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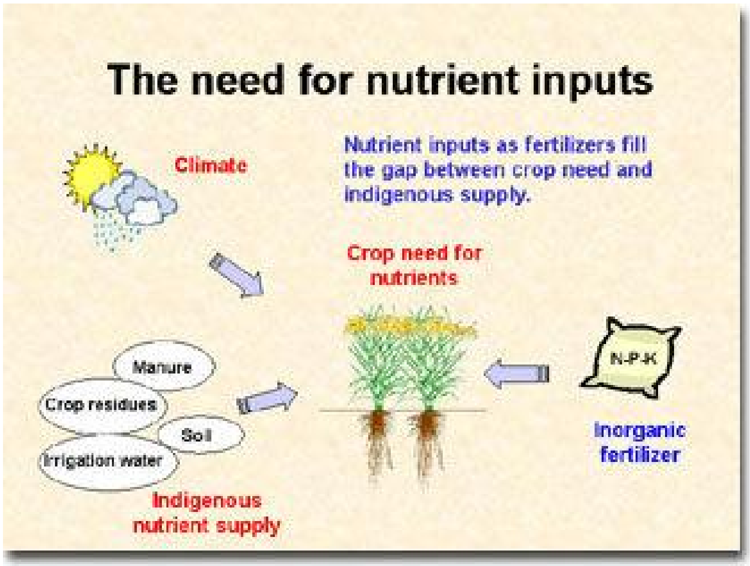
What is Site Specific Nutrient Management (SSNM)?

Many of the nutrients required by rice plants come from soil. But this supply of nutrients is typically insufficient to meet the nutrient requirements for high rice yields. The use of fertilizers is consequently essential to fill the deficit between crop needs for nutrients and the supply of nutrients from soil and available organic inputs.



Principles of SSNM

Site-specific nutrient management (SSNM) is an approach to feeding rice with nutrients as and when needed. The application and management of nutrients are dynamically adjusted to crop needs of the location and season. The SSNM approach aims to increase farmers' profit through: i) increased yield of rice per unit of applied fertilizer; ii) higher rice yields; and iii) reduced disease and insect damage. The features of SSNM are:

1) Optimal use of existing indigenous nutrient sources such as crop residues and manures.

2) Application of nitrogen (N), phosphorus (P), and potassium (K) fertilizer is adjusted to the location- and season-specific needs of the crop.

   a. Use of the leaf color chart ensures that nitrogen is applied at the right time and in the amount needed by the rice crop. This prevents wastage of fertilizer.

Leaf Color Chart

Initially IRRI promoted the 6 panel LCC.
More recent research has led to the development of the 4 panel.

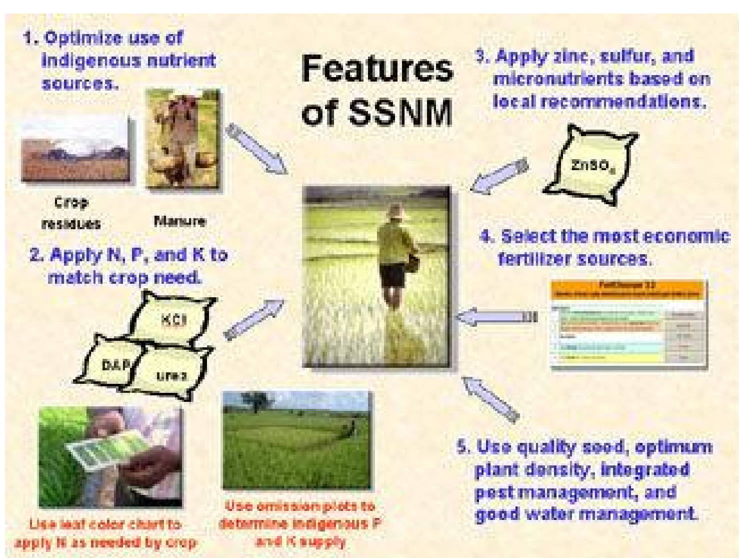
b. Use of nutrient omission plots to determine the P and K fertilizer required to meet the crop needs. This ensures that phosphorus and potassium are applied in the ratio required by the rice crop.

Nutrient Omission Plot

3) Local recommendation for application of zinc, sulfur, and micronutrients are followed.

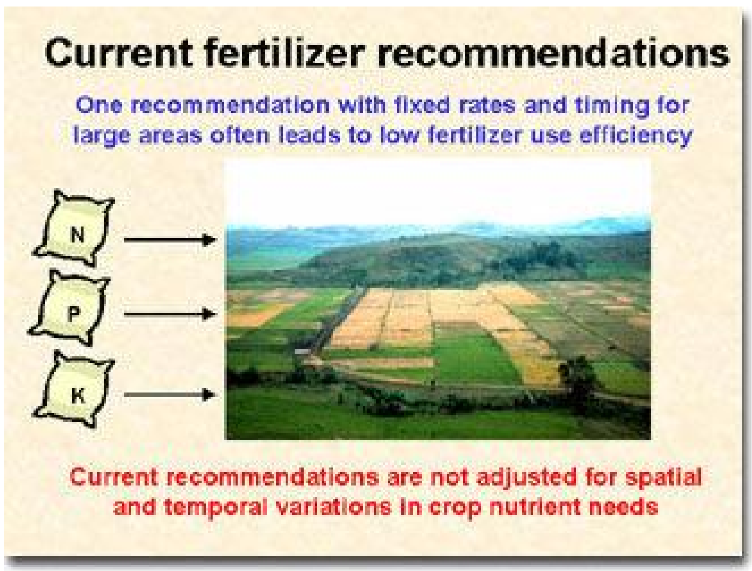
4) Selection of the most economic combinations of available fertilizer sources.

5) Integration with other integrated crop management (ICM) practices such as the use of quality seeds, optimum plant density, integrated pest management, and good water management.



Why Use SSNM?

Nutrient Use Efficiency
Under current management practices, only one bag in three of nitrogen (N) fertilizer applied to rice is taken up by the rice crop. Additionally, farmers often fail to apply N, phosphorus (P) and potassium (K) in the optimal ratio to meet the needs of rice plants. Site-specific nutrient management (SSNM) provides an approach for "feeding" rice with nutrients as and when they are needed.
Current fertilizer recommendations often advise fixed rates and timings for large rice-growing areas. Such recommendations assume the crop need for nutrients is constant from one place to another, one year to the next. But crop growth and crop demand for nutrients are strongly influenced by climate and other growing conditions, which can vary greatly according to location, season and year.



Increased Profitability
The major benefit for farmers from improved nutrient management strategies is an increase in the profitability of rice cropping (Dobermann et al., 2003). SSNM eliminates wastage of fertilizer by preventing excessive rates of fertilization and by avoiding fertilization when the crop does not require nutrient inputs. It also ensures that N, P and K are applied in the ratio required by the rice crop.

The principles of SSNM can accommodate a wide range of socio-economic conditions, including situations of labor shortage. Small amounts of additional labor may be required, but labor costs for nutrient management are relatively small compared to those for land preparation, transplanting or harvesting. Efficient N management may also result in off-farm environmental benefits through a reduction of fertilizer N use without a reduction in yield (Balasubramanian et al., 2000, Wang et al., 2001) especially in situations where N inputs are very large (e.g., China and Java Island in Indonesia). This may increase profitability, particularly in cases of very high fertilizer N inputs (China, Indonesia). Researchers have compared SSNM with current farmers' fertilizer practices in more than 200 farmers' fields in China, India, Indonesia, Philippines, Thailand, and Vietnam. In most cases, using SSNM increased grain yields and farmers' profit.

