Soil Fertility Management Strategies – Philosophies, Crop Response and Costs

Background

When it comes to soil fertility, farmers are likely to encounter different "paradigms" or philosophies that ask different questions.[1] Agricultural universities generally begin by asking "Is there *enough* fertility?" For each crop nutrient, they have developed soil tests with a *sufficiency,* or *critical, level* that represents the best tradeoff between crop yield and fertilizer cost when other nutrient levels are not limiting. The roots of this approach to soil fertility go back to the 1800s and scientists like Von Liebig, Mitscherlich, and Sprengel. It is commonly referred to as the *sufficient level of available nutrients*, or *SLAN* approach.

There is another way of looking at soil fertility, however, that asks not *how much* but *in what proportion* crop nutrients are present. Specifically, the ratio of each positively charged, or "cation," nutrient in comparison to total cations associated with the negatively charged sites that make up the soil "cation exchange" on the surface of clay particles and soil organic matter. The cation nutrients in question include calcium, magnesium, potassium, and sometimes zinc. This school of thought comes from 20th century agronomists such as Bear, McLean, and Albrecht. For purposes of this bulletin we will refer to it as the *cation ratio*, or *CR* approach.

What's the difference? Potentially quite large. The two approaches can result in different amounts of nutrients available to the crop and taken up by the growing plants. The "right" amount – and the right way of getting to that amount – depends on your philosophy. If you are a farmer who has at one time asked "What's the difference?" you may have had difficulty finding comparative information. Many soil fertility publications examine one school of thought or the other, not both.

The Research Project

These two approaches to soil fertility are good candidates for on-farm research, but farmers have lacked the equipment to spread liming materials in the narrow strips necessary for side-by-side comparisons.

This publication is based on on-farm research by members of Practical Farmers of Iowa and other Iowa producers.

[1] A paradigm is "a set of assumptions, concepts, values, and practices that constitutes a way of viewing reality for the community that shares them." American Heritage® Dictionary of the English Language, Fourth Edition. Copyright © 2000 by Houghton Mifflin Company.

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Fortunately, the North Central Region SARE (Sustainable Agriculture Research and Education) program of the USDA funded a three-year study on six private farms and two research farms of Iowa State University, the *Fertility Paradigms Project*. The grant allowed us access to the specialized application equipment that was needed.

The objective of the Fertility Paradigms Project was to document in side-by-side plots the outcomes that farmers can expect in the short-to-medium term by pursuing one fertility approach or the other. Between 1999 and 2001, a total of 450 people heard about the research and results in 13 project-related field days organized by Practical Farmers of Iowa.

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Because of turnover, a total of 11 Iowa farms participated at some time in the study. On these 11 farms, four sets of fields in which we worked were certified organic, one was transitioning to organic, and six farms practiced some form of conventional crop production on the fields used. On each field we applied amendments consistent with the production system in use on that farm.

SARE (Sustainable Agriculture Research and Education) support allowed us to use the Vicon oscillating spreader, which enabled application to field strips.

Amendments were based on soil tests (Midwest Labs) that were either evaluated according to Iowa State University guidelines or submitted to a collaborating crop consultant who employs the cation ratio approach in his business. Consequently recommendations were specific to the philosophy, or experimental "treatment" as well as to the farm and year of sampling. The two treatments were applied in side-by-side strips using a three-point-mounted oscillating spreader manufactured by Vicon. The pair of treatment strips was repeated, or *replicated*, an average of six times per field. These treatment strips remained stationary as crop rotations moved through the field from one year to the next.

As described, the SLAN and CR approaches use different standards to define the ideal soil fertility. The SLAN prescribes amendments to achieve *sufficient* fertility, while CR looks for certain *proportions* of nutrients. See Table 1 for examples. According to most interpretations of CR, Midwest soils are higher than desirable in magnesium and may be lower than optimal in calcium. The CR tools for adjusting magnesium and calcium ratios for these conditions include gypsum (calcium sulfate) and calcitic limestone, which is low in magnesium unlike the dolomitic limestone found in many parts of the Iowa.

