AgCom/09/32
A/09/68
May 2009

The Global "4R" Nutrient Stewardship Framework

for Developing and Delivering Fertilizer Best Management Practices

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

International Fertilizer Industry Association (IFA) - 28, rue Marbeuf - 75008 Paris - France
Tel. +33 1 53 93 05 00 - Fax +33 1 53 93 05 45/47 - ifa@fertilizer.org - www.fertilizer.org

The Global "4R" Nutrient Stewardship Framework

for Developing and Delivering Fertilizer Best Management Practices

Background

Meeting the fast growing food, feed, fiber and bioenergy requirements of the world population implies greater and more efficient use of mineral and organic nutrient sources. At the same time, new expectations are emerging, such as preserving the environment. Farmers also, when shifting from subsistence to commercial farming, expect a higher quality of life. Achieving sustainability in nutrient management is a key concern of a wide range of stakeholders. The diverse expectations among and within stakeholder groups may in fact be integrated and partially reconciled through the development of best management practices (BMPs) that can, for instance, simultaneously increase productivity and profitability, and protect the environment, and thus meet sustainable development goals.

The sustainability concept is built around three pillars: economic, social and environmental goals. Any sustainable option must keep a right balance between the three pillars. In an ideal world, the focus on each of the three pillars would be perfectly balanced. Reality is not as simple, and there is no single ideal mix. The right mix depends largely on the issue, the context and the stakeholders. The concept of sustainability evolves continuously with improvements in knowledge and changes in stakeholder expectations. It also differs widely among regions.

Soils are at the heart of numerous sustainability issues facing humanity today. Because of the many interactions of soil with food production, the environment and economic development, an integrated approach to soil and nutrient management is required. Farmers are pivotal as the direct stewards who care for a large portion of the land, as is the fertilizer industry as a key supplier of crop nutrients for replenishing soil nutrient reserves. Farmers and the fertilizer industry must partner with the other stakeholders (scientists, policy makers, environmental groups, etc.) to develop win-win solutions that improve performance and provide the greatest benefits to all. In the end, all stakeholders are stewards of soils and they need to work together to define and implement actions to maintain or increase soil fertility in a sustainable manner.

Options that best combine the economic, social and environmental expectations of different stakeholder categories can be called "best management practices". They are a critical component of fertilizer product stewardship programmes currently developed and disseminated by the fertilizer industry and its partners in many countries.

This paper describes a global framework (guidelines) designed to facilitate the development of site- and crop-specific fertilizer best management practices (FBMPs) based on sound science. It also defines principles for effective knowledge transfer and the wide adoption of FBMPs by farmers. The principles developed in this paper are universal, but their implementation must be adapted to the local context at different scales.

The Global "4R" Nutrient Stewardship Framework

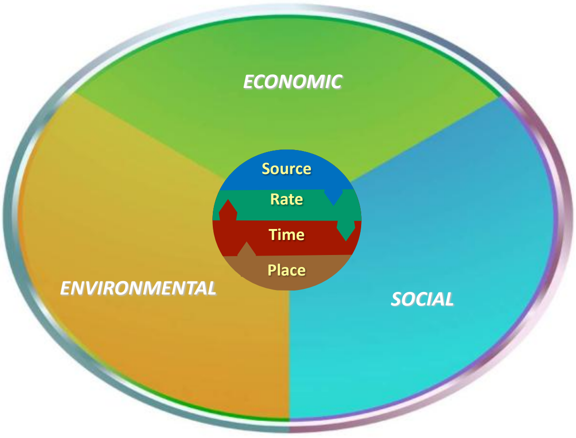
Fertilizer BMPs can be aptly described as the application of the right source (or product) at the right rate, right time and right place[1]. Under the Global "4R" Nutrient Stewardship Framework, the four "rights" (4R) comprehensively convey how fertilizer applications can be managed to achieve economic, social and environmental goals. The framework ensures that FBMPs are developed with consideration of the appropriate focus on all three areas of sustainable development (see Figure 1).

---

[1] *Right Product @ Right Rate, Right Time , Right Place*^{TM} is a trademark registered by the fertilizer industry.

Figure 1: The Global "4R" Nutrient Stewardship Framework

Under the framework, the source, application rate, timing and placement of fertilizers are managed to achieve the economic, social and environmental goals of sustainable development.



