EFFECTIVE NUTRIENT MANAGEMENT DECISIONS... LOOKING BEYOND THE NEXT HARVEST.

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Much is at stake when making nutrient management decisions. A recent review of long term studies from several parts of the world concluded that at least 30-50% of crop yield is attributable to commercial fertilizer nutrient inputs (Stewart et al., 2005). As yields continue to climb, the definition of balanced nutrition narrows while concern over on- and off-site environmental impacts of nutrient use intensifies. And, the recent increases in fertilizer prices have created additional financial incentive for economically optimal nutrient use. The importance, complexity and inherent uncertainty of managing soil-plant-nutrient systems makes nutrient management a daunting task, worthy of the very best that science and technology can offer. It is fortunate that science today has an impressive set of "knowledge nuggets" about the soil-plant system, and that industry has an impressive set of technologies to deliver to the farm. Perhaps our biggest challenge today is to deliver existing science and technology to the farm in an integrated package that effectively supports critical nutrient management decisions.

Nutrient Management Decisions

Nutrient management decisions can be viewed as illustrated in **Figure 1** (Fixen, 2005). In this conceptualization, potential factors influencing nutrient management decisions serve as input to a decision support device or devices. The support device offers some type of output which is considered during the decision making step. The decisions made lead to nutrient management actions which generate an outcome. That outcome has educational value and becomes part of a feedback loop, influencing future decisions.

Possible site factors. Crop factors include yield potential, crop value, in some cases tissue nutrient concentrations or leaf color, and crop cultural practices that could influence nutrient management. Soil factors often involve soil nutrient supplying indexes or other physical, chemical or biological properties that influence nutrient cycling and crop growth. Grower factors might include land tenure, capital supply, opportunity costs, or philosophical nutrient management objectives. Nutrient input factors incorporate information on sources available such as commercial forms or nutrient-containing wastes, fertilizer costs and application costs. Water quality factors might include restrictions on nutrient application in riparian zones or near other water bodies or considerations due to ground water. Climate factors drive some types of model-based support systems while others respond to near real-time weather information for a specific growing season and short term weather forecasts. What relevant technologies are available at the site in question may certainly influence the decision-making process.

Decision support, output and feedback. Decision support, represented as a box in the figures, may be as simple as soil tests and the resulting nutrient rate recommendations or as complex as a fully integrated computer program that considers many of the possible site factors and provides detailed output on recommended practices and outcome probabilities that can be updated through a growing season. In open support systems, the user not only sees how site factors are integrated to

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influence output, but is allowed inside the decision support box to alter the integration process as part of the feedback loop. When the feedback loop includes the integration process of the support system, output is dynamic and becomes more site-specific as time passes.

Additional information on decision support systems and tools for integrated nutrient management is available in a recent review paper on the topic (Fixen, 2005) and in a slide presentation available at (**http://www.ppi-ppic.org/ppiweb/napro.nsf**). The focus of this paper is on one set of site factors described above, those that consider longer-term consequences of effective nutrient management decisions … that "look beyond the next harvest". The emphasis will be on soil organic matter and the impact of phosphorus (P) budgets.

Effective vs Efficient Nutrient Management

Consideration of long-term impacts of nutrient management decisions requires an understanding of the difference between efficiency and effectiveness in nutrient management. Nutrient use efficiency can be expressed in different ways but most definitions result in the highest efficiency occurring when fertilizer is applied at rates considerably below economic optimum rates. **Figure 2** illustrates that such a rate results in high nutrient efficiency but is not likely effective because it does not accomplish the major objectives of nutrient use. The objectives of nutrient use can be either short-term or long-term. They vary with individuals but typical ones follow.

Short-term (usually single year):

- Maximize return to fertilizer investment
- Eliminate crop deficiencies
- Improve effectiveness of other inputs
- Meet short-term production goals

Long-term (multiple years):

- Improve soil productivity
- Increase land value
- Maximize effectiveness of other inputs
- Meet long-term production goals

Opportunity does indeed exist for improving **efficiency**, but there is even greater opportunity in improving long-term **effectiveness**. That is essentially the hoped for outcome of employing fertilizer best management practices (BMPs) … right product, right time, right place, and right rate … within intensively managed systems targeting both high yields and nutrient efficiency. The resulting "ecological intensification" promises to be an effective approach for agriculture (Cassman, 1999).