Table 1. Standards for nutrients according to typical SLAN and CR evaluations.

Nutrient	SLAN, ISU Extension †	CR ‡, §
Calcium	Considered non-limiting in Iowa. Liming recommendations are made separately from fertility.	65% ‡, 65-85% §
Magnesium	Considered non-limiting.	10% ‡, 6-12% §
Potassium	131-170 ppm (ammonium acetate- or Mehlich-3-extractable)¶	5% ‡, 2-5% §
Zinc	0.9 ppm (DTPA-extractable zinc) is termed adequate. Unusual to find zinc lower than 0.9 ppm in Iowa.	3-5 ppm # ††
Hydrogen	Not modified except through liming to change soil pH.	20% ‡

† ISU Extension Bulletin PM 1688, *A General Guide for Crop Nutrient and Limestone Recommendations.* Optimal ranges for corn grown in a soil with low subsoil potassium.
‡ Bear, F.E., et al. 1945. *The Potassium Needs of New Jersey Soils. New Jersey Agricultural Experiment Station.* Bulletin 721.
§ Graham, E.R. 1959. *An Explanation of Theory and Methods of Soil Testing*. Missouri Agricultural Experiment Station. Bulletin 734.
¶ At the time of this research, the Optimum soil test range for soils with low subsoil K was only 91-130 ppm. Thus if the experiment were repeated today, some additional potassium would probably be applied in the SLAN plots.
# K. Cuvelier, personal communication, 2004.
†† Zinc is customarily measured in chelated form rather than as the adsorbed cation.

Measurements

Sometimes it is said that the CR approach can have benefits for soil quality or grain quality or that weed problems can reflect an undesirable proportion of cation nutrients in the soil. For this reason we looked for treatment effects on soil quality and nutrients, weeds, grain quality and crop nutrient status, as well as grain yield and profitability. Table 2 shows the parameters that were measured.

Soil, Grain, Crop Nutrient Status, and Weeds

The parameters most affected by the two treatments were those directly related to the amendments applied. For instance, soil test zinc levels were often greater in CR field strips than in SLAN strips because zinc sulfate was frequently applied in CR but was never used in SLAN. By the final year of the study, after two or three years of each management, soil potassium was greater in the CR than the SLAN field strips. Calcium also represented a slightly greater percentage of the soil cation exchange in CR by the last year of the study. On the other hand, there was little indication that the percent magnesium on the exchange had changed in CR relative to soil under the SLAN treatment during this three-year project. (See Figure 1.)

Table 2. Crop, Soil, Weed, and Economic Parameters Measured or Generated

Soil Analysis
- Organic Matter
- Bray P1 Phosphorus, extractable
- Potassium, extractable
- Magnesium, extractable
- Calcium, extractable
- Soil pH (Midwest Labs)
- Buffer pH
- Cation Exchange Capacity (calculated)
- Potassium, percent on Cation Exchange Complex
- Magnesium, percent on Cation Exchange Complex
- Calcium, percent on Cation Exchange Complex
- Hydrogen, percent on Cation Exchange Complex
- Sulfur, extractable
- Zinc, DTPA extractable
- Manganese, DTPA extractable
- Iron, DTPA extractable
- Copper, DTPA extractable
- Boron, DTPA/sorbitol extractable
- Water pH (in organic matter analysis)

Soil Quality
- Aggregate Mass
- Microbial Carbon
- Nitrogen, total
- Carbon, total
- Particulate Organic Matter Carbon, per g soil
- Particulate Organic Matter Nitrogen, per g soil

