RECOMMENDATION DEVELOPMENT UNDER 4R NUTRIENT STEWARDSHIP

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Introduction

The 4R Nutrient Stewardship concept defines the right source, rate, timing and placement of plant nutrients as those leading to the economic, social and environmental benefits desired by stakeholders. This implies roles for both science and stakeholder engagement. Scientific data on the linkages to outcomes needs to be communicated to stakeholders to ensure their valid participation and to build public confidence. The 4R Nutrient Stewardship concept helps to link science to practice and communicate it to stakeholders.

Sustainability

The major manufacturers of NPK fertilizers are increasingly emphasizing sustainability. Already seven IPNI members have sustainability reports prominent on their main web page. Most of these reports conform to the international guidelines of the GRI, the Global Reporting Initiative, providing details on performance indicators linked to economic, social and environmental progress. The GRI guidelines require that all stakeholders—shareholders, employees, clients and consumers—for a particular business have input into the content of the sustainability report, particularly the performance indicators reported.

4R Nutrient Stewardship is a concept supported by the global industry. In addition to IPNI, organizations like The Fertilizer Institute (TFI) and the Canadian Fertilizer Institute (CFI) are identifying themselves with 4R and have recently published documents on it. Why are they going this way, and what does it mean?

The fertilizer industry's interest in sustainability reporting is part of a larger business trend. For example, Wal-Mart has adopted sustainability goals that include requiring its suppliers to document sustainable production. The video webcast from their November 12 milestone meeting emphasized agriculture and food products. Can our current crop nutrient recommendation systems provide the data that is needed to verify sustainability?

When Wal-Mart requires this kind of documentation from its suppliers, how far down the value chain will this requirement be passed along? It won't end with the grower. Growers rely on many sources of recommended practice. In the end those recommendations also must also be documented as to how they came about, and how they contribute to sustainability.

Internationally, sustainable development is recognized to consist of three nonnegotiable elements: economic, social, and environmental. Progress in each of those three areas is essential to sustainability. How the progress will be achieved requires input from stakeholders. For fertilizer use to be sustainable, it must support cropping systems that provide economic, social, and environmental benefits.

Right Source @ Right Rate, Right Time, Right Place

The fertilizer industry's nutrient stewardship concept links management of plant nutrition to sustainability. The fertilizer rights—source, rate, time, and place—are connected to the goals of sustainable development (Figure 1).

The connection between the practices and the benefits must be understood well, not only by crop producers and their advisers, but also by those who purchase the products of cropping systems and those who live in the environment impacted by those systems. Programs involving payments to farmers for ecological goods and services—for example, carbon offsets related to greenhouse gas mitigation, loading reductions for water quality credit trading, etc.—depend on a clear public understanding of these linkages and a common language and vocabulary relating to fertilizer management.

Many issues associated with fertilizer use and fertilizer recommendations relate to environmental, social and economic sustainability (Table 1). Some are positive, some negative, but in many the role fertilizer plays can go either way depending on management. On the one hand, nutrient applications increase yields of crops, nourishing the world while sparing land for other uses and increasing the return of organic carbon to the soil, thereby sequestering a greenhouse gas. On the other hand, unmanaged nutrient applications may increase nutrient losses, potentially degrading water and air quality in a number of ways and possibly increasing greenhouse gases. Fertilizer use also has longer-term and larger-scale impacts on soil productivity and the social and economic structure of rural areas. These issues are all part of sustainable development.

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For stakeholders, the 4Rs support an accurate understanding of the big picture, even for those who may not understand all the details of managing crop nutrients.

Who decides what's RIGHT?

The traditional answer to "Who decides what qualifies as a best management practice?" went something like "a team of farmers, researchers, natural resource managers, extension staff and agribusiness professionals." Today there is still no doubt that the expertise of all these people is important to determining the right management on a practical basis. A sustainability-focused approach, however, is more comprehensive and includes input from all stakeholders in determining the indicators, measures, benchmarks and targets for performance of the management practices implemented. So what's right is determined by how these people want the cropping system to perform.

