IPNI
INTERNATIONAL
PLANT NUTRITION
INSTITUTE

Improving Nutrient Management in Agriculture. Industry Perspective

Terry L. Roberts, Ph.D.

President, IPNI

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Second Global Conference on Land-Ocean Connections
Montego Bay, Jamaica

October 3, 2013

Better Crops, Better Environment … through Science

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Best Management Practices (BMPs)

Definition:

- Research proven practices that have been tested through farmer implementation to optimize production potential, input efficiency, and environmental protection (Griffith and Murphy 1991)

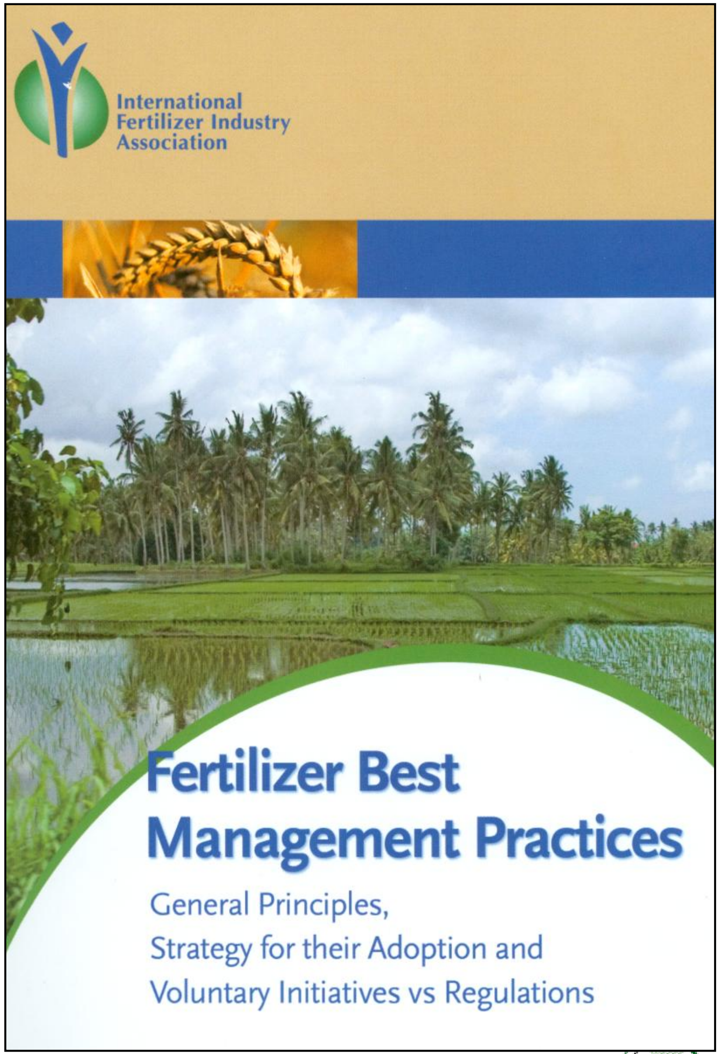
BMPs related to nutrients …

- Fertilizer best management practices, integrated plant nutrient management, integrated soil fertility management, code of best agricultural practices, site-specific nutrient management, etc. are components of plant nutrient management
- Goal — ensure plant nutrients are use efficiently and effectively in ways that are beneficial to society without adversely impacting our environment

IFA initiative on fertilizer BMPs

- International workshop in Brussels (2007) to define principles of fertilizer BMPs and a strategy for wider adoption … 2 outcomes:

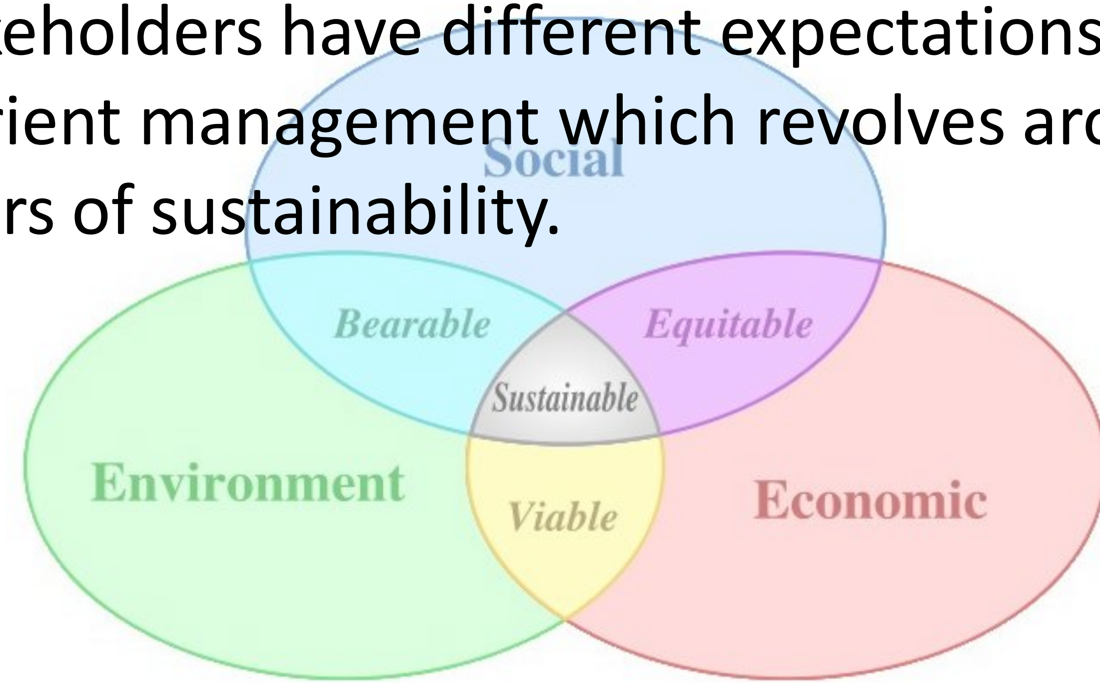
1. The 4Rs are the foundation and guiding principles of fertilizer BMPs (Roberts 2007)
2. A concept of a global framework for fertilizer BMPs was introduced (Fixen 2007)



Recognizing the role fertilizer BMPs in sustainability is new …

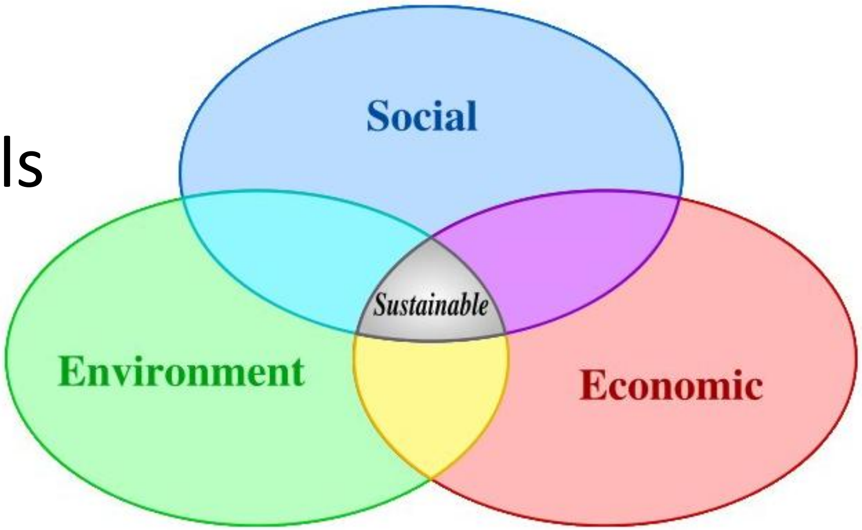
- Many stakeholders are interested in nutrient management
  - Farmers, crop advisers and consultants, policymakers, consumers, and general public

- Stakeholders have different expectations of nutrient management which revolves around the pillars of sustainability.