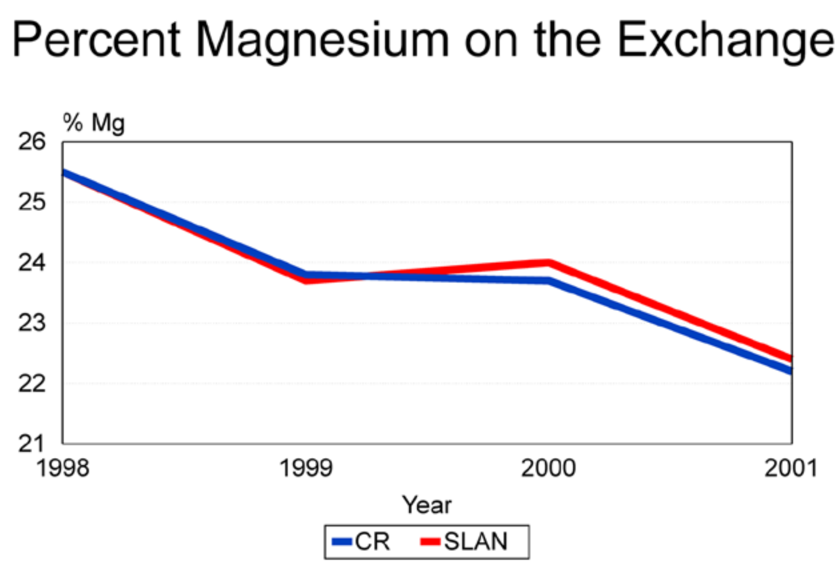
Weed Biomass
- Grassy Weed Biomass
- Broadleaf Weed Biomass

Productivity
- Grain Yield, moisture adjusted

Leaf Tissue Nutrients
- Nitrogen
- Sulfur
- Phosphorus
- Potassium
- Magnesium
- Calcium
- Iron
- Aluminum
- Manganese
- Boron
- Copper
- Zinc

Grain Quality
- Dry matter, percent
- Crude Fiber
- Acid Detergent Fiber
- Neutral Detergent Fiber
- Crude Protein
- Calcium, percent
- Phosphorus, percent
- Magnesium, percent
- Potassium, percent
- Zinc
- Crude Fat
- Total Digestible Nutrients
- Net Energy, Lactation
- Net Energy, Gain
- Net Energy, Maintenance

Economics
- Input Costs
- Net Profit, partial budget



Cation Ratio (CR) and Sufficient Level of Available Nutrients (SLAN). Soils were usually sampled in the fall after harvest. This graph combines the 5 farms that participated the in the full study and the 3 farms that joined in the fall of 1999.

Figure 1. Percent magnesium on the soil cation exchange over time in CR treatment and SLAN treatment for farms first sampled in fall of 1998 or fall of 1999. Magnesium saturation declined in both treatments, probably because of soil pH changes, but remained similar in the CR and the SLAN treatments.

What about the other parameters? Crop leaf nutrient concentrations were the next-most sensitive to the treatments, especially leaf sulfur, potassium, and magnesium, all nutrients contained in amendments that were applied. There were no treatment effects overall on grain quality, weeds, or soil organic matter; however, individual farms in some years yielded differences. These one-time differences may have reflected amendments applied for that year's crop, or they may have been random.

How do you decide what is "real" and what is random in a trial like this? In any experiment, you have to decide on a standard for what is "unusual." Differences less than that standard are considered to be merely random. If you set the standard too high, you may miss weak relationships. Too low a standard will yield many "false positives." With nearly 60 parameters on 11 farms, there are over 600 opportunities for false positive conclusions from each of the three years of the study. We chose an arbitrary but lenient standard of 89 percent certainty for any given parameter on a farm. At that liberal standard, we expect nearly 70 of these random, false positives to creep into the results every year. As mentioned, the treatment effects that appeared positive on a given farm in a particular year were not strong enough or consistent enough to be statistically significant over all farms and/or all years, except for some soil and leaf parameters directly related to the nutrients applied.

Beyond analyzing one parameter at a time, what about subtle *patterns* of response to the two treatments? To address this question, we used *principal components analysis*. A principal component is a grouping of the parameters measured. The first principal component is the grouping of variables that is most strongly associated with the treatment differences; the second principal component is the collection of parameters that is next strongest, and so on. Figure 2 shows the relationship between the first and second principal components. Each point on the graph is a farm-year-treatment combination. The important thing is that the data points are clustered by farm much more than by experimental treatment. The CR field plots are not all grouped in one part of the graph and the SLAN plots in another. This indicates site-specific conditions were more influential than responses to fertility amendments.

