LCC

The principal structure that helped us to develop, test, and evaluate the LCC was the Crop and Resource Management Network (CREMNET) started by IRRI in 1994. This network was coordinated by the author until December 2001. The goal was to facilitate the free exchange, participatory evaluation, and dissemination of promising crop and resource management technologies for higher sustainable productivity of rice-based cropping systems. In 1995, several national CREMNET Working Groups headed by national CREMNET coordinators were constituted in different countries. This network facilitated the systematic exchange of information and technologies, training of national partners, on-station and on-farm evaluation of technologies, collection of farmers' feedback, and organization of periodic workshops/meetings of collaborators. Among other technologies, the chlorophyll meter was initially evaluated for crop need-based N management in rice during 1995-2000. Since 1996, the LCC was evaluated as an alternative to the chlorophyll meter.

Collaborators of CREMNET included public, NGO, and private sector agencies (Annex1). For example, in the Philippines, the national research institute PhilRice, Department of Agriculture (DA), Land Bank, Rhone Poulenc (a pesticide company), PhilPhos and Atlas fertilizer companies and Green Corps Foundation Inc (GOFI, an NGO) are the agencies that work with IRRI to promote the LCC. Some fertilizer companies and input retailers provide the LCC at 50% cost or free to their customers (e.g. South Vietnam). The cooperative fertilizer company IFFCO in India wishes to add their message at the back of the LCC and then distribute them to farmers through their branch offices and retail outlets. The FAO community IPM program in Sri Lanka uses the LCC in Farmer Field School (FFS) training. They distribute the LCCs to IPM trainees to improve rice plants' health through crop-need-based N management. In other countries, national universities, local research institutes, government extension departments and fertilizer companies are involved in the promotion of the LCC.

The robustness and utility of the LCC technology is now well established. Other programs and projects such as the Irrigated Rice Research Consortium (IRRC), Rice-Wheat consortium, PETRRA project (Bangladesh), national universities and departments of agriculture have taken up the promotion of the LCC technology. The IRRC at IRRI coordinates the development and dissemination of technologies for irrigated rice farmers in Asia. It consists of six interdisciplinary technical Work Groups (WGs) to examine farmers' prioritized problems and an Impact WG that cuts across all technical WGs to facilitate farmers' uptake of technologies for wider impact. With such close collaboration between technical and Impact WGs, it is possible to effectively promote technologies to farmers and assess the impact of introduced technologies. The author now coordinates the Impact WG.

Training of national partners

IRRI scientists train the partners on LCC methodology (Figure 6). During the training, they learn about the various interfering factors that affect the LCC readings and how to tackle them while using the LCC method. They become conversant with different LCC critical values for different crop-growing conditions. They are also trained to appreciate the need for a combined use of LCC and other methods to optimize grain yield and N use efficiency in rice. They will understand not only the economic advantage of efficient N management techniques, but also their impact on resource base, environmental quality, and human health.

Figure 6. Training of national partners on how to use the LCC: (a) extension personnel of Haryana, India; and (b) farmers of Aduthurai, Tamil Nadu, India.

IRRI scientists work with national partners to develop the LCC evaluation protocols, provide them the LCC and other critical inputs, and support their work by periodic visits and counseling. The national partners evaluated the LCC first in research farms to convince themselves about the technology. Then, they introduced the LCC to a group of progressive farmers near the research station and helped them evaluate it in their own fields. IRRI and national researchers jointly collected and processed the evaluation data including farmers' feedback. Periodic workshops were organized to review progress, exchange ideas and experiences, and plan work for the next season.

After the LCC theoretical and field evaluation training, national researchers train the local staff (extension, private sector, and NGO groups) and farmers and prepare them for the widespread dissemination of the LCC technology. Often, farmer meetings and discussion groups as well as farmer field schools (FFS) are used for training. LCC extension sheets, posters, and video are produced for training and dissemination purposes.