Ideally … pillars of sustainability would be equally balanced, but in reality this does not occur

- Balance between economic, social, and environmental goals for nutrient management depend on the issue, its context, and the stakeholders (IFA Task Force 2009)



A Global Framework for Fertilizer BMPs

By T.W. Bruulsema, C. Witt, Fernando García, Shutian Li, T. Nagendra Rao, Fang Chen, and S. Ivanova

This paper describes a framework designed to facilitate development and adoption of best management practices (BMPs) for fertilizer use, and to advance the understanding of how these practices contribute to the goals of sustainable development. The framework guides the application of scientific principles to determine which BMPs can be adapted to local conditions at the practical level.

At the farm level, cropping systems are managed for multiple objectives. Best management practices are those that most closely attain those objectives. Management of fertilizer use falls within a larger agronomic context of cropping system management. A framework is helpful for describing how BMPs for fertilizer use fit in with those for the agronomic system.

The goals of sustainable development, in the general sense, comprise equal emphasis on economic, social, and ecological aspects (Brundtland, 1987). Such development is essential to provide for the needs of current and future generations. At the farm level, however, it is difficult to relate specific crop management practices to these three general aspects. Four management objectives are applicable to the practical farm level of all cropping systems (Witt, 2003). These four objectives are productivity, profitability, cropping system sustainability, and a favorable biophysical and social environment (PPSE). They relate to each other as illustrated in **Figure 1**.

Fertilizer use BMPs comprise an interlinked subset of crop management BMPs. For a fertilizer use practice to be considered "best", it must harmonize with the other agronomic practices in providing an optimum combination of the four objectives, PPSE. It follows that the development, evaluation, and refinement of BMPs at the farm level must consider all four objectives, as must selection of indicators reflecting their combined impact at the regional, national, or global level. Appropriate indicators for use at different scales are further discussed below in the section on performance indicators.

Figure 1. Illustration of a global framework for BMPs for fertilizer use. Fertilizer use BMPs–applying the right nutrient source at the right rate, time, and place–integrate with agronomic BMPs selected to achieve crop management objectives of productivity, profitability, sustainability, and environmental health. A balanced complement of indicators is needed to reflect the influence of fertilizer BMPs on the four crop management objectives at the farm level, and on the economic, ecological, and social goals for sustainable development on the broader scale for regional public policies.

Cropping System Management Objectives

Productivity. For cropping systems, the primary measure of productivity is yield per unit area of cropland per unit of time. Productivity should be considered in terms of all resources, or production factors, involved. Several indicators describing production and input use efficiencies are probably required to properly evaluate productivity.

Profitability. Profitability is determined by the difference between the value of the produce (gross benefit or revenue) and the cost of production. Its primary measure is net benefit per unit of cropland per unit of time. The profitability gain of a specific management practice is the increase in gross revenue it generates, less its marginal cost.

Sustainability. Sustainability—at the level of the cropping system—refers to the influence of time on the resources involved. A sustainable production system is one in which the quality (or efficiency) of the resources used does not diminish over time, so that "outputs do not decrease when inputs are not increased" (Monteith, 1990).

Environment (biophysical and social). Crop production systems have a wide range of effects on surrounding ecosystems through material losses to water and air. Specific effects can be limited to some extent by practices designed to optimize efficiency of resource use. Management choices at the farm level, when aggregated, also influence the social environment through demand for labor, working conditions, changes in ecosystem services, etc.

Fertilizer Management Objectives

Fertilizer use BMPs essentially support the four objectives identified for cropping systems management and can be aptly described as the selection of the right source for application at the right rate, time, and place (Roberts, 2007). Fertilizer source, rate, timing, and placement are interdependent, and are also interlinked with the set of agronomic management practices applied in the cropping system, as illustrated in **Figure 1**.

Scientific Principles

Specific scientific principles apply to crop and fertilizer use BMPs as a group and individually. These principles are

Abbreviations and notes for this article: N = nitrogen; P = phosphorus; K = potassium.

The concept was further developed by IPNI scientists

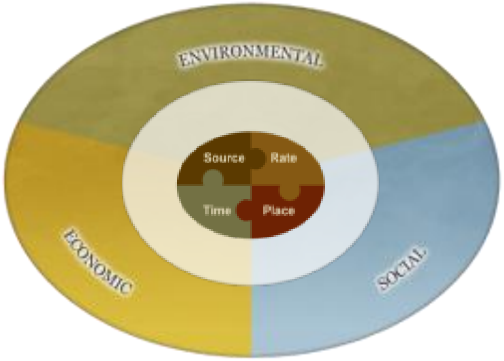
(Bruulsema et al. 2008)

4R Nutrient Stewardship –
Endorsed by American Society of Agronomy 2009

Know your fertilizer rights

By Tom Bruulsema, International Plant Nutrition Institute, Guelph, ON, Canada; ***Jerry Lemunyon***, USDA-NRCS, Fort Worth, TX; and ***Bill Herz***, The Fertilizer Institute, Washington, DC

Crops & Soils 42(2): Mar-Apr 2009



The four fertilizer rights: Selecting the right source

By Robert Mikkelsen, International Plant Nutrition Institute, Merced, CA; ***Greg Schwab***, University of Kentucky, Lexington; and ***Gyles Randall***, University of Minnesota, Waseca

Crops & Soils 42(3): May-Jun 2009

Selecting the right fertilizer rate: A component of 4R nutrient stewardship

By S.B. Phillips, International Plant Nutrition Institute, Owens Cross Roads, AL; ***J.J. Camberato***, Purdue University, West Lafayette, IN; and ***D. Leikam***, Fluid Fertilizer Foundation, Manhattan, KS

Crops & Soils 42(4): Jul-Aug 2009

The four fertilizer rights: timing

By W.M. Stewart, International Plant Nutrition Institute, Norcross, GA; ***J.E. Sawyer***, Iowa State University, Ames, IA; and ***M.M. Alley***, Virginia Tech, Blacksburg, VA

Crops & Soils 42(5): Sep-Oct 2009

Know Your Fertilizer Rights: Right Place

by T.S. Murrell (IPNI), G.P. Lafond (AAFC), and T.J. Vyn (Purdue U.)