Stakeholder objectives and site-specific soil, climate, crop, management systems and logistics all have a significant impact on fertilizer management and must be considered when selecting FBMPs for a specific farm.

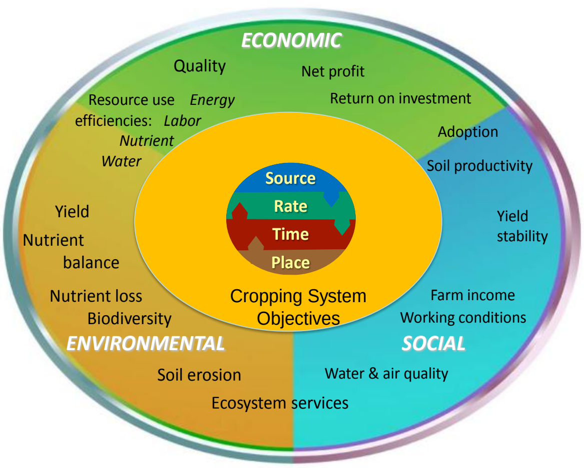
Focusing Efforts by Establishing Performance Objectives

While there are many economic, social and environmental indicators of performance that can be influenced through the "4R" framework, it is prudent to focus efforts on a few key objectives and establish related performance indicators. The selected indicators and objectives will vary depending upon site-specific conditions and stakeholder input. For example, a grower may choose FBMPs to achieve a target yield (for food supply and income generation) and to reduce nitrous oxide emissions, while striving to increase soil organic matter. Another grower will likely have different objectives.

Some of the possible sustainability indicators considered within the "4R" framework are illustrated in Figure 2. It is important to note that the outcome of implementation of fertilizer BMPs or specific combinations of source, rate, time and place is expressed in the performance of the cropping system. Cropping system performance can include objectives such as productivity in terms of yields produced, profitability to the producer, maintenance of long-term soil productivity, and minimized impact on air and water quality in the surrounding environment (Box 1). Performance indicators for the cropping system reflect the outcome of implementing the 4Rs, but are in addition influenced by other aspects of crop management. Performance evaluation of fertilizer practices, therefore, cannot be independent of that of crop production practices in general.

Figure 2: A Global Framework for FBMPs within Cropping Systems

Nutrient use BMPs—applying the right nutrient source at the right rate, time and place—integrate with agronomic BMPs selected to achieve crop management objectives. A balanced set of performance indicators can reflect the influence of nutrient use BMPs on crop management at the farm level, and on broader economic, environmental and social goals. Stakeholder input into performance indicators is an essential part of the process of sustainable development.



Box 1: Integrating Sustainability Goals and Cropping System Management Objectives

Because nutrients are managed as one of several sets of inputs within cropping systems, sustainability goals must be translated into terms that are self-explanatory to the managers of cropping systems. At the practical level, cropping systems are managed for multiple objectives. Best management practices are those that most closely attain those objectives.

At the field level, it is difficult to relate specific crop management practices directly to the three sustainability pillars. Therefore, it is useful to envision cropping system objectives as the vehicle for connecting practices to sustainability. System objectives vary with the region, sector and, often, over time, and they depend on the input of stakeholders as well, including farmers, consumers, rural residents, citizens and others. However, four common practical management objectives at the field or farm level are: productivity, profitability, cropping system durability[2] and environmental health.

Fertilizer BMPs fall within the larger contexts of nutrient, crop and farm management. They comprise an interlinked subset of crop management BMPs. For a fertilizer management practice to be considered “best”, it must harmonize, in a given context, with the other agronomic practices in providing an optimum combination of farm-level management objectives. It follows that the development, evaluation and refinement of BMPs at the farm level must consider these objectives, as must the selection of indicators reflecting their combined impact at different scales, from the field to global levels.

