A manual for the development and participatory evaluation of Site-Specific Nutrient Management for Maize in tropical, favorable environments

Introduction

Maize is the second most important cereal crop after rice in Asia. It is the substitute staple for people in the rural areas and mountainous regions and an important source of income for many Asian farmers. In 2004, the International Plant Nutrition Institute (IPNI) and its partners in Southeast Asia launched a regional initiative to increase the productivity and profitability of maize farming through improved crop and nutrient management (Witt and Pasuquin 2007). In 2004-2007, a series of researcher-managed on-farm and on-station experiments were conducted at 19 sites in Indonesia, Vietnam, and the Philippines covering a wide range of bio-physical and socio-economic conditions. Results showed that with good crop management, site-specific nutrient management (SSNM) significantly increased yield by on average 2 t/ha compared with the farmers' fertilizer practice (FFP). The SSNM concept has been simplified and is now ready for wider-scale, participatory evaluation in partnership with farmers.

This manual was written with the goal of providing technical guidance to agricultural practitioners who would like to:

- Communicate SSNM and its principles.
- Develop fertilizer recommendations based on the principles of SSNM.
- Evaluate recommendations with farmers in a participatory fashion.

As such, the manual is arranged into three major sections for easy reference:

- Section 1 gives an overview of the principles of SSNM including yield gap analysis, definition of terminology used in SSNM, and generic guidelines for the development of nutrient recommendations.
- Section 2 provides the practitioner with the opportunity to adapt the generic SSNM guidelines and integrate expert knowledge of local best management practices into a regional protocol for developing site-specific recommendations.
- Section 3 guides the practitioner in the participatory evaluation and wider-scale delivery of SSNM.

Technical details on the following are provided in the Appendix:

Appendix A: Basic SSNM guidelines in developing a fertilizer recommendation

Appendix B: Best Management Practices for Maize

Appendix C: Guidelines for participatory evaluation of SSNM in maize

Appendix D: Example for a one-page summary of guidelines for implementing SSNM for rice in Indonesia

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1. An overview of site-specific nutrient management (SSNM)

This section will provide you with

- An understanding of the principles of SSNM
- An understanding of yield gaps
- A common terminology to communicate SSNM
- A strategy to develop fertilizer recommendation based on the principles of SSNM

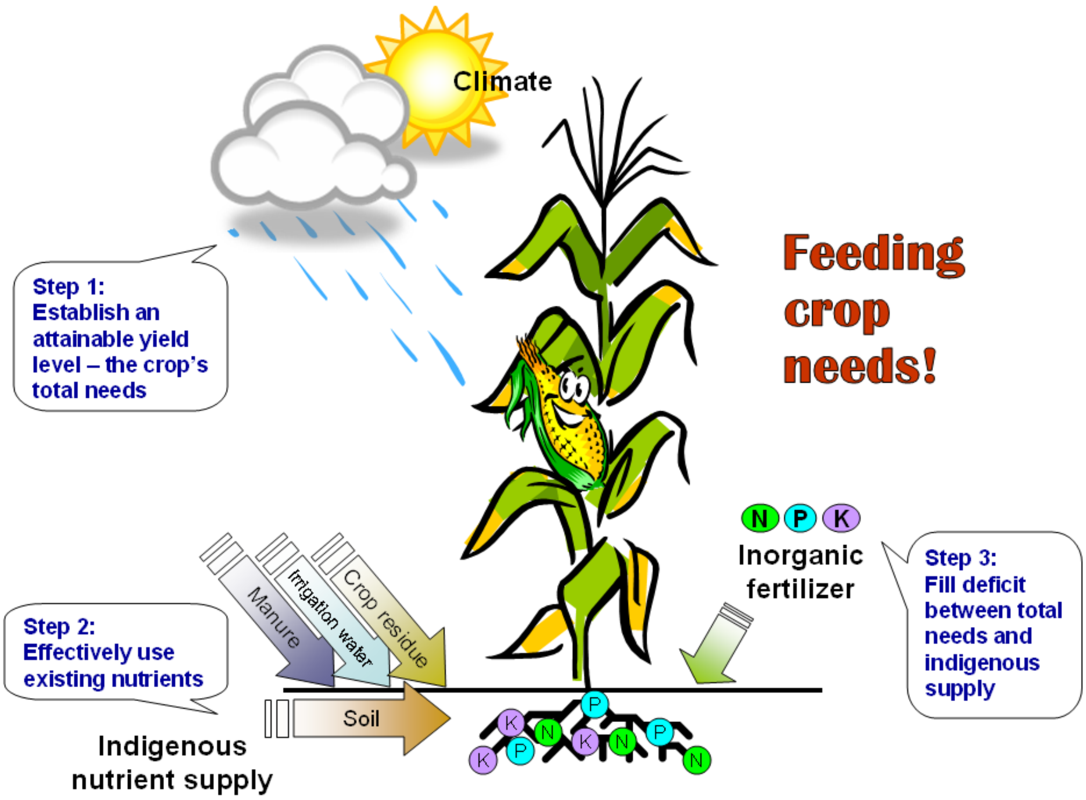
1.1. The principles of SSNM

The principles of site-specific nutrient management (SSNM) are generic and applicable to other crops. In the presentation below we apply the most recently published principles of SSNM developed for rice (Buresh and Witt 2007; IRRI 2007) to maize in Asia.

SSNM provides an approach for "feeding" crops with nutrients as and when needed. This approach advocates:

- optimal use of existing indigenous nutrient sources, including crop residues and manures, and
- timely application of fertilizers at optimal rates to meet the deficit between the nutrient needs of a high-yielding crop and the indigenous nutrient supply

The SSNM approach is illustrated below in three basic steps:



Step 1: Establish an attainable yield level

Maize yields are location and season specific — depending upon climate, variety, and crop management. The attainable yield for a given location and season is estimated from farmers' fields where good crop management was practiced and nutrients were not limiting yield. The amount of nutrients taken up by a maize crop is directly related to yield. The attainable yield level therefore indicates the total amount of nutrients that must be taken up by the crop.

Step 2: Effectively use existing nutrients

The SSNM approach promotes the optimal use of existing (indigenous) nutrients coming from the soil, organic amendments, crop residue, manure, and irrigation water. The uptake of a nutrient from indigenous sources can be estimated from the nutrient-limited yield, which is the grain yield for a crop not fertilized with the nutrient of interest but fertilized with other nutrients to ensure they do not limit yield.

Step 3: Apply fertilizer to fill the deficit between crop needs and indigenous supply

Fertilizer N, P, and K are applied to supplement the nutrients from indigenous sources and achieve the yield target (= attainable yield). The quantity of required fertilizer is determined by the deficit between the crop's total needs for nutrients — as determined by the attainable yield level — and the supply of these nutrients from indigenous sources — as determined by the nutrient-limited yield.

1.2. Yield gaps

Yield and profit of maize farmers could be increased in a sustainable and environmentally-sound fashion if we have a better understanding of yield gaps. To isolate the most important constraints to achieving optimal yield and profit, yield gaps are analyzed stepwise by estimating the yield potential, the attainable yield, and the actual yield (Fig. 1).

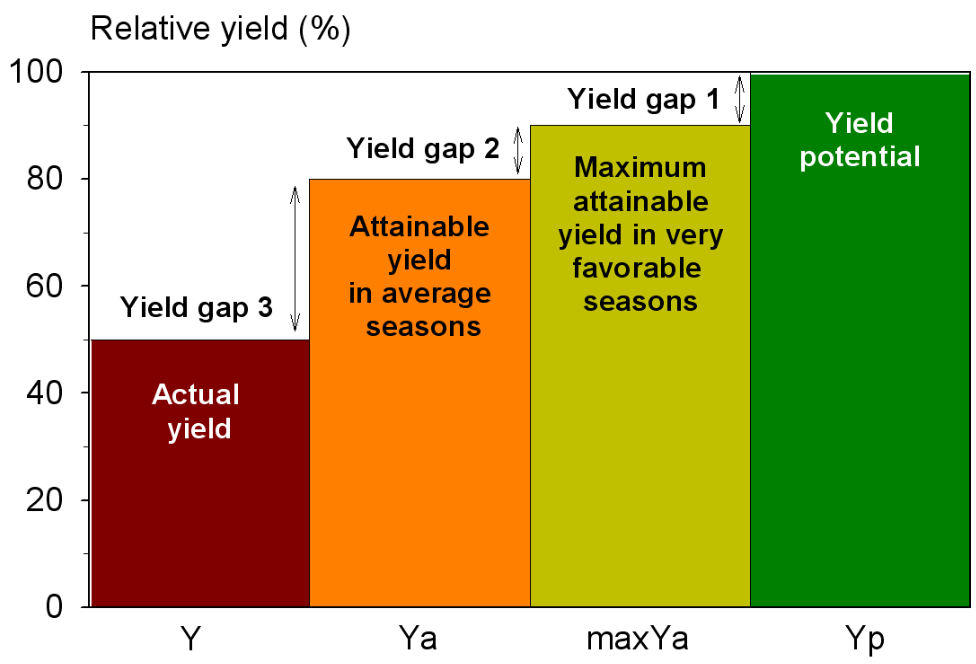


Fig. 1. Example for the effect of nutrient and crop management on actual yield (Y), attainable yield (Ya), and maximum attainable yield (maxYa) in relation to the yield potential (Yp).