Crops & Soils 42(6): Nov-Dec 2009

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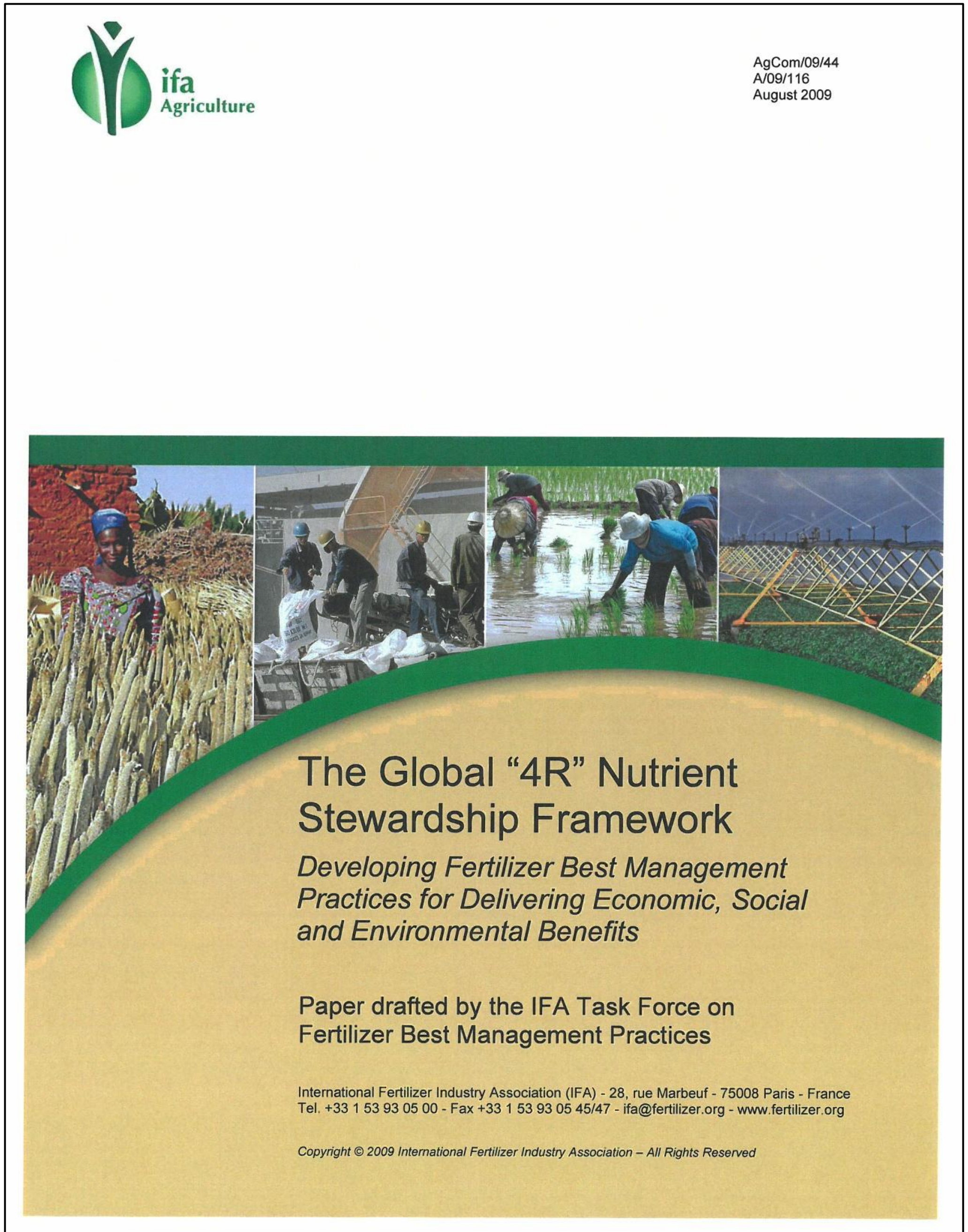

ifa Agriculture

AgCom/09/44
A/09/116
August 2009

The Global "4R" Nutrient Stewardship Framework

Developing Fertilizer Best Management Practices for Delivering Economic, Social and Environmental Benefits

Paper drafted by the IFA Task Force on Fertilizer Best Management Practices

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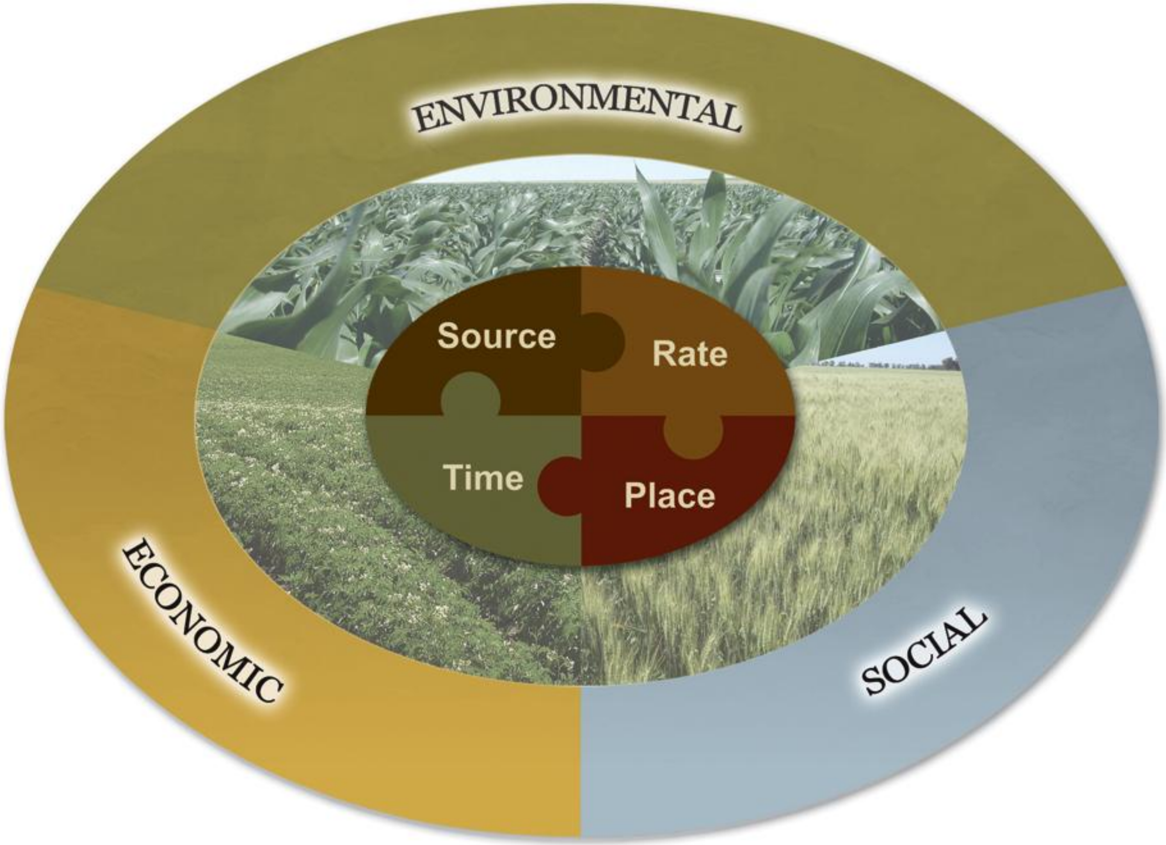
The framework is intended to aid the development and adoption of nutrient BMPs that meet the goals of sustainable development.

Source, rate, time, and place describe any nutrient application

Right means Sustainable

- Right source, rate, time, and place
- Outcomes valued by stakeholders



Examples of key scientific principles

Source	Rate	Time	Place
◆ Ensure balanced supply of nutrients ◆ Suite soil properties	◆ Assess nutrient supply from all sources ◆ Assess plant demand	◆ Assess dynamics of crop uptake and soil supply ◆ Determine timing of loss risk	◆ Recognize crop rooting patterns ◆ Manage spatial variability




Examples of practical choices

Source	Rate	Time	Place
◆ Commercial fertilizer ◆ Livestock manure ◆ Compost ◆ Crop Residue	◆ Test soils for nutrients ◆ Calculate economics ◆ Balance crop removal	◆ Pre-plant ◆ At planting ◆ At flowering ◆ At fruiting	◆ Broadcast ◆ Band/drill/inject ◆ Variable-rate application




