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ScienceDirect
Procedia Engineering 83 (2014) 365 – 370
Procedia Engineering
www.elsevier.com/locate/procedia

“SYMPHOS 2013”, 2nd International Symposium on Innovation and Technology in the Phosphate Industry

4R Nutrient Stewardship for Improved Nutrient Use Efficiency

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Abstract

Fertilizers play a significant role in securing the production of food crops around the world. In fact, it is estimated that fertilizers currently support 40-60% of all crop production currently. Meeting future food security targets requires the responsible use of fertilizer nutrients. The 4R Nutrient Stewardship guidelines were developed by the fertilizer industry as a process to guide fertilizer Best Management Practices (BMP) in all regions of the world. This approach was required to address the growing concern that fertilizers are applied indiscriminately to the detriment of the environment. Given that farmers purchase fertilizers at world prices in most regions, and these prices have been steadily increasing over time, most users are very cautious about the rates of nutrients they apply. To avoid unnecessary policy intervention by governments, the fertilizer industry needs to be unified in their promotion of BMPs that support improved nutrient use efficiency and environmental sustainability, while supporting the farmer’s profitability. This ultimately comes down to developing appropriate recommendations that match crop nutrient requirements fertilizer additions and minimize nutrient losses from fields. This lead to the 4R Nutrient Stewardship concept, applying the Right Source of nutrients, at the Right Rate, at the Right Time and in the Right Place. Right source means matching the fertilizer to the crop need and soil properties. A major part of source is balance between the various nutrients, a major challenge globally in improving nutrient use efficiency. Finally, some fertilizer products are preferred to others based on the soil properties, like pH. Right rate means matching the fertilizer applied to the crop need – simple as that. However, this is far from being a simple concept when you consider the variations in yield goals, previous crop management, crop residue management, influence of legume crops in rotation, etc. Adding too much fertilizer leads to residual nutrients in the soil and losses to the environment. Ultimately, striking a balance between the crop needs, environmental conditions and the farmers economic situation is required. Right time means making fertilizer nutrients available to the crop when they are needed. Nutrient use efficiency can be increased significantly when their availability is synchronized with crop demand. Split time of application, slow and controlled release fertilizer technology, stabilizers and inhibitors are just a few examples of how fertilizer nutrients can be better timed for efficient crop uptake. Right place means making every effort to keep nutrients where crops can use them. This is an issue which poses the greatest challenge in small holder agricultural systems, where most fertilizer is broadcast applied, and in many cases without incorporation. Research indicates that fertilizer placement can not only improve crop response, but also improve fertilizer use efficiency significantly by lowering nutrient application rates. Adaptation to non-mechanized agriculture have been made in certain regions which clearly support efforts to modify fertilizer placement as a BMP.

Peer-review under responsibility of the Scientific Committee of SYMPHOS 2013

Keywords: Nutrient Stewardship, fertilizers, soil, food;

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1877-7058
Peer-review under responsibility of the Scientific Committee of SYMPHOS 2013
doi:10.1016/j.proeng.2014.09.029

1. Introduction

Current and future food security needs are becoming ever more dependent on a sufficient supply and efficient use of mineral and organic nutrient resources. The growing and competitive demand for food, feed, fiber and bioenergy crop products is seriously taxing the worlds soil resources. This is occurring at the same time as society becomes ever more concerned about resource management practices and the environment, especially when it comes to nutrient management. On the farm, a global shortage of labor and increasing cost of production has heightened interest in increasing production in an efficient manner. These diverse expectations from farmers and the community in general may be addressed through the development of best management practices (BMPs) that can both increase productivity and profitability, while ensuring improved environmental protection.

Soil health and productivity is one of the principal issues influencing food security and sustainable communities around the world. The linkage between soil quality and food production are clear, with chemical, physical and biological limitations of world soils seriously limiting future productivity increases. Correcting this requires the implementation of integrated management approaches, with nutrient management playing a significant role. However, it is ultimately the profitability of such practices on the farm that will govern the direction with which farmers will change to address productivity challenges. Success in improving farm management practices to support food production and soil health will come from partnership, linking the interests of farmers with those who can develop win-win solutions.