The yield potential (Yp) is the theoretical maximum yield of a maize crop in any given season determined solely by climate and germplasm. Water and nutrients are at optimal levels and yield-reducing factors such as pests and diseases are absent. Yp is commonly estimated using plant growth models and could fluctuate from year to year (±10%) because of climate.

The attainable yield (Ya) is defined as the yield achieved in farmers' fields with best management practices including water, pest, and general crop management where nutrients are not limiting. The attainable yield varies – like the yield potential – from season to season and year to year depending on climate. The optimal economic yield is often linked to the attainable yield. The maximum attainable yield (maxYa) in any given season could be close to the yield potential, if management is excellent and weather conditions are very favorable.

The actual yield (Y) in farmers' fields is often lower than the attainable yield due to constraints like water availability, pests and diseases, and poor crop and nutrient management practices.

Actual, attainable, and potential yield can be used to identify exploitable yield gaps (Fig. 1). A management objective of farmers should be to minimize yield gap 3, the difference between attainable and actual yield (Ya-Y). To narrow this yield gap, farmers need to evaluate promising new technologies (e.g., planting density, nutrient management) that offer improvements in yield and/or productivity against current practices. Larger yield increases can be achieved when several constraints (e.g. pests and disease problems and inappropriate nutrient management) are overcome simultaneously.

Yield gap 2 is largely determined by factors that are difficult or impossible to control including the variation in climatic conditions. Best management practices such as the use of a leaf color chart (LCC) for fine tuning N management increase the likelihood of keeping yield gap 2 small.

Yield gap 1 provides important guidance in the identification of constraints. If yield gap 1 is large despite following best management practices, attainable yield must be limited by an unknown constraint. If yield gap 1 is small, there is no further room for yield improvement and efforts might focus on enhancing productivity. It is usually not economical to aim at fully reducing yield gap 1 because of the large amounts of inputs required and the high risk of crop failure and profit losses. This yield gap is smaller in seasons with very favorable weather conditions.

Farmers need to understand the effect of specific practices on productivity and profitability and the synergy achievable when several constraints are overcome simultaneously, for example when pest or disease problems are alleviated through more appropriate nutrient management. Fertilizer recommendations can then be developed based on the attainable yield (= yield target) to achieve high yield and profit while minimizing the risk of crop failure. Recommendations should be sufficiently flexible (N) and robust (PK) to achieve maxYa in exceptionally favorable seasons.

1.3. The SSNM terminology

Table 1. Definition of terminologies

Attainable yield	The average grain yield of maize in farmers' fields with good management practices and without nutrient limitation to yield.
Nutrient-limited yield	The grain yield for a crop not fertilized with the nutrient of interest but with good management and ample supply of all other nutrients from indigenous sources or fertilizer. The nutrient limited yield is an indirect measurement of the soil indigenous nutrient supply.

Indigenous nutrient supply	The amount of a particular nutrient from all sources except mineral fertilizer (i.e., soil, crop residues, irrigation water, manure) available to the crop during a cropping season.
Nutrient omission plot	A plot not fertilized with the nutrient of interest while all other nutrients are applied in sufficient amounts. Used to measure grain yield and plant biomass as an indicator of the effective indigenous nutrient supply.
Yield response (to fertilizer)	Measured by the difference in grain yield from a fully-fertilized plot and a nutrient omission plot. The yield response largely determines the total requirement for fertilizer N, P, and K to meet the crop's nutrient demand for a high yield at maximum economic return.

1.4. The development of fertilizer recommendations with SSNM

Estimating attainable yield and yield responses in farmers' fields

The fertilizer N, P, and K requirements of a maize crop are estimated from the difference between the attainable yield, an indicator of the total amount of nutrients that must be taken up by the crop, and the nutrient-limited yield, an indicator of the supply of nutrients from indigenous sources. This difference, also called the yield response, can be measured with the nutrient omission plot technique. In this technique, four 36m^2 plots with the following treatments are placed in a farmer's field (Fig. 2):

1. Full fertilization: ample fertilizer NPK applied
2. N omission (0-N): No fertilizer N but fertilizer P and K applied
3. P omission (0-P): No fertilizer P but fertilizer N and K applied
4. K omission (0-K): No fertilizer K but fertilizer N and P applied

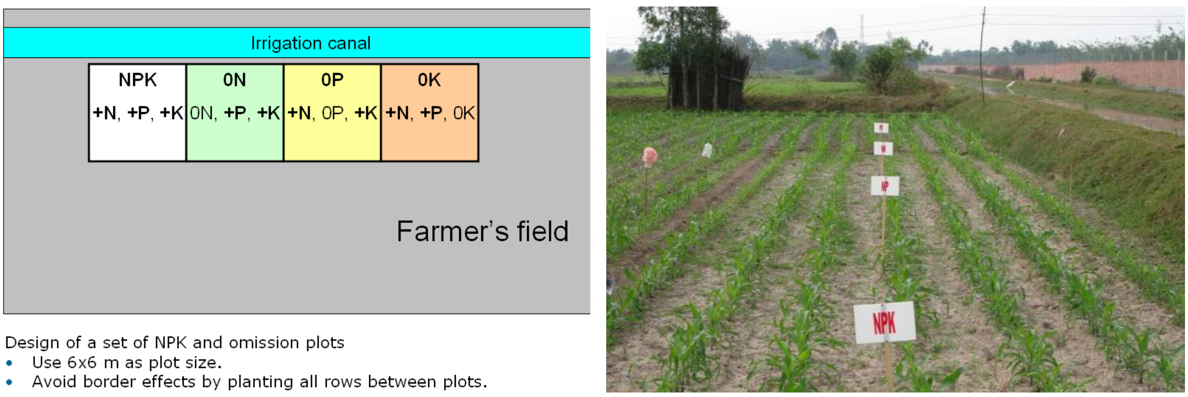


Fig. 2. Field layout to estimate attainable and nutrient limited yield in farmers' fields.

The main objective of these field trails is to avoid nutrient limitation to plant growth, thus special fertilizer recommendation rates and splitting patterns are suggested. In the fully-fertilized plot (NPK), fertilizer N, P, and K are applied at sufficiently high rates to ensure that yield is not limited by nutrient supply. Fertilizer rates typically range from 150 to 250 kg N/ha, 70 to 150 kg P_2O_5/ha, and 60 to 180 kg K_2O/ha. Grain yield in NPK plots with ample nutrient supply and good crop management is used to estimate the attainable yield. Nutrient-limited yields are determined from nutrient omission plots. For example, the N-limited yield is determined in an N omission plot receiving no N fertilizer but sufficient P and K to ensure that the latter nutrients do not limit yield. P and K limited yield are estimated from P and K omission plots, respectively.

In NPK, 0-P, and 0-K treatments, fertilizer N is ideally applied in three splits with 30% N given very early in the season and each 35% topdressed at growth stages V6-8 and V10-12. This is especially for sites with good water control and where expected yield response to N is high. In rainfed systems with erratic rainfall and expected yield response to N of < 3 t/ha, fertilizer N can be applied in two splits with 40% given early in the season and the rest applied as late as possible before tasselling stage (VT). All fertilizer P is applied at crop establishment and fertilizer K is applied in two equal splits at crop establishment and V10-12.

Developing SSNM guidelines based on experimental data from farmers' fields

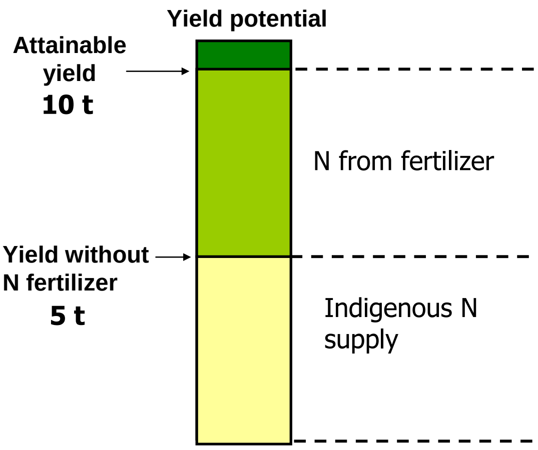


Fig. 3. Estimating fertilizer N requirements with SSNM.