Communication methods used for promoting LCC

Scientific dissemination of the LCC technology is being achieved through publications and organization of conferences/workshops/seminars. Scientists and students can consult published journal articles and reports on the LCC to know more about the LCC technology. For a wider audience including farmers, local language manuals on how to use the LCC, a training guide on the LCC, extension fact sheets and posters, video, etc. are available. All these materials are public goods and can be downloaded from IRRI's Knowledge Bank at http://www.knowledgebank.irri.org/knowledgebytes/lcc/lcc_htm/default.htm. Selected success stories of and farmers' experiences with LCC are being published in local language newspapers and magazines for wider dissemination.

Farmer-to-farmer communication and spread of information are critical while disseminating any technology. The national staff organizes farmers' days in which the first adopters of the LCC method explain their experiences to other farmers. They publish farmers' experience with the LCC technique in local news media, conduct dialogues with selected farmers on radio talks, and show the LCC video on local TV or village video parlors to spread the new technology. The guide on 'How to use the LCC' has been translated into Bengali, Bahasa Indonesia, Hindi, Nepalese, Myanmar language, Tagalog, Tamil, and Vietnamese languages for farmers to easily follow the instructions on how to use the LCC properly.

Working with policy makers

We also work with policy makers (directors, secretaries, and ministers of agriculture) in different countries by introducing them to the LCC technology, explaining to them the benefits of the LCC, and arranging their visits to pilot villages where farmers are using the LCC method. For example, in Haryana State of India, the Chief Minister has been convinced about the benefits of using the LCC in rice. The Tribune News Service, Chandigarh, May 15 (2003), reports:

"*Mr. (Om Prakash) Chautala (Chief Minister of Haryana State) also announced that paddy growers of Haryana would be provided with 'leaf colour chart' designed and developed by the International Rice Research Institute, Philippines to enable them to assess the requirement of nitrogen application in the crop. Mr. Chautala directed the Agriculture Department to distribute at least 5000 'leaf colour charts' to the farmers in the paddy-growing districts of Panipat, Karnal, Kurukshetra and Kaithal this season so as to educate them about nitrogenous fertiliser. The Chief Minister said farmers of Karnal district were educated to use nitrogenous fertilisers with the help of 'leaf colour chart' during the last crop season and the results were encouraging*".

In Indonesia, the Minister and the Secretary of Agriculture and the Director General of the Agency for Agricultural Research and Development have been briefed about the LCC technology. The Government of Indonesia supports the nationwide promotion of integrated crop management (ICM) in which the LCC is a major component. In Vietnam, the Vice-Minister for the Ministry of Agriculture and Rural Development is committed to the expansion of the LCC and other technologies through ICM.

Commercialization of LCC

Private companies are encouraged to produce and market the LCC in different countries. There are two companies in India, one in the Philippines, and one in Vietnam that produce and market the LCC widely in Asia. During commercialization, strict maintenance of the LCC color shades is vital for its reliable use in Asia and elsewhere. Therefore, a quality certification program is organized to certify the charts produced by various agencies in different countries, using the

IRRI-produced LCC as the standard. Here is an example of quality certification for the LCC produced by Nitrogen Parameters in India.

IRRI

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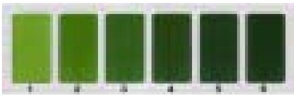
certifies that

The color of the panels 1 to 6 of the Leaf Color Chart (LCC) prototype produced and sent to us by the Nitrogen Parameters Company, Chennai, India conforms to the color panels of the LCC produced by the International Rice Research Institute (IRRI), Los Baños, Philippines. The quality check was done by recording and comparing the spectral signatures of the Nitrogen Parameter's LCC prototype with that of the LCC produced by IRRI.

Rice farmers use the LCC as a simple decision making tool for need-based N fertilization in rice. It is, therefore, critical that the Nitrogen Parameters Company strictly maintains the color shades of panels 1 to 6 in each batch of LCC production in the future.

Attached below is the sample of the Nitrogen Parameter's LCC prototype that we examined here at IRRI for quality check with IRRI-produced LCC.