RIGHT is not primarily a scientific term. It's an ethical term. It depends on the values and beliefs of the stakeholders of the system in question. When it comes to cropping systems, the range of stakeholders is broad – it extends to those who consume the products and to those who live in the environment impacted by the cropping system. The perspectives of all these stakeholders must be reflected in the economic, social and environmental goals that are set for the cropping system. Fertilizer management, to be considered "right," must support those goals. All stakeholders have input to the goals. However, the farmer—the manager of the land—is the final decision-maker in selecting the practices suited to the local site-specific soil, weather, and crop production conditions that have the highest probability of meeting the goals. Because all these conditions can influence the decision on the practice selected, right up to and including the day of implementation, local decision-making performs better than a regulatory approach.

The four "rights" of plant nutrition stewardship also have an ethical component. There is a value judgment to choosing the right nutrient source, metering out the right rate at the right time and in the right place. The value judgment is based on how this combination of actions meets sustainability goals. These goals are determined, not by science, but by people—informed by science—who apply their beliefs and values to choose targets for outcomes. For example, in a setting where a pre-plant application of nitrogen optimizes yield but results in excess groundwater nitrate, a stewardship approach would seek a management strategy (perhaps split-application, perhaps a controlled-release source, perhaps a technology yet to be developed) that both optimizes yield and limits nitrate loss to groundwater. If these benefits are understood by the stakeholders, support for changes in technology should be easier to obtain.

Setting sustainability goals involves science communication. Many scientists feel their work is not adequately understood or appreciated, and is not appropriately used in development of policy, regulation and practical recommendations. Science can help define the right management to achieve particular sustainability goals, but scientists must recognize the ethics, beliefs and values of their audience to meaningfully engage public dialogue on such goals.

Scientific Principles

Having described the framework of 4R Nutrient Stewardship, I'd now like to focus on the role of science. Recommendation development begins with the application of scientific principles to questions of nutrient source, rate, timing and placement. The sciences of physics, chemistry and biology are fundamental to the mineral nutrition of plants growing in soils. The application of these sciences has led to development of the scientific disciplines of soil fertility and plant nutrition.

Science studies and describes both underlying process 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 indicators shown in this diagram 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.

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 the 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, producers and their advisers make decisions – based on local site factors --

and implement them. Progressive producers always evaluate outcome. 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. 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 producers, advisers and research scientists work.

Do farmers have the same definition of performance as the other stakeholders? Likely, they put more than a bit more emphasis on profit! Getting fair emphasis on some of the other sustainability goals takes innovation at the policy level. We'll explore examples as we go along.

Where do you envision yourself in the diagram shown in Figure 2? How are you evaluating outcomes? Who are the partners and stakeholders you relate to in evaluating the outcome of your recommendations? How does your advice to growers help them address local site factors? How does your input work its way up to the policy level? Can you envision where the Certified Crop Adviser program fits into this? Are we working together sufficiently to establish the regulatory environment that will allow this system to flourish?

Applying the 4R Nutrient Stewardship Framework poses further questions: What sustainability goals are our recommendations designed to meet? And whose? What performance indicators are being used on-farm? What performance measurements are taken in research? How well are we documenting the performance measurements made? How well are we communicating performance to stakeholders?

Adaptive management – defined as an ongoing process of developing improved management practices for efficient production and resource conservation by use of participatory learning through continuous systematic assessment (Tom Morris, University of Connecticut, personal communication) – matches fairly closely with the 4R Nutrient Stewardship concept as illustrated in Figure 2. The participants are also quite similar. However, its goals – efficient production and resource conservation – are somewhat narrower. Continuous improvement in overall sustainability is an important goal because it is so comprehensive. Adaptive management forms an important component of 4R Nutrient Stewardship.

Example 1 – Nitrous Oxide Emission Reduction Protocol

A recent example of a specific development involving the 4Rs is the Nitrous Oxide Emission Reduction Protocol (NERP). This is being developed by an organization called ClimateCheck in Alberta, and is supported by the fertilizer industry.

One of the first issues addressed was the trade-off between yield and nitrous oxide emissions. International inventories calculate nitrous oxide emissions as functions of amount of fertilizer applied. But reducing N rates could reduce yields, lower water use efficiency and increase soil erosion – not to mention increase demand for crop land to make up for the lost production. By applying principles of 4R nutrient stewardship, source timing and placement are addressed as well as rate, and outcome is evaluated in terms of nitrous oxide per unit of yield rather than per unit of land area.