Input Costs

There was a difference in the cost of inputs recommended in the two systems (See Figure 3.) According to SLAN analysis, many Midwest soils test in the optimal or excessive range for potassium due to years of fertilization. The SLAN approach considers other cation nutrients, like calcium and zinc, to be at levels in Iowa that do not limit yields. The cation ratio (CR) philosophy, on the other hand, calls for a proportion among nutrients that Midwest soils seldom achieve without intervention.

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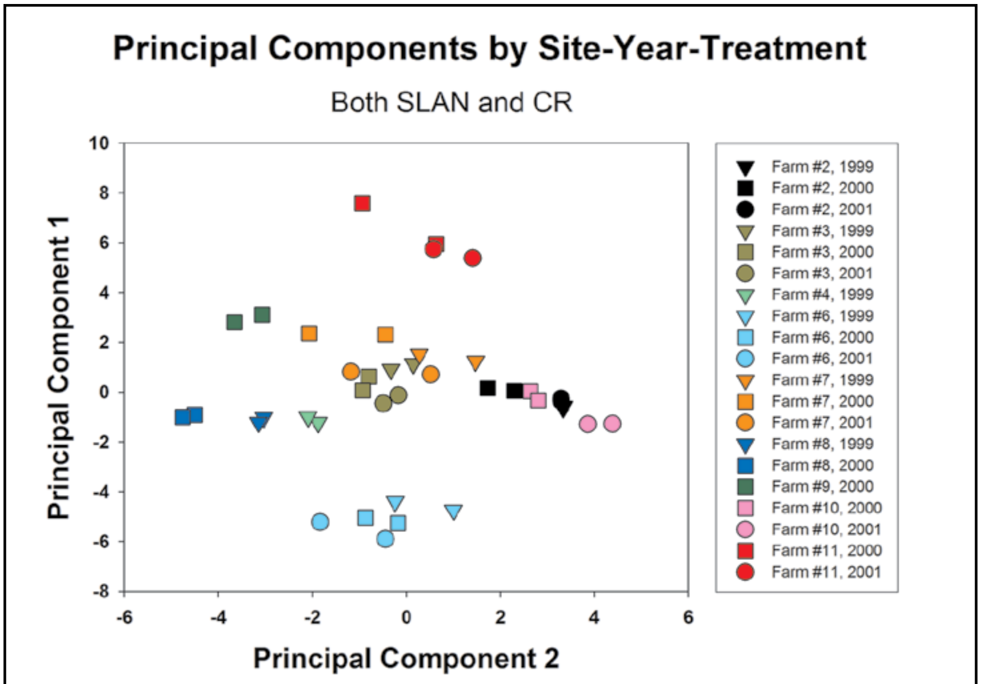

Figure 2. Plot of the first two principal components, CR and SLAN treatments. Data points are clustered by farm, not by experimental treatment; the treatments made less difference in the parameters measured than did location.

Consequently CR field strips in this study frequently received amendments when the SLAN plots received none.

The average annual difference in input costs was $9.27 per acre, of which $0.81 was due to lime and $8.46 was from potassium, zinc, and other sources of calcium. Fertilizer prices were based on 1-ton bags or local trucking of bulk materials. These costs reflect the expense of getting the inputs to the farm but not application costs, which would vary depending on equipment used. Local sources of limestone were assumed; however, calcitic limestone (low in magnesium) is not common in some parts of Iowa. At the time of the study, producers could expect to pay in the range of $0.15 per ton-mile to import high-calcium limestone from outside their community.

During the three years of this study, the difference in costs did not decline. Would the CR approach eventually require less of these inputs as soils approached the balance considered ideal?