Given at IRRI, Los Baños, Laguna, Philippines
this 30th day of January 2002.



V. Balasubramanian
Impact Workgroup

Ronald Cantrell
Director General

Uptake of LCC

As of December 2002, about 400,000 farmers are estimated to use the LCC method in rice in six Asian countries (Bangladesh, India, Indonesia, Maynmar, Philippines, and Vietnam), based on the observation the one LCC is used by more than one farmer and some farmers do not use them. A smaller number of LCCs has been sent to 21 other countries in Asia, Africa, and Latin America (Figure 7). The actual number of LCCs distributed or sold to farmers or sent to researchers for research purpose in 27 countries is given in Annex 2.

Figure 7. Global distribution of the LCC as of May 2003 (See Annex 2 for the list of countries that received the LCC for research, farmer evaluation and promotion purposes).

SUMMARY AND CONCLUSIONS

Rice farmers are increasingly constrained by the high production cost and low price for rice leading to relatively low income. The future of rice farming in Asia depends on the ability of research and extension agents to ensure improved profit and livelihoods for rice farmers. We require precision crop management technologies for small rice farms of Asia to produce rice efficiently and economically from limited land and water resources. The LCC technology, an important element of site-specific nutrient management, is a very useful tool for crop need-based N management in rice; it has several benefits as shown below.

LCC as a precision N management tool: The LCC method is simple, easy to learn and use, and inexpensive (US$ 1.00 per chart). It helps farmers to match N fertilizer application with actual crop demand. It helps to integrate all sources of N (organic manure, biologically fixed N, or chemical fertilizer) to timely meet crop need.

LCC vs. N-use efficiency: The LCC is designed to improve the efficiency of farmers' N fertilizer use by optimizing N rates and improving the time of application. It corrects both the inadequate and over-application of N to rice crops. Thus, a kilogram of applied N fertilizer produces 15 to 30 kg grain over a zero-N control with the use of the LCC in contrast to a mean value of 12 kg of grain with the farmers' existing N management practices.

Maintenance of soil health: In areas with over-application of N fertilizers, farmers using the LCC save about 8-20 kg N per ha per season without reducing rice yield. These farmers are encouraged to adopt balanced use of other nutrients such as P, K and micronutrients as required, to enhance soil health and sustain rice production over time.

LCC as an IPM tool: By avoiding excessive N use and minimizing crop lodging, farmers manage to raise healthier crops and thus avoid the excessive use of pesticides. The LCC has already been adopted as an IPM tool in parts of Bangladesh, India, Sri Lanka, and Vietnam.

Profit in rice cultivation: Saving in fertilizer and pesticide cost plus any additional profit from increased yield and/or grain quality/market value add to farmers' profit. With improved nutrient management alone, farmers obtain an additional profit of about 46 US$ ha^{-1} $crop^{-1}$ (Dobermann et al 2002). If critical crop management factors are combined with the LCC method, the profit can be increased further.

Environmental benefits: Indirectly, less pesticide use due to the adoption of the LCC method has potential to improve the quality of the farming environment. Efficient N fertilizer use will also help conserve the fossil fuel energy sources used for the manufacture of N fertilizers.

Popularization and uptake of LCC: Institutional partnership with four private companies is established to commercialize the LCC in Asia. National R&D organizations, fertilizer companies, land bank, farmer cooperatives, input retailers, and NGOs participate in the popularization of LCC among farmers. Audiovisual materials and mass communication methods are used to spread the message to farmers at large.

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I place a deep feeling of gratitude for the late Mr. Antonio C. Morales who worked with me as assistant scientist and helped me enormously in the development and promotion of the LCC during 1996-2002. My former secretary Ms. Fe Danglay and present secretary Ms. Jennifer Hernandez and the staff of the IRRI Training Center help me a lot in working with national partners and meeting their needs to introduce and promote the LCC technology in different countries.