The difference in grain yield between a fully fertilized plot and an N omission plot illustrates the deficit between the crop demand for N and indigenous supply of N, which must be met by fertilizers (Fig. 3). Similarly, the difference in grain yields between a fully fertilized plot and a K omission plot illustrates the deficit between the crop demand for K and indigenous supply of K, which must be met by fertilizers.

The total fertilizer requirement for N is estimated from the yield response to fertilizer N and the expected agronomic efficiency of N. The agronomic efficiency is an indicator used for both estimating total fertilizer N needs and optimizing N management. AEN is the yield increase per unit fertilizer N applied (Fig. 4). It is calculated as the attainable yield minus the nutrient limited yield divided by the amount of fertilizer N applied. The agronomic efficiency of nitrogen should be estimated experimentally in a few, representative field trials. Benchmark values for AEN exist for many rice, maize, and wheat growing environments. Low AEN compared to these benchmark values indicate either sub-optimal N management or yield-limiting constraints other than N. Higher than benchmark AEN may indicate insufficient N supply to meet the crop's need for nitrogen to achieve high yield at maximum economic return.

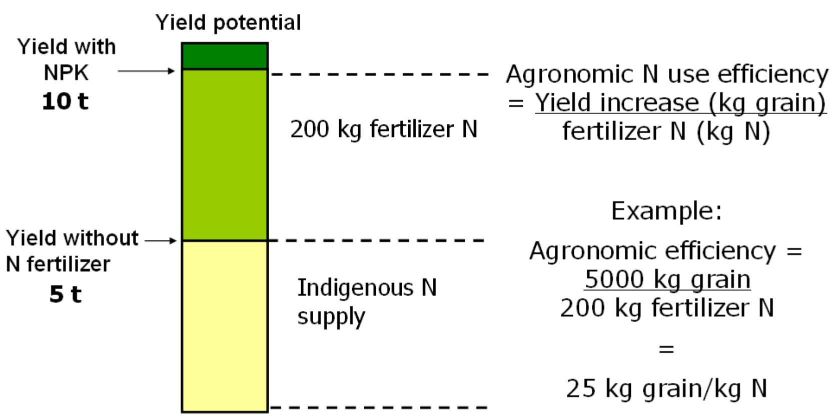


Fig. 4. Estimating the agronomic efficiency of N.

The suggested total fertilizer requirements for N, P, and K are provided in Tables 2-4. Fertilizer N rates are estimated depending on the expected grain yield response to fertilizer N application and the expected agronomic N efficiency (Table 2). Note that the table is based on the assumption that the agronomic efficiency of fertilizer N is linked to the yield response to fertilizer N application that can be achieved depending on climate, bio-physical growing conditions, and management.

Table 2. Estimated fertilizer N requirements for maize based on expected grain yield response and expected agronomic N efficiency.

Yield response to N	V – L	L	L – M	M	M – H	H	V – H
Expected yield increase (t/ha) to fertilizer N application over 0N →	≤ 2	2-3	3-4	4-5	5-6	6-7	7-8
Expected agronomic efficiency (kg grain increase/kg applied N)	15-17	17-25	21-29	25-31	28-33	30-35	32-36
	Fertilizer N rate (kg/ha)						
Total	**100**	**120**	**140**	**160**	**180**	**200**	**220**

Fertilizer P and K requirements provided in Tables 3 and 4 are estimated based on an attainable target yield and the expected grain yield response to fertilizer application. The SSNM approach advocates sufficient use of fertilizer P and K to both overcome P and K deficiencies and avoid the mining of soil P and K. Thus, fertilizer P and K are recommended even when the P-limited or the K-limited yield is comparable to the yield target (that is, no response to fertilizer P or K) to replenish the P and the K removed with grain. The determination of fertilizer P and K requirements for maize follow in essence an approach developed for rice (Witt and Dobermann 2004), which maintains the scientific principles of the underlying QUEFTS model (Janssen et al 1990); (Witt et al 1999).

In the absence of directly determined P- and K-limited yields by the nutrient omission

Table 3. Total fertilizer P_2O_5 requirements for maize in non-P fixing soils depending on yield target and yield response to fertilizer P application (updated 23/01/09).

Yield target (t/ha) →	4 – 6 t/ha	7 – 9 t/ha	10 – 12 t/ha
Expected yield response to fertilizer P over 0P plot (t/ha) ↓	Fertilizer P_2O_5 rate (kg/ha)		
0	10 – 20	20 – 30	30 – 40
0.5	20 – 30	30 – 40	40 – 50
1.0	30 – 40	40 – 50	50 – 60
1.5	40 – 50	50 – 60	60 – 70
2.0	50 – 60	60 – 70	70 – 80
2.5	60 – 70	70 – 80	80 – 90

- Based on a P requirement of 20 kg P_2O_5/t grain yield response (AEP of 112 kg grain/kg P) plus a 75% return of P removal with grain.
- Apply 100% of fertilizer P with basal application.

Table 4. Estimated fertilizer K_2O requirements for maize based on yield target and estimated yield response to fertilizer K (updated 23/01/09).

Yield target (t/ha) →	4 – 6 t/ha	7 – 9 t/ha	10 – 12 t/ha
Expected yield response to fertilizer K over 0K plot (t/ha) ↓	Fertilizer K_2O rate (kg/ha)		
0	15 – 25	25 – 35	35 – 45
0.5	30 – 40	40 – 50	50 – 60
1.0	45 – 55	55 – 65	65 – 75
1.5	60 – 70	70 – 80	80 – 90
2.0	75 – 85	85 – 95	95 – 105
2.5	90 – 100	100 – 110	110 – 120

- Based on a K requirement of 30 kg K_2O/t grain yield response (AEK of 40 kg grain/kg K) plus a 100% return of K removal with grain.
- Apply 100% of fertilizer K_2O with basal application, if ≤ 60 kg K_2O/ha.
- Apply each 50% of fertilizer K_2O basal and mid-season, if > 60 kg K_2O/ha.

plot technique, P- and K-limited yields can be estimated based on soil testing, farmers' use of organic amendments, soil properties, or previous measurements of P- and K-limited yield on similar soils.

Meeting the crop demand for nutrients at critical growth stages

Yield responses to the application of fertilizer N, P, and K are highly variable among fields and/or seasons. The SSNM strategy for nitrogen with total N rate, split N applications, and dynamic N management using the leaf color chart (LCC) provide assurance that additional yield can be attained in years more favorable than the average. Likewise, the SSNM strategy for P and K aims at achieving at least 1-2 t/ha additional grain yield, if conditions for the year are favorable for markedly higher than average yields.

The required fertilizer N is distributed in several applications during the crop growing season. This is particularly so in the tropics, to meet the crop's need for supplemental N. Fertilizer P and K are applied in sufficient amounts early in the season to overcome deficiencies and maintain soil fertility. Fertilizer K is often applied in two split applications early and near mid-season.

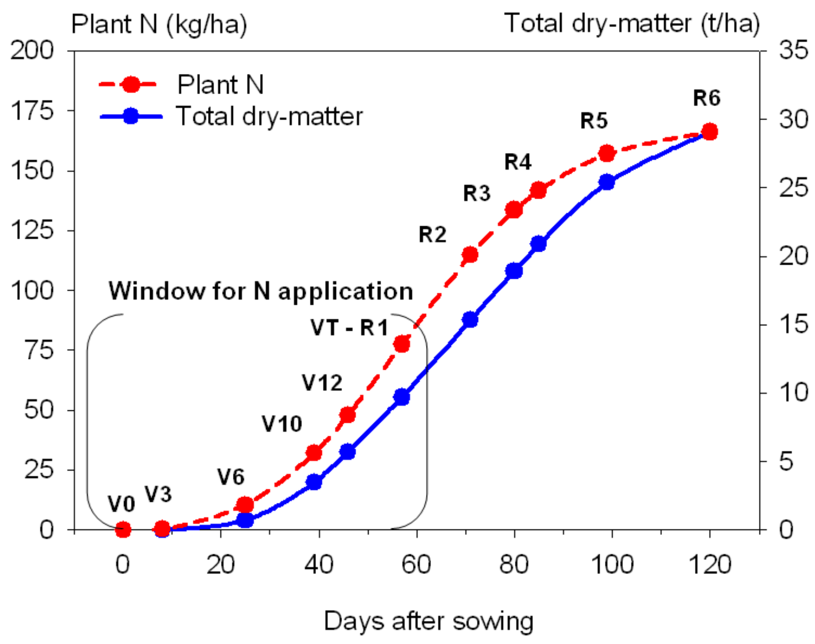


Fig. 5. Schematic overview of the plant N demand depending on growth stage. The window for fertilizer N application ranges from seeding to tasseling (VT).