- At the rates of change we measured, 8-17 years would be required to increase cation exchange potassium to the 5 % saturation sometimes cited as the ideal according to the cation ratio approach to fertility (Table 1). By the more relaxed standard of 2-5 % saturation, however, potassium in most of the soils was in balance by the end of the study.
- Calcium saturation changed with soil pH much more than it changed with the experimental treatments in this study. Levels were generally

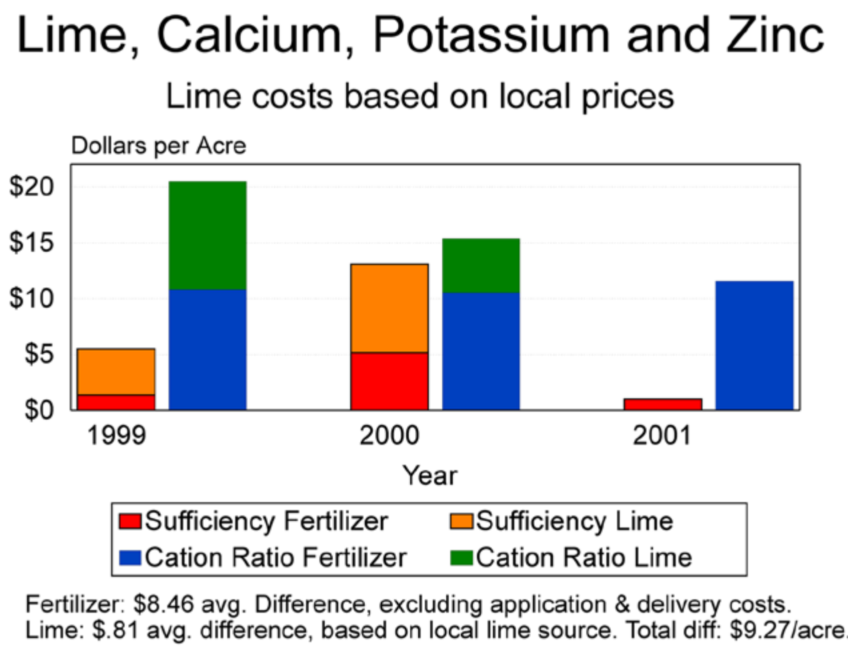

Figure 3. Fertilizer and lime cost for the CR and SLAN treatments averaged over all farms.

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between 60 and 70% under both treatments; the ideal has variously been stated as 65% or 65-85% calcium.

- Magnesium on the soil cation exchange also reflected pH changes more than the difference between SLAN and CR. Soil samples in the two treatments after the last cropping year showed nearly identical magnesium saturation of the soil cation exchange, about 22% (Fig. 1). The ideal proportion has been set, variously, at 10% and 6-12% (Table 1). Applications of gypsum and calcitic lime to reduce magnesium saturation could be expected to continue indefinitely under the CR regimen as implemented in this project.

Crop Yields – What Do They Mean?

There were three site-years of the 18 in which the CR treatment was associated with yields that may be considered statistically greater then SLAN, and there was one site-year in which the reverse was true. For the study as a whole, there was not a statistically significant treatment effect on crop yield. Overall, there were small yield differences for each of the crops that were not statistically significant even at the easy standard we set.

The yield differences were small, but let's assume for the sake of discussion that they were not just random occurrences. What would that suggest? One way of regarding these results is as a vindication of the cation ratio approach to soil fertility. At the same time, recall that the CR treatment often applied fertilizer in cases where the SLAN approach

Table 3. Yield Difference & Economic Difference.

	1999	2000	2001	Overall Return Gross	Overall Return Net ††
Corn yield difference	1.9	0.9	2.1	2.0	
conventional crop price	$1.65	$1.35	$1.80		
difference value	$3.21	$1.19	$3.82	$2.74	–$6.53
organic crop price	$3.00	$3.50	$4.00		
difference value	$5.83	$3.09	$8.50	$5.80	–$3.47
Soybean yield difference	1.0	0.9	0.7	0.9	
conventional crop price	$4.55	$4.25	$4.15		
difference value	$4.43	$3.88	$3.00	$3.77	–$5.50
organic crop price	$12.00	$14.00	$12.00		
difference value	$11.68	$12.77	$8.68	$11.04	$1.77
Small grain yield difference			1.8	1.8	
conventional crop price			$1.55		
difference value			$2.77	$2.77	–$6.50
organic crop price			$4.00		
difference value			$7.14	$7.14	–$2.13