The set of cropping system management objectives at the field or farm level mentioned above can be defined and measured as follows:

- **Productivity.** For cropping systems, the primary measure of productivity is yield per unit area of cropland per unit of time. The quality of the yield is part of the productivity measure. Both can influence profitability, through volume and value, respectively. Productivity should be considered in terms of all resources involved. Multiple efficiencies can and should be calculated to accurately evaluate productivity.
- **Profitability.** Profitability is determined by the difference between the value and the cost of production. Its primary measure is net profit per unit of cropland per unit of time. The profitability impact of a specific management practice is related to its economic efficiency, the increase in yield value in response to the cost of the practice.
- **Cropping system durability.** Durability at the level of the cropping system refers to the influence of time on the resources involved. A durable production system is one in which the quality (or efficiency) of the resources used does not diminish over time, so that for a given cropping system outputs do not decrease when inputs are not increased. One important attribute of crop production systems is that the productivity of the soil resource on which they depend can be enhanced or decreased by changing crop productivity, since the assimilates provided by photosynthesis contribute to soil organic matter, which in turn contributes to many soil characteristics that enhance or decrease crop growth (e.g. porosity, water and nutrient retention, and support for biodiversity within the soil).
- **Environmental health.** Crop production systems have a wide range of effects on surrounding ecosystems through material losses to water and air. These impacts can be felt at local, national, continental or global levels. Specific effects can be limited or controlled by practices designed to optimize resource use efficiency. However, not all effects are controlled to the same level. Some environmentally important losses, such as those of phosphorus or nitrous oxide, involve only a small fraction of the input applied. Others such as ammonia emission or dinitrogen emission from denitrification may involve large losses, and they are largely controlled by consideration of impacts on profitability. Environmental health and cropping system durability are intertwined.

[2] In this context, the term “cropping system durability” refers to the long-term effect of the management practices on the resources used, e.g. maintenance of soil organic matter, fertility and structure, and avoiding soil contamination. It is distinct from “environmental health” in that the impacts are not external to the production system.

Meeting Sustainability Objectives Using the 4Rs

The core of the "4R" framework is the selection of FBMPs to ensure that the right source(s) of plant nutrients are applied at the right rate, time and place to meet sustainabitly objectives. The FBMPs are based on scientific principles and applied research. The application of these scientific principles may differ widely depending on the specific cropping system (region and crop combination) and socio-economic context under consideration (e.g. equipment availability, income levels). Examples of elements of FBMPs are given in Table 1.

Table 1: Examples of Elements of FBMPs

Right Product(s)/ Source(s)	**Right Rate**	**Right Time**	**Right Place**
• Balanced fertilization *(N, P, K, secondary and micronutrients)* • Nutrient form *(urea, nitrate, ammonium)*	• Soil testing • Yield goal analysis • Crop removal balance • Plant tissue analysis • Crop inspection • Record keeping • Variable-rate application technology	• Application timing • Slow- and controlled-release fertilizers • Urease and nitrification inhibitors	• Application method • Incorporation of fertilizer • Applicator maintenance and calibration

The nutrient source(s), 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 2. In addition, the management objectives will vary according to local conditions and stakeholder input. These objectives will significantly influence what is defined as "right" in terms of source, rate, time, and place.

In the following section the scientific principles utilized in the development of FBMPs are discussed and outlined for each area of performance.

Guiding Scientific Principles

1) All Fertilizer BMPs

a) Be consistent with understood process mechanisms.

Take into account the scientific disciplines of soil fertility, plant nutrition, soil physics and chemistry, hydrology, agro-meteorology, etc.

b) Recognize interactions with other cropping system factors.

Examples include cultivar, planting date, plant density, crop rotation, etc.

c) Recognize interactions among nutrient source, rate, time and place.

For example, a controlled-release source does not need to be applied with the same timing as a water-soluble source.

d) Avoid detrimental effects on plant roots, leaves and seedlings.

For example, amounts banded near seedlings need to be kept within safe distances, recognizing ammonia, biuret, and overall salt index of the source.

e) Recognize effects on crop quality as well as yield.

For example, nitrogen influences both yield and the protein content. Protein is an important nutrient in animal and human nutrition, and it influences bread-making quality in wheat, but over-application has a negative impact on plant health and yield quality.

2) **Fertilizer Source**

a) Supply nutrients in plant-available forms.

The nutrient applied is plant-available, or is in a form that converts readily into a plant-available form in the soil.

b) Suit soil physical and chemical properties.

Examples include avoiding nitrate application to flooded soils, surface applications of urea on high pH soils, etc.

c) Recognize interactions between nutrient elements and sources.

Examples include the phosphorus-zinc interaction, nitrogen increasing phosphorus availability, fertilizer complementing manure, etc.

d) Recognize blend compatibility.

Certain combinations of sources/products attract moisture when mixed, limiting uniformity of application of the blended material; granule size should be similar to avoid product segregation, etc.

e) Recognize crop sensitivities to associated elements.