I value and acknowledge the contribution of Dr. R. Cruz of the Philippine rice research institute (PhilRice) in the initial development of the LCC. Several national research and development partners including NGOs and private sector agencies in Bangladesh, Cambodia, India, Indonesia, Myanmar, Nepal, Philippines and Vietnam worked hard to introduce and popularize the LCC and train and support farmers in its proper use in their respective countries, and I thank them all for their valuable contributions. Fertilizer companies such as Atlas and Philphos in the Philippines and IFFCO in India play an active role in promoting the LCC for responsible fertilizer use in rice farming.

I thank my wife, my two sons and their families, and my close friends for their patience with me for my frequent spells of absence caused by work and work-related travel, and for their continuous love, support, and encouragement for my work.

Above all, I am grateful to thousands of farmers who volunteered to use the LCC technology for the first time and provided several insights into how to improve and refine the methodology to meet their needs in the field.

Finally, I thank the International Fertilizer Industry Association (IFA) for creating an international award to recognize outstanding research works in plant nutrition and fertilizer use. I am honored to be this year's recipient of this prestigious award. This recognition will further strengthen the collaborative efforts of IFA with national and international research institutes and universities to help farmers improve their livelihood.

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Annex 1. Major national partners and IRRI scientists* involved in the development, testing and evaluation, and promotion of LCC, 1995-present.

Country	**NARES institutions**	**Lead NARES and IRRI scientists***	**Type of research & evaluation**	**Period**
Bangladesh	BRRI & Research stations	M. Panaullah & team + V. Balasubramanian*	Chlorophyll meter & LCC on-station evaluation	1996-99
	PETRRA Project & BRRI-Kushtia	M. Alam, R.J. Buresh*, J.K. Ladha*	LCC critical values for rice varieties in BD; On-farm evaluation & farmer training	2001-present
China	Zhejiang Ag. Univ. (ZAU)-Hanghzou		Correlation of SPAD & LCC	1995-96
Myanmar	Central Ag. Res. Inst. (CARI)-Yezin	La Tin & V. Balasubramanian*	Correlation of SPAD & LCC on TPR; farmer training	1998-99
India	TNAU-Coimbatore	T.M. Thiaygarajan, M. Velu & team; V. Balasubramanian*	On-station/on-farm eval. of SPAD & LCC; PG res. on SPAD & LCC; extension & farmer training	1997-present
	TNRRI-Aduthurai	S. Ramanathan, S. Natarajan, B. Chandrasekaran and team + V. Balasubramanian*	On-station & on-farm eval. of SPAD & LCC; extension & farmer training	1996-present
	SWMRI-Thanjavur	R. Nagarajan, R. Rajendran, M. Ravi, M. Babu, Mohandoss + V. Balasubramanian*	On-station & on-farm eval. of SPAD & LCC; measurement intervals and varietal response; extension & farmer training	1996-present
	MSSRF-Pondichery	R. Balasubramanian, R.S.S. Hopper, V. Balasubramanian*	On-farm eval. of LCC; extension & farmer training	1996-2000
	DRR-Hyderabad	S.V. Subbaiah & team + V. Balasubramanian*	On-station eval. of SPAD & LCC with rice varieties	
	RWC-N. India	R.K. Gupta, J.K. Ladha*, V. Balasubramanian*	OFT & promotion of LCC; extension & farmer training	2000-present
	PDCSR, Modipuram	A. Shukla, J.K. Ladha*, V. Balasubramanian*	Critical LCC values for varieties, on-station & on-farm eval.	2000-present
	PAU- Ludhiana	Bijay-Singh & Yadvinder-Singh; J.K. Ladha*, V. Balasubramanian*	On-station & on-farm eval. of SPAD & LCC on rice & wheat; critical LCC values for rice varieties; extension & farmer training	1999-present
	DA, Karnal	S. Mehla, Khurana, & team; J.K. Ladha*, V. Balasubramanian*	OFT on LCC; extension & farmer training	1999-present
	Tata Chemicals	G. Gross, J.K. Ladha*	Promotion of LCC to farmers	2003-

