INSECT RESPONSE TO APPLIED NUTRIENT INPUTS IN ORGANIC FIELD CROP PRODUCTION[1/]

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Soil Fertility, Plant Health, and Insect Responses – An Overview

Because organic farmers have relatively few control options when insect pest populations reach problem levels, a preventive approach to pest management is essential in organic systems. However, given the limited research base regarding relationships between soil fertility, plant health, and insect growth and reproduction, it's unclear in many situations exactly what this should mean to farmers in terms of inputs and practices.

What do we know so far? In general, mineral nutrition status is known to influence factors such as growth and yield of crop plants by affecting changes in growth pattern, plant morphology and anatomy, and particularly chemical composition. For example, thickness of epidermal cells, degree of lignification, sugar concentrations, amino acid content in phloem sap, and levels of defensive compounds are all influenced by nutritional status of the plant, and in turn either affect or are presumed to affect resistance to insects (Marschner, 1995, Patriquin et al., 1995). Much of the work done to explore plant-insect relationships has involved aphids and nitrogen. For example, there is substantial evidence that aphid reproduction is increased by high levels of soluble N (e.g., amines, amides, amino acids) in host plant leaves (McKee 1962; Auclair, 1963, 1965; van Emden et al., 1969).

We can also say at least a few specific things about the connections between soil fertility management and insect pest problems at the farm scale. For example, both overfertilization with N (Mattson, 1980; Koritsas and Garsed, 1985) and insufficient soil K (Myers et al., 2005; Myers and Gratton, 2006, Walter and DiFonzo, 2007) seem to make crops more susceptible to aphids and other pests by increasing free amino acids in plant tissue.

Overall, the state of research so far with respect to soil fertility management and prevention of insect pest problems doesn't suggest a clear course of action in most cropping systems other than regular soil testing and fertilization as needed to meet the needs of each crop. There are anecdotal observations that a "healthy" soil makes for "healthy" plants capable of repelling (or at least tolerating) feeding by insects, but "healthy" can be defined many ways. Both organic and conventional growers have proposed managing pests through the addition of livestock manure, green manures, compost, mineral fertilizers, and a host of other measures. Researchers have found hints regarding which of these methods might contribute to insect pest suppression (e.g., Chaboussou, 1976; Eigenbrode and Pimentel, 1988; Listinger, 1993; Phelan et al., 1995; Alyokhin et al., 2005; Arancon et al., 2007), but the work of teasing apart how they work and how best to make use of them has largely not been done. When evaluating nutrient management practices as a researcher in field trials, it is important (but difficult) to separate effects on pest populations that occur as a result of changes in levels of plant-available nutrients from effects observed as a result of other simultaneous changes such as an increase in crop residues that might harbor predators (e.g., Schmidt et al., 2007).

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The Base Cation Saturation Ratio (BCSR) approach

One specific fertility management approach that has been advocated to help plants repel or tolerate feeding by insects is the "basic cation saturation ratio" (BCSR) concept (sometimes referred to as the "soil balance" approach). The BCSR concept, use of which is not limited to organic agriculture, proposes that chemical, physical, and biological soil conditions are optimal for plant growth when the negatively charged exchange sites on soil clay and humus are filled with particular proportions of the cations Ca, Mg, and K (Exner, 2007). For Bear et al. (1945, 1948, 1951), on whose work the idea primarily rests, these proportions were 65% Ca, 10% Mg, and 5% K, with protons filling the remaining exchange sites. Graham (1959) and Albrecht (1975), important proponents of the concept, later gave ranges from 65 to 85% Ca, 6 to 20% Mg, and 2 to 5% K that they felt were acceptable. As a practical matter, since many soils of the Upper Midwest have Ca saturation levels lower than these target ratios, growers interested in the BCSR approach usually try to add Ca ions to their soil (and, consequently, displace Mg and K ions) by fertilizing with either calcitic limestone [calcium carbonate, $CaCO_3$], or gypsum [calcium sulfate, $CaSO_4{\cdot}(H_2O)_2$].

As a guide to fertilizer application, the BCSR concept is often contrasted in the literature and in recommendations made by soil testing labs with the "sufficient levels of available nutrients" (SLAN) concept (McLean, 1977; Eckert, 1987; Exner,2007). Under the sufficiency level concept, there are "Definable levels of individual nutrients in the soil below which crops will respond to added fertilizers with some probability and above which they likely will not respond" (Eckert, 1987).

Reviews of early work by Bear, Albrecht, and others on the BCSR concept reveal significant methodological flaws. In particular, the method by which given Ca saturations were obtained resulted in changes in pH such that what was actually being measured was plants' response to pH and not Ca or ratios of cations (Kopittke and Menzies, 2007). Dozens of studies reviewed by Kelling and Peters (2004) and Kopittke and Menzies (2007), including a series of field and laboratory experiments by McLean, one of Albrecht's students, failed to find significant benefits in yield or tissue composition by using the BCSR concept as a guide to fertilization rather the SLAN concept. Work by Olson et al. (1982), Exner (2007) and others has also demonstrated higher costs to the BCSR approach relative to the SLAN concept.

