A Global Framework for Best Management Practices for Fertilizer Use

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Abbreviations for this article: N = nitrogen; P = phosphorus; K = potassium; BMP = best management practice; PPSE = productivity, profitability, sustainability, and environmental health; NUE = nutrient use efficiency.

A Global Framework for Best Management Practices for Fertilizer Use

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 practical 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. On the practical level, however, it is difficult to relate specific crop management practices to these three general aspects. Four practical management objectives are applicable to the practical farm level of all cropping systems (Witt, 2003). These four objectives are **p**roductivity, **p**rofitability, cropping system **s**ustainability, and a favorable biophysical and social **e**nvironment (PPSE). They relate to each other as illustrated in Figure 1.

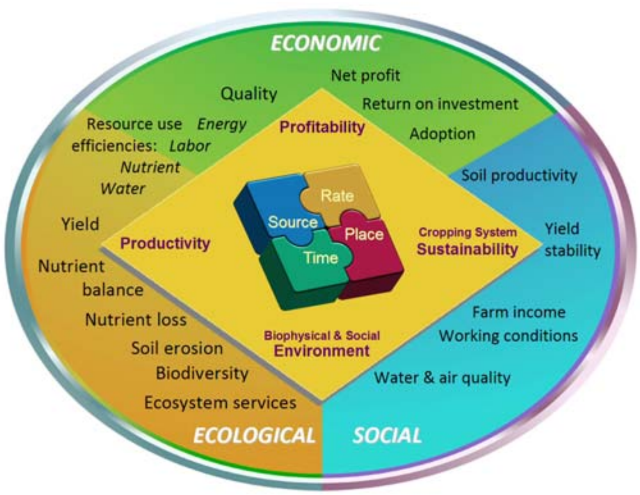

Figure 1. A global framework for best management practices (BMPs) for fertilizer use. *Fertilizer use BMPs—applying the right nutrient source at the right rate, time, and place—integrate with agronomic BMPs selected to achieve crop management objectives of productivity, profitability, sustainability, 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.*

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.

Cropping System Management Objectives

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, or production factors, 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 the amount of increase in gross revenue it generates, less its 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 or controlled by practices designed to optimize efficiency of resource use. However, not all effects are controlled to the same level. Some environmentally important losses, like those of phosphorus (P) or nitrous oxide, involve only a small fraction of the input applied. Others like ammonia emission or denitrification may involve large losses, and they are largely controlled by consideration of impacts on profitability. Environmental health and sustainability are intertwined. 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 management objectives are essentially to support the four objectives identified for cropping systems management. Fertilizer use BMPs can be aptly described as the selection of the right source for application at the right rate, time, and place (Roberts, 2007). Specific scientific principles apply to these BMPs as a group and individually. These principles are both global and applicable at the farm management level. The application of these scientific principles may differ widely depending on the specific cropping system (region and crop combination) under consideration.

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. In addition, the relative priority among the four management objectives (PPSE) varies according to local conditions. These priorities will guide the degree to which each of the scientific principles is reflected in the choice of BMPs.

Scientific Principles

1) <u>Crop Management BMPs (includes all fertilizer BMPs)</u>

   a) **Seek practical measured validation.**

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

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

   b) **Recognize and adapt to risks.**

      i) Weather, pests, socioeconomic conditions influence management practices, crop growth, nutrient uptake, and response to fertilizers.

   c) **Define performance indicators.**

      i) Using a participatory process, identify practical measurements that describe local impact on all four crop management objectives (PPSE).

   d) **Ensure two-way feedback between the global scale and the practical farm level.**

      i) "BMPs are dynamic and evolve as science and technology expands our understanding and opportunities, and practical experience teaches the astute observer what does or does not work under specific local conditions" (Fixen, 2007). Decision support guiding the adoption of fertilizer BMPs requires a dynamic process of local refinement (Figure 2). Involvement of individuals knowledgeable in both scientific principles and local conditions is important to this process. Palis et al. (2007) emphasized the importance of building on farmer knowledge, experiential learning, and social capital for ensuring adoption of fertilizer BMPs for small scale farmers in Asia.