The demand of maize for N is strongly related to growth stage with a window for N application between crop establishment and tasseling stage (Fig. 5). In order to achieve high yield, maize plants require sufficient N in early growth to promote general shoot development, during the formation of kernel rows per ear beginning with the 5-leaf stage (V5). Likewise N is required at subsequent growth stages leading to the determination of kernels per row before tasseling (VT), and during ripening stages to enhance grain filling. The supply of N from soil and organic sources is seldom adequate for high yield, and supplemental N is typically essential for higher profit from maize fields. The SSNM approach enables farmers to apply fertilizer N in several, usually two to three doses to ensure the supply of sufficient N is synchronized with the crop need for N. An additional late N application before tasseling is recommended when high yields are expected or when N deficiency is observed as determined using a leaf color chart.

Optimize nutrient use efficiencies

Site-specific nutrient management in maize calls for flexible N management strategies that allow adjustments in N rates according to rainfall events and plant N demand using the leaf color chart (LCC). The LCC was developed for rice (Balasubramanian et al 1999); (Witt et al 2005) and is also suitable for maize as indicated by spectral reflectance measurements performed on rice and maize leaves (Witt et al 2004). Detailed experiments with several maize varieties conducted at the Cereals Research Institute in Maros, South Sulawesi, Indonesia, in 2005-2006 showed that yield losses of more than 20% can be expected when LCC readings consistently fall below the color of panel four (S. Saenong, personal comment). The LCC is now being evaluated together with farmers to fine-tune N management in participatory trials with maize. The amount of fertilizer N at critical growth stages is adjusted depending on leaf color which serves as an indicator of the plant N status. Guidelines on LCC use in maize are provided in Table 5. The time for N fertilization is preset at critical growth stages with adjustments in rain-fed environments to ensure sufficient soil moisture. Farmers then adjust the dose of N upward or downward based on the leaf color. The effective management of N requires adequate planting densities, good crop management, and sufficient supply of P, K, and other macro- and micro-nutrients to achieve high and profitable yield.

Table 5. Guidelines for the timing and splitting of fertilizer N application during the season with the LCC. At yield responses of < 2 t/ha, fertilizer N is often applied in only two split applications.

Yield response to N		V – L	L	L – M	M	M – H	H	V – H
Expected yield increase (t/ha) to fertilizer N application over 0N →		≤ 2	2-3	3-4	4-5	5-6	6-7	7-8
Expected agronomic efficiency (kg grain increase/kg applied N) →		15-17	17-25	21-29	25-31	28-33	30-35	32-36
Growth stage	Leaf color	Fertilizer N rate (kg/ha)						
Pre-plant or V0	-	**30**	**36**	**42**	**48**	**54**	**60**	**66**
2nd application at V6-V8	yellow green	40	48	57	66	75	83	92
	green / dark green	**35**	**42**	**49**	**56**	**63**	**70**	**77**
3rd application at V10 or later*	yellow green	40	48	57	66	75	83	92
	green	**35**	**42**	**49**	**56**	**63**	**70**	**77**
	dark green	30	36	41	46	51	57	62
V14-VT*	green	-	-	-	25	30	35	35
Total (range based on LCC readings before V14)		**100** (90-110)	**120** (108-132)	**140** (124-156)	**160** (140-180)	**180** (156-204)	**200** (174-226)	**220** (190-250)

* Fertilizer N is only applied at sufficient soil moisture (rainfall)

Leaf color and LCC values for most hybrid maize varieties:

Yellow green:	LCC < 4.0
Green:	LCC 4.0 - 4.5
Dark green:	LCC > 4.5

Appendix A provides detailed guidelines and step-by-step instructions on how to develop a fertilizer recommendation.

2. Adaptation of generic SSNM principles to regional protocols for developing site-specific nutrient management recommendations

This section will provide you with • Guidelines on the development of a regional protocol on SSNM

The practical guide to site-specific nutrient management for maize in tropical, favorable environments is a generic document on SSNM principles and guidelines for developing fertilizer recommendations. This generic manual needs to be adapted, particularly Appendix A, B, and C, so that the resulting document meets regional requirements. Here are some guidelines on how to adapt the generic SSNM Manual into becoming a Regional SSNM Manual for Maize in a country or region within a country, which would become the technical reference for people working on SSNM:

- Adjust tables on estimated fertilizer N, P_2O_5, and K_2O requirements to show rates only for yield levels and or responses that are attainable in the region.
- Decide on the necessity of applying micronutrients in the region and whether to include this as part of the regional recommendation.
- Identify best management practices that are currently not practiced by farmers in your region and that may have the greatest potential to increase yield and farmers' profit. These practices will be evaluated with farmers through participatory evaluation.

An example of a one-page technical guideline for developing site-specific fertilizer recommendation for rice in Indonesia can be found in Appendix 4.

3. Participatory evaluation and wider scale delivery

This section will provide you with • A brief description of proposed steps towards wider scale delivery including the development of a regional manual, team development and training, and participatory evaluation. • An outlook on future activities towards wider-scale delivery of SSNM for maize

Current activities on the adaptation and participatory evaluation of SSNM in key maize growing areas in the Indonesia, the Philippines, and Vietnam are part of a regional strategy towards wider-scale delivery of SSNM to maize farmers in Southeast Asia (Fig. 6).

SSNM Manual
A manual to the development and participatory evaluation of site-specific nutrient management for maize in tropical, favorable environments (IPNI 2008) is a generic document on SSNM aimed at providing technical guidance to agricultural practitioners on the principles of SSNM and adapting these principles in developing site-specific fertilizer recommendations for evaluation with farmers.

Regional Manual
The Regional Manual is a document adapted from the generic *A manual to the development and participatory evaluation of site-specific nutrient management for maize in tropical, favorable environments* (IPNI 2008) and contains the protocol for developing site-specific

recommendations in a country or region (i.e. Luzon, Visayas, and Mindanao in the Philippines), including identified best management practices that can contribute significantly to improving productivity and profitability of maize farming in the region and will be evaluated with farmers through participatory evaluation.

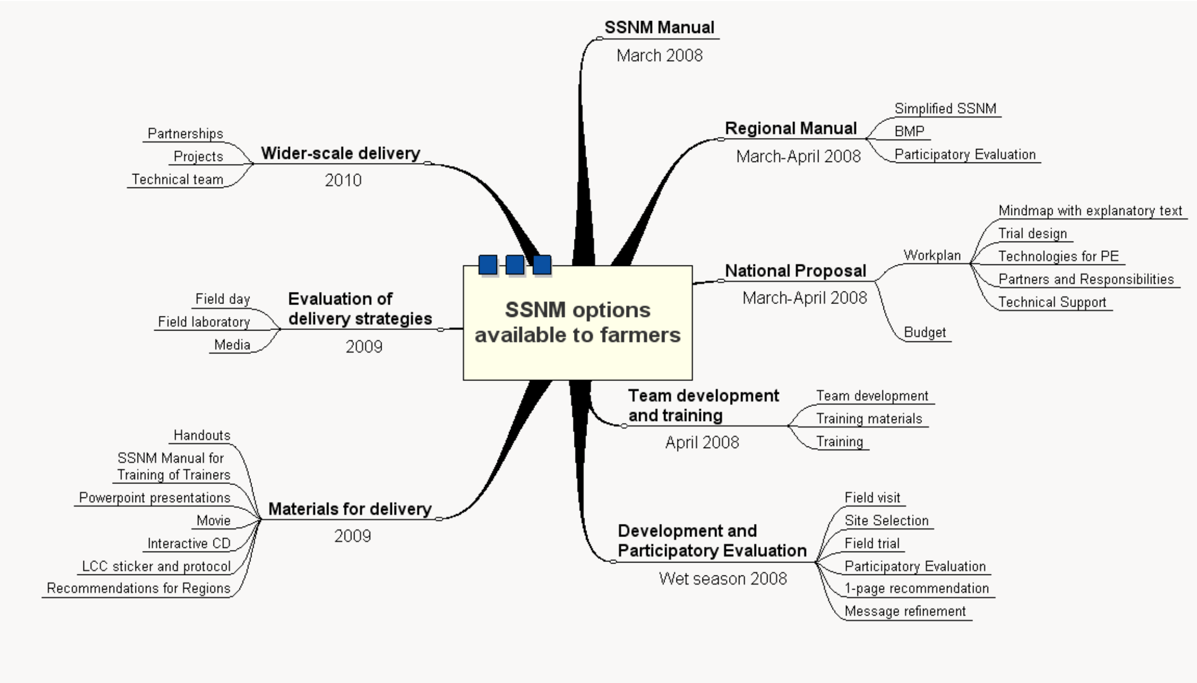


Fig. 6. Example of anticipated milestones towards the wider-scale delivery of SSNM for maize in the Philippines.