Equal attention to all 4Rs

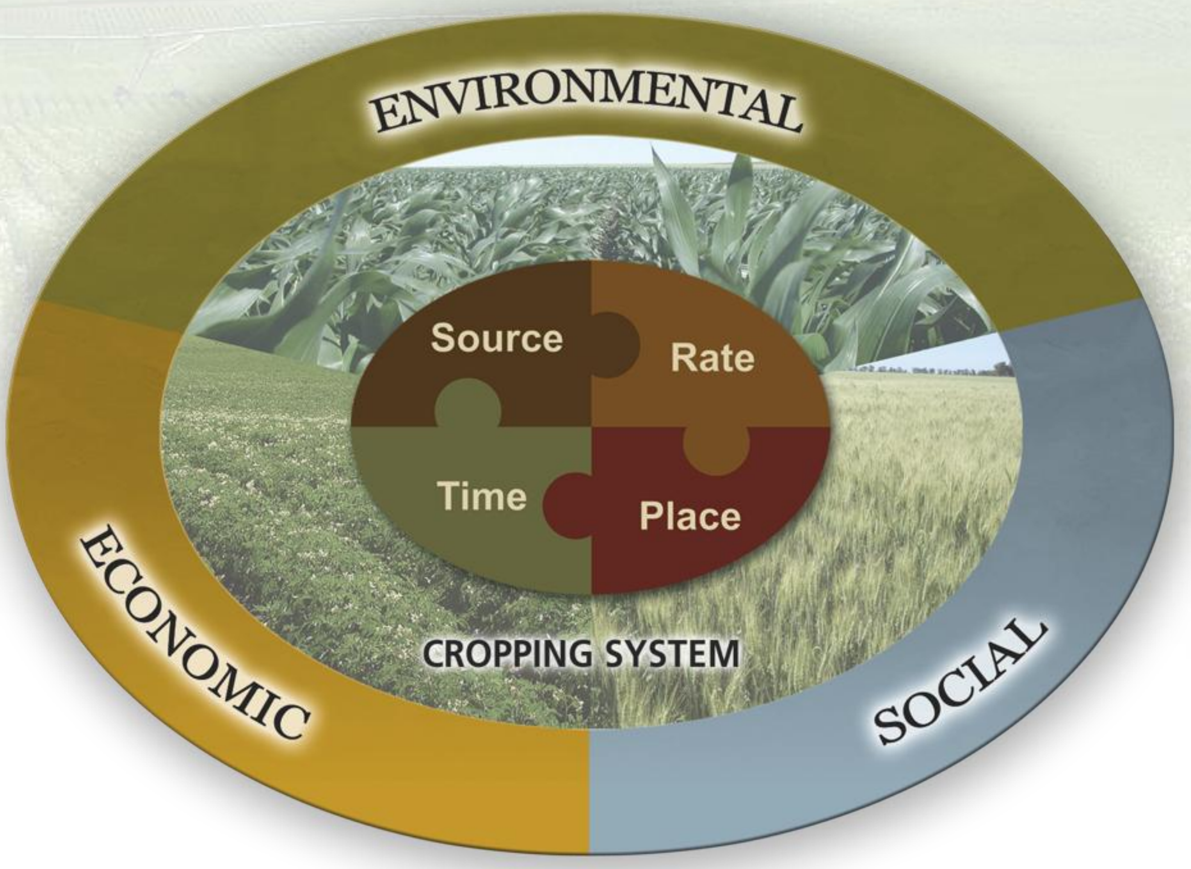
- Balance attention to all 4Rs
- Rate: easily overemphasized
- Source, Time, Place: often require major changes and investments

The 4Rs interconnect

- with each other
- with local soil and climate factors
- with management of soils and crops
- other factors can limit productivity even when levels of plant nutrients are adequate

The 4Rs connect to the cropping system

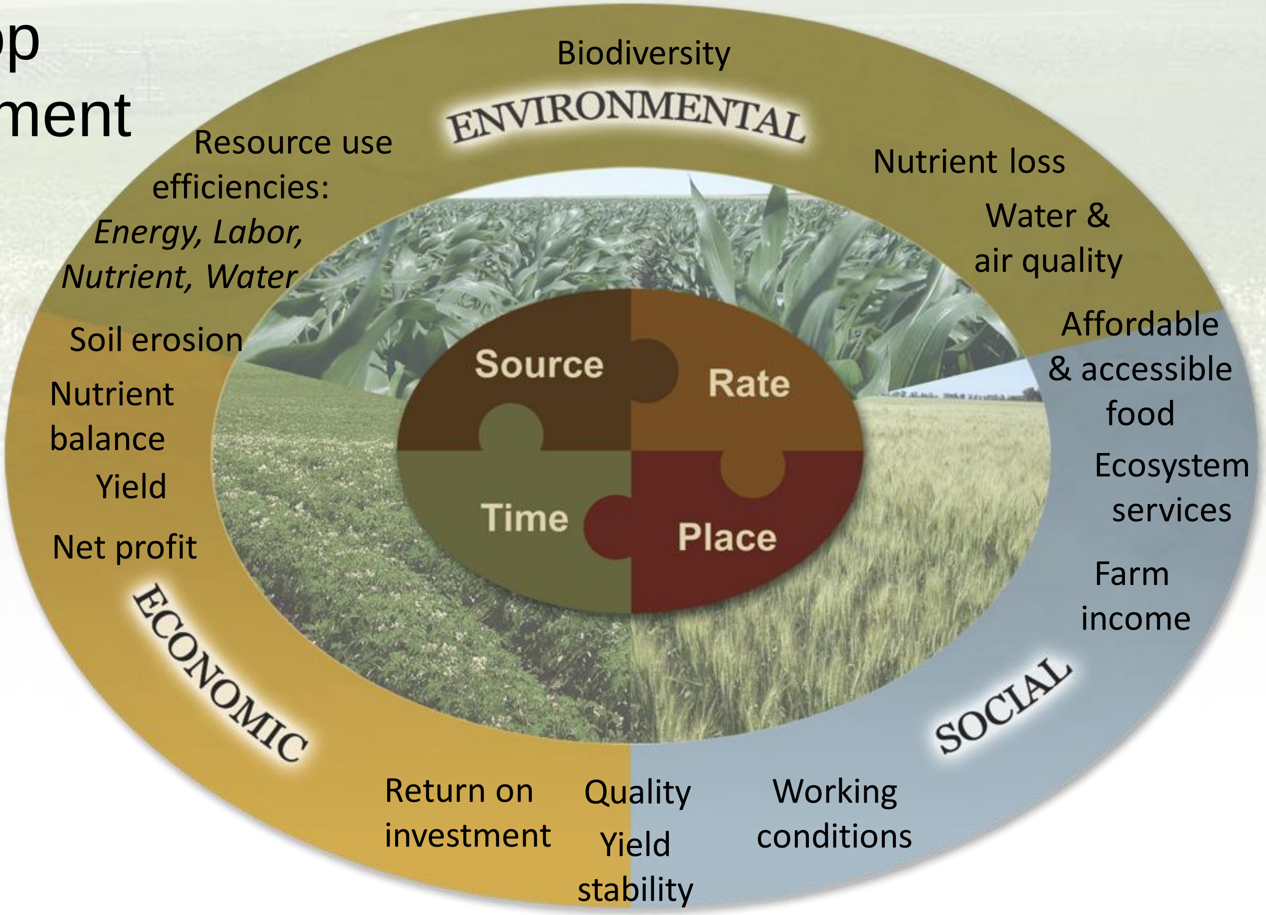
- Soil water, air, and temperature influence nutrient availability.