When to Use SSNM

Overview

Suitable target areas for the introduction of improved nutrient management strategies will likely have one or more of the following characteristics:

- Insufficient or unbalanced use of fertilizer, resulting in a low attainable yield despite high yield potential. Find out about local fertilizer use from farmers, fertilizer suppliers, and extension workers.

- Occurrence of nutrient deficiency symptoms.

- Occurrence of pest problems linked to nutrient imbalance or overuse of fertilizer N (e.g., sheath blight and rice blast).

- Inefficient fertilizer N use because of high total N rates or inadequate splitting and timing, for example, if farmers:
  - use fertilizer N rates of >175 kg/ha;
  - apply large amounts of fertilizer N during early crop growth (>50 kg N per ha within the first 10 days after transplanting/days after sowing (DAT/DAS) or >75 kg N per ha within the first 20DAT/DAS);
  - apply topdressings of >50 kg N per ha per split;
  - need to apply >45 kg fertilizer N per ha (100 kg urea per ha) per ton yield increase over yield in an unfertilized field; and
  - encounter problems with lodging.

- Evidence of strong mining of soil indigenous P or K, for example, if farmers
  - grow two or more crops per year at moderate to high yield levels, and in the past five years:
    - applied <20 kg P_2O_5 per ha per crop or
    - applied <10 kg K_2O per ha per crop and removed most straw (Fairhurst and Witt, 2002).

NP&K Deficiency Symptoms

N Deficiency Symptoms

Stunted, yellowish plants. Older leaves or whole plants are yellowish green.

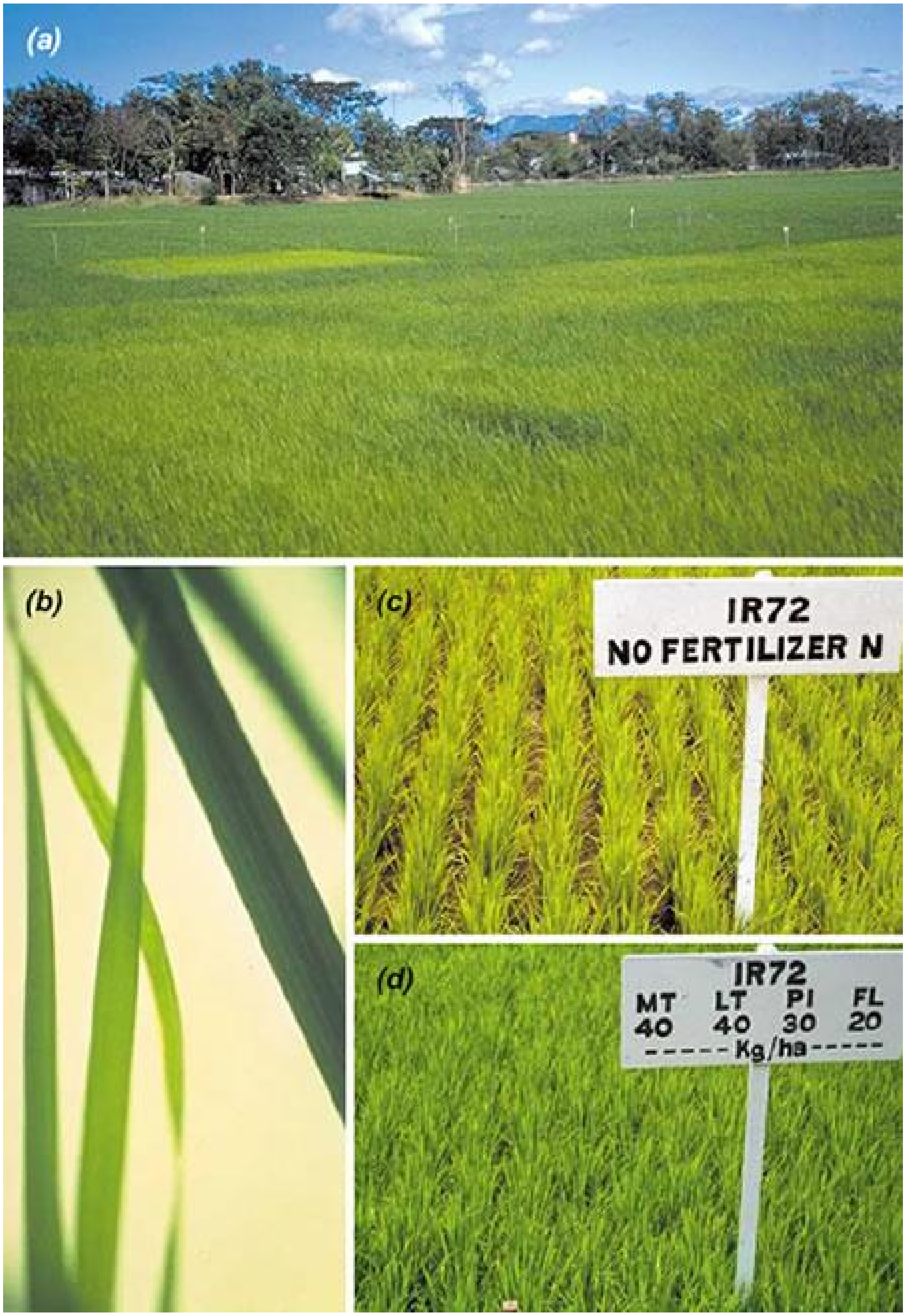
Old leaves and sometimes all leaves become light green and chlorotic at the tip. Leaves die under severe N stress. Except for young leaves, which are greener, leaves are narrow, short, erect, and lemon-yellowish green. The entire field may appear yellowish. N deficiency often occurs at critical growth stages such as tillering and panicle initiation when the demand for N is large. N deficiency results in reduced tillering, small leaves, and short plants. Grain number is reduced. The visual symptoms of N deficiency can be confused with those of S deficiency, but S deficiency is less common and tends to first affect younger leaves or all leaves on the plant.

Deficiency Symptom Photos

Refer to photo captions below:

(a) Leaves are yellowish green in the plot, where N fertilizer is not applied.

(b) Leaves of N-deficient plants are light green, narrow, and smaller.
(c) Tillering is reduced where N is deficient.
(d) Tillering is greater where N fertilizer has been applied.



(Fairhurst and Witt, 2002)