4R Nutrient Stewardship

The definition of BMPs varies considerably, but can best be described here as "practices which have been proven in research and tested through farmer implementation to give optimum production potential, input efficiency and environmental protection" (1). This definition comes from the fertilizer industry, and places emphasis on practicality and productivity, while at the same time including efficiency and environmental protection. It is from this background that fertilizer use practices were evaluated in the effort to come up with acceptable fertilizer BMPs. With this in mind the fertilizer industry has formulated and launched the Global 4R Nutrient Stewardship Framework as a means of linking science to practice, and supporting effective communications with all stakeholders (2-3).

The 4R Nutrient Stewardship framework promotes the application of nutrients using the right source (or product) at the right rate, right time and right place (Figure 1). The framework was established to help convey how fertilizer application can be managed to ensure alignment with economic, social and environmental goals. The objectives of farmers, specifically the soil, climate, crop, management system and logistics all have an overarching impact on the success of such practices and need to be considered when selecting fertilizer BMPs for an individual farm. This highlights the need to bring those people with the science-based principles together with those focused on farm-based implementation so as to develop a flexible framework that can result in economic and efficient adoption of practices (4). It is important to also clarify here that while a presentation on fertilizer BMPs may need to have sufficient technical detail to enable a farmer and his advisor to implement it, there is also a need to ensure the overall objective of the Framework is described in a non-technical manner to impact both policy makers and the general public.

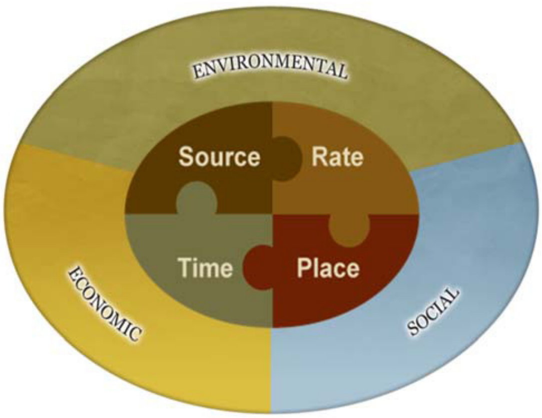

Figure 1. The 4R nutrient stewardship concept defines the right source, rate, time, and place for fertilizer application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the plant ecosystem.

Scientific Principles

Recommendations used for fertilizers begin with the application of scientific principles to address the questions of which nutrient source to select, what rate of application to use, what is the best time to apply nutrients and is there a preferred placement option for the nutrient application to improve the nutrient use efficiency. If we can properly use the fundamental sciences of physics, chemistry and biology, we should be able to properly understand the growing of plants in soil. In fact, it is the application of these sciences that has developed the disciplines of soil fertility and plant nutrition in agriculture.

Science studies and describes both the underlying processes and whole systems. We can categorize the underlying processes under headings of source, rate, time and place. Science also studies and describes whole systems. Both levels of science are relevant, because there are gaps in the knowledge of the fundamental processes, and crop production systems or plant ecosystems are complex, and can respond in unanticipated ways to the application of nutrients. So the science backing a particular practice needs to include both that which documents how the practice works at the basic level, and that which measures the outcome in terms of changes in performance of the cropping system in which fertilizers are applied.

The scientific principles of managing crop nutrients are universal. They underscore the physical processes relating the use of nutrients to their impact on crops and soils and to their fate. They represent what science has discovered about the links between management and possible performance goals. They give an excellent framework to ensure that none of the known laws of nature are ignored in the development of recommendations. You can draw these principles from any textbook on soil fertility, and pull out further information on them.

However, we need to acknowledge gaps in scientific knowledge, and limitations to our application of such knowledge. Thus the need still arises for evaluation of outcomes, even when recommendations are developed on the best scientific principles available. Evaluating the outcome requires performance indicators.

Performance Indicators

Performance is the outcome of implementing a practice. The impacts of fertilizer management are expressed in the performance of the cropping system. Performance includes the increase in yield, quality, and profit resulting from a fertilizer application and extends to long-term effects on soil fertility levels and on losses of nutrients to water and air. It also includes impacts on the regional economy and social conditions—for example, affordable food. Not all aspects of performance can be measured on each farm, but all should be assessed. Performance indicators are simpler measures that can be done on actual farms. Stakeholders need to agree that they reflect their aspirations for performance, and that the indicators correlate well to actual measurements. For example, where soil erosion is a major issue and a large source of nutrient loss, an indicator measuring crop residues covering the soil at critical times may be suitable.

