Concepts for Facilitating the Improvement of Crop Productivity and Nutrient Use Efficiency

By Paul E. Fixen

The global character of the demand for agricultural products and many of the most critical environmental issues creates a tight linkage between improving productivity and minimizing environmental impact. Merging these two objectives into one goal is likely the only strategic approach that will allow either objective to be accomplished. Sustainably meeting this challenging goal will require close cooperation and understanding among disciplines, across geographies, and between public and private sectors. Three concepts are offered that may facilitate this interaction.

- **The 4R Nutrient Stewardship Framework: Application of the right nutrient source, at the right rate, right time, and right place is a concept that when seen within a framework connecting practices to on-farm objectives and sustainability goals, along with critical performance indicators, can help keep individuals working on "parts" cognizant of the "whole".**
- **Mainstreaming of Simulation Models: Models recently developed can help identify unrealized yield potential and better manage the growing uncertainty of weather and climate.**
- **Global Data Networks: More extensive exploitation of electronic technology that facilitates global data collection, sharing, analysis, and use could expedite the acquisition and application of agronomic and plant nutrition knowledge.**

The Critical Role of Soil Fertility in Food and the Environment

Three underlying factors that encompass many of the major issues humankind will be facing for the next several decades are human nutrition, carbon (C), and land **(Figure 1)**. Two of these factors, C and land, were recently discussed in an inspiring paper presented by Dr. Henry Janzen at the International Symposium on Soil Organic Matter Dynamics (Janzen, 2009). Carbon issues include climate change, cheap energy, and bioenergy. Land issues include land use, soil quality, water use and quality, and waste disposal. Dr. Janzen astutely pointed out that soil organic matter is the common ground between these two factors. The addition of human nutrition as a third factor brings into the picture the issues of food quantity, food quality, and food cost. Of critical importance in the discussion of nutrient management is that a significant component of the common ground of all three of these huge factors is soil fertility and how the management of plant nutrients affects our food supply, our land, and the C cycle.

Agricultural Productivity and Nutrient Use Efficiency (NUE) as One

Sustainable development is widely recognized as consisting of economic, social, and environmental elements. Sustainable nutrient management must support cropping systems that contribute to all three of these elements. Considering the increasing societal demand for food, fiber, and fuel, intense global financial stress, and growing concerns over impacts on water and air quality, simultaneous improvement of productivity and NUE is an essential goal for global agriculture. Striving to improve NUE without also improving productivity simply increases pressure to produce more on other lands that may be less suited to efficient production. Likewise, the squandering of resources to maximize productivity resulting in increased adverse environmental impact puts more pressure on other lands to reduce environmental impact while meeting productivity needs.

Abbreviations and notes: N = nitrogen; BMPs = best management practices.

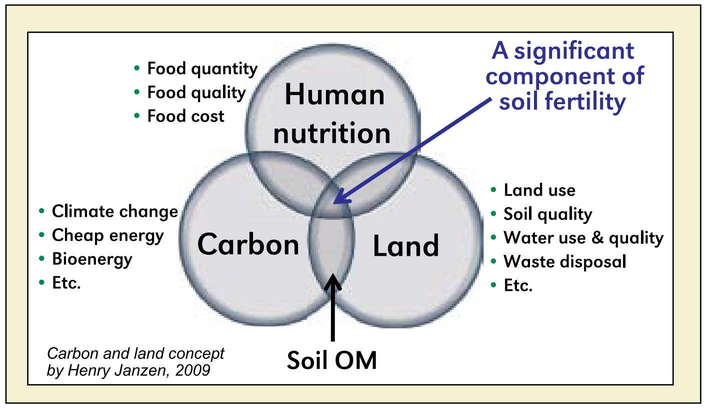


Figure 1. Underlying factors for the challenges of the coming decades.

Simultaneous pursuit of higher productivity and NUE requires caution in how NUE is being measured. Methods of NUE determination and their interpretation were recently reviewed by Dobermann (2007). He also summarized the current status of NUE for major crops around the world, pointing out that

Photo by José Espinosa

Soil fertility greatly impacts the productivity of our land and the carbon cycle.