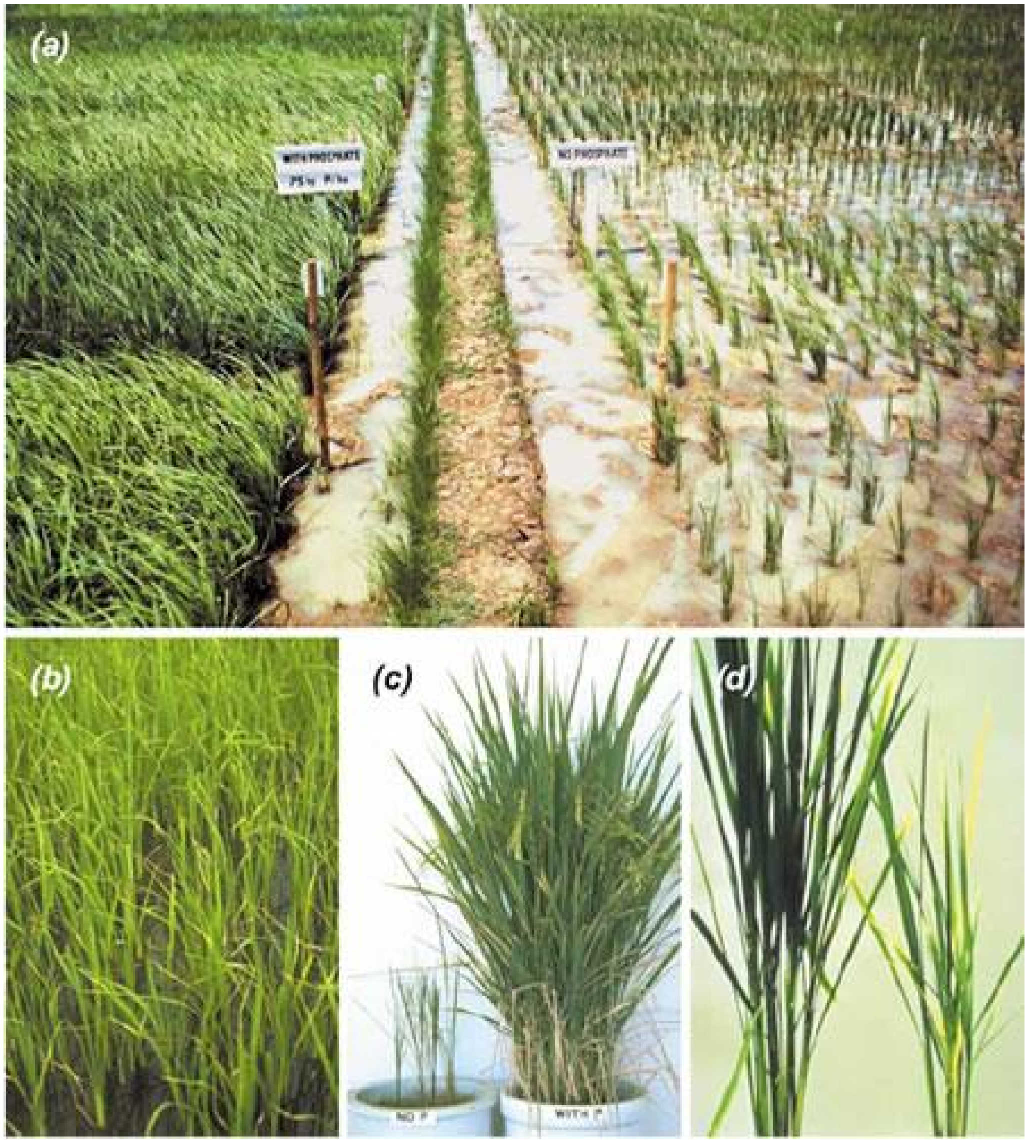
P Deficiency Symptoms

Stunted dark green plants with erect leaves and reduced tillering.

P-deficient plants are stunted with greatly reduced tillering. Leaves are narrow, short, very erect, and “dirty” dark green. Stems are thin and spindly and plant development is retarded. The number of leaves, panicles, and grains per panicle is also reduced. Young leaves appear to be healthy but older leaves turn brown and die. Maturity is delayed (often by 1 week or more). When P deficiency is severe, plants may not flower at all. Red and purple colors may develop in leaves if the variety has a tendency to produce anthocyanin. Leaves appear pale green when P and N deficiency occur simultaneously. Moderate P deficiency is difficult to recognize in the field. P deficiency is often associated with other nutrient disorders such as Fe toxicity at low pH, Zn deficiency, Fe deficiency, and salinity in alkaline soils.

Deficiency Symptom Photos

Please refer to photo captions below:
(a) Tillering is reduced where P is deficient.
(b) Even under less pronounced P deficiency, stems are thin and spindly and plant development is retarded.
(c), (d) Plants are stunted, small, and erect compared with normal plants.



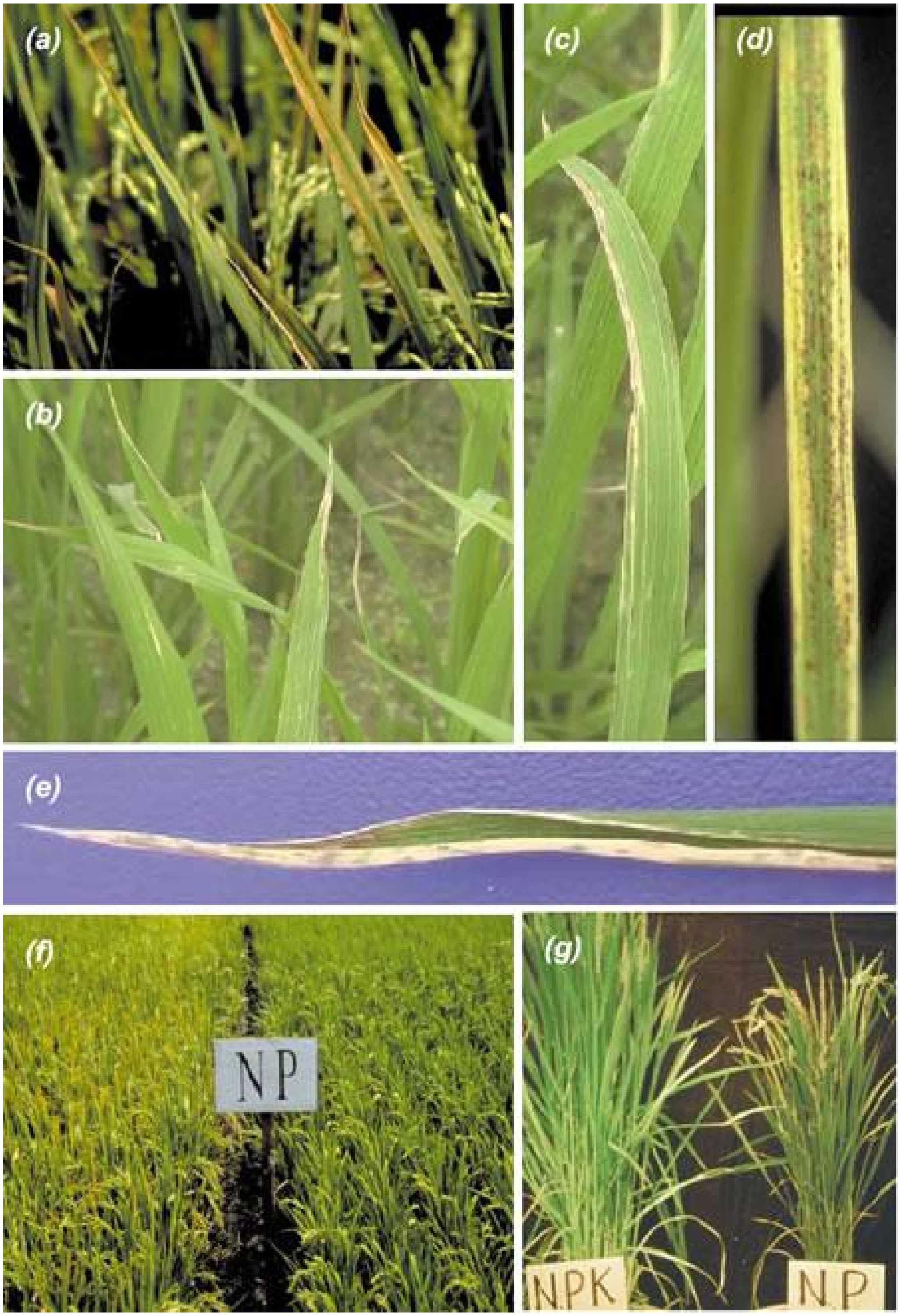
(Fairhurst and Witt, 2002)

K Deficiency Symptoms

Dark green plants have yellowish brown leaf margins or dark brown necrotic spots first appear on the tips of older leaves.