†† Net return after $9.27 per acre additional input cost

Averaged over the three crops, the additional amendments would not pay, even with the price premiums received on an organic farm.

recommended none. The SLAN recommendations were based on Iowa State University calibrations. ISU soil test categories represent "a decreasing probability of an economic yield response to applied nutrients." (ISU Extension bulletin PM-1688). "Economic yield" means that there may be a crop response to amendments beyond the levels that are economically optimum – just not a profitable response. In terms of crop yields, then, this study does not prove one treatment or the other, since each philosophy can account for the yields.

Profitability

Was the yield effect, in fact, economical? Table 3 weighs the $9.27 greater input cost against the annual yield margins and commodity prices. Calculated on the basis of typical commodity grain prices for those years, the average yield advantage before input costs comes to $2.74, $3.77, and $2.77 per acre per year for corn, soybean, and small grains, respectively, which gives negative net returns for CR after subtracting $9.27 per year in inputs. Table 3 also provides representative organic grain prices. Using organic grain prices approximately doubles the gross advantage for CR corn and for small grains and triples it for organic CR soybean. But based on those assumptions, soybean would be the only grain crop in the organic rotation for which the yield difference would carry a higher value than the increased input cost. Averaged over the three crops, the additional amendments would not pay, even with the price premiums received on an organic farm.

Summary

This project was designed to document for producers the short-to-medium-term outcomes they can expect from adopting the SLAN approach (sufficiency level of available nutrients) or the CR (cation ratio) approach to soil fertility and fertilization. We monitored for differences in soils, crop nutrient status, grain quality and yield, weeds, and costs. A total of nine private farms and two ISU farms participated over the three years of the study.

- The most consistent and pronounced treatment effects were in soil and crop tissue, for nutrients that were present in the amendments used. Individual farms sometimes showed differences in other parameters, but they were inconsistent and not strong enough to be considered real treatment effects.
- Soil fertility treatment did not affect crop yield to the extent of achieving statistical significance. The small yield differences that were observed cannot be positively attributed either to the effectiveness of the cation ratio philosophy or to what the sufficiency approach would class as excessive fertilization.
- Fertilizer and lime costs averaged $9.27 per acre per year greater with the cation ratio (CR) approach than the SLAN (sufficiency level of available nutrients). This is before application expenses and assuming local sources for calcitic limestone. The expense outweighed the possible yield advantages at conventional grain prices. Assuming organic prices, only soybean demonstrated a yield increase of greater value than the input cost; overall, the three-crop organic system was less profitable using the CR approach.

Recommendations

- CR recommendations in this study were made by a consultant who uses the cation ratio approach in his business. If you are a producer working with a different information provider and/or in a different location than Iowa, you might face a different cost-benefit balance. Ideally, you would run test strips as were done in this study.[2]
- At the very least, we recommend to farmers who are considering a change in their fertilization practices that they "do their research," considering a range of information sources.
- There is nothing in either the CR or SLAN approaches that prohibits a step-by-step approach, so individual nutrients and amendments can indeed be compared in side-by-side strips, and always more than a single pair of strips. In this way a farmer can move ahead in a logical way that provides ongoing opportunities for observation, discussion, and control.

[2] There are farmer research guides that provide step-by-step guidance on designing, carrying out and analyzing a research trial. See, for example, *The Paired Comparison, a Good Design for On-farm Trials, by Exner and Thompson*. http://www.practicalfarmers.org/

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This fact sheet was prepared by Rick Exner, Ph.D., extension/PFI Farming Systems Coordinator; Kathleen Delate, extension organic specialist, Iowa State University, and; Douglas Karlen, USDA-ARS National Soil Tilth Laboratory and reviewed by John Sawyer, extension soil fertility specialist, Iowa State University and Antonio Mallarino, extension soil fertility specialist, Iowa State University.

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