The quantification approach of the NERP is based on the methods used in Canada's National Inventory Report, prepared to meet Canada's Kyoto commitments and validated by the IPCC. The NERP is developed according to the ISO 14064-2 standard, which meets the requirements of the Alberta Offsets System, and which is compatible with the stated intentions of Canada's Offsets System, of the California Climate Action Registry, and of other voluntary GHG programs in North America. The NERP is the first of its kind in the world, and is being promoted for implementation in the US by The Fertilizer Institute.

The NERP is developed through a process of comprehensive and transparent consultation with science experts for approval under the Alberta Offset System. These science experts represent the major agricultural universities in Canada, Agriculture and Agri-Food Canada, the International Plant Nutrition Institute, provincial soils specialists, and industry stakeholders.

The initial Consultation Workshop for the NERP was held in Calgary, 28 & 29 October 2008. At this Workshop, participating experts approved the general design of the NERP according to the Right Source @ Right Rate, Right Time, Right Place™ (4R) stewardship model of the Canadian Fertilizer Institute, and implementing the country-specific quantification method of Canada's National Inventory Report. Despite achieving consensus on the main elements of the NERP, the participants of the Consultation Workshop identified some gaps requiring further development.

> (For description of the Workshop results, including the decisions and gaps, see http://carbonoffsetsolutions.climatechangecentral.com/files/microsites/OffsetProtocols/ABProtocolDevelopmentWorkshops/NitrousOxideReduction09/NERP-WorkshopReport.pdf)

The gaps identified in the Consultation Workshop were addressed in a Decision Paper, which was submitted to the science experts in an on-line webinar format to further the consensus-building process. The webinar participants resolved the development of the NERP to allow standardization and submission to the formal review and approval process of the Alberta Offset System.

> (For description of the webinar discussion points and decisions, see http://carbonoffsetsolutions.climatechangecentral.com/files/microsites/OffsetProtocols/ABProtocolDevelopmentWorkshops/NitrousOxideReduction09/NERP_Webinar_Discussion_Paper_July_09.pdf)

The NERP will be available in the public domain, as this is required to meet the criteria of the comprehensive and transparent consultation undertaken. That is, the NERP is developed in a standards-setting process which must be public to achieve the highest level of acceptance.

IPNI has developed education materials on this topic. Snyder (2008) discusses the linkage of nutrient source, rate, timing and placement to nitrogen losses and nitrous oxide emissions. This article relates fertilizer management practices to their comprehensive outcomes on greenhouse gas emissions. Large knowledge gaps become apparent as soon as one tries to do this, but this becomes a mechanism for guiding research priorities directed at filling these knowledge gaps.

Example 2 – The P Index in the USDA-NRCS 590 Nutrient Management Practice Standard

The 4R Nutrient Stewardship concept is highly relevant to the application of the phosphorus index as well. The current controversy over the role of the phosphorus index within the USDA-NRCS 590 nutrient management practice standard can be resolved by applying 4R principles. The processes governing P loading to water are universal. Practices to control P loading to water are site-specific.

We need to ask ourselves, Can we define P Index principles for source, rate, time, and place? Also, regarding targets for water quality: Can they be set by stakeholders, informed by science? Can science relate source, rate, time and place to the targets?

A 4R approach would have advantages of consistency, and would help to clarify the roles of individuals and organizations working to resolve nutrient loading issues.

Example 3 – Adapting Corn N Recommendations to Weather

Here's an example of another nutrient recommendation challenge that I don't believe has been resolved. The issue is the impact of weather on nitrogen recommendations for corn. **Figure 3** illustrates just one part of the puzzle, the soil N supply to the plant. Bev Kay's research examined a full-scale field with significant landscape for over six years. Soils within the field ranged from 10 grams/kg organic carbon on the top of the slope to 30 near the bottom. The fascinating finding from the research was the differential response of low and high organic matter soils to the amount of rain received in the spring, between planting and side-dress time. Low organic matter soils on the top of the hill supplied less N the more it rained. High organic matter soils supplied more N with moderate rain than in dry years, but much less N in the wettest years. With such complexity in response, isn't it clear that any recommendation system to improve N use efficiency is going to have to address both weather and within-field spatial variability?

Accountability and Data Access

Sustainable development requires accountability for every step in the process of production.