Under severe K deficiency, leaf tips are yellowish brown. Symptoms appear first on older leaves, then along the leaf edge, and finally on the leaf base. Upper leaves are short, droopy, and "dirty" dark green. Older leaves change from yellow to brown and, if the deficiency is not corrected, discoloration gradually appears on younger leaves. Leaf tips and margins may dry up. Yellow stripes may appear along leaf interveins and lower leaves become droopy. Leaf symptoms of K deficiency (particularly the appearance of yellowish brown leaf margins) are similar to those of tungro virus disease. Unlike K deficiency, however, tungro occurs as patches within a field, affecting single hills rather than the whole field. When K deficiency is severe, rusty brown spots appear on the tips of older leaves and later spread over the whole leaf, which then turns brown and becomes desiccated. Irregular necrotic spots may also occur on panicles.

Deficiency Symptom Photos
Please refer to photo captions below:
(a), (b), (c) Leaf tips and margins become yellowish brown and dry up under K deficiency.
(d) Plants are more susceptible to pests and diseases, and secondary infections are common.
(e) Leaf rolling may occur.
(f) Hybrid rice produces more biomass and therefore has a greater K requirement than inbred rice so that K-deficiency symptoms may occur earlier in hybrid (left) than inbred rice (right).
(g) Plant growth is restricted in the absence of K.



(Fairhurst and Witt, 2002)

Implementing Site Specific Management of N, P, and K

Overview

Once you have determined that implementing site-specific nutrient management (SSNM) will be beneficial to farmers in a particular area, you should follow 3 main steps to carry out a successful extension campaign.

Step 1: Select an economic yield target. This is essential to determining the required application rates of N, P, and K nutrients. Only if you know what yield increase you are targeting can you determine appropriate nutrient application rates.

Step 2: Estimate soil nutrient supplies using nutrient omission plots. Only if you know what nutrients are deficient, as evidenced by grain yield, can you determine appropriate nutrient application rates. Application rates will be calculated by subtracting the yield attained in nutrient deficient plots from the target yield for a crop identified in step 1.

Step 3: Manage N, P, and K nutrient inputs based on fertilizer rates calculated from data gathered in steps 1 and 2.

Step 1 - Select a Yield Target

Selecting a yield target for a crop is essential to determining the required application rates of N, P, and K nutrients. Only if you know what yield increase you are targeting can you determine appropriate nutrient application rates. Select an economic yield target based on the following criteria:

- As a general rule, select a yield target that is based on the average yield of the past 3–5 crops (same season) plus 10–20% to achieve a visible yield increase, unless the primary goal is to avoid fertilizer overuse at current yield levels.

- Select a yield target of not more than 75–80% of the potential yield determined at experimental stations. If such information is not available, use the highest yields reported from farmers' fields. Yield targets that are too close to the potential yield may require excessive amounts of fertilizer inputs and increase the risks of crop failure and profit losses.

- Select a higher yield target in the high-yielding season (favorable climatic conditions) and a moderate yield target in lower-yielding seasons (less favorable climatic conditions and greater risks of crop failure because of lodging or pests and diseases).

Step 2 - Estimate Soil Nutrient Supplies

What are Omission Plots?

Omission plots visually demonstrate to farmers the nutrient deficits in their fields. The required rate of P or K fertilizer can be calculated from the deficit in yield between the respective omission plot and a fully fertilized area with no nutrient limitation. The use of omission plots consequently helps ensure that P and K are applied in the ratio required by the rice crop.


Nutrient Omission Plot

Farmers establish small omission plots embedded within their fields. In P omission plots, no P fertilizer is applied, but other nutrients are adequately supplied. Similarly, in K omission plots, no K fertilizer is applied, but other nutrients are adequately supplied. The supply of soil nutrients can be estimated from yield in omission plots because the deficient nutrient that is not supplemented with fertilizer limits plant growth and yield.

Why Establish Omission Plots?

Only if you know what nutrients are deficient, as evidenced by grain yield, can you determine appropriate nutrient application rates. Application rates will be calculated by subtracting the yield attained in nutrient deficient plots from the target yield for a crop identified in step 1.

How to Establish Omission Plots

Use grain yield in nutrient omission plots (under favorable weather conditions and good growing conditions) as an indicator of the potential soil supply of N, P, and K in a cropping season. Use good-quality seeds and follow proper crop management, including water and pest control.

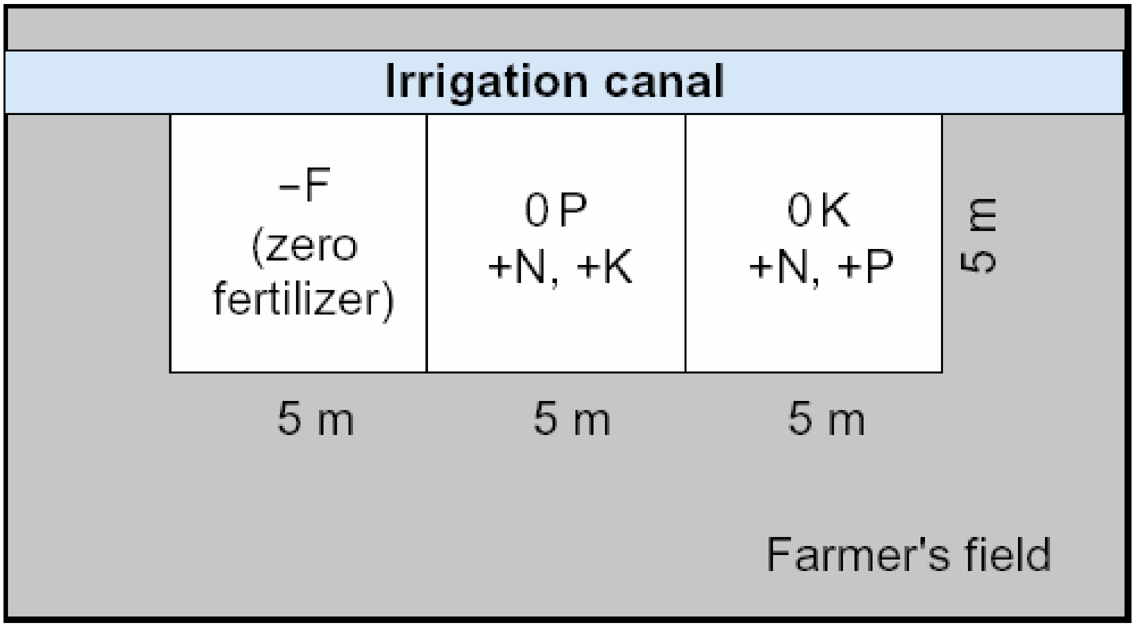
1. Select 10–20 representative farmers' fields for a recommendation domain and establish a 15 x 5-m plot in each farmer's field. Divide the plot into three 5 x 5-m omission plots. Construct bunds 25 cm wide and 25 cm high to prevent nutrient movement between plots (see photos below):

   a. *-F Plot: Measuring N Supply*
      The N-limited yield is measured in a minus-fertilizer plot (-F) that should not receive any fertilizer N, P, or K. Install bunds to prevent cross-plot contamination when the farmer applies fertilizer N to other parts of the field during the season.

   b. *0 P Plot: Measuring P Supply*
      The P-limited yield is measured in a zero-P omission plot. The plot receives fertilizer N and K, but no fertilizer P. Apply sufficiently large amounts of fertilizer N and K to reach the yield target for the recommendation domain. Avoid lodging by following a proper splitting pattern for fertilizer N using the LCC.

   c. *0 K Plot: Measuring K Supply*

The K-limited yield is measured in a zero-K omission plot. The plot receives fertilizer N and P, but no fertilizer K. Apply sufficiently large amounts of fertilizer N and P to reach the yield target for the recommendation domain. Avoid lodging by following a proper splitting pattern for fertilizer N using the LCC.