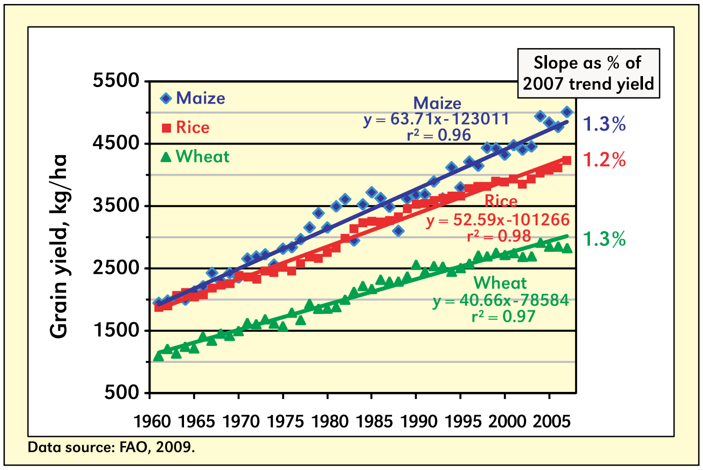


Figure 2. Global cereal yield trends.

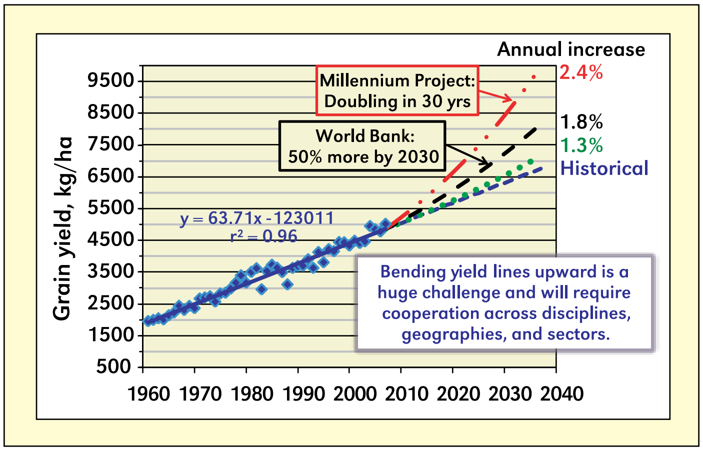


Figure 3. Future demand projections applied to maize yields.

single-year average recovery efficiency for N in farmer fields is often less than 40%, but that the best managers operated at much higher efficiencies. Dobermann used a 6-year study in Nebraska on irrigated continuous maize managed at recommended and intensive levels of plant density and fertilization to illustrate how NUE expressions can be easily misinterpreted. In this study, comparing a higher yielding, intensively managed system to the recommended system for the region, the partial factor productivity (PFP or grain produced per unit of N applied) index indicated that the intensive system was considerably less N efficient than the recommended system. Because fertilizer N contributed to the buildup of soil organic matter in the intensive system, when the change in soil N was taken into account, the two systems had nearly the same system level N efficiency. Dobermann pointed out that over time, this increased soil N supply should eventually reduce the need for fertilizer N, resulting in an increase in PFP. Such effects are particularly noteworthy when striving to increase productivity with more intensive methods where new practices are being implemented that differ from the history for the research plot area or farm field. If cultural practice changes are such that soil organic matter is no longer in steady state, temporary net nutrient immobilization or mineralization can impact apparent NUE.

Some have estimated that the world will need twice as much food within 30 years (Glenn et al., 2008). That is equivalent to maintaining a proportional annual rate of increase of over 2.4% over that 30-year period. Others predict a 50% increase in food demand by 2030 which translates into a 1.8% annual increase (Evans, 2009). Sustainably meeting such demand is a huge challenge and will require close cooperation and understanding among disciplines, across geographies, and between public and private sectors. The magnitude of the challenge is appreciated when such a proportional rate of increase is compared to historical cereal yield trends which have been linear for nearly half a century with slopes equal to only 1.2 to 1.3% of 2007 yields **(Figure 2** and **Figure 3)**. Three concepts are offered here that may facilitate cooperation among the groups needed to accomplish the required productivity and efficiency improvements.