Fixen (2009) noted "The National Academy of Sciences (2009) now tells beginning scientists that researchers have a responsibility to devise ways to share their data in the best ways possible, mentioning repositories of astronomical images, protein sequences, archaeological data, cell lines, reagents, and transgenic animals as examples. To address unmet communication needs of collaborating scientists, Purdue researchers developed the Network for Computational Nanotechnology (NCN). An outcome of this network was nanoHUB (http://www.nanohub.org). This online community of over 90,000 annual users provides web access to the tools scientists need to collaborate on modeling, research and educational efforts in nanotechnology. Is there need for a "Nutrohub," a global plant nutrition research and education community? Such a community could have numerous groups, each with its own focus, but sharing communication and computing tools. Groups could develop integrated data management processes such as the one illustrated in **Figure 4**, developed for IPNI's Global Maize Project."

The calculation of response probabilities as a function of soil properties requires large assemblies of data sets. Scientists involved in developing recommendations for managing crop nutrients have opportunity to improve by making use of data standardization and sharing tools.

Summary

4R Nutrient Stewardship emphasizes sustainability with a simple message – Right source, rate, time & place. Crop nutrient recommendations will be required to have increased documentation of impact on economic, social, and environmental sustainability. The concept of adaptive management, embedded in 4R Nutrient Stewardship, needs support at the policy level governing regulations impacting the managing of crop nutrients.

References

Kay, B.D., A.A. Mahboubi, E.G. Beauchamp, and R.S. Dharmakeerthi. 2006. Integrating Soil and Weather Data to Describe Variability in Plant Available Nitrogen. Soil Sci. Soc. Am. J. 70:1210–1221.

Fixen, P.E. 2009. Maximizing (Productivity and Efficiency) in Contemporary Agriculture. Proceedings of the International Plant Nutrition Colloquium XVI, University of California, Davis. http://escholarship.org/uc/item/5g87n01k

Murrell, T.S. 2008. Personal communication.

Snyder, 2008. Fertilizer Nitrogen BMPs to Limit Losses that Contribute to Global Warming. June 2008 Ref. # 08057 Item 30-3210. International Plant Nutrition Institute (IPNI), 3500 Parkway Lane, Suite 550, Norcross, Georgia 30092-2806 USA. http://www.ipni.net/bmp

Table 1. Sustainability issues related to fertilizer recommendations.
• Food and nutrition security • Employment • Soil fertility • Cadmium in soil • Eutrophication • Non-renewable resources • Greenhouse gas emissions • Stratospheric ozone depletion (N_2O) • Air quality: ammonia, smog • Water quality: nitrate, algae • Public perception

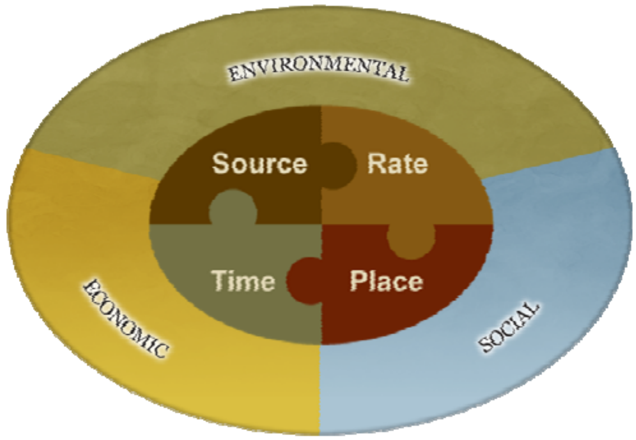

Figure 1. The 4R nutrient stewardship concept defines the right source, rate, time, and place for fertilizer application as those producing the economic, social, and environmental outcomes desired by all stakeholders to the plant ecosystem.