Design of a set of omission plots in a farmer's field. The -F plot receives no fertilizer, while the 0 P plot receives fertilizer N and K and the 0 K plot receives fertilizer N and P.

Apply sufficient Zn and other micronutrients to all omission plots if deficiencies of these nutrients commonly occur.

2. At crop maturity, measure grain yield from a central 2 m x 2.5-m area in each omission plot. Cut all panicles and place them on a plastic sheet to prevent yield loss. Strip all spikelets carefully, remove unfilled spikelets, and spread the grain on the plastic sheet. Dry the grain in full sunlight for one whole day to reach grain moisture content of about 12–16%. It may take 2–3 days to sun-dry the grain fully in a rainy season. Express grain yield (GY) in t/ha.

3. Average the yield estimates obtained from the 10–20 farmers' fields for each omission plot type to obtain the average N-limited yield (yield in -F plots), the average P-limited yield (yield in 0 P plots), and the average K-limited yield (yield in 0 K plots) for the recommendation domain.

4. If yield measurements in the omission plots indicate large differences in soil nutrient supply within particular areas of your recommendation domain, consider dividing the domain into two or more areas. As a rule of thumb, the average yield in omission plots should differ consistently by at least 1 t/ha to justify two separate domains.

For a photographic description of this process, view the captions and photos below:

(a) Install omission plots (5 x 5-m size) at the long side of the field, not in a corner.
(b) Construct bunds of 25-cm height to avoid fertilizer contamination.
(c) Double bunds effectively reduce fertilizer contamination and bunds need to be well maintained throughout the season.
(d) Irrigation is ideally performed for individual plots, avoiding water running through all plots, which may cause fertilizer contamination.
(e) A well-established -F plot in a farmer's field at midseason.
(f) Sufficient and well-timed fertilizer N topdressing using the leaf color chart is important in 0 P and 0 K plots to make sure that N is not limiting growth.
(g) Excellent omission plot with a pronounced difference in growth when compared with the adjoining farmer's field.
(h) At full maturity, harvest all plants from a central 5-m2 area and avoid plants from border rows. Carefully remove all grain from the spikelets, then dry and weigh the grain.

(Fairhurst and Witt, 2002)

NOTES:

- It is essential to adopt a proper N management strategy for 0 P and 0 K plots, as the P and K uptake of rice is affected strongly by the management of N, the most commonly limiting nutrient. Fertilizer N rates should be sufficiently high to reach about 75–80% of the yield potential, and timing and splitting of fertilizer N should be optimal (Step 3). Do not follow the current farmers' N management practice in 0 P and 0 K plots!

- Depending on yield and season, apply at least 30–45 kg P_2O_5 per ha in 0 K plots and 50–100 kg K_2O per ha in 0 P plots.

- The use of GY as an indicator of potential nutrient supply is only valid if measured in a season with favorable climatic conditions and proper crop management. Yield should not be limited by other factors such as the supply of other nutrients, water supply, and pests and diseases. Do not use data if yield losses from lodging, rats, pests, etc., were large.

- Nutrient supply measured as GY is smaller in wet broadcast-seeded rice than in transplanted rice because plant-based measures of indigenous nutrient supply are also affected by variety and crop establishment method. It is therefore important to measure the soil nutrient supply in farmers' fields using the farmers' crop establishment methods.

- If the current farmers' practice includes the application of organic fertilizers such as farmyard manure in addition to inorganic fertilizer, apply the same amount of organic fertilizer in each omission plot.

Step 3 - Manage NP&K

Overview

Once you have selected a yield target (Step 1) and estimated soil nutrient supply (Step 2), you can begin to manage N, P and K nutrient inputs. The management of N uses visual indicators of deficiency, while the management of P and K primarily involves preventing deficiency in the soil rather than treating observable deficiency symptoms in the crop.

Nitrogen (N)

Overview

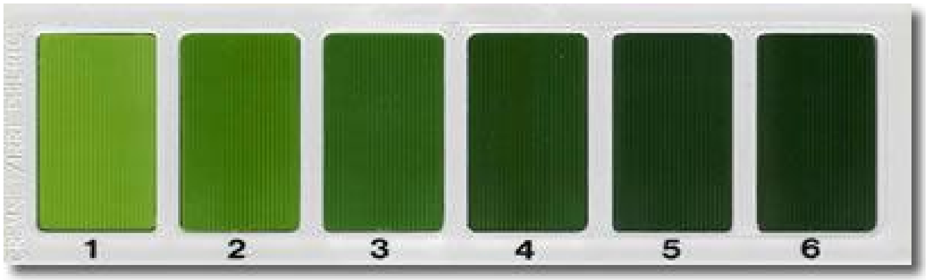
Two complementary approaches - the leaf color chart (LCC) and the fixed-splitting pattern approach - have been used successfully in farmers' fields to manage fertilizer N efficiently. We recommend testing both strategies side by side using participatory approaches in farmers' fields to evaluate their performance before wider-scale dissemination. Consider socioeconomic factors when developing fertilizer N management strategies (labor availability and cost, prices of rice and fertilizer, available fertilizer sources, current application practices).

Leaf Color Chart (LCC)

What is the LCC?

Farmers often use leaf color during the cropping season as a visual indicator of the rice crop's nitrogen status and to determine the need for fertilizer N application. The leaf color chart (LCC) is an easy-to-use and inexpensive diagnostic toll to monitor plant N status during the season and as a decision aid to plan fertilizer N topdressings. A predetermined amount of fertilizer N is applied when the color of rice leaves falls below a critical LCC threshold that indicates N deficiency in the crop. This helps farmers to adjust fertilizer N applications to season-specific climatic conditions that affect crop growth (termed "real-time" N management). Good real-time N management reduces N fertilizer needs, increases N-use efficiency, and reduces the crops' susceptibility to pests and diseases.

The LCC contains six strips of green color from yellowish green (No. 1) to dark green (No .6).



Leaf Color Chart (LCC)

The color of a single leaf is measured by placing the middle part of the leaf in front of the chart and comparing the leaf color with the standard color strip.


Using the LCC to assess leaf N status

When the LCC reading is taken, it is compared to the critical LCC value, which may range from 2 to 4 depending on the rice variety and crop establishment (direct-seeded or transplanted) method. If the value is below the critical value for the rice variety and planting method, a fertilizer N application is required.

How to Use the LCC

1. Start LCC readings from 14 DAT or 21 DAS.
2. The last reading is taken when the crop starts to head.

3. Randomly select at least 10 disease-free rice plants or hills in a field with uniform plant population.
4. Select the topmost fully expanded leaf from each hill or plant.
5. Place the middle part of the leaf on a chart and compare the leaf color with 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.
6. Do not detach or destroy the leaf.
7. Measure the leaf color under the shade of your body, because direct sunlight affects leaf color readings.
8. If possible, the same person should take LCC readings at the same time of the day every time.
9. Repeat the process at 7- to 10-d intervals (see Table below) or at critical growth stages (early tillering, active tillering, panicle initiation, and first flowering) and apply N as needed (see step 10).