National Proposal
The National Proposal is a document containing the proposed workplan and budget for regional activities on SSNM including on-farm trials and farmer participatory evaluation. This document will be submitted to national organizations for funding approval.

Team development and training
Team development and training involves the identification and training of partners in the country who will be involved in activities related to the development and participatory evaluation of SSNM recommendations. Team development and training should be carried out before the maize season when on-farm trials and farmer participatory evaluation will be conducted.

Development and participatory evaluation
This involves on-farm trials and farmer participatory evaluation of SSNM. Activities may continue for several seasons to further refine recommendations before being promoted at wider-scale.

Materials for delivery
Some of the materials needed for wider-scale delivery of SSNM recommendations include Training for Trainers Manual, powerpoint presentations, interactive CDs, 1-page recommendations, handouts, protocols, etc. These are targeted to be available in 2009.

Evaluation of delivery strategies
Wider-scale delivery strategies such as field days, field laboratories, etc will be evaluated in 2009.

Wider-scale delivery
Wider-scale delivery of SSNM is planned for 2010. This involves establishing partnerships with government and non-government units, extension, and the private sector working together to promote SSNM recommendations at wider-scale. A technical team will provide guidance and support on technical issues of SSNM.

Appendix A. Basic SSNM guidelines in developing a fertilizer recommendation

In this section, you will go through a series of steps that outlines the basic SSNM guidelines in developing a fertilizer recommendation. In each step, you will be required to provide estimates of grain yield and make management decisions. Write down your answers on the right hand portion of the table below for easy reference. At the end of this exercise, you will need to copy these answers to a summary table for an overview of the fertilizer recommendation you have developed. Each guideline is briefly discussed with some helpful information to help you make your estimates or management decisions.

A1. Estimate an attainable yield level in farmers' field Estimate attainable yield from a crop grown in a regular season in farmers' fields with good management practices and without nutrient limitation to yield. <u>Suggestion</u>: *Despite sufficient nutrient supply and good crop management, yield in farmers' fields can vary substantially from i) field-to-field, e.g. because of small scale variation in soil moisture, and ii) from season-to-season, e.g., because of seasonal differences in climatic conditions. Estimate the attainable yield level from the average attainable yield across several seasons.*	**Attainable yield, GYa** (t/ha) Season 1 ___________ Season 2 ___________
A2. Estimate nutrient related yield response Estimate yield response from the difference in grain yield in a fully-fertilized plot with no nutrient limitations and a nutrient omission (-N, -P, -K) plot. <u>Suggestion</u>: *If there is no information available on grain yield from omission plots, you may choose to estimate the status of soil indigenous nutrient supply (low, medium, high) basing on the historical use of manure and other organic amendments, residue management, or soil test results for P and K.*	**Yield response, ΔGY** (t/ha) **ΔGY_N** Season 1 _______ Season 2 _______ **ΔGY_P** Season 1 _______ Season 2 _______ **ΔGY_K** Season 1 _______ Season 2 _______
A3. Calculate fertilizer requirements based on yield response and attainable yield level from the following tables	**Fertilizer N requirement** (kg/ha) **FN** Season 1 _________

	FN Season 2 __________

Fertilizer N requirements

Yield response to N	V – L	L	L – M	M	M – H	H	V – H
Expected yield increase (t/ha) to fertilizer N application over 0N →	≤ 2	2-3	3-4	4-5	5-6	6-7	7-8
Expected agronomic efficiency (kg grain increase/kg applied N)	15-17	17-25	21-29	25-31	28-33	30-35	32-36
	Fertilizer N rate (kg/ha)						
Total	**100**	**120**	**140**	**160**	**180**	**200**	**220**

Fertilizer P_2O_5 requirements

Non-P fixing soils

Yield target (t/ha) →	4 – 6 t/ha	7 – 9 t/ha	10 – 12 t/ha
Expected yield response to fertilizer P over 0P plot (t/ha) ↓	Fertilizer P_2O_5 rate (kg/ha)		
0	10 – 20	20 – 30	30 – 40
0.5	20 – 30	30 – 40	40 – 50
1.0	30 – 40	40 – 50	50 – 60
1.5	40 – 50	50 – 60	60 – 70
2.0	50 – 60	60 – 70	70 – 80
2.5	60 – 70	70 – 80	80 – 90

- Based on a P requirement of 20 kg P_2O_5/t grain yield response (AEP of 112 kg grain/kg P) plus a 75% return of P removal with grain.
- Apply 100% of fertilizer P with basal application.

Yet to be considered:
P fixation, available P, other soil properties, cropping system

Fertilizer P_2O_5 requirement (kg/ha)

FP Season 1 __________

FP Season 2 __________

Fertilizer K_2O requirements

Yield target (t/ha) →	4 – 6 t/ha	7 – 9 t/ha	10 – 12 t/ha
Expected yield response to fertilizer K over 0K plot (t/ha) ↓	Fertilizer K_2O rate (kg/ha)		
0	15 – 25	25 – 35	35 – 45
0.5	30 – 40	40 – 50	50 – 60
1.0	45 – 55	55 – 65	65 – 75
1.5	60 – 70	70 – 80	80 – 90
2.0	75 – 85	85 – 95	95 – 105
2.5	90 – 100	100 – 110	110 – 120

- Based on a K requirement of 30 kg K_2O/t grain yield response (AEK of 40 kg grain/kg K) plus a 100% return of K removal with grain.
- Apply 100% of fertilizer K_2O with basal application, if ≤ 60 kg K_2O/ha.
- Apply each 50% of fertilizer K_2O basal and mid-season, if > 60 kg K_2O/ha.

Yet to be considered:
Exchangeable K, other soil properties, cropping system

Fertilizer K_2O requirement (kg/ha)

FK Season 1 __________

FK Season 2 __________

A4. Adjust N, P_2O_5, and K_2O rates depending on soil properties (e.g. for P-fixing soils), cropping system, etc. Decide on the amount of micronutrients that might be needed.	**Adjusted FP** (kg/ha) **FPa** Season 1 __________ **FPa** Season 2 __________ **Adjusted FK** (kg/ha) **FKa** Season 1 __________ **FKa** Season 2 __________ **Micronutrients** (kg/ha) 1. _____________ 2. _____________ 3. _____________

Fill in the table below with your answers from rows 1 to 4.

Parameter	Row		Unit	Season 1	Season 2
Attainable yield level	A1	GYa	t/ha		
Expected yield responses					
to fertilizer N	A2	ΔGY_N	t/ha		
to fertilizer P	A2	ΔGY_P	t/ha		
to fertilizer K	A2	ΔGY_K	t/ha		
Fertilizer rates					
Fertilizer N	A3, A4	FN	kg/ha		
Fertilizer P	A3, A4	FP	kg/ha		
Fertilizer K	A3, A4	FK	kg/ha		

A5. Decide on the basal application of N, P_2O_5, and K_2O (and other nutrients), how much to apply and when to apply (at sowing or several days after sowing, DAS). <u>*Recommendation*</u>*:* *For N, apply in three splits (30:35:35) if* • *N rate >120 kg N/ha,* • *Area has no water problems, or*	**Basal fertilizer application schedule**: ____________ DAS $\mathbf{FN_{basal}}$ (kg/ha) _________ $\mathbf{FP_{basal}}$ (kg/ha) _________

- *Area has sandy soils with strong rains and high risk of leaching.*

Otherwise, apply N in two splits (50:50 or 40:60).

For P, apply all basal.

For K, apply all K early if rates <60 kg K_2O/ha, otherwise apply 50% at basal and 50% as topdressing.

Yield response to N		V – L	L	L – M	M	M – H	H	V – H
Expected yield increase (t/ha) to fertilizer N application over 0N →		≤ 2	2-3	3-4	4-5	5-6	6-7	7-8
Expected agronomic efficiency (kg grain increase/kg applied N) →		15-17	17-25	21-29	25-31	28-33	30-35	32-36
Growth stage	Leaf color	Fertilizer N rate (kg/ha)						
Pre-plant or V0	-	**30**	**36**	**42**	**48**	**54**	**60**	**66**
2nd application at V6-V8	yellow green	40	48	57	66	75	83	92
	green / dark green	**35**	**42**	**49**	**56**	**63**	**70**	**77**
3rd application at V10 or later*	yellow green	40	48	57	66	75	83	92
	green	**35**	**42**	**49**	**56**	**63**	**70**	**77**
	dark green	30	36	41	46	51	57	62
V14-VT*	green	-	-	-	25	30	35	35
Total (range based on LCC readings before V14)		**100** (90-110)	**120** (108-132)	**140** (124-156)	**160** (140-180)	**180** (156-204)	**200** (174-226)	**220** (190-250)

* Fertilizer N is only applied at sufficient soil moisture (rainfall)

Leaf color and LCC values for most hybrid maize varieties:
Yellow green: LCC < 4.0
Green: LCC 4.0 - 4.5
Dark green: LCC > 4.5

FK_{basal} (kg/ha) ________

A6. Decide on fertilizer N topdressing and LCC use

<u>Recommendation</u>:

Apply N whenever soil moisture is suitable.