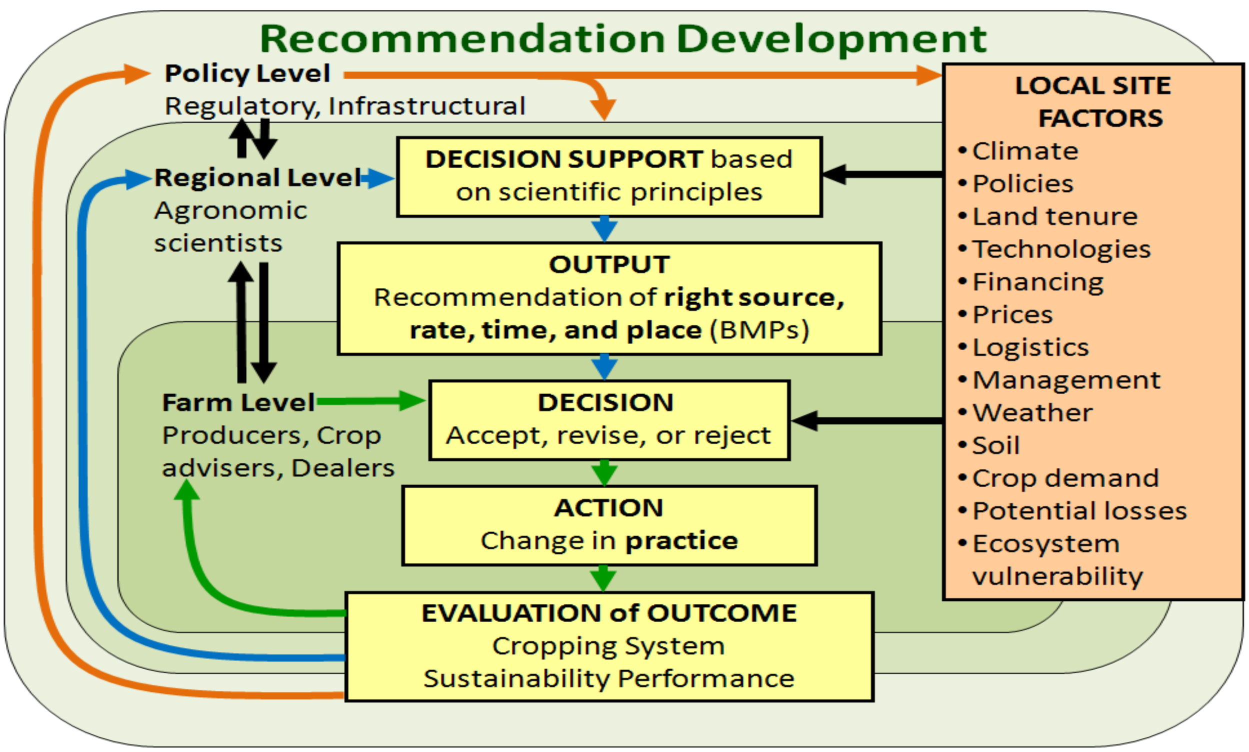

Figure 2. The 4R Nutrient Stewardship concept requires evaluation of sustainability performance, whether applied on-farm by producers and advisers, in recommendation development by agronomic scientists, or in consideration at the policy level. Practical decisions depend on close attention being paid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