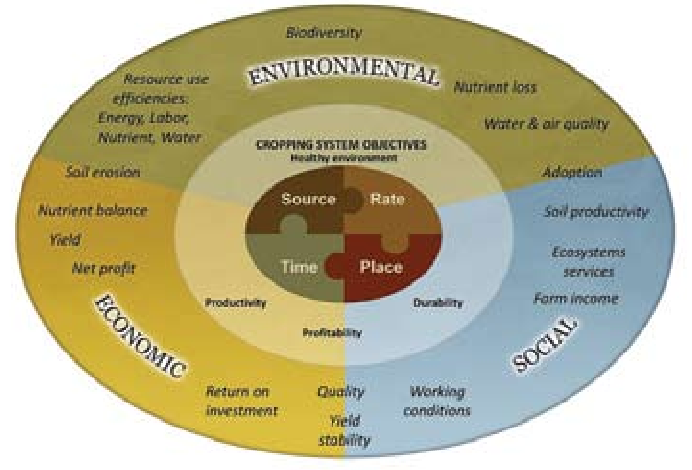


Figure 4. The 4R nutrient stewardship framework (after Bruulsema et. al., 2008).

The 4R Nutrient Stewardship Framework

For plant nutrition science to work well across disciplines, between public and private sectors, and across geographies, a common framework for viewing goals, practices, and performance is likely helpful. The seeds for such a framework were planted more than 20 years ago by Thorup and Stewart (1988) when they wrote: "This means using the right kind of fertilizer, in the right amount, in the right place, at the right time." **Figure 4** is a schematic representation of the 4R nutrient stewardship framework based on the concepts described by Thorup and Stewart (Bruulsema et al., 2008). At its core are the 4Rs – application of the right nutrient source at the right rate, right time, and right place. Best management practices are the in-field manifestation of these 4Rs.

The 4Rs are shown within a cropping system circle because they integrate with agronomic BMPs selected to achieve crop management objectives. Those farm-level crop management objectives contribute toward the larger economic, social and environmental goals of sustainable development. Furthermore, the 4Rs cannot truly be realized if problems exist with other aspects of the cropping system. Darst and Murphy (1994) wrote about the lessons of the Dust Bowl in the USA in the 1930s coupled with a multitude of research studies showing the merits of proper fertilization and other new production technology, catalyzing the fusing of conservation and agronomic BMPs. Science and experience clearly show that the impact of a fertilizer BMP on crop yield, crop quality, profitability and nutrient loss to water or air is greatly influenced by other agronomic (plant population, cultivar, tillage, pest management, etc.) and conservation practices (terracing, strip cropping, residue

Table 1. A comparison of long-term average maize yields in an intensive management study to local average farmer yields (experimental data from Adviento-Borbe et al., 2007).

Average of 2000-2005	Continuous maize	Maize/ soybean
Lancaster County irrigated farmer average, t/ha	10.6	
University recommended treatment, t/ha	14.0	14.7
Intensive high yield management treatment, t/ha	15.0	15.6

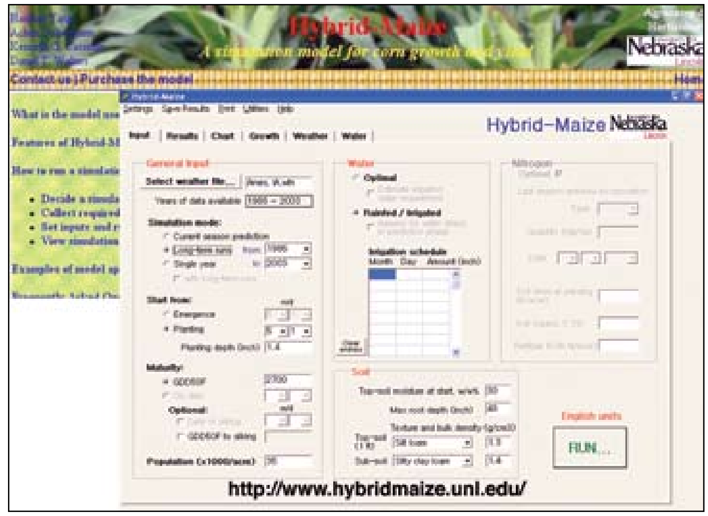
management, riparian buffers, shelter belts, etc.). Practices defined with sufficient specificity to be useful in making on-farm fertilizer use decisions, often are "best" practices only when in the appropriate context of other agronomic and conservation BMPs. A fertilizer BMP can be totally ineffective if the cropping system in which it is employed has other serious inadequacies.