Part of the challenge in nutrient management is to avoid confusing true gains in system level efficiency or effectiveness with practices that simply borrow from future productivity by depletion of soil nutrients or that undervalue positive residual effects on future productivity. Dobermann and colleagues (2005) recently summarized four case studies illustrating this challenge on cotton in California, soybeans in Hawaii, rice in the Philippines, and maize in Nebraska. The maize study (**Table 1**) illustrated that if the impact of management practices on N in soil organic matter had not been accounted for across the four-year period, the wrong conclusions would have been drawn concerning long-term N use efficiency of the systems being evaluated.

Soil Organic Matter

Soil quality is a term soil scientists use to refer to how well a soil performs critical functions such as nutrient cycling, water partitioning and storage, and plant root growth. Total organic carbon (organic matter) has been found to be a sensitive indicator of soil quality (Karlen et al., 2006). Therefore, it seems logical to consider this soil parameter when evaluating the impact of management practices on future soil productivity.

Trends in soil organic matter levels in the Pampas have been similar to those in the U.S. Corn Belt (**Figures 3 and 4**; Andriulo and Cordone, 1998; Lal et al., 1998). In both countries, agriculture has decreased organic matter to about half of the original levels. Other studies in Argentina have estimated similar reductions in organic matter (Echeverria and Ferrari, 1993; Urricarriet and Lavado, 1999; Alvarez, 2001). The simulation shown in **Figure 4** indicates that levels may now be rebounding in some cases due to implementation of reduced or no-till farming systems.

"So what?" is a question worth considering at this point. In both countries during this era of dramatic reductions in soil organic matter, crop yields climbed as genetics, technology

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and management improved. So was any harm to soil productivity really done? An excellent paper addressing the issues surrounding this question was recently published by Janzen (2006). In this paper he discusses the soil carbon dilemma where studies show that organic matter offers the most benefit, biologically, when it decays, yet we say that it's good to build organic matter in soils which implies less decay. Janzen uses a hydroelectric plant driven by water from a small reservoir as an analogy (**Figure 5**). In the analogy water inflow represents crop residues, water in the reservoir represents soil organic matter, water outflow represents organic matter decay, and electrical power generation represents biological benefits. Rapid decay increases biological benefits, but at the expense of stored soil organic matter if decay rate exceeds crop residue addition. Once the reservoir is depleted, biological benefits diminish and in theory the soil becomes less productive.

Sustainable management of the soil (hydroelectric plant) requires finding a balance between crop residue addition and organic matter decay that generates adequate biological benefits. Janzen offers two management approaches to sustainably maximize benefits: 1) optimize the timing of organic matter decay such that crops benefit most from the decay process and, 2) increase carbon input to the soil. Some opportunity for nutrient management, especially with N, may exist in the former approach, but verified opportunity clearly exists in the latter approach.

Numerous studies have demonstrated how fertilization and the resulting increase in crop residues can either increase soil organic matter levels or slow the decline. For example, a 40-year study in Uruguay demonstrated that the addition of pastures to row crop rotations could be used to stabilize organic matter levels, but that fertilization of row crops significantly slowed organic matter decline as well (Moron, 2003). An on-going 45-year study in Kansas in the U.S. is showing how maintaining an optimum soil P level and using optimum fertilizer N rates over many years can result in higher soil organic matter levels than under sub-optimal nutrient management (**Figure 6**; Schlegel, 2006). A study in Colorado conducted by the USDA demonstrated a measurable increase in soil organic carbon in the top 8 cm of soil one year after P fertilization and before any surface residue had been incorporated into the soil (Halvorson and Reule, 1999). They suggested that the cause was stimulation of root growth by P fertilization. Recent studies have also demonstrated that plants suffering from P deficiency utilize more of their daytime net carbon assimilation on root respiration (Lynch and Ho, 2005).

Whether from direct increases in the supply of crop residue or more efficient retention of captured CO_2, appropriate nutrient management decisions can have a positive impact on soil organic matter and provide an opportunity for greater benefits from organic matter turnover. Consideration of organic matter impact should be part of effective nutrient management decisions.

Phosphorus Budgets and their Impact

Nutrient removal by the crop gives a basic reference point for nutrient management decisions. It offers a crude estimate of the quantity of nutrient that must be replaced by some source to maintain existing soil fertility levels and is therefore a factor in system sustainability.

Removing more P from the soil than is applied over the long-term results in declining soil test levels. Numerous small-plot studies have demonstrated this fact around the world. On a larger scale, similar results have been observed. For example in the Corn Belt of the U.S., in the late 1980's, following many years of surplus P budgets, crop removal began exceeding P fertilizer and manure use. Soil test summary information for this region indicates that this roughly coincided with a switch from increasing soil test P levels to slowly declining levels for Corn Belt soils (Fixen and Murrell, 2002). In 2005, farmers in major Corn Belt states replaced 60 to 90% of the P removed by harvested crops with either fertilizer or recoverable manure. However, because of those early years of surplus P additions, median Bray-1 equivalent soil P levels in 2005 were 36, 29, 25, and 18 ppm for Illinois, Indiana, Iowa and Minnesota respectively (Murrell, 2006). In other words, much of the Corn Belt continues to feed off soil P reserves built up more than 20 years ago. In some states, those reserves remain significant, but in others reserves are now getting very thin.