Table 1. Intervals of LCC readings by variety

Measurement (Interval/days)	7	10
Measurement period	14-49 (DAT) 21-56 (DAS)	15-65 (DAT) 20-70 (DAS)

10. If more than 5 out of 10 leaves read below a set critical value, apply:
- 23-30 kg N ha-1 for wet season or low-yielding season
- 30-35 kg N ha-1 for dry season or high-yielding season

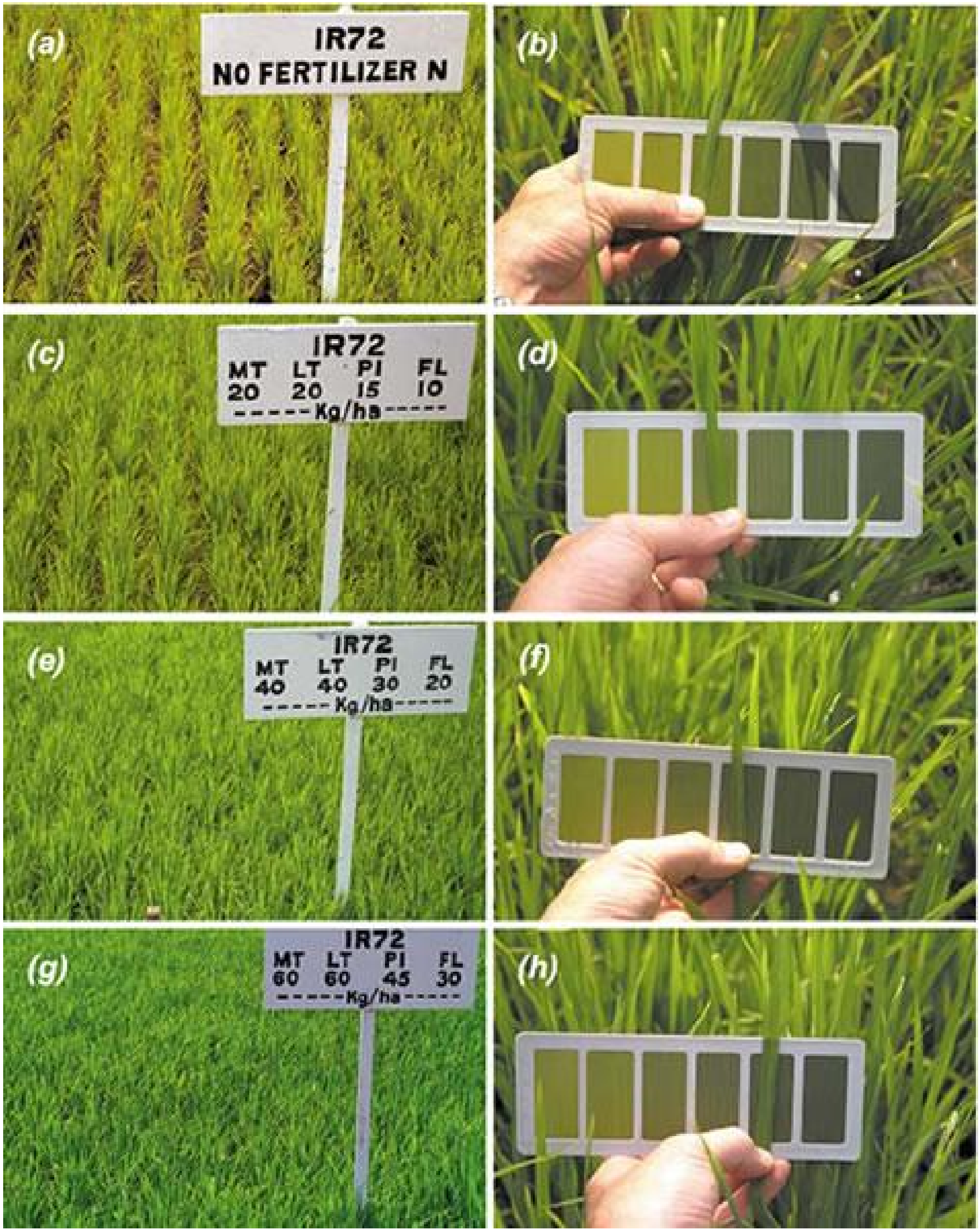
Table 2. Examples of critical LCC values depending on variety and crop establishment method.

Scented or aromatic	-------	2
Semidwarf indica	Direct-seeded	3
Semidwarf indica	Transplanted	3.5-4
Hybrid	Transplanted	3.5-4

NOTE: Local calibration is always required: test different LCC threshold values.

The LCC in Use
Refer to the photo captions below for examples of LCC use:
(a) Plants look N-deficient in this field without fertilizer application.
(b) This was confirmed through an LCC measurement, since the yellowish leaf color matched color panel no. 3.
(c), (d) At low fertilizer N rates, plant appearance is better developed, but the low LCC reading still indicates N deficiency.
(e), (f) Plants look well developed and the canopy is closed at the higher fertilizer rates, while the LCC reading matches panel no. 4, which is the critical LCC value for transplanted rice. Thus, fertilizer would not need to be applied in this plot at this stage.
(g) Plants look very dark at the very high N rate. Leaf color is very dark green and matches the LCC panel no. 5 indicating a surplus of fertilizer N.

(h) Apply fertilizer N only when the leaf color falls below the critical leaf color. In general, it is not recommended to apply more than 50 kg N per ha as a single N application.



(Fairhurst and Witt, 2002)

Calibrating the LCC

Critical LCC values should be calibrated for local conditions.

Guidelines

1. LCC calibration trials can be established at a research farm or in farmers' fields. Select 3–4 of the most common local varieties and compare the performance of the rice crop using different critical LCC values (e.g. 3, 4, and 5). Apply fertilizer N using the LCC as described above. In addition to fertilizer use, also record grain yield and yield components (optional), qualitative scores for insect pest and disease incidence, and the extent of lodging.

2. Choose a factorial design for on-station experiments, for example, three varieties and three critical LCC values as treatments in a randomized complete block design with four replications.

3. Use farms as replicates if you decide to conduct the calibration trials in farmers' fields. Select at least four farmers' fields per variety as replicates and test 2–3 critical LCC values in each field.

4. Include a plot without fertilizer application to calculate the agronomic efficiency (AE, kg grain yield increase per unit fertilizer N applied) for different treatments.

5. The critical LCC values mainly depend on variety and crop establishment method, while the amount of fertilizer N to be applied per split application is season-specific and depends mainly on the expected yield increase as affected by climate.

NOTES:

1. Because the LCC approach is a plant-based N management approach, only an approximate estimate of N-limited yield is required to decide on the need for basal N application in transplanted rice. Elimination of a basal N application may reduce tillering in fields with low soil N-supplying capacity. In general, consider basal N application when yield without fertilizer N (-F plot) is <3 tons/ha.

2. LCC-based N management will be more successful when used as part of an integrated site-specific nutrient management strategy. To obtain an optimum response to N fertilizer, other nutrients (P, K, S, Zn) must not be limiting. Apply P and K as outlined in Steps 4 and 5, and micronutrients (S, Zn) based on soil tests or local recommendations.

3. P deficiency may cause darker leaf color, which leads to misleading LCC readings.

4. Local calibration of the LCC is always required. A simple instruction sheet in the local language should accompany the chart and explain to farmers how to determine the correct timing and amount of N to apply to their rice crops in a particular season (Fairhurst and Witt, 2002).

Applying N Based on LCC Readings

Once you have determined that your LCC readings fall below the critical value for the rice variety and crop establishment method, you can determine the amount of fertilizer N to be applied per split application.

Critical LCC Values
The critical LCC values mainly depend on variety and crop establishment method as indicated in the table below.

Table 3. Examples of critical LCC values depending on variety and crop establishment method.