Around the outer circle of the 4R framework are examples of performance indicators. A balanced complement of these indicators can reflect the influence of nutrient BMPs on accomplishment of the goals of sustainable development. The framework shows clearly that system sustainability involves more than yield and NUE, though these are critical indicators. Stakeholder input into performance indicators is an essential part of the process.

Mainstreaming of Simulation Models

Defining the gap between current and potential yields is a useful step towards maximizing productivity and efficiency. FAO recently published a set of such estimates for six maize-producing countries (FAO, 2008). Their evaluation showed a yield gap varying from 4 or 5 t/ha in Mexico or India to zero for the USA. However, such existing general estimates should not be taken too literally relative to specific locations. For example, if one compares the Nebraska irrigated maize yields for the intensively managed treatments discussed earlier to the county average farmer yields for the same time-period, a difference of 4 to 5 t/ha is observed **(Table 1)**, suggesting that a yield gap exists in at least some areas of the USA as well.

Crop simulation models can be useful tools for site-specific estimation of yield gaps. Significant progress has been made in user-friendly crop simulation models with the potential to assist with gap analysis and crop and nutrient management. One example is Hybrid Maize, developed by the University of Nebraska (Yang et al., 2006). Nutrient management functionality for the model is under development. Crop and nutrient management is complex in part because critical processes in plants and in soils are highly dependent on weather. In practice, managers have two options, either base decisions on climatic probabilities or on in-season, near real time information. Simulation models can assist with either approach. Climate change adds another dimension to the utility of weather/climate driven models. A recent report by the National Research Council (2009) stated that the end of climate stationarity requires organized, data-based decision support for climate-sensitive decisions. It would seem that crop and soil management would fall into that category of climate-sensitive decisions. Implications of climate change on plant nutrition



Hybrid-Maize is an example of a crop simulation model for site-specific estimation of the gap between current and potential corn yield.

were recently reviewed by Brouder and Volenec (2008). A thorough review of crop yield gaps with a focus on wheat, rice, and maize, including use of simulation models, was recently published by Lobell et al.(2009).

Global Data Networks

In its recent synthesis report, the International Assessment of Agricultural Knowledge, Science and Technology for Development stated that the main challenge for agricultural knowledge, science and technology (AKST) is to increase the productivity of agriculture in a sustainable manner (IAASTD, 2009). It proposed that one of six high priority natural resource management (NRM) options for action is to "Develop networks of AKST practitioners (farmer organizations, NGOs, government, private sector) to facilitate long-term NRM to enhance benefits from natural resources for the collective good. A second option was to "connect globalization and localization pathways that link locally generated NRM knowledge and innovations to public and private AKST."

In her plenary lecture at the 2008 annual meeting of the American Association for the Advancement of Science, Dr. Nina Fedoroff, Administrator of USAID, said that the only alternative to higher food prices and progressive deforestation is to use contemporary science, including molecular modification, to increase the productivity of the land we already farm and decrease its water demands (Fedoroff, 2008). She went on to say that our research universities and institutes, working together with the business sector and using contemporary electronic resources, have a unique opportunity to accelerate global collaboration.

Can current communication and data management technologies be put to better use in pursuing our productivity and NUE goals? 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 University researchers developed the Network for Computational Nanotechnology (NCN). An outcome of this network was nanoHUB (http://www.nanohub.org). This

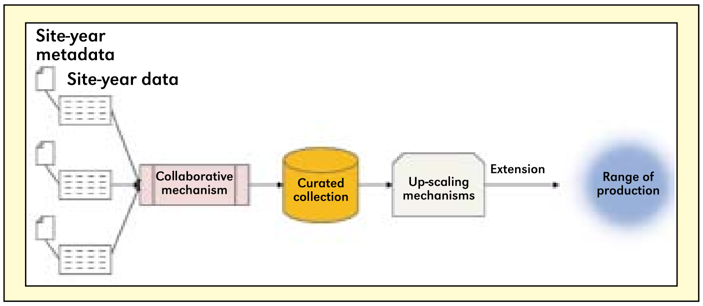


Figure 5. A conceptual model of the process of developing and testing field data across large geographic scales (Murrell, 2008).

on-line 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 5**, developed for IPNI's Global Maize project (Murrell, 2008). BC

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References

Adviento-Borbe, M.A.A., M.L. Haddix, D.L. Binder, D.T.Walter, and A. Dobermann. 2007. Global Change Biology 13:1972-1988.