Most nutrients have an accompanying ion that may be beneficial, neutral or detrimental to some crops. For example, the chloride accompanying potassium in muriate of potash is beneficial to maize but can be detrimental to the quality of some fruits and vegetables.

f) Control effects of non-nutritive elements.

For example, natural deposits of phosphate are enriched in several non-nutritive trace metals, including cadmium. The level of addition of these elements should be kept within acceptable limits.

3) **Fertilizer Rate**

a) Assess soil nutrient supply.

Practices used may include soil and plant analysis, response experiments, etc.

b) Assess all available nutrient sources.

Includes quantity and plant availability of nutrients in crop residues, green manures, animal manure, composts, biosolids, irrigation water, atmospheric deposition and manufactured fertilizers.

c) Assess plant demand.

The quantity of nutrient taken up in one season depends on crop yield and nutrient content. Accurate assessment of attainable yield is important.

d) Predict fertilizer use efficiency.

Some loss is unavoidable, so to meet plant demand, the amount must be considered.

e) Consider season-to-season variability in nutrient demand.

Yield potential and nutrient demand are affected by season-to-season variability in climate and other factors, including management, providing opportunities for real-time nutrient management with variable fertilizer rates (technologies include chlorophyll meter, leaf color chart, etc.).

f) Consider nutrient budgets.

If the output of nutrients from a cropping system exceeds inputs, soil fertility declines in the long term. In the opposite situation, environmental quality may be affected.

g) Consider rate-specific economics.

Taking into account spatial and temporal yield variability, for nutrients unlikely to be retained in the soil, the most economic rate of application is where the last unit of nutrient applied is equal in value to the increase in crop yield it is anticipated to generate (law of diminishing returns).

Residual value of soil nutrients to future crops should be considered.

4) Fertilizer Timing

a) Assess timing of crop uptake.

Depends on planting date, plant growth characteristics, sensitivity to deficiencies at particular growth stages, etc. Nutrient supply must be synchronized with the crop's nutrient requirements, which usually follows an S-shaped curve.

b) 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 the release through mineralization, deficiencies may limit productivity.

c) Assess nutrient release and availability from fertilizer products

Release rate and availability of fertilizer nutrients are influenced by weather and soil moisture conditions at application, resulting in potential significant nutrient and yield losses if not synchronized with the crop's requirements.

d) Recognize timing of weather factors influencing nutrient loss.

Specific forms of a nutrient can perform better than others under certain climate conditions and in certain seasons. For example, in temperate regions, leaching losses tend to be more frequent in the spring and fall.

e) Evaluate logistics of field operations.

For example, multiple applications of nutrients may or may not combine with those of crop protection products.

Nutrient applications should not delay time-sensitive operations such as planting.

5) Fertilizer Placement

a) Recognize root-soil dynamics.

Roots of annual crops explore soil progressively over the season. Placement needs to ensure nutrients are intercepted as needed. An example is the band placement of phosphate fertilizer for maize, ensuring sufficient nutrition of the young seedling, increasing yields substantially even though amounts applied and taken up are small.

b) Manage spatial soil variability within fields and among farms.

Soils may affect crop yield potential and vary in nutrient supplying capacity or nutrient loss potential.

c) Fit needs of tillage system.

Recognize logistics of soil preparation.

Ensure subsurface applications maintain soil coverage by crop residue.

d) Limit potential off-field transport of nutrients.

Identify fields and field areas most prone to surface runoff, drainage discharge and gaseous losses.

Keep nutrient losses through runoff, leaching, volatilization and denitrification within acceptable limits.

The number of scientific principles applicable to a given practical situation is considerable. Narrowing down to a practical set of appropriate BMPs requires the involvement of individuals who are qualified to deal with these principles and knowledgeable in implementation. To varying degrees, producers and advisers need education on BMPs and their underlying scientific principles.

Box 2: Cropping System Considerations

The following professional and pragmatic practices should be considered when integrating FBMPs and cropping system objectives to achieve sustainability goals.

- <u>Seek practical measured validation.</u>

  Applied field testing should reflect effects on crop management objectives, with control for natural sources of variability through replication and randomization, and verified by peer-reviewed publication in appropriate science literature.

  Specify claimed benefits in clear language, identifying necessary context and associated costs, risks and drawbacks.