Scented or aromatic	-------	2
Semidwarf indica	Direct-seeded	3
Semidwarf indica	Transplanted	3.5-4
Hybrid	Transplanted	3.5-4

Fertilizer N Rates
The amount of fertilizer N to be applied per split application is season-specific and depends mainly on the expected yield increase as affected by climate. General guidelines are as follows:

Table 4. Proposed amounts of fertilizer N to be applied to semidwarf indica varieties each time leaf color falls below the critical LCC value.

1-2	25
2-3	30
3-4	35

Fixed-Splitting Pattern Approach

What is a Fixed-Splitting Approach?

The splitting pattern approach provides a recommendation for the total N fertilizer requirement (kg/ha) and a plan for the splitting and timing of applications in accordance with crop growth stage, cropping season, variety used, and crop establishment method. The leaf color chart (LCC) can be used to adjust individual topdressings.

Applying N Based on a Fixed-Splitting Approach

Estimate the required total amount of fertilizer N and develop a splitting pattern. Use the leaf color chart (LCC) at critical growth stages to adjust predetermined fertilizer N rates.

1) Estimating Required Fertilizer N
Use Table 5 to derive the total fertilizer N rate based on

- the yield target (Step 1 of implemeting SSNM); and
- the estimate of N-limited yield in -F plots (Step 2 of implementing SSNM).

Table 6. Fertilizer N rates according to yield target and N-limited yield in -F plots.

Yield target (t/ha)	4	5	6	7	8
Yield in -F plot (t/ha)	Fertilizer N rate (kg/ha)				
2	80	120	160	◂	◂
3	40	80	120	160	◂
4		40	80	120	160
5			40	80	120
6				40	80

◂ indicates unrealistic yield targets.

(Fairhurst and Witt, 2002)

In order to avoid the risk of crop failure caused by lodging or pests and diseases from excessive N fertilizer use, the maximum estimated yield increase over the yield in -F plots is 4 tons/ha. A reduction in the yield target is suggested for cases in which a yield increase of >4 t/ha over the yield in the -F plot is estimated.

As a general rule: Apply 40 kg fertilizer N per ha for each ton of grain yield increase required (difference between target yield and yield in -F plot).

2) Determining Splitting Patterns

Use the following tables to draw up splitting patterns for fertilizer N for the recommendation domain. The suggested splitting patterns cover most common rice-cropping systems, but further adaptation to local conditions with farmer participation may be required. Growth stages, including approximate ranges for application dates (DAT or DAS), are given, but the actual application date depends on variety (crop duration) and plant N status in the field. Use the LCC to arrive at the best application date and to vary the amount of N topdressings within the season based on the actual crop performance.

Transplanted rice (inbred variety)

With 20–40 hills/m2, high-yielding conventional variety, continuous flooding. Transplanted rice has slower leaf area development, dry matter accumulation, and N uptake during early growth, but high growth rates and N uptake after midtillering to grain filling.

Table 6. Suggested fertilizer N splitting for transplanted inbred rice.

Timing	Total fertilizer rate (kg/ha)				
	DAT	40	80	120	160
Basal (preplant)			[a]	[a]	20
Early tillering	14–20	20	25	35	35
Midtillering	20–35		25	40 ± 10	45 ± 10
Panicle initiation	40–50	20	30	45 ± 10	50 ± 10
Heading to 1st flowering	55–65				(15–20)
Range of fertilizer N[b]		40	80	100–140	130–170

[a] If yield without fertilizer N is <3 t/ha, apply about 20 kg N per ha as basal before transplanting and reduce subsequent topdressings accordingly.
[b] Excluding optional N.

(Fairhurst and Witt, 2002)

Transplanted rice (hybrid)
With 20–30 hills/m2, hybrid rice, continuous flooding or intermittent irrigation, favorable climatic season with high yield potential, for example, the dry season. Transplanted hybrid rice requires more N during early crop growth to enhance tillering but also responds well to late N application.

Table 7. Suggested fertilizer N splitting for wet-seeded inbred rice.

Timing	Total fertilizer rate (kg/ha)				
	DAT	40	80	120	160
Basal (preplant)				30–40	40–50
Early tillering to midtillering	15–25	Not likely for hybrid rice		30 ± 10	45 ± 10
Panicle initiation	35–45			40 ± 10	55 ± 10
Heading to 1st flowering	50–60			(15–20)	(15–20)
Range of fertilizer N[a]				100–140	140–180

[a] Excluding optional N.

(Fairhurst and Witt, 2002)

Wet-seeded rice
With 100–150 kg seed per ha, broadcast, high-yielding conventional variety, continuous flooding after crop emergence. Broadcast wet-seeded rice has more rapid leaf area development, dry matter accumulation, and N uptake during early growth, but a slower growth rate and N uptake after panicle initiation, particularly during grain filling. Direct-seeded rice needs little or no late N application.

Table 8. Suggested fertilizer N splitting for wet-seeded inbred rice

Timing	Total fertilizer rate (kg/ha)				
	DAS	40	80	120	160
Early tillering	10–20	20	20–25	20–30	30–35
Midtillering	25–35	20	25	35 ± 10	45 ± 10
Panicle initiation	40–50		30	45 ± 10	50 ± 10
Heading to 1st flowering	55–65				(15–20)
Range of fertilizer N[a]		40	80	100–140	130–170

[a] Excluding optional N.

(Fairhurst and Witt, 2002)

NOTES:

- Conservative fertilizer N management is required in seasons with expected high pest and disease pressure to avoid risks of crop failure. Apply lower N rates with single topdressings.
- Do not apply N topdressings when heavy rainfall is expected.
- On acid-sulfate soils, drain the field to remove the floodwater before applying topdressed N, and then reirrigate.

Phosphorous (P)

Overview

The major objective of P management is to prevent P deficiency rather than treat P-deficiency symptoms. If low soil P supply is the reason the targeted yields are not achieved, management must focus on the buildup and maintenance of adequate soil-available P levels to ensure that P supply does not limit crop growth and N-use efficiency.

P is not easily lost from the system, but inputs from sources such as irrigation water and straw are generally small. P fertilizer application has residual effects that can last several years, and maintenance of soil P supply requires long-term strategies tailored to site-specific conditions that consider P inputs from all sources.

Sustainable P management may require the application of fertilizer P, even if a direct yield response to P application is not expected. In some soils, the indigenous P supply would decline after only for a few seasons if fertilizer P was not applied. A suitable maintenance strategy would then have to balance the nutrient removal with grain and straw to replenish the soil P reserves.

Applying P Based on Omission Plot Yields and Yield Target

General Rule: Where the soil P supply is small, apply 20 kg fertilizer P_2O_5 per ha for each ton of target grain yield increase (difference between yield target and yield in 0 P plot).

The maintenance fertilizer P rates given in the table below are designed to replenish the P removed with grain and straw, assuming a low to moderate return of crop residues. Look up the fertilizer P_2O_5 rate based on:

- the yield target (Step 1 of implementing SSNM) and
- an estimate of soil P supply measured as yield in a 0 P omission plot (Step 2 of implementing SSNM).

Table 9. Maintenance fertilizer P_2O_5 rates according to yield targets and P- limited yield in 0 P plots

Yield target (t/ha)	4	5	6	7	8
Yield in 0 P plot (t/ha)	Fertilizer P_2O_5 rate (kg/ha)				
3	20	40	60	◂	◂
4	15	25	40	60	◂
5	0	20	30	40	60
6	0	0	25	35	45
7	0	0	0	30	40
8	0	0	0	0	35

◂ indicates unrealistic yield targets.