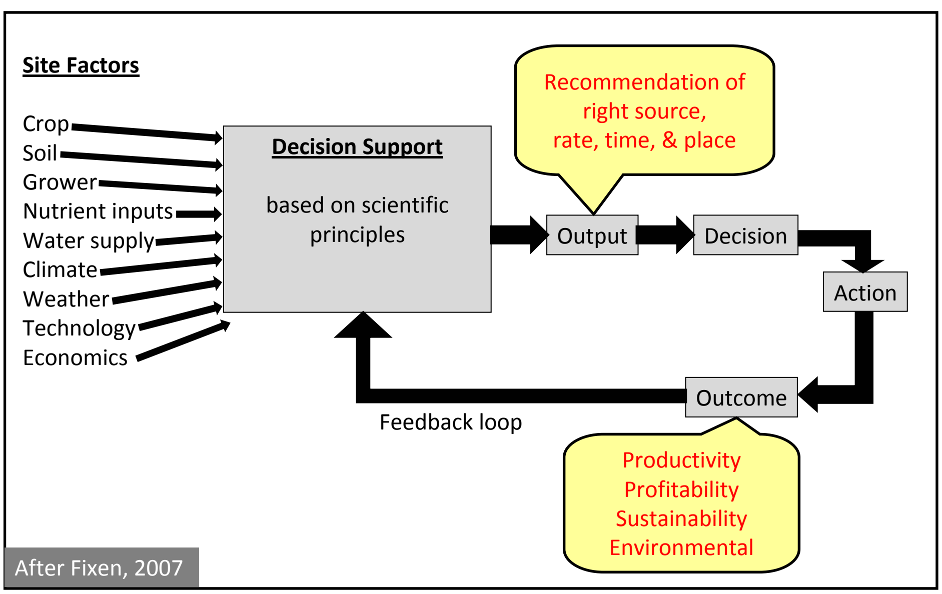

Figure 2. *Decision support for the development, evaluation, and adaptation of fertilizer BMPs requires a dynamic process of local refinement.*

2) **Fertilizer BMPs (includes source, rate, place, and time)**

   a) **Be consistent with understood process mechanisms.**

      i) Specific to the scientific disciplines of soil fertility, plant nutrition, soil chemistry, hydrology, agrometeorology, etc.

   b) **Recognize interactions with other cropping system factors.**

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

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

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

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

      i) For example, amounts banded near seedlings need to be kept within safe limits, recognizing ammonia and/or biuret content and overall salt index of the source.

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

      i) For example, N influences protein as well as yield. Protein is an important nutrient in animal and human nutrition, and influences bread-making quality in wheat.

   f) **Consider economics.**

      i) Specific costs and potential returns for each practice.

3) **Fertilizer Source**

   a) **Supply nutrients in plant-available forms.**

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

   b) **Suit soil physical and chemical properties.**

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

   c) **Recognize synergisms among nutrient elements and sources.**

      i) Examples include the P-zinc interaction, N increasing P availability, fertilizer complementing manure, etc.

   d) **Recognize blend compatibility.**

      i) 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.

   e) **Recognize benefits and sensitivities to associated elements.**

      i) Most nutrients have an accompanying ion that may be beneficial, neutral or detrimental to the crop. For example, the chloride accompanying K in muriate of potash is beneficial to corn, but can be detrimental to the quality of tobacco and some fruits. Some sources of P fertilizer may contain plant-available Ca and S, and small amounts of Mg and micronutrients.

f) **Control effects of non-nutritive elements.**

   i) For example, natural deposits of phosphate rock are enriched in several metals, including cadmium. The level of addition of these elements should be kept within acceptable thresholds.

4) <u>Fertilizer Rate</u>

a) **Use adequate methods to assess soil nutrient supply.**

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

b) **Assess all available indigenous nutrient sources.**

   i) Includes quantity and plant availability of nutrients in manure, composts, biosolids, crop residues, and irrigation water, as well as commercial fertilizers.

c) **Assess plant demand.**

   i) Yield is directly related to the quantity of nutrients taken up by the crop until maturity. The selection of a meaningful yield target attainable with optimal crop and nutrient management and its variability within fields and season to season thus provides important guidance on the estimation of total crop nutrient demand.

d) **Predict fertilizer use efficiency.**

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

e) **Consider soil resource impacts.**

   i) If the output of nutrients from a cropping system exceeds inputs, soil fertility declines in the long term.

f) **Consider rate-specific economics.**

   i) 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 generates (law of diminishing returns).

   ii) For nutrients retained in the soil, their value to future crops should be considered.

   iii) Assess probabilities of predicting economically optimum rates and the effect on net returns arising from error in prediction.

5) **<u>Fertilizer Timing</u>**

   a) **Assess timing of crop uptake.**

      i) Fertilizer 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.

   b) **Assess dynamics of soil nutrient supply.**

      i) 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.

   c) **Recognize timing of weather factors influencing nutrient loss.**

      i) For example, in temperate regions, leaching losses tend to be more frequent in the spring and fall.

   d) **Evaluate logistics of field operations.**

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

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

6) **<u>Fertilizer Placement</u>**

   a) **Recognize root-soil dynamics.**

      i) 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 P fertilizer for corn, ensuring sufficient nutrition of the young seedling, increasing yields substantially even though amounts applied and taken up are small.