- genetic yield potential
- weeds
- insects
- diseases
- mycorrhizae
- soil texture & structure
- drainage
- compaction
- salinity
- temperature
- precipitation
- solar radiation

The 4Rs influence many performance indicators

- Social, Economic and Environmental performance
- Influenced by crop and soil management as well
- Whole system outcomes



Stakeholders have a say on performance indicators and sustainability goals

- Stakeholders define goals
- Indicators relate to goals

Producers choose management practices

- Practices selected to suit local site-specific soil, weather, and crop conditions
- Conditions may change even on the day of application
- Local decisions preferred

4R PLANT NUTRITION

Adaptive management at the farm level

Farm Level
Producers,
Crop advisers

DECISION
Accept, revise, or reject

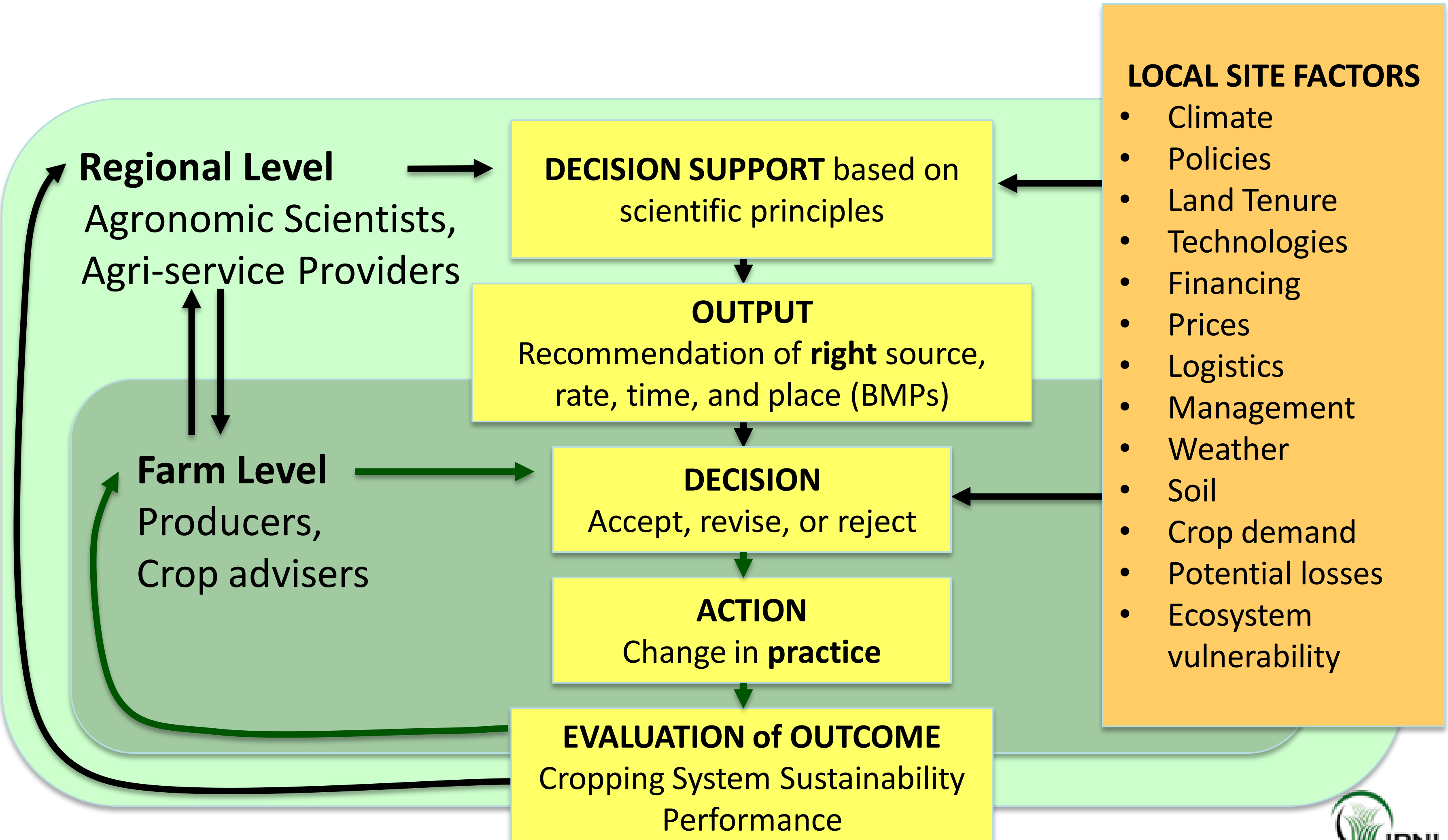
ACTION
Change in **practice**

EVALUATION of OUTCOME
Cropping System Sustainability Performance

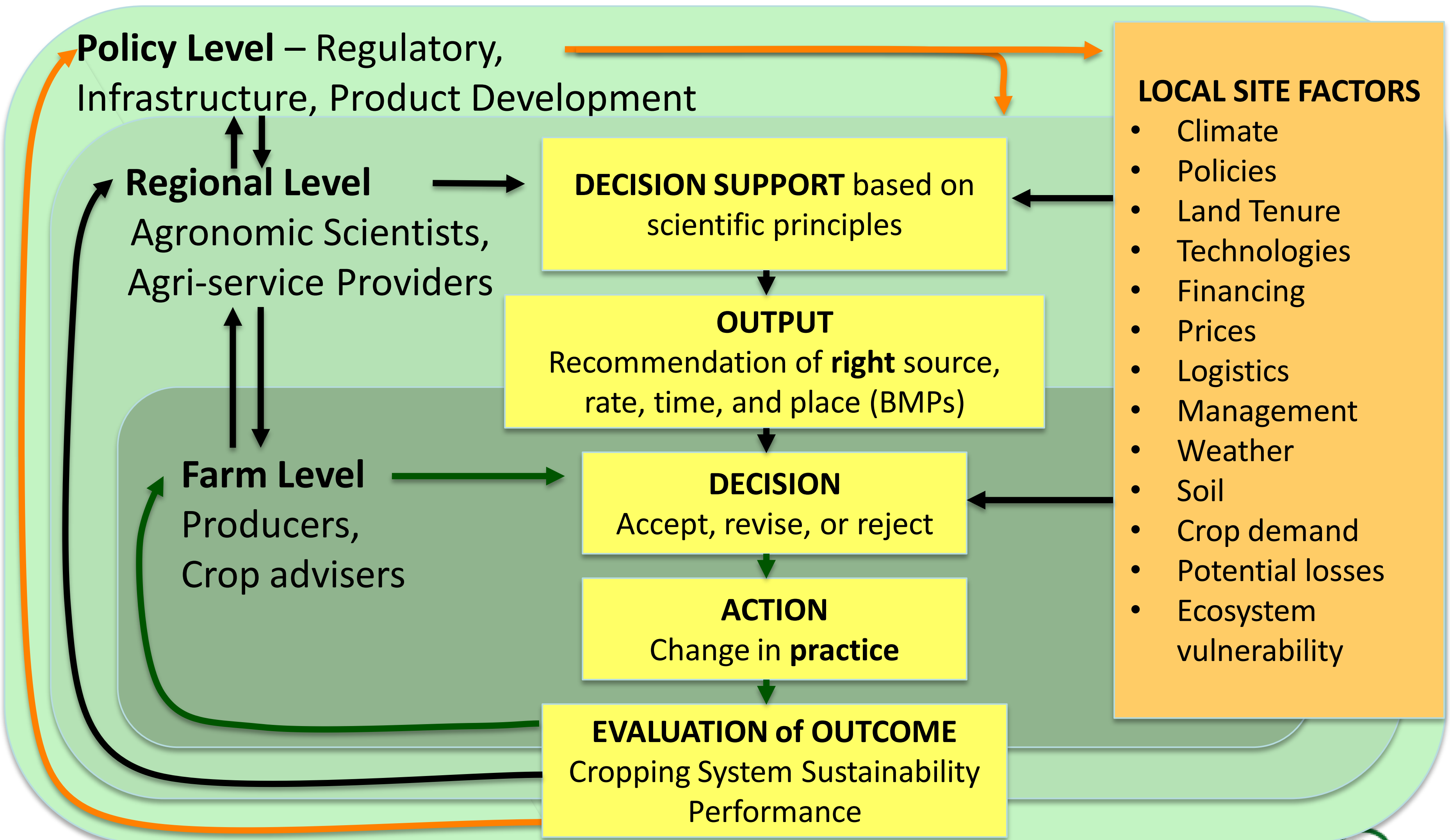
LOCAL SITE FACTORS

- Climate
- Policies
- Land Tenure
- Technologies
- Financing
- Prices
- Logistics
- Management
- Weather
- Soil
- Crop demand
- Potential losses
- Ecosystem vulnerability