- <u>Recognize and adapt to risks.</u>

  Weather, pests and diseases influence crop growth, nutrient uptake and response to fertilizers. Socio-economic factors must be considered in adapting response to risk.

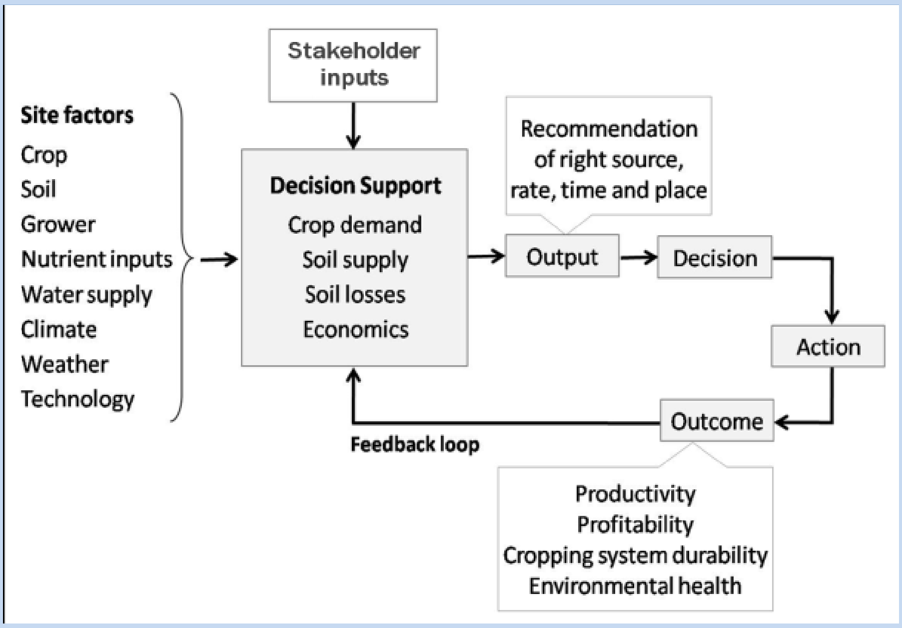
- <u>Define performance indicators and benchmarks.</u>

  Using a participatory process, identify practical indicators that portray performance on crop management objectives and on sustainability goals.

- <u>Ensure two-way feedback between global and practical levels.</u>

  Best management practices are site- and context-specific, dynamic, and they evolve as the context and the environment change, as science and technology expands understanding and opportunities, and practical experience teaches the astute observer what does or does not work under specific local conditions. Decision support guiding the adoption of FBMPs requires a dynamic process of local refinement (Figure 3). Involvement of farmers, scientists, industry and all other relevant stakeholders knowledgeable in both scientific principles and local conditions is important to this process. It is important to build on farmers' knowledge, experiential learning and social capital for ensuring adoption of FBMPs for small-scale farmers.

Figure 3: Decision Support System for FBMP Adoption



- <u>Consider economics.</u>

  There are varying costs and potential returns for each practice, at the regional and farm levels. These economic factors should be considered in conjunction with cropping system variables.

Effective Delivery of FBMPs

Effective knowledge and technology transfer is an integral part, if not the most challenging part, of FBMPs. To be considered "best", fertilizer management practices must be identified and shaped by and acceptable to the farmers for ensuring their wide adoption. It is important that the recommended practices and transfer mechanisms fit the socio-economic and cultural

environment of the recipients. This approach is valid for all the categories of farmers, but it is more compelling in the case of small-scale subsistence farmers (Box 3).

To achieve adoption, FBMPs must be developed through multi-stakeholder dialogue involving farmers, the fertilizer industry, agricultural research, extension, policy makers, environmental NGOs and other relevant groups. Without such a participatory approach involving farmers' representatives, the recommended FBMPs might not be acceptable to and adopted by farming communities.

Box 3: Diversity of Contexts

IFA has analyzed the diversity of existing fertilizer management contexts. In IFA's "Global Assessment of the Situation of Fertilizer Best Management Practices (FBMPs)", countries have been grouped into four categories of increasing intensification of crop and nutrient management, namely (i) subsistence farming, (ii) farming in transition, often mixed with estate and/or plantation farming, (iii) high technology farming with mostly voluntary practices in nutrient management and (iv) high technology farming with substantial governmental mandate in nutrient management.