For two topdressings, apply N at V6-V8 stage (20-25 DAP) and at V10 stage or later. Use the LCC each time to adjust N rates depending on leaf color and plant stand.

For single topdressing, apply N at V8-V10 stage (25-35 DAP) and use LCC.

Always do another LCC reading not later than 1 wk before tasseling to check on leaf color.

Fertilizer N topdressing application

1st topdressing: ___________ DAS

FN_{top1} (kg/ha) _________

2nd topdressing: ___________ DAS

FN_{top2} (kg/ha) _________

A7. Decide on fertilizer K topdressing

<u>Recommendation</u>:

Use crop stand and weather conditions as basis for decision to apply K at mid-season. Apply together with the last N topdressing.

Fertilizer K topdressing application

___________ DAS

FK_{top} (kg/ha) ________

A8. Translate nutrient recommendations into sources.

Recommendation:

Some adjustments to the fertilizer rates may be needed to match available fertilizer sources.

Fill in the table below with your answers from rows 5 to 7 (See sample recommendation table).

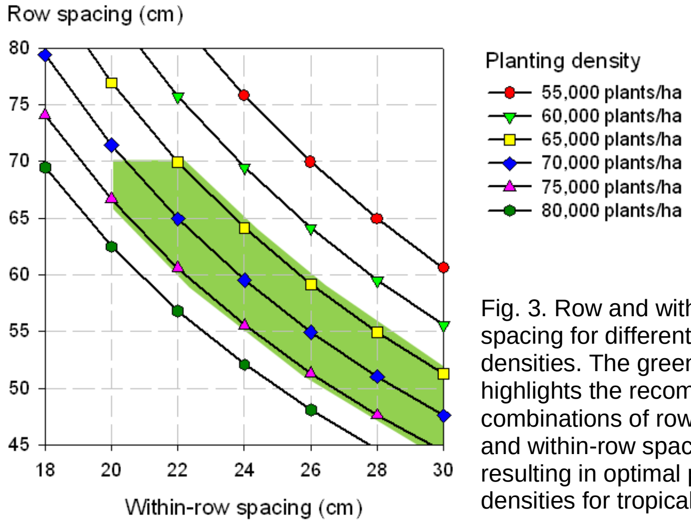
Season [ ]	Leaf color	Fertilizer source	Fertilizer source (bags/ha)	Fertilizer source (kg/ha)	N	P_2O_5	K_2O
					(kg/ha)		
Calculated fertilizer rates (FN, FP, FK)							
Growth stage							
DAS							
V6-V8	Yellow green						
	Green/dark gr.						
V10 or later	Yellow green						
	Green						
	Dark green						
V14-VT*							
Total (range based on LCC readings before V14)							

Sample recommendation for a maize crop with 4-5 t/ha yield response to N, 0.5 t/ha yield response to P and K at a yield level of 7-9 t/ha and an opportunity for 3 N-split applications.

Season [Dry season]	Leaf color	Fertilizer source	Fertilizer source (bags/ha)	Fertilizer source (kg/ha)	N	P_2O_5	K_2O
					(kg/ha)		
Calculated fertilizer rates (FN, FP, FK)					**160**	**30-40**	**40-50**
Growth stage							
0 DAS		14-14-14	5.5	275	**39**	**39**	**39**
V6-V8	Yellow green	Urea	3.0	150	69	-	-
	Green/dark gr.	Urea	2.5	125	**58**	-	-
V10 or later	Yellow green	Urea	3.0	150	69		
	Green	Urea	2.5	125	**58**		
	Dark green	Urea	2.0	100	46	-	-
V14-VT	Green	Urea	1.0	50	23	-	-
Total (range based on LCC readings before V14)					**154** (143-177)	**39**	**39**

Appendix B. Best Management Practices for Maize

In the table below, use your expert knowledge of local conditions to identify management practices that may have a huge impact in improving the current production and profit of maize farmers in your region and which will be evaluated with farmers through participatory evaluation. For the tropics, most favorable planting densities for high yield is probably around 65,000 to 75,000 plants/ha.

Crop management issues	Best management practice
Plant spacing and planting density	Select planting densities of about 65,000 to 75,000 plants/ha with one seed per hole for a more uniform crop stand. A population of less than 65,000 plants/ha is not advisable because a 10% loss of plants is not uncommon under rain-fed field conditions and the planting density at harvest should be at least 60,000 plants/ha to achieve high yield. Planting more than 75,000 seeds/ha will not increase yield unless growing conditions are very favorable with a yield potential of >13 t/ha. In drought-prone environments, planting density should not be more than 75,000 plants/ha. The distance between rows should be narrow and just wide enough to allow field operations while plant spacing within the row should be wide to minimize plant competition for light, water, and nutrients. The optimal combination of row and within-row spacing should create a favorable microclimate in the canopy reducing the risk for pests and diseases. For optimal row spacing, plants should be spaced 60-70 cm apart. Optimal plant spacing within rows should be about 20 to 30 cm.  Fig. 3. Row and within-row spacing for different planting densities. The green area highlights the recommended combinations of row spacing and within-row spacing resulting in optimal planting densities for tropical maize.
Variety (hybrid? GM-maize?)	
Land preparation (tillage? raised beds?)	

Crop establishment (use of farmalite?)	
Fertilizer application (covered with soil? Use of farmalite?)	
Weeds, pests, water mgt (manual weeding? irrigation?)	
Residue management (complete removal?)	
Organic amendments (manure?)	

Appendix C. Guidelines for participatory evaluation of site-specific nutrient management (SSNM) in maize

Objective of participatory evaluation

- To discuss current crop and nutrient management practices with farmers and identify opportunities for higher productivity and profitability based on the principles of best management practices and SSNM.
- To reach a consensus on the practices to be evaluated by farmers in the participatory evaluation.
- To identify volunteering farmers who agree to join in the participatory evaluation.
- To agree with participating farmers on responsibilities by farmers and resource team during the evaluation.

Role and responsibilities of the resource team in the participatory evaluation

- To share technologies and approaches with local partners in delivery (capacity building) and define their role in the participatory evaluation.
- To provide technical guidance on issues related to crop and nutrient management to farmers and local partners throughout the season.
- To assist farmers and local partners in record keeping and yield measurements.
- To analyze and discuss results of the participatory evaluation with farmers and local partners in delivery.

Role and responsibilities of the local partners in the participatory evaluation

- To identify project sites, establish contact with farmers, arrange for meetings with farmers, provide assistance in data collection and yield measurements, and develop a plan for wider scale delivery of successful technologies.
- To assist farmers in record keeping and yield measurements.

Role and responsibilities of farmers in the participatory evaluation

- To implement all practices agreed upon with the resource team in a sufficiently large portion of their fields using own funding. This should include a side-by-side comparison of new and current practices.
- To keep records of variety selection, crop and nutrient management related activities by growth stage, information related to decision making (e.g., rainfall events, etc).

WORK PLAN AND ACTIVITIES BEFORE THE SEASON:

1. **Meet with resource team and local partners in delivery including local government unit officials, extension officers, farmer leaders, etc. to prepare for the participatory evaluation.**
    - Discuss the objectives of farmer participatory evaluation, time frame and activities, and the responsibilities of all involved including resource team, local partners, and farmers.

- Discuss the program and expected output of the first meeting with farmers including the role of the resource team and local partners in the meeting and in the conduct of the on-farm participatory evaluation.
- It should be made clear to local stakeholders that only technical assistance will be provided to the farmers who will join the participatory evaluation. Subsidies for seeds, fertilizer, labor, etc (either from the project or from local stakeholders) are not in the spirit of participatory evaluation as they would create incentives for farmers that are not related to the technology. Farmers are encouraged to participate voluntarily providing unbiased feedback.
- If local partners in delivery would like to contribute financially to the participatory evaluation, they are welcome to pay for the farmers' meeting (transportation, lunch), but they should NOT provide fertilizer or any other incentives or inputs that would influence farmers' decision making on crop and/or nutrient management. This needs to be clearly communicated to stakeholders (e.g., mayor…) who are not taking part in the preparations but will be present at the first meeting with farmers.

2. **Hold a farmers' meeting at each location and invite the collaborator plus neighboring farmers.**

<u>Expected output of first meeting with farmers</u>

- Current practices described and discussed with farmers.
- Promising new practices identified and agreed upon with participating farmers.
- Responsibilities of all stakeholders involved in PE agreed upon and accepted.
- List of volunteering farmers to join the participatory evaluation including name and contact details.