Since fertilizer applications have multiple impacts, no single measure or indicator provides a complete reflection of performance. Neither can all possible impacts be measured. Stakeholders need to select the performance measures and indicators that relate to the issues of greatest concern. The performance indicators shown in Table 1 form a partial list. It is important to recognize that none of these is affected by fertilizer management alone. All can be improved by applying 4R nutrient stewardship, but they also depend on sound management of all practices applied to the cropping system. Crop managers or crop advisers cannot select the most important performance indicator on their own. Stakeholder input is required to select performance indicators representing progress on the goals considered important by all.

Table 1. Sustainability issues related to fertilizer recommendations.

1. Food and nutrition security
2. Employment
3. Soil fertility
4. Cadmium in soil
5. Eutrophication
6. Non-renewable resources
7. Greenhouse gas emissions
8. Stratospheric ozone depletion (N2O)
9. Air quality: ammonia, smog
10. Water quality: nitrate, algae
11. Public perception

In 4R Nutrient Stewardship, individuals working on the parts remain cognizant of the whole. Scientists working on optimum rates pay attention to source, timing and placement as well, and make sure the performance is assessed comprehensively. Stakeholders with specific interests in a certain outcome – for example, practices to improve water quality – are informed of the linkages of such practices to other aspects of performance. The integrated effect on system performance as a whole needs to be the main guiding criterion.

Evaluating Outcomes

The evaluation of outcomes takes place on several levels within 4R nutrient stewardship (Figure 2). At the farm level, farmers and their advisers make decisions – based on local site factors and implement them. Progressive farmers always evaluate the outcome of the decision. If they follow 4R nutrient stewardship, this evaluation of outcome is based on sustainability performance informed by stakeholders, and this evaluation influences the next cycle of decisions. At a more regional level, agronomic scientists work to provide decision support tools for farmers. Their output is a recommendation of the right source, rate, time and place – again in relation to local site factors. Progressive researchers also need to evaluate outcome, and if they follow 4R nutrient stewardship, this evaluation of outcome is based on sustainability performance informed by stakeholders – and influences the next revision of their recommendations. The same applies to the policy level, which supports research and extension and influences the context within which farmers, advisers and research scientists work together. Ultimately, the goal is to develop a process of adaptive management in which improved management practices come from a process of continuous assessment.