Adaptive management at the regional level



Adaptive management at the policy level



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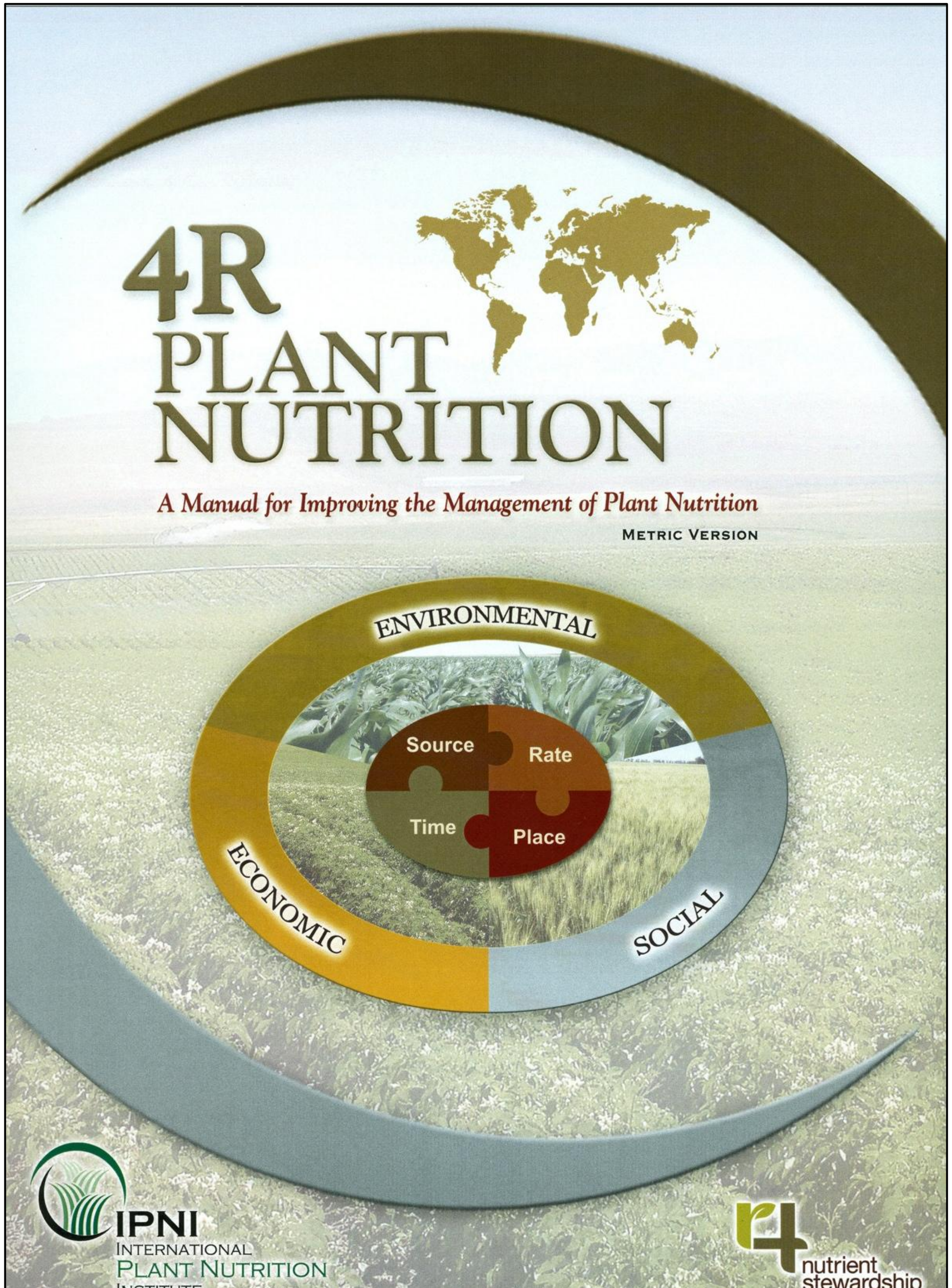
4R Nutrient Stewardship

- Relates management practices to sustainability goals
- Sustainability indicators are long-term
  - short term efficiencies can lead to long-term soil nutrient depletion
  - nutrient balance in context of inputs and outputs
- 4R Nutrient Stewardship emphasizes impact on outcomes

Source, Rate, Time, and Place

- Every application has all four
- Get all four right!
- Completely interconnected
- 4R Nutrient Stewardship emphasizes impact on outcomes