Application to removal ratios in Argentina are climbing, but P replacement remains less than 45% (**Figure 7**) resulting in declining soil P levels (**Figure 8**) (Montoya et al., 1999). At current soil P levels shown in this data set for the western Pampas, soil test calibration information indicates that most crops will be highly dependent on annual P fertilization at rates approaching crop removal. Lower rates will likely result in lost

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production and continuation of the decline in soil P levels leading to additional damage to future crops.

A recent six-year study involving five corn-wheat/soybean rotation trials in southern Santa Fe conducted within the CREA network, evaluated the economics of fertilizing the cropping system by replenishing all the N, P, and S removed by the grain crops grown (corn, wheat, soybean). This resulted in average annual application rates of 126, 36, and 21 kg/ha for N, P, and S respectively. The gross margin calculated by subtracting fertilizer cost from the increase in gross income was US$417/ha. Residual effects on crops following the study were also substantial. With applied fresh fertilizer of 88, 26 and 10 Kg/ha of N, P, and S respectively, wheat, soybeans, and corn grown where replacement fertilizer had been applied previously out yielded crops grown on check areas by 2204, 559, and 1031 kg/ha respectively. Those conducting the evaluation believe this residual response is due more to an effect of balanced fertilization on the soil environment (more crop residues, more roots, more soil carbon, and more microbial activity) than a direct residual effect of N, P, and S on plant nutrition.

A critical component of this discussion of long-term P management is the distinction between response to soil fertility as reflected by soil tests and response to P fertilizer. Perhaps, the group with greatest experience with this issue is the research team at the Rothamsted experiment station in England. They manage the oldest soil fertility studies in the world. A.E. Johnston, in summarizing some of their long-term studies has stated "On impoverished soils (<10 ppm Olsen P) even the largest fresh applications of broadcast P did not raise yields to those achieved on enriched soils (>25 ppm P) in the absence of fresh phosphate" (Johnston, 1986). In other words, studies show that fertilizer cannot substitute completely for soil fertility. The practical message is that optimum P management should include definition of target soil P levels based on relevant calibration research followed by nutrient management programs that maintain levels at least at those targets.

The Soybean on Rented Land Dilemma in Argentina and the U.S.

One can certainly argue that long-term P management only makes sense to those involved in the land for the long-term. For example, Murrell and Fixen (2006) recently used a modeling approach developed by PPI (1993) and soil test calibration data from Iowa State University to estimate most profitable target soil test P levels when capital supply is limited for a corn/soybean rotation for durations of land use of 1, 4, and more than 8 years. Target Bray-1 P levels estimated were 6, 16, and 21 ppm respectively. Clearly it makes no sense to build soil levels if you do not reap at least a portion of the future benefits from build-up.

Short-term leases can then be an impediment to the long-term process of maintaining or building soil productivity. It is estimated that about 50% of the cropped land in the Pampas is leased and a recent survey of 131 farmers in southern Santa Fe (central Pampas) showed that 60% of the farms over 200 ha were leased (Cloquell et al., 2005). The situation in the U.S. Corn Belt is similar with USDA reporting that most Corn Belt counties have more than 40% of the land rented or leased.

The final component of the dilemma is the soybean crop, the dominant crop in the rotation of the Pampas, sometimes the only crop, and a dominant crop in the Corn Belt of the U.S. It offers low carbon input to the system, contributing to soil organic matter decline, and studies often show it to be less P responsive than other crops such as wheat or corn (Schwab et al., 2006). Therefore, growth of soybeans can allow programs that mine soil P to be more profitable over the short term. However, over the long term soybeans can negatively impact biological, physical, and chemical soil properties and as time passes make it increasingly more difficult to profitably grow other crops. In this way, the short-term focused manager gets trapped into even more soybean production, resulting in a downward spiral of declining soil quality that gets harder and harder to climb out of as time passes.

Worth considering as a partial solution to the dilemma, is the negotiation of lease agreements where investments in soil productivity are shared equitably with landlord and tenant since both can benefit over time from a more long-term approach.

Summary

Appropriate nutrient management decisions today need to consider numerous site-specific factors ranging from crop or soil characteristics to weather and available technologies. Some sort of decision support device is usually necessary to help integrate those factors and create output than can be considered in making decisions and taking action to manage nutrients.