(Fairhurst and Witt, 2002)

Theoretically, fertilizer P application would not be required if a yield response were not expected for the selected yield target (i.e., if yield target = yield in nutrient omission plot). This "zero-P fertilizer" strategy results in mining the soil of P reserves and may affect yields in the medium to long term, especially if other nutrient sources such as straw or manure are not applied.

NOTES:

- In order to avoide excessive P fertilizer use, arising from overly optimistic yield targets, the maximum yield increase over yield in the O P plot is 3 tons/ha (Table 9). A reduction in the yield target is suggested for cases where a yield increase of more than 3 t/ha over the yield in the 0 P plot is required.

- To prevent mining of soil P reserves, the following rules of thumb can also be applied:

    - If most of the straw is retained in the field (e.g., after combine harvest or harvest of panicles only) and the nutrient input from manure is small, apply at least 4 kg P_2O_5 per ha for each t grain harvested (e.g., 20 kg P_2O_5 for a yield of 5 t/ha) to replenish P removed with grain.

    - If most of the straw is removed from the field and nutrient input from other sources (manure, water, sediment) is small, apply at least 6 kg P_2O_5 per ha for each t grain harvested (e.g., 30 kg P_2O_5 for a yield of 5 t/ha) to replenish P removed with grain and straw.

- Maintenance fertilizer P rates can be reduced if
    - soils receive organic amendments such as farmyard manure. Organic material can contribute substantially to the buildup and maintenance of

soil P reserves depending on nutrient concentration and amount applied. Apply organic amendments in nutrient omission plots to assess the combined nutrient-supplying capacity of soil and applied organic materials.
    - soils are periodically flooded with substantial nutrient inputs from sedimentation (e.g., Mekong Delta in Vietnam).

- P applied to either rice or wheat has a residual effect on the succeeding crop, but direct application to each crop is more efficient. Phosphorus fertilizers should be incorporated in the soil before seeding or transplanting.

- Fertilizer P application is not recommended if yield in a 0 P plot with favorable conditions is greater than the yield target.

- It may be necessary to reassess the soil P supply after 8–10 cropping cycles.

Potassium (K)

Overview

The general strategy for K management follows the same principles given for P, but the K uptake requirement of rice is much greater than for P. Furthermore, >80% of K taken up by rice remains in the straw after harvest, making straw an important input source to consider when calculating fertilizer K requirements.

Sustainable K management may require the application of fertilizer K, even if a direct yield response to K application is not expected. In some soils, the indigenous K supply would decline after only a few seasons if fertilizer K was not applied. A suitable maintenance strategy would then have to balance the nutrient removal with grain and straw to replenish the soil K reserves.

Applying K

General rule: Where the soil K supply is small, apply 30 kg fertilizer K_2O per ha for each ton of target grain yield increase (difference between yield target and yield in 0 K plot).

The maintenance fertilizer K rates given in Table 11 are designed to replenish the K removed with grain and straw by considering the amount of straw returned to the field from the previous crop.

Look up the required fertilizer K_2O rate in Table 11 based on

- the yield target (Step 1 of implementing SSNM),
- the estimate of soil K supply measured as yield in a 0 K omission plot (Step 2 of implementing SSNM), and
- the amount of K recycled with straw yield and the straw management level in the previous season (Table 10).

Substantial mining of soil K reserves may affect yields in the medium to long term, especially if most straw is removed.

Table 10. Input of K with recycled straw according to yield and straw management practices in the previous season.

Straw management	Previous season	
	Low-yielding season 4–5 t/ha	High-yielding season 6–8 t/ha
Surface cut and full straw removal <10% straw remaining as stubble: *India, Nepal, Bangladesh, N. Vietnam*	Straw K input: **Low** (0–1 t straw recycled)	Straw K input: **Low** (0–1 t straw recycled)
Low cut Short stubble (25–30 cm) in the field, no burning of the whole field: *Philippines*	Straw K input: **Medium** (2–3 t straw recycled)	Straw K input: **Medium to High** (3–5 t straw recycled)
High cut Long stubble (>30 cm) in the field, no burning of the whole field: *Philippines, Indonesia*	Straw K input: **Medium to High** (3–4 t straw recycled)	Straw K input: **High** (5–7 t straw recycled)
Combine harvest with high cut Long stubble plus threshed straw in windrows in the field, burning of the whole field: *Thailand, S. Vietnam, northern India*	Straw K input: **High** (4–5 t straw recycled, but 20–25% P and K losses because of burning (P) and leaching of K	Straw K input: **High** (6–8 t straw recycled, but 20–25% P and K losses because of burning (P) and leaching of K

(Fairhurst and Witt, 2002)

Table 11. Maintenance fertilizer K_2O rates according to yield target and K-limited yield in 0 K plots.

	Yield target (t/ha)	4	5	6	7	8
Rice straw inputs	Yield in 0 K plot (t/ha)	Fertilizer K_2O rate (kg/ha)				
Low (<1 t/ha)	3	45	75	105	◄	◄
	4	30	60	90	120	◄
	5		45	75	105	135
	6			60	90	120
	7				75	105
	8					90
Medium (2–3 t/ha)	3	30	60	90	◄	◄
	4	0	35	65	95	◄
	5		20	50	80	110
	6			35	65	95
	7				50	80
	8					65
High (4–5 t/ha)	3	30	60	90	◄	◄
	4	0	30	60	90	◄
	5		0	30	60	90
	6			10	35	70
	7				25	55
	8					40

◄ indicates unrealistic yield targets.

(Fairhurst and Witt, 2002)

NOTES:

- In order to avoid excessive K fertilizer use arising from overly optimistic yield targets, the maximum estimated increase over yield in the 0 K plot is 3 tons/ha (Table 11). A reduction in the target yield is suggested for cases where a yield increase of >3 t/ha over the yield in the 0 K plot would be required.

- In the short term, fertilizer K application would not theoretically be required if a yield response is not expected for the selected yield target (i.e., if yield target = yield in 0 K plot). This strategy results in mining of soil K reserves and may affect yields in the medium to long term, especially if other nutrient sources such as straw or manure are not applied.

- To prevent mining of soil K reserves, the following general rules can also be applied:

  - If most of the straw is retained in the field (e.g., after combine harvest or harvest of panicles only) and the nutrient input from manure is small, apply at least 3.5 kg K_2O per ha for each t grain harvested (e.g., 17.5 kg K_2O for a yield of 5 t/ha) to replenish K removed with grain.

  - If most of the straw is removed from the field and nutrient input from other sources (manure, water, sediment) is small, apply at least 12 kg K_2O per ha for each t grain harvested (e.g., 60 kg K_2O for a yield of 5 t/ha) to replenish K removed with grain and straw.

- The maintenance fertilizer K rates given in Table 12 can be reduced if:
  - soils receive organic amendments such as farmyard manure. Organic material can contribute substantially to the buildup and maintenance of soil K reserves depending on nutrient concentration and amount applied. Apply organic amendments in nutrient omission plots to assess the combined nutrient-supplying capacity of soil and applied organic materials; or
  - soils are periodically flooded with substantial nutrient inputs from sedimentation (e.g., Mekong Delta in Vietnam).

- When the total amount of K fertilizer to be appl8ied is small, it can all be applied at seeding or transplanting. For larger applications (40–120 kg K_2O per ha), apply in two splits (50% as basal application before crop establishment or within the first 2 wk after crop establishment and 50% at panicle initiation, PI). With large applications (>120 kg K_2O per ha), apply in three splits (1/3 basal, 1/3 at PI, and 1/3 at heading to first flowering).

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