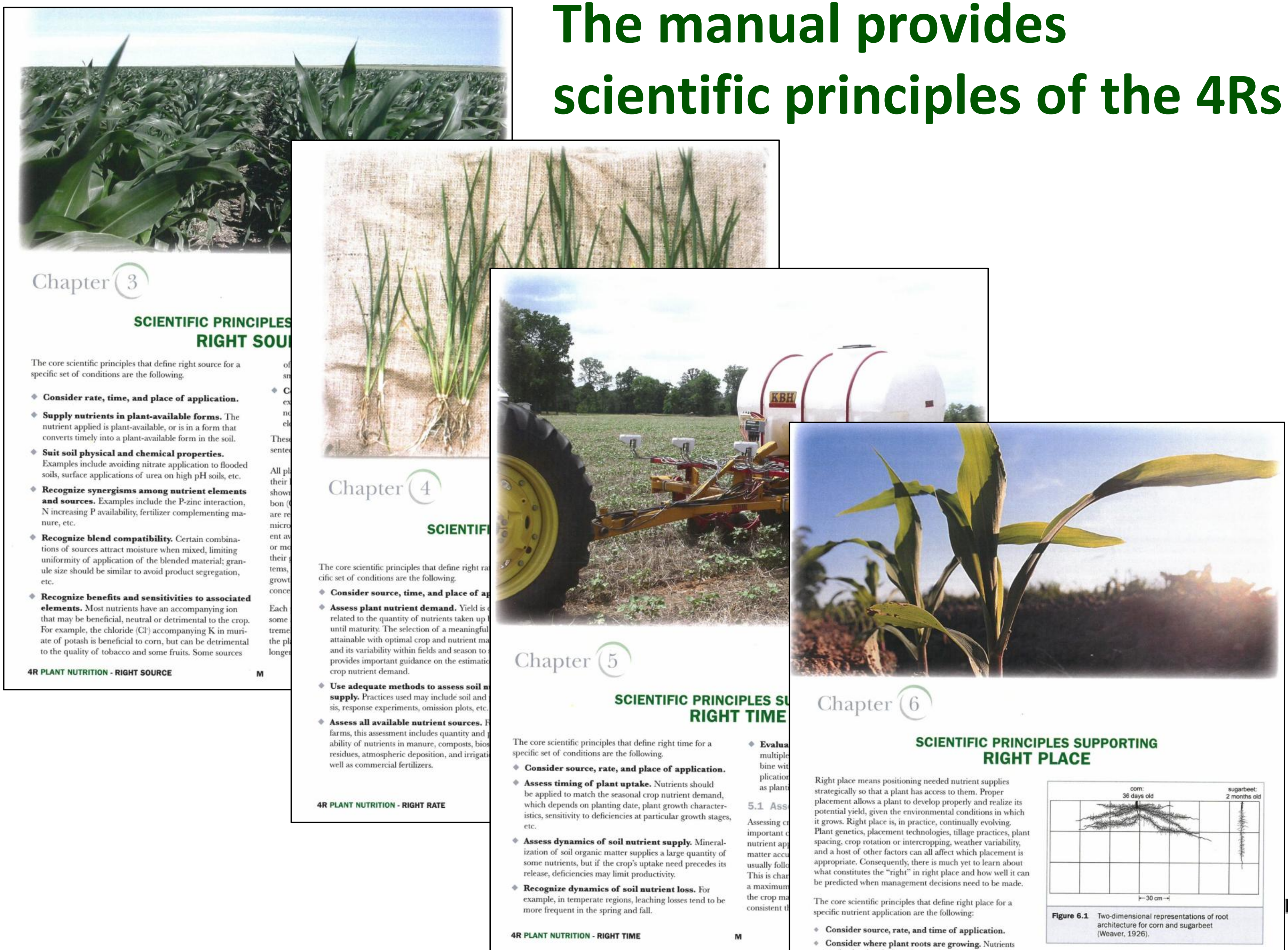


Manual available from IPNI

www.ipni.net/4r

QR Code

The manual provides scientific principles of the 4Rs



Chapter 3

SCIENTIFIC PRINCIPLES
RIGHT SOU

The core scientific principles that define right source for a specific set of conditions are the following.

- **Consider rate, time, and place of application.**
- **Supply nutrients in plant-available forms.** The nutrient applied is plant-available, or is in a form that converts timely into a plant-available form in the soil.
- **Suit soil physical and chemical properties.** Examples include avoiding nitrate application to flooded soils, surface applications of urea on high pH soils, etc.
- **Recognize synergisms among nutrient elements and sources.** Examples include the P-zinc interaction, N increasing P availability, fertilizer complementing manure, etc.
- **Recognize blend compatibility.** Certain combinations of sources attract moisture when mixed, limiting uniformity of application of the blended material; granule size should be similar to avoid product segregation, etc.
- **Recognize benefits and sensitivities to associated elements.** Most nutrients have an accompanying ion that may be beneficial, neutral or detrimental to the crop. For example, the chloride (Cl^-) accompanying K in muriate of potash is beneficial to corn, but can be detrimental to the quality of tobacco and some fruits. Some sources

4R PLANT NUTRITION - RIGHT SOURCE

Chapter 4

SCIENTIFI

The core scientific principles that define right ra cific set of conditions are the following.

- **Consider source, time, and place of ap**
- **Assess plant nutrient demand.** Yield is related to the quantity of nutrients taken up until maturity. The selection of a meaningful attainable with optimal crop and nutrient ma and its variability within fields and season to provides important guidance on the estimatio crop nutrient demand.
- **Use adequate methods to assess soil n supply.** Practices used may include soil and sis, response experiments, omission plots, etc.
- **Assess all available nutrient sources.** F farms, this assessment includes quantity and ability of nutrients in manure, composts, bios residues, atmospheric deposition, and irrigati well as commercial fertilizers.

4R PLANT NUTRITION - RIGHT RATE

Chapter 5

SCIENTIFIC PRINCIPLES SU
RIGHT TIME

The core scientific principles that define right time for a specific set of conditions are the following.

- **Consider source, rate, and place of application.**
- **Assess timing of plant uptake.** Nutrients should be applied to match the seasonal crop nutrient demand, which depends on planting date, plant growth characteristics, sensitivity to deficiencies at particular growth stages, etc.
- **Assess dynamics of soil nutrient supply.** Mineralization of soil organic matter supplies a large quantity of some nutrients, but if the crop's uptake need precedes its release, deficiencies may limit productivity.
- **Recognize dynamics of soil nutrient loss.** For example, in temperate regions, leaching losses tend to be more frequent in the spring and fall.

4R PLANT NUTRITION - RIGHT TIME

Chapter 6

SCIENTIFIC PRINCIPLES SUPPORTING
RIGHT PLACE

Right place means positioning needed nutrient supplies strategically so that a plant has access to them. Proper placement allows a plant to develop properly and realize its potential yield, given the environmental conditions in which it grows. Right place is, in practice, continually evolving. Plant genetics, placement technologies, tillage practices, plant spacing, crop rotation or intercropping, weather variability, and a host of other factors can all affect which placement is appropriate. Consequently, there is much yet to learn about what constitutes the "right" in right place and how well it can be predicted when management decisions need to be made.

The core scientific principles that define right place for a specific nutrient application are the following:

- **Consider source, rate, and time of application.**
- **Consider where plant roots are growing.** Nutrients

corn: 36 days old
sugarbeet: 2 months old
30 cm

Figure 6.1 Two-dimensional representations of root architecture for corn and sugarbeet (Weaver, 1926).

Learning modules and case studies are included in the manual …

M

Module 4.1-2 Calculating fertilizer rates in cereals using omission plot data. The nutrient omission plot approach for calculating fertilizer rates for cereals (rice, wheat, maize) utilizes information on grain yields obtained in plots with the nutrient in question omitted and at ample levels. Other nutrients are applied to ensure they are not limiting yield. The yield of the omission plot is used as an indirect estimate of soil supplying capacity of the omitted nutrient. The grain yield difference between the omission plot and the one fertilized at an ample level can be used to estimate fertilizer rate required for various target yields.

Table 1. Yields from an omission plot experiment in winter wheat from India.

Treatment	Yield, kg/ha
1. Ample rates of N, P, and K	5,556
2. N omitted; ample rates of P and K	1,667

Since the rate of N applied in the "ample" plot in **Table 1** was 150 kg/ha, agronomic efficiency (AE_N) of this plot was (5,556 – 1,667)/150 or 26 kg of grain per kg of N fertilizer.

If one assumes similar soil N supply capacity, and a similar level of efficiency (26 kg/kg), for other fields in the area, **Table 2** shows the resulting rates that would be recommended for different target yields (e.g. fields #1 and #2). If an omission plot in the area with a different preceding crop was conducted and gave a yield as for field #3 below, that information too could be used in the rate calculation.

Table 2. Rate calculation for three example winter wheat fields.

Field #	Yield target, kg/ha	Omission plot yield, kg/ha	Calculated N rate, kg/ha
1	6,500	1,667	(6,500 – 1,667)/26 = 186
2	4,500	1,667	(4,500 – 1,667)/26 = 109
3	6,500	2,500	(6,500 – 2,500)/26 = 154

Compared to values obtained across many trials, the AE_N calculated from the data in **Table 1** is relatively high (see Section 4.4 and **Table 3**). Recommendations are most accurate when site-specific local values for AE_N, omission plot yield, and target yield can be obtained.

Table 3. Observed ranges of AE_N for cereals from selected agronomic experiments in India.

Crop	N applied only[1]	N with ample P and K[1]	Farmers' practice, Punjab[2]	Site-specific nutrient management
Maize	4-7	7-14	–	26-28[3]
Wheat	7-12	17-24	–	20-28[3]
Rice	7-12	14-23	8-10	22-34[4]

[1] Biswas, P.P. and P.D. Sharma. 2008. Indian J. Fert. 4(7):59-62.
[2] Khurana, H.S. et al., 2007. Agron J. 99:1436-1447.
[3] IPNI Unpublished data, 2011.
[4] Singh, B. et al. 2012. Field Crops Research 126:63-69.

The nutrient omission approach can be a sound alternative to a soil test-based approach, in regions of the world where reliable soil analysis services are unavailable. This situation is prevalent in many developing countries.

Module 4.1-2 Calculating fertilizer rates in cereals using omission plot data.