Some of those site-specific factors involved in effective nutrient management decisions deal with long-term consequences of management practices because of residual effects that impact productivity and profitability.

Soil organic matter changes can be a sensitive indicator of soil productivity. Sustainable management involves finding a balance between crop residue addition and the benefits obtained from organic matter decay. Increasing carbon input to the soil is a major means of increasing benefits associated with organic matter. Whether from direct increases in the supply of crop residue or more efficient retention of the carbon fixed by photosynthesis, appropriate nutrient management decisions can positively impact soil organic matter and soil productivity.

Phosphorus removal in harvested crops currently exceeds use in both the Pampas and the U.S. Corn Belt. The point at which these deficit budgets reduce productivity and profitability is predictable by soil testing. It is highly likely that some farms are already experiencing lost production as soil tests drop below optimal levels, while in other cases it may still take many years before losses will be experienced.

Due to the high frequency of rented land in both the Pampas and the U.S. Corn Belt, increased use of leases that equitably share the short-term costs of practices that return long-term benefits will likely be an ingredient in developing programs aimed at increasing soil productivity.

The Pampas of Argentina and the Corn Belt of the U.S. have similar soils, grow similar crops, and share several nutrient management challenges associated with long-term consequences of existing practices. Changes from current practices will be necessary in both regions for agriculture to be sustainable. Continued sharing of research results and effective cooperative educational programs, like the AAPRESID Congress, should help expedite those needed changes and help us all look … beyond the next harvest.

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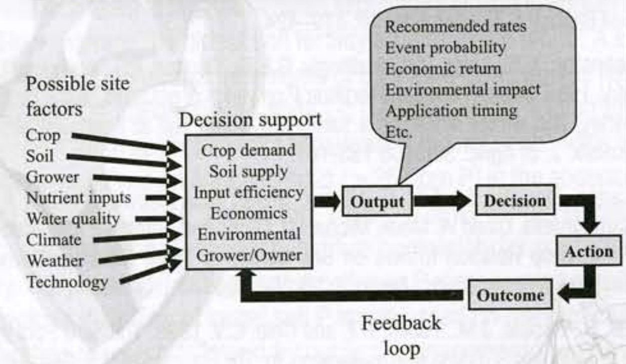
Figure 1. Typical nutrient management decision process.



Fixen, 2005

Figure 2. Efficiency vs. effectiveness: a single-season crop response example.

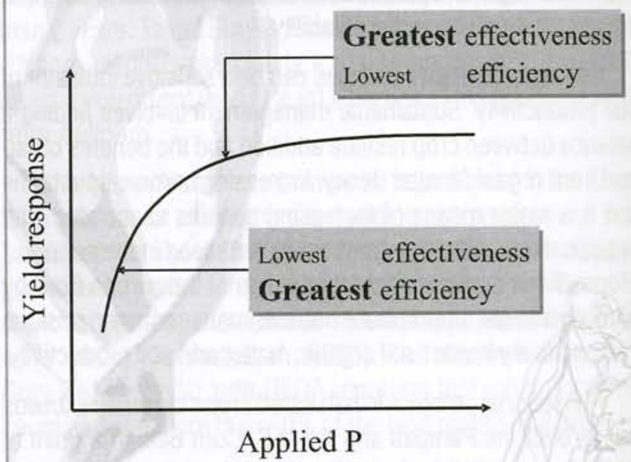


Table 1. N use efficiency in irrigated maize in Nebraska with recommended or intensive management.

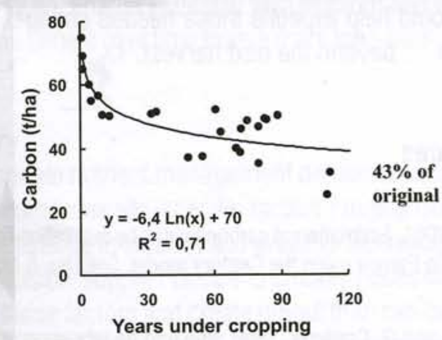
Recommended: 7,500 p/ha; soil test-based fertilizer rates; 2 N splits.
Intensive: 10,500 p/ha; higher fertilizer rates; 4 N splits + fall N on residue.