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

      i) Soils vary in nutrient supplying capacity and nutrient loss potential.

   c) **Fit needs of tillage system.**

      i) Recognize logistics of soil preparation.

      ii) Ensure subsurface applications maintain soil coverage by crop residue.

   d) **Limit potential off-field transport of nutrients.**

      i) Identify fields and field areas most prone to surface runoff or drainage discharge.

      ii) Keep nutrient losses in surface runoff and drainage water 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.

Performance Indicators

Performance indicators need to reflect the influence of fertilizer BMPS on all four crop management objectives, as shown in Figure 1. Nutrient use efficiency (NUE) is often used as the first or most important indicator. While there are many different measures of NUE (Dobermann, 2007; Snyder and Bruulsema, 2007), any of them describe only part of the role of fertilizer management in cropping system performance. For example, one of the most important performance indicators particularly for N is the agronomic efficiency, i.e. the increase in grain yield per unit fertilizer nutrient applied. However, a low agronomic efficiency is acceptable for nutrients such as P and K where the aim of a fertilizer strategy could be to avoid soil nutrient depletion.

The partial list of indicators shown in Figure 1 is described further in Table 1. A detailed description of these indicators is beyond the scope of this concept paper. There may be additional performance indicators needed to evaluate the performance of specific crops or in specific environments.

The set of performance indicators that describes the complete impact of a combination of fertilizer BMPs varies depending on the scale of consideration. Obviously a wide range of stakeholders need to contribute to the selection of indicators in order to achieve optimum attainment of the four management objectives, PPSE. The framework proposed above is helpful in ensuring that the suite of indicators chosen provides a balanced reflection of the four objectives, in harmony with sustainable development goals.

Conclusion

Best management practices for fertilizer are those that support the achievement of the four main objectives of cropping systems management: productivity, profitability, sustainability, and environmental health. A strong set of scientific principles guiding the development and implementation of fertilizer BMPs has evolved from a long history of agronomic and soil fertility research. Those principles—when seen as part of the global framework—show that the most appropriate set of fertilizer BMPs can only be identified at the local level where the full context of each practice is known. The global framework for these BMPs also shows the need for employing a balanced complement of indicators to accurately describe the benefits and risks of fertilizer use in the context of sustainable development.

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Table 1. Performance indicators for fertilizer BMPs related to crop management objectives.

Management Objective	**Performance Indicator**	**Description**
Productivity	Yield	Amount of crop harvested per unit of cropland per unit of time.
	Quality	Can reflect amounts of crop components harvested (sugar, protein, minerals, etc) or other attributes that add value to the harvested product.
	Nutrient Use Efficiency	Reflects yield or nutrient uptake per unit of nutrient applied.
	Water Use Efficiency	Yield per unit of water applied or available. Relevant to irrigated and rainfed production.
	Labor Use Efficiency	Labor productivity. Labor demand and supply critically linked to number and timing of field operations.
	Energy Use Efficiency	Crop yield per unit of energy input. Critically important for biofuel production.
Profitability	Net Profit	Reflects both volume and value of crop produced, per unit of time, relative to all costs of production. Limitation is inability to deal with externalities that have not been attributed an economic value.
	Return on Investment	Similar to net profit, adding consideration of capital investment and amortization.
Sustainability	Adoption	Proportion of producers using particular BMPs. Often easily measured, but context is important.
	Soil Productivity	Reflects changes in soil fertility levels, soil organic matter, and other soil quality indicators.
	Yield Stability	Resilience of crop yields to variations in weather and pests.
	Farm Income	Improvements in livelihood.
	Working conditions	Quality of life issues.
Environmental Health	Water & Air Quality	Concentration and nutrient loading in water bodies of the agricultural watershed or airshed. Limited ability to monitor at farm scale; monitoring at the watershed, regional and global scales is an important public service.
	Ecosystem Services	Difficult to quantify. Important to identify. Can include crop dependence on natural predators, link to outdoor recreation, hunting, fishing, etc.
	Biodiversity	Difficult to quantify – can be descriptive.
	Soil Erosion	Degree of soil coverage by actively growing crops and crop residues.
	Nutrient Loss	Specific losses of nutrients to water and air. Since there are many pathways, these can be difficult to measure at the farm level.
	Nutrient Balance	A total account of nutrient inputs and outputs, at the soil surface or farm gate. The requirement for nutrient inputs is often linked to the increasing nutrient removal with harvested products as yields increase.

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