	United Rice Land	A. Tiwari, J.K. Ladha*, V. Balasubramanian*	Critical LCC values for Basmati rice varieties and grain quality	2000-present
Indonesia	RIR-Sukamandi	S. Abdulrachman; V. Balasubramanian*	On-station and on-farm eval. of SPAD & LCC; extension & farmer training	1996-present
	AIAT- N. Sumatra	Z. Zaini; V. Balasubramanian*	OFT on LCC; extension & farmer training	1996-99
	AIAT- W. Sumatra	V. Balasubramanian*	OFT on LCC; extension & farmer training	1996-97
Nepal	NARC	A.P. Regmi, J.K. Ladha*, V. Balasubramanian*	Critical LCC values for rice varieties; on-station & on-farm eval.; extension & farmer training	1999-present
	SDC	B. Tripathi, J.K. Ladha*	On-farm evaluation of LCC, farmer training & promotion	2001-present
Pakistan	PARC	F. Hussain, J.K. Ladha*	Critical LCC values for rice varieties; on-station & on-farm eval.; training & farmer promotion	2000-present
Philippines	PhilRice-Maligaya	R.T. Cruz (1996-99), G.S. Gines (2001-), R.J. V. Balasubramanian*, Buresh*, C. Witt*	On-station, on-farm eval. of SPAD & LCC on inbred & hybrid rice; critical LCC values for rice varieties; on-farm eval.; extension & farmer training	1996-99; 2000-present
	GOFI (NGO)-Isabella	--	On-farm evel. of LCC; farmer training	1999-2000
	Philphos/Atlas-Manila	J.S. Umadhay	Farmer eval. of LCC; extension & farmer training	2002-present
Sri Lanka	Rice Res. Inst. & IPM FFS Project	--	Farmer eval. of LCC; extension & farmer training	1999-present
Vietnam	CLRRI-Omon	P. S. Tan, V. Balasubramanian*, C. Witt*, R.J. Buresh*	On-station & on-farm eval. of SPAD & LCC, survey; extension & farmer training	1996-present
	FSR&D-Cantho	N.N. De, V. Balasubramanian*	LCC critical value for rice varieties, OFT on LCC; extension & farmer training	1996-99
	MARD-Cai Lay	L.H. Hai, V. Balasubramanian*	OFT on LCC; extension & farmer training	1996-present
	Plant Protection Dept.-Ho Chi Minn City	N.H. Huan and team, K.L. Heong*, M. Escalada*, V. Balasubramanian*, R.J. Buresh*	On-farm eval. of LCC and ICM; extension & farmer training; impact assessment	1999-present

Annex 2. Total Number of LCC Distributed to Farmers in Different Countries (March 1997 - May 2003)

	1997	1998	1999	2000	2001	2002	2003	*TOTAL/country*
Africa								
Egypt		25						25
Madagascar		50	35					85
Nigeria					2			2
Uganda	5							5
Asia								
Bangladesh	70	158	200	50	350	1	1800	2629
Bhutan			50					50
China	15				6	30		51
India	405	369	1431	1830	218	9407	15,002	28662
Nepal	25	2	100	40	525		200	892
Pakistan		2		5		2		9
Sri Lanka			50			50	500	600
Southeast Asia								
Cambodia			5		200			205
East Timor							45	45
Indonesia	5	400	1900	2868	705	6570	2850	15298
Philippines	2232	16285	816	617	1288	2198	422	23858
Laos					5	50		55
Malaysia			5			720		725
Thailand		105	34	42				181
Vietnam	410	6802	1103		1100	300120		309535
Central America & the Caribbean								
Costa Rica					2			2
Cuba				15	25	22		62
Haiti		20						20
North America								
United States	20	12	2		1			35
South America								
Guyana			10					10
Brazil							10	10
Europe								
United Kingdom		9						9
Oceania								
Papua New Guinea	3							3
Total/year	***3190***	***24239***	***5741***	***5467***	***4427***	***319170***	***20829***	***383063***