Brouder, S.M. and J.J. Volenec. 2008. Physiol. Plant. 2008:1-20.

Bruulsema, T.W., C. Witt, Fernando García, Shutian Li, T. Nagendra Rao, Fang Chen, and S. Ivanova. 2008. Better Crops 92(2):13-15.

Darst, B.C. and L.S. Murphy. 1994. Keeping agriculture viable: Industry's viewpoint. J. Soil and Water Conservation 46(2):8-14.

Dobermann, A. 2007. *In* Fertilizer Best Management Practices. International Fertilizer Industry Assoc., Paris, France.

Evans, Alex. 2009. The Feeding of the Nine Billion: Global Food Security for the 21st Century (A Chatham House Report). Royal Institute of International Affairs, London.

FAO. 2008. State of Food and Agriculture (page 62). Food and Agriculture Organization of the United Nations. Rome. On line at http://www.fao.org/catalog/inter-e.htm.

Fedoroff, Nina V. 2008. American Association for the Advancement of Science Annual Meeting.
On line at http://www.pitt.edu/~super1/lecture/lec31911/001.htm.

Glenn, J.C., T.J. Gordon, and E. Florescu. 2008. The Millenium Project: State of the Future.World Federation of UN Associations, Washington, DC.

IAASTD. 2009. International Assessment of Agricultural Knowledge, Science and Technology for Development -Executive Summary of the Synthesis Report. Island Press, Washington, D.C.

Janzen, H. 2009. SOM research in 2030: what scientists then might ask of us now. *In* Program and Abstracts for the International Symposium on Soil Organic Matter Dynamics: Land Use, Management and Global Change. Colorado State University, Fort Collins. p. 114.

Lobell, D.B., K.G. Cassman, and C.B. Field. 2009. Annu. Rev. Environ. Resour. 34:4.1-4.26.

Murrell, T.S. 2008. Personal communication.

National Academy of Sciences. 2009. On Being a Scientist – a Guide to Responsible Conduct in Research, Third Edition. Committee on Science, Engineering and Public Policy. The National Academies Press. Washington, D.C.

National Research Council. 2009. Informing decisions in a changing climate. Panel on Strategies and Methods for Climate-Related Decision Support of the Committee on the Human Dimensions of Global Change, National Research Council of the National Academies. The National Academies Press. Washington, D.C. On-line at http://books.nap.edu/catalog/12626.html/.

Thorup, J.T. and J.W.B. Stewart. 1988. Optimum fertilizer use with differing management practices and changing government policies. *In* Proceedings of the 25th Anniversary Symposium of Division S-8, Advances in Fertilizer Technology and Use. Published for the Soil Sci. Soc. A. by the Potash & Phosphate Institute (now the International Plant Nutrition Institute, Norcross, GA).

Yang, H., A. Dobermann, K.G. Cassman, and D.T. Walters. 2006. Agron. J. 98:737–748.

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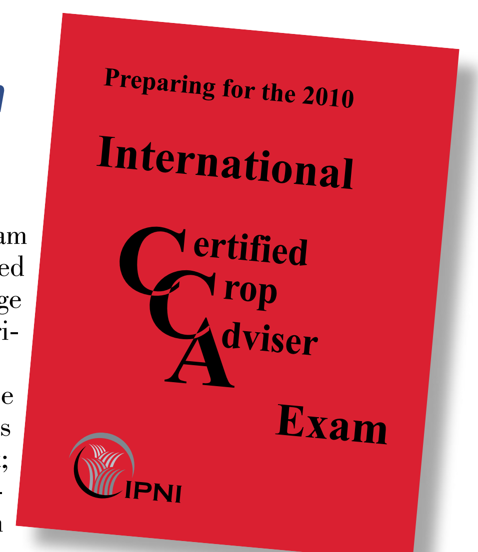

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