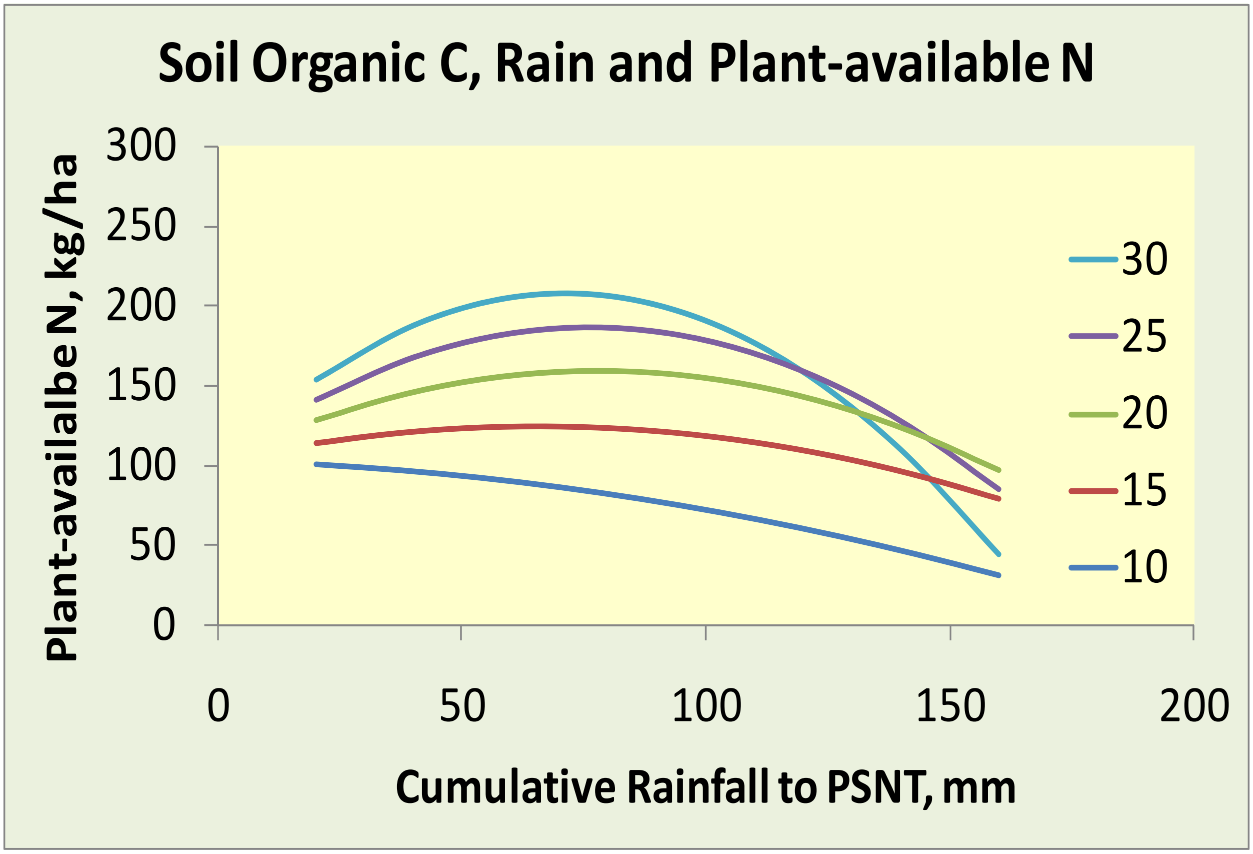

Figure 3. Soil N-supplying capacity responds in a complex fashion to weather. Across a variable landscape, soil ranging in soil organic C content from 10 to 30 g/kg responded differentially to years with differing amounts of rainfall between planting and sidedress (PSNT) time (adapted from Kay et al., 2006).

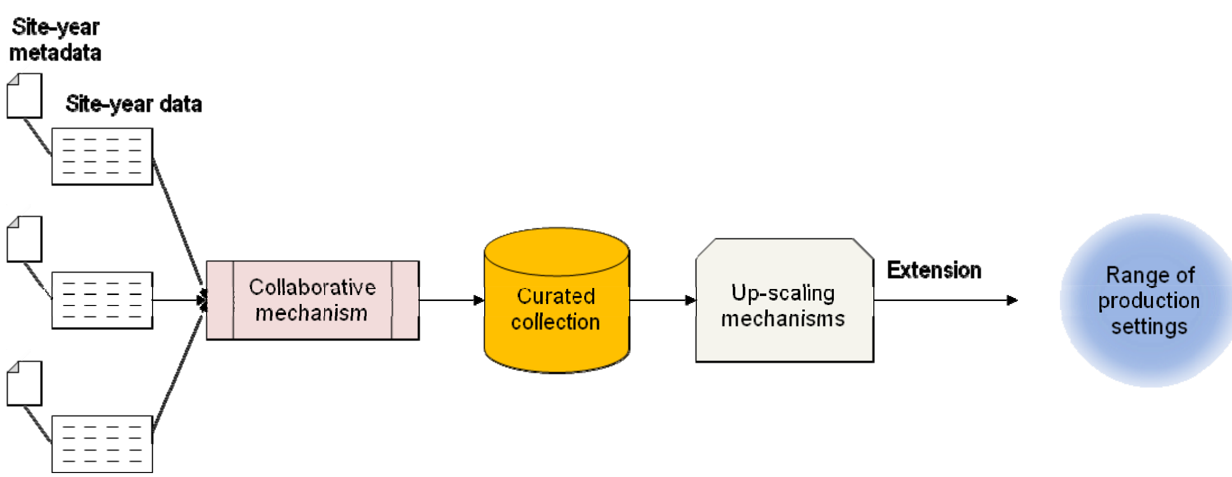

Figure 4. A conceptual model of the process of developing and testing field data across large geographic scales (Murrell, 2008).