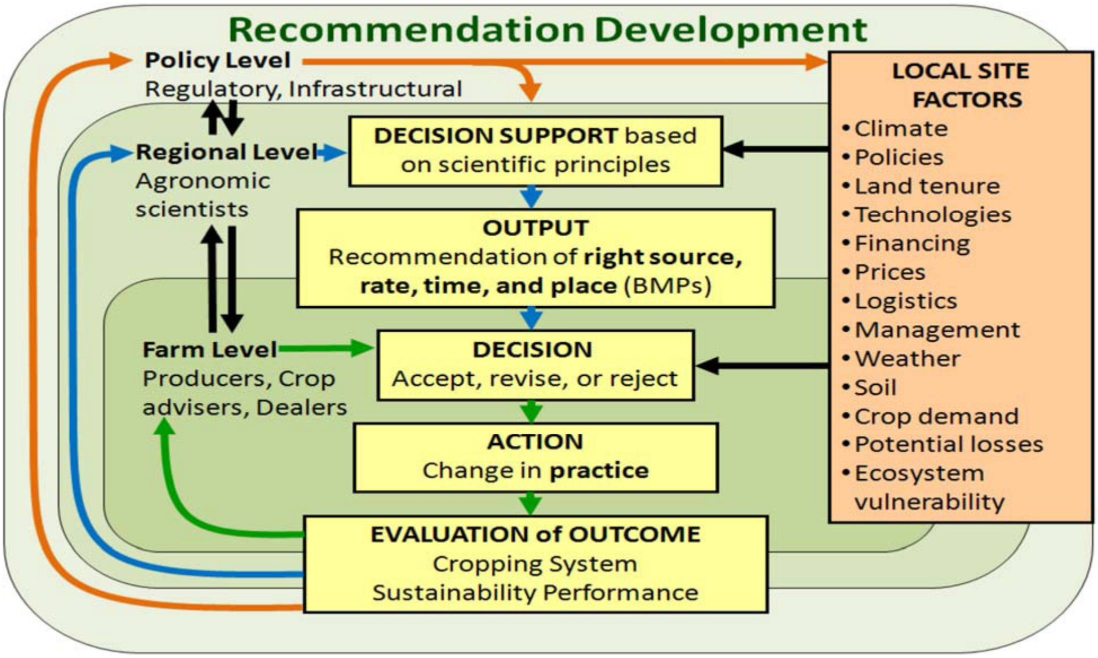

Figure 2. The 4R Nutrient Stewardship concept requires evaluation of sustainability performance, whether applied on-farm by producers and advisers, in recommendation development by agronomic scientists, or in consideration at the policy level. Practical decisions depend on close attention being paid to the full range of local site factors.

4R Nutrient Stewardship – Considerations for Phosphorus Management

1. Selecting the Right Source

While the selection of the most appropriate fertilizer source seems a simple enough task, there are many factors that ultimately impact on this decision (3, 5). Likely the most important factor is the availability of various materials to the farmer, particularly when we talk about small-holders who are seriously limited by transportation. This situation is particularly evident in countries like China, where most farmers have access to two fertilizer products, a compound fertilizer and urea, seriously limiting any opportunity to apply nutrient rates tailored specifically for their field. Selecting a fertilizer source starts with an assessment of which nutrients are necessary. This information comes from some form of site diagnostics, such as soil or tissue testing, crop removal rates in harvested crops or deletion plot assessment. IPNI has been working in Asia and Africa to develop a nutrient decision support system tool which guides fertilizer application decisions in the absence of soil testing, the most common situation on small-holder farms.

It is common for farmers to often focus their fertilizer source decision on a single nutrient which is in greatest need at the exclusion of other nutrients. This often comes from experience in seeing demonstration plots showing crop response to N. However, the maximum value obtained from N only comes if other macro, secondary and in some cases micronutrients are addressed. How often have we encountered situations where continued application of N, or N + P, have resulted in yield stagnation, all a result of serious K, S and Zn deficiencies. In the absence of balanced nutrition it is impossible to support healthy plant growth,

Fertilizer forms include fluid fertilizers, fertilizer suspensions and dry granular products in the form of straight grades (e.g., Urea), compound fertilizers (e.g., 20-20-20) and bulk blends developed for a specific crop or location. Selection of a fertilizer source also requires attention to how it is to be managed. For example, if placed with the seed the salt index of the fertilizer, and tolerance of the crop, must be considered.

The most commonly used fertilizer P sources are mono-ammonium P (MAP) and diammonium P (DAP). Both of these products are also N sources, supporting the research which has clearly shown enhanced P uptake when applied with ammonia N in a common granule or in a concentrated band (6-7). These two products differ in the pH directly around the granule following dissolving – the solution of MAP has a pH of <4, while that of DAP has a pH = 8. So in high pH soils, DAP will release ammonia and harm germinating seedlings. On alkaline soils, surface applied DAP can release more N as ammonia than MAP. However, there is no agronomic difference in the P value of the two products. Liquid P is normally sold as ammonium poly-phosphate (APP), with half the product's P in the orthophosphate form (plant available) and the remaining in polyphosphate compounds. On reaction with soil water the polyphosphate compounds convert to plant-available orthophosphate and become available for plant uptake.

2. Selecting the Right Rate

Under- or over application of nutrients posses a major challenge to agriculture production in most parts of the developing world (3, 8). The selection of that fertilizer rate which is most likely to achieve optimized production and profit requires careful attention to a number of soil, crop and environmental parameters. While over application may seem an unrealistic scenario for most farmers, it is actually very common in areas where there is an absence of analytical methods or inappropriate recommendations. Under application of course has been identified by many agricultural workers as the principal cause of low productivity, and profitability of small-holder farming systems. The first step in establishing the right rate of fertilizer is understanding the yield commonly grown in a field, and the associated removal of nutrients from the field. Secondly, we need to somehow assess the soil's indigenous nutrient supplying ability, that is how much nutrients can we count on coming from the soil? In those areas of the world where only the grain is removed from a field, the nutrient requirements are considerably lower than where the crop residue is also removed for livestock or sale purposes.