Leaf Color Chart for Crop Need-based N Management in Rice

V. Balasubramanian

Agronomist/Soil Scientist
Training, Delivery & Impact
IRRI, DAPO Box 7777
Manila, Philippines

Rice Production vs. N Fertilizer Needs

Year	Production (10^6 t)	Irrigated rice yield (t ha^{-1})	N-recovery efficiency (%)	N rate (kg ha^{-1})*	Total N need for rice (10^6 t)
2000	599	5.1	33	111	10
2020**	729	6.7	33 **50**	242 **161**	24.2 **16.1**

* Assuming 3.8 t ha^{-1} of control yield & AE 12 kg grain per kg N
** Projected: IFFRI's Impact Model

Improving Rice Farming in Asia: Challenges

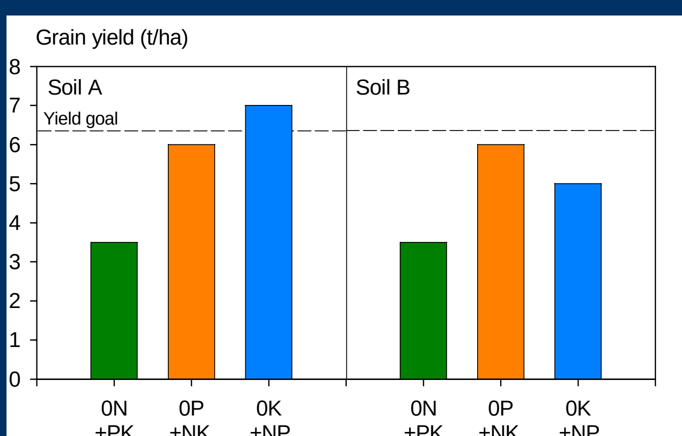
- How to achieve high yield consistent with high profit
- How to develop precision farming for small farms
- How to reach and educate millions of farmers with less literacy & low resources
- How to tackle high variability in space & time

N Management in Rice

Sources of N for Rice Crops

- **Indigenous supply**
  - ✓ Soil
  - ✓ Crop residues and manures
  - ✓ Irrigation water
  - ✓ Biological N_2 fixation
- **External supply**
  - ✓ Chemical fertilizers

N is the Most Limiting Nutrient in Almost All Soils



Blanket Recommendations

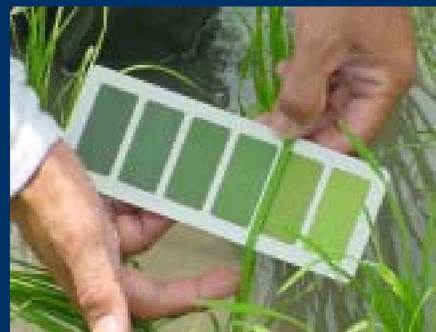
- Does not consider variability in soil N supply and dynamic changes in crop demand
- Farmers generally apply too much N fertilizers (and too little P and K)

Variability in Nutrient Supply and Demand

- High field-to-field variability in native nutrient supply
- High variability in crop growth & nutrient demand among locations & seasons
- Rice crops thus require different amounts of nutrients in different fields
- However, we cannot make fertilizer recommendations for individual fields
- We need simple strategies and tools for handling variability in small farms

Crop Need-based N management

Chlorophyll meter



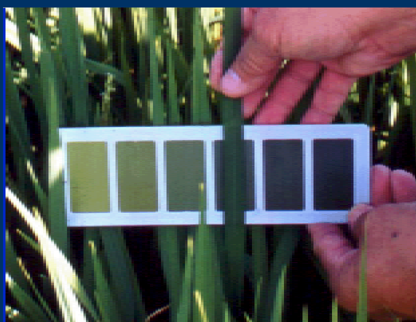
Leaf color chart (LCC)

Scientific Principles of LCC

- Leaf color intensity is directly related to leaf chlorophyll content that relates to leaf N status
- Thus, leaf color intensity is used a proxy for leaf N status
- Both the SPAD and LCC values are related to leaf N conc. as follows:

  SPAD 36 or LCC 4 = 1.4-1.5 g N per m^2 leaf area
- Below this critical level, rice crops suffer from N deficiency and N must be applied immediately

Leaf Color Chart (LCC)



- It is simple, easy to learn and use, & inexpensive
- It helps farmers determine crop N status & the right time of N application
- It measures leaf color intensity that relates to leaf N status
- It helps to integrate all sources of N to timely meet crop need

Development of the LCC

'How to Use the LCC' Guide in Different Languages

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Suggested Critical LCC values*

Variety / crop establishment method	Critical value
Semidwarf indica varieties, direct-seeded	3
Scented or aromatic varieties, transplanted	3
Semidwarf indica varieties, transplanted	3.5-4.0
Hybrid rice varieties, transplanted	4.0

* Local calibration is always recommended

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Decision Making Based on LCC Readings

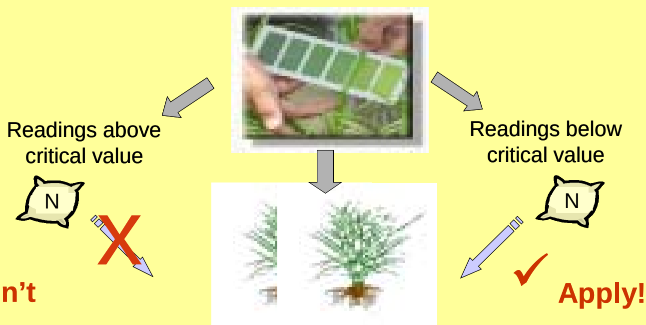

Fig. 3. Leaf color is monitored with the LCC, and N applied when leaf color falls below a critical value.

Training of Extension Personnel & Farmers

Extension personnel

Farmers, TN, India

Field Evaluation of the LCC: Efficiency Criteria Used

- Grain yield at 14 % MC
- <u>Agronomic efficiency of applied N (AEN)</u>: increase in grain yield over zero-N control per unit of N applied
- <u>Partial factor productivity of N (PFP-N)</u>: total grain yield divided total N applied

Case1: Inadequate N Application

- An increase in grain yield, but with a higher fertilizer N use.
- Efficiency values are similar for both the farmers' practice and the LCC method.
- Here the LCC helps farmers to increase yield by higher N fertilizer use, e.g., DS TPR trials, Philippines.

The LCC method vs. Farmers' practice
Maligaya, Philippines, 1996-99

Treatment	N used, kg ha^{-1}	Grain yield, kg ha^{-1}	AEN	PFP-N	N saved, kg ha^{-1}
TPR, 1998 DS (14 farms)					
Control	0	3838 b	-	-	-
Farmers' practice	116	5749 a	19 a	49	-
LCC-4	130	6046 a	19 a	46	-14
TPR, 1999 DS (9 farms)					
Control	0	3327 b	-	-	-
Farmers' practice	121	5104 a	15 a	42	-
LCC-4	135	5296 a	16 a	39	-14

In a column, means followed by the same letter(s) are not significantly different at 5% level by DMRT.

Case 2: Over-application of N

- Grain yields are similar for both the farmers' and LCC methods, but with lower amount of N applied in the LCC plot.
- N-use efficiency is higher in the LCC plot than in farmers' own field.
- Thus, the LCC helps farmers save N fertilizer use without reducing the grain yield.
- It prevents the over-application of N.

Use of the LCC corrects over-application of N

Treatment	N applied kg ha-1	Gr. Yield, kg ha-1	PFP-N	N saved, kg ha-1
FFP	149	6359	42.7	-
LCC-N	124	6371	51.4	25

Total number of FP trials: 165 (Karnal, India, 2001)

Case 3: Excessive & Improper N use

- Higher yield & lower N use in the LCC plot
- N-use efficiency (NUE) is much higher for the LCC method than for the farmers' practice
- In this case, a lot of improvement in farmers' N-use practice is needed to increase grain yield & NUE, e.g., DS trials in Vietnam