A. <u>Before the meeting</u>

  - Prepare all the materials and data needed in the farmers' meetings (e.g. results of past experiments, summary of agronomic survey if one was done in the area, economic analysis of yield, etc).
  - Prepare a one-page handout for discussion with farmers containing proposed changes in practices (e.g. optimum plant spacing/planting density, fertilizer rates, timing of fertilizer application, when to use the leaf color chart, etc). The message should be simple, easy to understand and remember preferably written in the local language/dialect.
  - Simplify SSNM fertilizer recommendations in units that would be easily understood and/or of practical implementation by farmers (e.g. # of spoons of urea per bucket of water if fertilizer is mixed with irrigation water and applied by hand as in the degraded soils of North Vietnam or in the heavy clay soils of Central Java).

B. <u>During the meeting</u>

  - Make the atmosphere of the meeting as informal as possible to encourage interaction and farmer participation in discussions. Avoid "lecture-type" speeches or "classroom-type" seating arrangements.

- Inform farmers of the objectives of the meeting and the farmer-participatory evaluation of SSNM. This can be brief and would not need elaborate and lengthy introductions to the project.
- Summarize survey results on current farmers' practice (if you have) and ask farmers to confirm whether the portrayed practice is commonly followed. A discussion on current practices will encourage farmers to participate in the meeting right from the beginning.
- Start the dialogue on modifications of existing practices by explaining that we have reason to believe that there are opportunities to improve productivity and profitability of maize farming. Clearly inform the farmers that they are very welcome to propose modifications to the recommendations suggested by the researchers.
  - Discuss proposed changes in management practices by growth stage not by topic. Thus, topics could be discussed in the following order:
    - Field preparation: Plowing, zero tillage, etc
    - Crop establishment: Planting density, plant spacing, seeds per hole
    - Early season application of N, P, K, other nutrients: rate, timing, sources
    - Topdressing of fertilizer N: number of applications, rate, timing, sources
    - Topdressing of fertilizer K: rate, timing, sources
    - Use of leaf color chart in fine tuning N management
  - For example, before the season starts, farmers need to decide on plant spacing and planting density. Discuss the options for desirable plant spacing, planting densities, and seeds per hole with farmers. Explain the reason for choosing optimal planting densities of 65,000 to 75,000 plants per ha at sowing with plant spacing of 50 to 70 cm between rows and 20 to 28 cm within rows. Use the diagram on optimal planting densities to discuss the options. Discuss with farmers whether proposed changes are feasible. Would they be willing to evaluate a different plant spacing/planting density/seeds per hole? Only move on to the next topic (e.g. basal fertilizer application) once the practices for evaluation are agreed upon.
  - Discuss only those practices where changes are suggested.
  - Allow sufficient time for discussions and do not rush through the growth stages. Take the opportunity to elicit from the farmers what they think of each practice discussed, their comments, why it will or will not work, and their suggestions for improvements to suit their needs or make it work.
  - If farmers do not agree with our recommendations, ask what would be an acceptable modification to the recommendation for evaluation and why. Discuss farmers' proposed amendments whether they are acceptable and are not based on the scientific principles developed for best management practices and SSNM. Back up arguments with data from on-farm experiments, if needed. Be flexible in making adjustments but remember that the modifications should not violate the scientific principles. Also, the practice you agree upon for evaluation should be sufficiently different from the current practice so that we can see treatment differences! Farmers don't have to be

convinced of a certain practices, but it is important that everybody agrees on what practices to evaluate.

    - Both farmers and researchers need to come to a general agreement on what to evaluate before proceeding to the next issue.
    - At the end, summarize the recommendations that you jointly agreed upon for evaluation.

- Discuss about the proposed design of on-farm trials. For comparison, farmers are encouraged to compare the new practice including SSNM in a portion of their field ($\geq$ 1000 m^2, in the Philippines $\geq$ 0.25 ha) with the existing practice in the rest of the field.
    - Identify five farmer collaborators who will strictly follow the agreed practice including SSNM. These could be the farmers we had collaborated with during the development of SSNM. In these farms, it is recommended to install a 0N plot receiving fertilizer P and K but no fertilizer N in a corner of the trial plots to measure the yield response to N and its agronomic efficiency. Researchers need to ensure that farmers do not apply fertilizer N to the 0N plot.
    - All other farmers joining in the participatory evaluation do not need to install a 0N plot.
- Ask for volunteers to join in the participatory evaluation. Inform them that this is the farmer-participatory phase of the project and they are now the active partners. Explain the responsibilities of farmers and resource team in the season-long evaluation. Be explicit about the fact that we will only provide them with technical advice on how to try the new practices in their farms and monitor the crop performance with them during the season. We will work with them if they feel that they need to modify the technology, and we will provide guidance based on what we have learned from our experiments. If they join, they need to be willing to evaluate the agreed practice in a portion of their field. The will implement these practices by themselves.
- Clarify what you will provide or offer to farmers (recommendation agreed upon, LCC, notebook, pen, backstopping during farm visits). Note down name of farmers, mobile phone, and address.
- Discuss with farmers about record keeping of all their on-farm activities (fertilization, crop management, dates for phonological stages, yield record, etc) in both the evaluation plot and the rest of the field.
    - Also ask the farmers to note down drought and rainfall events particularly when related to N management (dates and severity of rainfall), LCC readings (dates, reading, and decision made on fertilizer N application).
- We call this the farmer-managed field set up and we note that the role of site coordinators will now largely entail advice, feedback, and monitoring during field visits. The visits will have to be frequent however to allow for quick review and recall of missed inputs to the monitoring/logbook. This monitoring form is very important as it actually documents what modification the farmers did on the SSNM technology

C. <u>Resource team after the meeting</u>

- Conduct an evaluation/review of what transpired during the farmers' meeting. Discuss on things that need to be improved in subsequent meetings.
- Follow-up on farmers who agreed to join the on-farm participatory evaluation. How large is the size of land they allot for the on-farm evaluation?
- Provide participating farmers with a tool kit for the participatory evaluation:
  - Leaf color chart with sticker of recommendation at the back
  - Laminated 1-page SSNM recommendation/guideline for the season as agreed upon during the meeting with farmers
  - Notebook (calendar-based) for farmers to keep good records of farm activities, rainfall occurrence, yield history
  - Good pen
- Discuss schedule of farm visits during the season with resource team in cooperation with the local government unit and other partners in delivery.

WORK PLAN AND ACTIVITIES DURING THE SEASON:

1. **Meet with resource team and local partners in delivery (local government unit officials, extension officers)**
   - Discuss schedule of on-farm visits and role of resource team and local partners in delivery.
2. **Conduct visits to the on-farm evaluation trials at regular intervals or at critical growth stages**

   Checklist of things to bring during the on-farm visits

   Researchers' kit:
   - ➢ Pocket notebook (for researcher to take down notes of observations in each farm)
   - ➢ Pocket calculator
   - ➢ Measuring tape/ruler
   - ➢ Camera

   - Establish rapport with the farmers.
   - Collect and document feedback regarding the SSNM technology
   - Discuss observations during the season and provide technical assistance to farmers but leave the final decision to farmers. Keep record of the discussions.
   - Do LCC readings with the farmers at least 3 times during the season (1st side-dressing, 2nd side-dressing, just before tasselling) and discuss the difference in leaf color with SSNM and FFP strategy
   - Monitor crop growth stage at each visit and plan with farmers on a tentative schedule of harvesting.

WORK PLAN AND ACTIVITIES AT THE END OF THE SEASON:

1. **Meet with resource team and local partners in delivery (local government unit officials, extension officers), and farmer-collaborator**
   - Plan and schedule farm visit at harvesting
   - Create a 'yield crew' composing of members from the resource team, local government unit, and farmer-collaborator(s) who will do the harvesting in farmers' fields

2. **Harvest at about 1-2 weeks after physiological maturity, when grain moisture has dropped to about 20-25%**
   - Take yield measurements together with participating farmers and immediately calculate the results in the presence of the farmer.
   - 2-3 crop cuts would be needed from the SSNM plot and FP portion of the field and 1 crop cut from the 0N plot.
   - Checklist of things to bring at harvest:
     - Pocket notebook to record yield at each site
     - A simple kitchen scale or spring (hanging) scale for weighing things in the 0.3 to 3 kg range, mechanical or battery powered
     - Grain moisture determination:
       - Option 1: grain moisture meter used by the group (for extension workers, too expensive for mass distribution)
       - Option 2: on the calculation sheet, the farmers chooses empirically between 3 levels (dry, normal, wet) and we assign default moisture values to those (standard factors for the calculation)
     - 3-m long string (e.g., color-coated wire, plastic string) to mark out the harvesting rows (four rows at 3m length each = 12 meter rows)
     - Calculator
     - Measuring tape/ruler to measure the distance between rows.
     - Cloth, net, or plastic bags

WORK PLAN AND ACTIVITIES AFTER THE SEASON:

Conduct a meeting with farmers after the season to discuss the results of the participatory on-farm trials and develop modifications of practices, if necessary. Repeat the evaluation for a second season and/or develop a campaign for wider scale delivery.