4-year averages	Rec.	Int.
Maize yield, t/ha	14.0	15.8
Avg. fertilizer N rate, kg/ha	195	305
N removed in grain, kg/ha	167	198
Partial factor prod., kg grain/kg N applied	72	52
Removal efficiency, %	86	65
Measured change in soil organic N, kg/ha/yr	-58	+55
(N removal + change in soil N)/N applied, %	**56**	**83**

System level efficiency

Dobermann et al., 2005

Figure 3. Organic C levels in soils of the northern Pampas since beginning of agriculture (Argiudolls)



Source: Alvarez y Steinbach (2006) from data of Andriulo and Cordone (1998)

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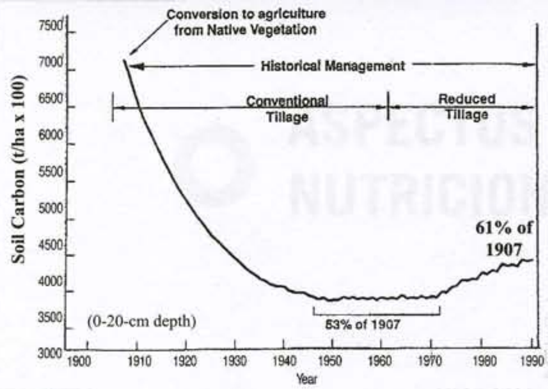
Figure 4

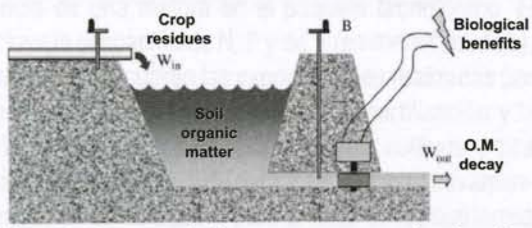
Simulated total soil C changes for the central U.S. Corn Belt



Lal et al., 1998

Figure 5

Hypothetical hydroelectric plant and analogy to soil carbon

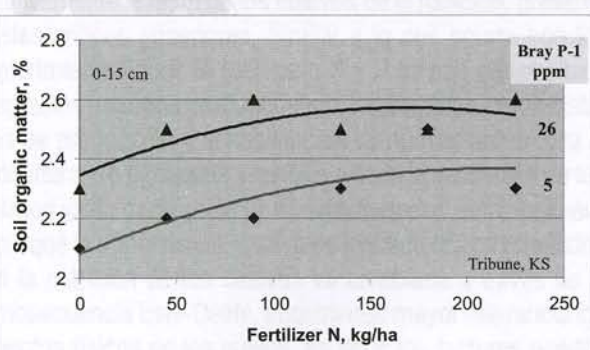


- Opening valve B temporarily increases power generation, but at the expense of water storage.
- Closing valve B increases water stored, but reduces power generation.
- Increasing both storage and power requires an increase in water inflow.

Janzen, 2006

Figure 6

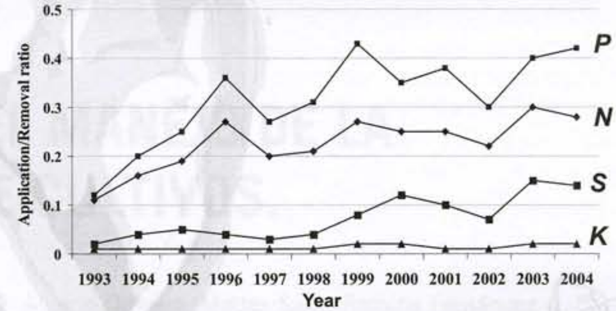
Influence of 45 years of N and P fertilization of irrigated maize on soil organic matter content



Schlegel, 2006

Figure 7

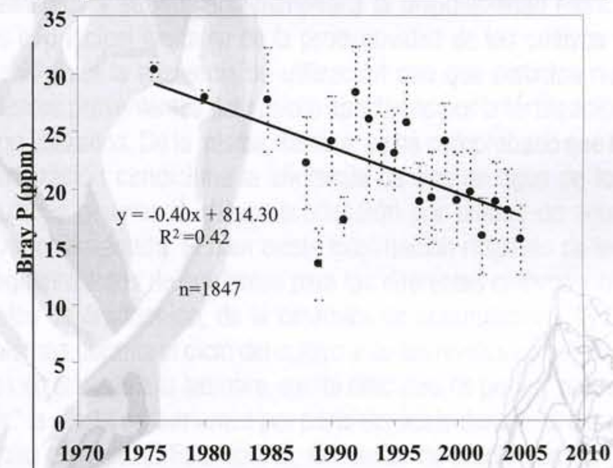
Application/removal ratios for N, P, K and S in field crops in Argentina.



The ratios are increasing by 1.2%, 2.1%, 0.1%, and 1.1% per year for N, P, K, and S, respectively

Figure 8

Available P in soils of the western pampas



Diaz Zorita, Duarte & Asoc. (2005)

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