The LCC method vs. Farmers' practice
South Vietnam, 1997-99

Treatment	N used, kg ha^{-1}	Grain yield, kg ha^{-1}	AEN	PFP-N	N saved, kg ha^{-1}
Omon and Thotnot Districts, Cantho Province: B-WSR, 1999 DS (20 farms)					
Farmers' practice	108	4440 b	-	41	-
LCC-3	98	4811 a	-	49	10
Huyen District, Cantho Province: B-WSR, 1999 DS (18 farms)					
Farmers' practice	98	4631 b	-	47	-
LCC-3	80	4917 a	-	62	18

In a column, means followed by the same letter(s) are not significantly different at 5% level by DMRT.

Farmers' Feedback on the LCC Method

- Simple, easy to learn & use, & inexpensive.
- Prevents too much or too little application of N to rice crops
- Plants remain healthy & thus less need for pesticide use
- Reduces crop lodging, especially in WSR (Vietnam)
- Improved grain quality & market value in non-lodged crop

Integrating the LCC Method with Other Practices -- ICM

Less seed | Optimum N | Less pesticides

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Commercialization of the LCC

- Two private companies in India and one each in BD, Philippines, and Vietnam manufacture and market the LCC in Asia.
- Strict maintenance of the LCC color shades is critical for its reliable use by farmers in Asia and elsewhere.
- A quality certification program is organized using the IRRI-produced LCC as the standard.

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IRRI

INTERNATIONAL RICE RESEARCH INSTITUTE

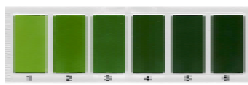
certifies that

The color of the panels 1 to 6 of the Leaf Color Chart (LCC) prototype produced and sent to us by the Nitrogen Parameters Company, Chennai, India conforms to the color panels of the LCC produced by the International Rice Research Institute (IRRI), Los Baños, Philippines. The quality check was done by recording and comparing the spectral signatures of the Nitrogen Parameter's LCC prototype with that of the LCC produced by IRRI.

Rice farmers use the LCC as a simple decision making tool for need-based N fertilization in rice. It is, therefore, critical that the Nitrogen Parameters Company strictly maintains the color shades of panels 1 to 6 in each batch of LCC production in the future.

Attached below is the sample of the Nitrogen Parameter's LCC prototype that we examined here at IRRI for quality check with IRRI-produced LCC.

Given at IRRI, Los Baños, Laguna, Philippines
this 30th day of January 2002.



V. Balasubramanian
Impact Workgroup

Ronald Cantrell
Director General

Partners in the Promotion of the LCC

- Public sector: University, Extension, DA
- NGO: BRAC (BD), GOFI (Phil), MSSRF & CER (India)
- Private sector:
  - ✓ Fertilizer companies (Atlas, Philphos, IFFCO, TATA Chemicals, VILTEDCO)
  - ✓ Land bank (Phil)
  - ✓ Pesticide companies (Rhone Poulenc)
  - ✓ FAO IPM projects use LCC as an IPM tool

Distribution of the LCC in 27 countries

Conclusions - 1

- <u>LCC for precision N mgt.</u>: simple & easy to use; matches N application with actual crop demand; integrates all N sources to timely meet crop need.
- <u>LCC vs. N-use efficiency</u>: corrects both under- & over-application of N; improves AE: a kg of N produces 15 to 30 kg of grain over control in contrast to 12 kg for current FFP.
- LCC as an IPM tool: With optimum N use, farmers raise healthy crops with least lodging >>> less pesticide use (BD, India, Sri Lanka, Vietnam).

Conclusions - 2

- Profit to farmers: savings in fertilizer + pesticide cost and gain from yield and/or grain quality (~ US$ 46 ha^{-1} per crop; ~ US$ 100 ha^{-1} per crop with ICM)
- Grain quality: with less pesticide use and least lodging, grain quality & market value are improved
- Environmental benefits: less pesticide use has potential to improve environmental quality in farming areas

IRRI colleagues & National Partners

National R&D Partners

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Farmer collaborators

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Thank You