Soil testing has traditionally been the most commonly recommended means of assessing fertilizer rates. A soil test really involves 3 components, the sampling, the chemical analysis of the sample, and finally the recommendation based on the philosophy of the laboratory or advisory service. Plant based approaches to assessing nutrient requirements are also used in areas where access to soil testing is limited by either cost, excessive number of farm holdings or timeliness in multiple cropping systems. Factors affecting a recommendation include the crop to be grown, the soil nutrient supply, the yield goal of the farmer and environmental factors that impact on yield such as water supply and temperatures. In season tools like leaf color charts, SPAD meters and optical sensors have also been used to assess in-season N requirements of crops. These tools provide a means of assessing the crop nutrient supply based on the color or biomass production of the crop.

3. Right Timing of Application

The optimum timing of nutrient applications to crops ensures their adequate supply during peak uptake and critical growth stages (3, 9). Timing also plays a major role in reducing the loss of nutrients into the environment by ensuring a supply when crop demand is high. Timing considerations are usually site specific, being impacted by the local environmental conditions and management practice capabilities of the farmer. An excellent example of this is the growing practice in China of farmers applying all of their N to crops at planting due to the shortage of mid-season labor to support split applications. This comes as a time management reality for these farmers, after years of research has clearly demonstrated the benefits of splitting fertilizer N application to optimize crop yield response and improve N use efficiency.

The fertilizer form selected can often impact on optimal timing of application. The best example of this is where N is fall applied before the planting of a spring crop, with only ammonia N sources being recommended. Avoiding nitrate-N sources is critical to avoid over-winter losses of N. Fertilizer technology has provided us with some opportunities to change the traditional fertilizer timing recommendations, in particular the technologies which slow the conversion to nitrate-N or release of N from the fertilizer granule (controlled release). These products have great potential to support applying all N at planting, given that the release will be delayed to such time it mimics a split application.

Phosphorus fertilizer application timing has largely been dealt with using basal, or planting time, application. This helps to ensure the P is available to early developing plants, as well as concentrating the fertilizer application close to the crop seeds minimizing any P fixation by the soil. On soils which have low P fixation potential, it is common to see P fertilizer applied in advance of crop planting, and in some cases the P is applied for multiple crops in rotation. An example of this are the silt loam soils commonly found in the Corn Belt states of the US mid-West. This is not the case in P fixing soils, where high amounts of free Ca, Al or Fe require that annual applications of P close to the planted seeds becomes more important to ensure adequate crop uptake.

4. Right Placement

Fertilizer placement can play a major role in nutrient uptake, especially with immobile nutrients and in those soils with a capacity to fix nutrients. So for nutrients like P, where early season access to the nutrient is critical for cereal crop growth, placement in or near the seed row can have a major impact on crop response. This response occurs as a result of increased branching on the part of cereal crops when they intercept bands of P and N, increasing crop uptake (3, 10). These root responses have not been observed with K, and tend to be less significant when N is placed alone.

Farm management practices play a significant role in determining fertilizer placement. Those farmers who have adopted no-till seeding systems are keen to incorporate a banding operation for fertilizer placement as part of their seeding operation. This has resulted in a number of tillage tool innovations which allow independent seed and fertilizer band placement when no-till seeding. Positioning of the band, relative to the seedrow, becomes critical to ensure the easy access of growing seedlings, while at the same time minimizing any negative impact of fertilizer salts. On the other hand, most small-holder farmers broadcast by hand all fertilizers and most seeds into their fields, preventing them from capturing any benefits which could come from positional placement of fertilizers.

Making 4R Work on the Farm – Adaptive Management

A major component of implementing improved nutrient management practices as outlined in the 4R Nutrient Stewardship strategy is adaptation to each farm and farming operation. The many factors which impact on an individual's ability to make changes in their farming operation are too numerous to mention here. However, crops grown, multiple cropping in a single year, availability of labor, sources of fertilizer nutrients, access to analytical laboratories (both distance and cost) are just a few items which come to mind as being major challenges for most small holder farmers. Let's face it, most of the 4R strategies outlined here are easily adapted to farms in the developed world. Our challenge as we go forward is to find ways to make improvements in the nutrient use efficiency and profitability in farming with fertilizers in the developing world.

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