To be attractive to farmers, FBMPs have to be practical, profitable, productive, resource use efficient and socially acceptable.

Measurement and Continuous Improvement

Performance indicators need to reflect the influence of FBMPs on the sustainability goals, as shown in Figure 2. To be "best", a management practice must address more than one, and preferably all of the three pillars of sustainable development.

Nutrient use efficiency is often used as the first or most important indicator of performance. While there are many different measures of nutrient use efficiency, any of them describe only part of the role of fertilizer management in cropping system performance. For example, a high partial nutrient balance of 1.0, reflecting nitrogen removal equal to its input, is neither sustainable nor desirable if the soil is losing large amounts of nitrogen by mineralization, as reflected in indicators of soil productivity and nutrient loss. Similarly a recovery efficiency of only 50% for a specific crop can be acceptable if it can be shown that unrecovered nitrogen additions are contributing to the stabilization of soil organic matter, thus keeping nutrient loss indicators at acceptable levels.

Some potential examples of indicators are described in Table 2.

The quantification of these indicators or the definition of complementary sets of indicators is beyond the scope of this paper. There are certainly more indicators for measuring sustainability that could be described and developed, and stakeholder input into this process is essential. The set of indicators and benchmarks that describes the complete impact of FBMPs varies depending on the scale of consideration, and the interests of stakeholders.

The definition of a set of indicators for a specific local condition should involve all relevant stakeholders in order to ensure that the set chosen reflects progress towards the three sustainable development goals. Farmers and agronomists are some, but not all, of the important stakeholders whose interests must be represented. Efforts are underway to add clarity and develop more specific guidance for the process of engaging stakeholders to define management objectives and performance indicators.

Table 2: Examples of Potential Indicators for Measuring Sustainability of FBMPs.

Performance Indicator (*)	**Measurement**	**Comments**	**Related Sustainability Goals**
Yield	Amount of crop harvested per unit of cropland per unit of time.	High yields also reflect high net primary productivity, important for maintaining soil organic matter and soil quality.	Economic Social Environmental
Yield Stability	Resilience of crop yields to variations in biotic and abiotic factors.		Economic Social
Produce Quality	Amount of crop constituents harvested (sugar, protein, minerals, etc.) or other attributes that add value to the harvested product.		Economic Social
Soil Productivity	Monitoring of soil organic matter and/or other soil quality indicators (to be determined) that reflect changes in soil fertility levels.		Economic Environmental
Nutrient Balances	Budgeting of nutrient inputs and outputs, at the soil surface or farm gate.	Nutrient inputs match increasing removals associated with increasing yields.	Economic Environmental
Nutrient Use Efficiency	Yield or nutrient uptake per unit of nutrient applied.	Many expressions are available. Should be measured over multiple years.	Economic Environmental
Water Use Efficiency	Yield per unit of water applied or available.	Relevant to both irrigated and rainfed production.	Economic Social Environmental
Energy Use Efficiency	Yield per unit of energy input.	Critically important for biofuel production.	Economic Social Environmental
Value/Cost Ratio of Fertilization	Value of additional crop volumes and/or higher value of better quality crop thanks to fertilization, relative to fertilization cost.		Economic Social
Adoption	Proportion of producers using a particular BMP.		Social Environmental

** The relative importance among these and other indicators needs to be determined by stakeholder input.*

Conclusion

Through the implementation of FBMPs under the Global “4R” Nutrient Stewardship Framework, farmers can continuously improve their performance and sustainability. The process of implementing practices consisting of specific combinations of source, rate, time and place must be guided by a strong set of scientific principles. Those principles, when seen as part of the global framework, show that the most appropriate set of FBMPs can only be identified at the local level where the full agronomic and socio-economic context of each practice is known. While there is a long history of agronomic and soil fertility research, significant additional work is needed to determine how performance can be further improved by integrating region-specific FBMPs.

Knowledge and technology transfer for the wide adoption of FBMPs is the most challenging phase, in particular in small-scale farming contexts. Multi-stakeholder dialogue and participatory approaches, which take into account the expectations of farming communities and of the wider society, are avenues to knowledge transfer that can result in greater adoption and greater benefits.

The global framework also shows the need for employing a full complement of collectively-agreed indicators to accurately measure performance improvements achieved through adoption of the recommended practices, and to identify areas for continuous improvement and further research.