FEEDBACK ON PARTICIPATORY EVALUATION:

List issues that came up with farmers during participatory evaluation.

What was the feedback from farmers on the various components of best management practice and SSNM including planting density, plant spacing, basal fertilizer rates, number of N split applications, use of leaf color chart, etc. Did farmers change their practice in any way? If so, what did they change and why? What did farmers not change even though you recommended changing it?

-

Questions to ask farmers during participatory evaluation.

List important questions to ask when meeting with farmers during the season:

Question and Answers

Q: Would a farmer qualify for participatory evaluation, if he/she did not have the financial means to invest in the optimal fertilizer program?

A: Yes, but the resource team would need to modify the recommendation until it is affordable to farmers. Decisions need to be made whether to save on cost for fertilizer N, P, K or all and at what growth stages.

Q: Would this low-cost SSNM have to be followed by all farmers?

A: No, farmers can do as they please.

Q: Would the low-cost SSNM still qualify as a true SSNM? How do you do an impact analysis of a sub-optimal, low cost SSNM?

A: Try to help farmers in getting loans to purchase inputs or develop guidelines that would allow them to start with low NPK inputs at the beginning of the season and then increase rates only, if the season turns out to be very good. This would help famers avoid financial losses when facing heavy rainfall or drought after an initial investment in high basal fertilizer NPK rates.

Q: What if the farmer does not want to apply the third N split because cost for fertilizer N and labor is high?

A: If weather conditions turn out to be less favorable than expected so that the yield goal will not be reached and if the LCC reading indicates a high plant N status, recommend not to apply the third N split. If weather conditions are average or above, suggest to observe the plant N status using the LCC and apply the proposed third N split only in a portion of the field. Compare yield in the area with and without the third N split based on yield of four 3-m harvesting rows.

Q: The SSNM guidelines suggest three applications for N rates of more than 120 kg N/ha. However, our farmers don't like to apply fertilizer N three times, i.e. basal application followed by two N topdressings, they prefer to apply N only two times to save on labor cost. Is that acceptable?

A: You could develop a N management strategy with slightly higher N rates than originally planned for each application in the 3-N split strategy and then make the last application optional depending on the LCC reading. Or propose to the farmer to compare a 2-N split strategy with a 3-N split strategy in a portion of his/her field.

Q: How should we do yield measurements after the season?

A: Take 4 rows of each 3m; 2 sampling plots if possible. Measure row distance. Measure moisture content of grain with moisture meter or have a protocol on how to express MC in the field using qualitative descriptors (e.g. low, medium, high) – *JMP to develop protocol.*

Q: How shall we use SSNM + PE at sites without data?

A: Need to visit new sites to assess how different the soil/site characteristics are from our sites. If new sites are not so different from existing ones, may use SSNM/PE; however, if totally different, may have to do some omission plot trials there.

Appendix D. An example for a one-page summary of guidelines for implementing SSNM for rice in Indonesia.

Implementing site-specific nutrient management (SSNM) for transplanted rice in Indonesia

The guidelines given below apply for irrigated rice with

- Yield targets of 5, 6, 7 or 8 t ha^{-1}
- Yield expressed at 14% water content

Apply fertilizer nitrogen (N), phosphorus (P_2O_5), potassium (K_2O) and sulfur (S) at critical growth stages as indicated below

Fertilizer	Early growth 0 to 14 days after transplanting (DAT)	Active tillering	Panicle initiation	Maturity
Nitrogen (N)	Moderate amount	LCC-based (see part 2)	LCC-based (see part 2)	-
Phosphorus (P_2O_5) and Sulfur (S)	100%	-	-	-
Potassium (K_2O)	50–100%	-	As needed (see part 3)	-

Part 1. Apply fertilizer during early growth within 14 DAT

Use the following steps and the table below to determine fertilizer needs for a specific field:

Step 1. Select a yield target from the three options of 5, 6, 7, or 8 t ha^{-1}.
Step 2. Select a fertilizer N rate from the table based on yield target.
Step 3. Identify whether the historical level of fertilizer P_2O_5 application is above or below 30 kg ha^{-1} per season in the past five seasons.
Step 4. Select a fertilizer P_2O_5 rate from the table based on yield target and past fertilizer P_2O_5 use.
Step 5. Identify whether rice straw is historically removed or returned to the field.
Step 6. Select a fertilizer K_2O rate from the table based on yield target, straw management, and geographical location.
Step 7. For rice-growing areas where fertilizer S is recommended select an ammonium sulfate rate from the table based on yield target.

Fertilizer	Target location	Application (kg ha^{-1}) Yield target ≈ 5 t ha^{-1}	Yield target ≈ 6 t ha^{-1}	Yield target ≈ 7 t ha^{-1}	Yield target ≈ 8 t ha^{-1}
N	All fields	20–25	25–30	30–40	40–50
P_2O_5	Fields receiving >30 kg P_2O_5 ha^{-1} in each season for past 5 seasons	20–25	25–30	30–35	35–40
P_2O_5	Fields receiving ≤30 kg P_2O_5 ha^{-1} in each season for past 5 seasons and on P-fixing (red) soils	25–35	35–40	40–50	50–60
K_2O	Fields with straw removed	20–30	30	30–40	30–40
K_2O	Fields with straw returned in rice-growing areas with relatively low soil K supplying capacity[a]	30	30	30–40	30–40
K_2O	Fields with straw returned in rice-growing areas with relatively high soil K supplying capacity[b]	0	10	15–25	20–30
Ammonium sulfate	Rice-growing areas where S is recommended	75	100	100	100–125

[a] Western half of Java and South Sumatra
[b] Eastern half of Java and South Sulawesi

Single-element fertilizers or compound (NPK) fertilizers can be used to obtain the desired amounts of N, P_2O_5, and K_2O at the lowest cost.

Part 2. Topdress N as needed by the crop, based on leaf color.

Option 1. Take LCC readings at active tillering and panicle initiation and apply urea as indicated below.

- Panicle initiation (PI) is about 60 days before harvest.
- Active tillering is midway between 14 DAT and panicle initiation.

LCC reading (immediately before N application)	Application of urea (kg/ha) Low response to fertilizer N (Yield target ≈ 5 t ha^{-1})	Medium response to fertilizer N (Yield target ≈ 6 t ha^{-1})	High response to fertilizer N (Yield target ≈ 7 t ha^{-1})	Very high response to fertilizer N (Yield target ≈ 8 t ha^{-1})
LCC ≤3	75	100	125	150
LCC = 3.5	50	75	100	125
LCC ≥4	0	0–50	50	50

Option 2. Take LCC readings every 7–10 days from tillering to booting. Apply urea when the LCC reading falls below the critical value as indicated below.

LCC critical value (apply N when leaf color reaches critical value)	Application of urea (kg/ha) Low response to fertilizer N (Yield target ≈ 5 t ha^{-1})	Medium response to fertilizer N (Yield target ≈ 6 t ha^{-1})	High response to fertilizer N (Yield target ≈ 7 t ha^{-1})	Very high response to fertilizer N (Yield target ≈ 8 t ha^{-1})
LCC <4[a]	50	75	100	125

[a] Value is midway between 3 than 4.

Part 3. Apply fertilizer K_2O at panicle initiation

Use the following steps and table for targeting fertilizer K_2O to specific locations with high need for K:

Step 1. Select a yield target from the three options of 5, 6, 7, or 8 t ha^{-1}.
Step 2. Identify whether rice straw is historically removed or returned in the field.
Step 3. Select a fertilizer K_2O rate from the table based on yield target, straw management, and geographical location.
Step 4. Encourage farmers to apply recommended K_2O to a small plot and compare yield between the plot with additional K_2O and an adjacent field without additional K_2O.

Target location	Application (kg ha^{-1}) Yield target ≈ 5 t ha^{-1}	Yield target ≈ 6 t ha^{-1}	Yield target ≈ 7 t ha^{-1}	Yield target ≈ 8 t ha^{-1}
Fields with straw removed in rice-growing areas with relatively low soil K supplying capacity	5–15	15–25	25–35	40–50
Fields with straw removed in rice-growing areas with relatively high soil K supplying capacity & Fields with straw returned in rice-growing area with relatively low soil K supplying capacity	0	0	0–20	15–35

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