Treatment	Yield, kg/ha
1. Ample rates of N*, P and K	5,556
2. N omitted; ample rates of P and K	1,667

* Ample N rate = 150 kg/ha

Agronomic efficiency (AE_N) = (5,556 – 1,667)/150

AE_N = 26 kg of grain per kg of N fertilizer

Module 4.1-2 Calculating fertilizer rates in cereals using omission plot data.

- Assuming the similar soil N supplying capacity and similar level of efficiency (26 kg/kg) for other fields in the area … can calculate the N application rate for different target yields

Field #	Yield target, kg/ha	Omission plot yield, kg/ha	Calculated N rate, kg/ha
1	6,500	1,667	(6,500 - 1,667)/26 = 186
2	4,500	1,667	(4,500 - 1,667)/26 = 109

Module 4.1-2 Calculating fertilizer rates in cereals using omission plot data.

- Recommendations are most accurate when site-specific local values for AE_N omission plot yield and target yield data can be obtained

Crop	N applied only[1]	N with ample P and K[1]	Site-specific nutrient management
Maize	4 - 7	7 - 14	26 - 28[2]
Wheat	7 - 12	17 - 24	20 -28[2]
Rice	7 - 12	14 - 23	22 - 34[3]

[1]Buswas and Sharma. 2008. Indian J. Fert. 4(7):59-62

[2]IPNI unpublished data

[3]Singh et al. 2012. Field Crops Res. 126:63-69

Example Case Studies

CS

Case Study 7.4-1 Use of *Nutrient Expert*, a decision support tool, increased profitability of maize production.
In the Indonesian maize growing regions of Central Lampung and North Sumatra, on-farm trials were conducted to validate Nutrient Expert. Within each region, results were drawn for each practice from five fields in close vicinity to one another.

The Nutrient Expert tool uses information about the field's nutrient supply that is derived either in omission plots or from site and management characteristics that serve as proxies for nutrient supply. The tool recommends rates and timings for application of N, P, and K that differ from the farmers' fertilization practices, which are based on generalized one-size-fits-all regional recommendations, or are estimates that usually do not consider precise site-specific indigenous nutrient supply.

In this case, nutrient supply was estimated from proxy information including soil texture, depth and color, as well as cropping and fertilization history. The attainable maize yield in these two favorable environments was estimated at 9 t/ha, and was used as the yield target for the season. Seed, fertilizer, and grain prices are actual values recorded when the trials were conducted.

On average, use of Nutrient Expert recommendations in Indonesia achieved higher yields with less fertilizer. The higher efficiency and profitability was attained by more closely matching the rate of each nutrient applied to the site's nutrient need, and through the use of improved timing, generally by increasing the number of split applications.

Table 1. Yield and profitability of maize production comparing the farmers' fertilization practice (FFP) based on traditional recommendations and the Nutrient Expert (NE) decision support tool. **Source:** IPNI Southeast Asia (unpublished data).

Maize management parameters	Central Lampung		North Sumatra	
Values per hectare	FFP	NE	FFP	NE
Yield (15.5% moisture, t)	**7.60**	**8.99**	**8.20**	**9.03**
Revenue (USD)	**2,085**	**2,480**	**2,258**	**2,490**
Inorganic fertilizer cost (USD)	130	124	173	163
N (kg)	218	195	175	168
P_2O_5 (kg)	40	34	59	23
K_2O (kg)	23	34	42	53
Organic fertilizer cost (USD)	199	86	-	46
N (kg)	43	20	-	4
P_2O_5 (kg)	24	11	-	4
K_2O (kg)	41	18	-	4
Seed and fertilizer costs (USD)	444	322	286	321
Expected benefit (USD)	**1,640**	**2,158**	**1,972**	**2,169**

References

Pampolino, M. et al. 2011. IPNI, Penang, Malaysia. [On-line].
Witt, C. et al. 2009. IPNI, Penang, Malaysia. [On-line].

IPNI

Case Study 7.4-1. Use of Nutrient Expert, a decision support tool, increased profitability of maize production in on-farm trials in Central Lampung and North Sumatra, Indonesia.

- Nutrient Expert* uses information about the field's nutrient supply that is derived either in omission plots or from site and management characteristics that serve as proxies for nutrient supply.
- The tool recommends rates and timings for application of N, P, and K that differ from the farmers' fertilization practices, which are based on generalized one-size-fits-all regional

*Pampolina et al. 2012. Computers and Electronics in Agric. 88:103-110

Nutrient Expert* recommendation:

- tailored to location-specific conditions
- consistent with 4R approach

Name and/or location: Here; Site A **Field size:** 1 ha

Current yield: 110 cavan (FW) 5.3 t/ha (15.5% MC)

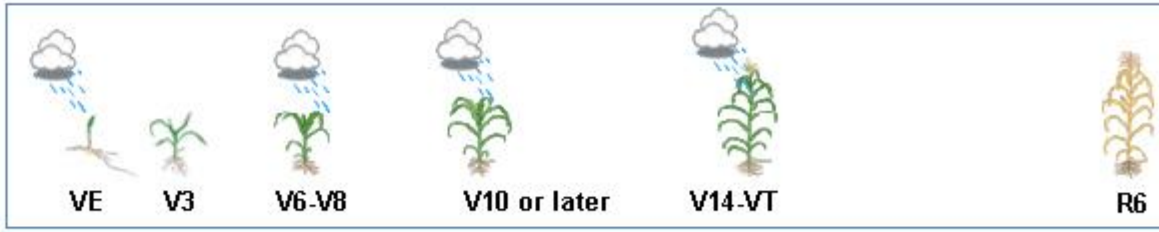
Growing environment: Favorable rainfed

Recommended alternative practice for hybrid maize

Yield goal: 165 cavan (FW) 8.0 t/ha (15.5% MC)

Planting density: 69,444 plants/ha

Distance between rows: 60 cm **Distance between plants:** 24 cm



Growth stage	Days after planting	Soil moisture	Fertilizer sources	Weight of full bag (kg)	Amount (bags)
Basal	0	sufficient	14-14-14	50	6.5
			Urea	50	0
			MOP	50	0.5
V6	25	sufficient	Urea	50	2.5
V10	35	sufficient	Urea	50	2

Other sources of nutrients:

Fertilizer rates are adjusted to field size

Crop residue (maize): high

Organic fertilizer: 0 t

Case Study 7.4-1. Nutrient Expert (NE) improved profitability over Farmers' fertilization practice (FFP) in Indonesia.

Maize management parameters, values per ha	FFP	NE
Yield (15.5% moisture, t)	**7.60**	**8.99**
Revenue (USD)	2,085	2,480
Inorganic fertilizer cost (USD)	130	124
NPK (kg)	218-40-23	195-34-34
Organic fertilizer cost (USD)	199	86
NPK (kg)	43-24-41	20-11-18
Seed and fertilizer cost (USD)	444	322
Expected benefit (USD)	**1,640**	**2,158**

Source: Pampolino, M. et al. 2011. IPNI, Penang, Malaysia. [On-line].
Witt, C. et al. 2009. IPNI, Penang, Malaysia. [On-line].

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Year	Treatment	n	Grain yield (t/ha)	Fertilizer rate (kg/ha)			Profit
				N	P_2O_5	K_2O	(USD/ha)
2010	FP	138	8.6	225	53	33	2,155
	Soil test	138	8.7	195	47	69	2,237
	NE	**127**	**8.8**	**138**	**50**	**52**	**2,219**
2011	FP	185	10.0	222	64	36	2,931
	Soil test	185	10.2	215	65	86	2,990
	NE	**90**	**10.6**	**161**	**49**	**51**	**3,048**

Source: He, P. et al. 2012. Plant Nutrition and Fertilizer Science, 18(2): 499-505.

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