Despite the lack of definitive research support for the BCSR concept, McLean (1977) and Kopittke and Menzies (2007) document that it remains popular around the world among both conventional and organic growers, as well as consultants and some private soil testing labs. With the exception of Schonbeck (2000), working in vegetable systems in the southeastern U.S., no one has explored the impact of BCSR-based fertilization in certified organic production or with respect to insect pest problems. As a result, with the encouragement and participation of seven certified organic growers throughout southern Wisconsin (three of whom use the BCSR approach as a guide to fertility management), we are conducting a long-term field study with the primary objective of evaluating the role of the BCSR concept in crop plant nutrient uptake and insect pest and natural enemy response in an organic field and forage crop rotation.

BCSR, Plants, and Insects – Introduction to Field and Greenhouse Experiments

Working in a Plano silt loam at the Arlington Agricultural Research Station near Madison, Wisconsin, we have been comparing two different organic soil fertility systems for their impact on a variety of insect pests since 2007. The first of these two systems, the standard organic fertility (SOF) system, relies on livestock manure, alfalfa hay in the rotation, and cover crop green manures for nitrogen and most other crop nutrients. The second (BCSR) system involves all of the management practices just described but also entails addition of either high-calcium aglime (a single application averaging 3,000 lb per acre in spring 2007) or gypsum (average of 2,600 lbs per acre in spring 2008, and average of 3,000 lb per acre in late fall 2009) regardless of soil pH levels. There are 32 0.77-acre plots, 16 of each organic fertility treatment, and each plot is being moved through a four-year rotation (alfalfa/forage grass plus small grain, alfalfa/forage grass, corn, soybeans) typical of many farms in the region. The plots received formal organic certification in fall 2009.

Plant tissue mineral analyses and standard tests of soil physical and chemical properties (including organic matter, pH, and ratios of exchangeable cations) have been conducted at appropriate times (for example, after exposure to a full season's rainfall, in the case of calcium inputs) either annually or as needed to choose levels of inputs. Weed management has involved delayed planting dates typical of organic field crop production, pre-plant flushing of weeds with shallow cultivation (average of three separate operations), and post-plant cultivation with rotary hoes, tine weeders, hilling cultivators, and other tillage implements common to both organic and conventional production (average of 5-6 total separate operations). Data on weed populations and weed species composition (not presented here) have now been collected for four growing seasons.

Beginning in 2008, we also added a set of conventionally managed plots (rotated between corn and soybeans) in an adjacent field of the same soil type. These plots receive urea and other synthetic fertilizers as dictated by soil tests and crop removal. They also receive preplant application of appropriate herbicides but no insecticides. Rather than comparing organic and conventional systems *per se*, the purpose of these plots is to help determine whether any plant or insect effects seen in the organic plots are a function of organic management in general as opposed to the BCSR method in particular.

In all three systems, we have focused our data collection on three crop-pest associations: soybean aphid on soybeans, potato leafhopper on alfalfa, and a set of Lepidopteran larvae (European corn borer, corn earworm, and western bean cutworm) on corn. Phelan et al. (1995, 1996) found that the history of soil fertility management (standard organic versus conventional, in their studies) affected egglaying preferences by European corn borers. Together with differences in population densities and timing of population establishment, this represents the kind of changes we might expect to find.

Because it is possible that one or another of our fertility management approaches might help plants regulate pests to levels that naturally occurring predators are better able to suppress, we are measuring both pest populations and the interactions between pests and natural enemies. Work with natural enemies thus far has focused largely on predators of the soybean aphid.

To complement the long-term field experiments, we have also conducted a set of greenhouse studies. These studies involved rearing two different insects (soybean aphids and beet armyworm larvae) on soybean plants grown in soil modified in the laboratory to a set of different cation ratios. These studies allowed us to explore possible effects of the BCSR fertility management approach on insect feeding and population growth under controlled conditions, and also to compare and contrast these response variables for chewing and sucking insect pests. Soybean tissue from these experiments was also sampled for its concentrations of calcium oxalate. Calcium oxalate is a mineral that most vascular plants accumulate in crystalline form in their tissue. In some studies by other researchers (e.g., Korth et al., 2006**)**, calcium oxalate appears to help plants defend themselves against predators. As a result, possible increases in calcium oxalate concentration as a result of BCSR fertility management could provide a mechanism to explain insect pest effects observed in the field.

BCSR, Plants, and Insects – Field and Greenhouse Results and Discussion

Selected characteristics of soil from the standard organic and BCSR organic treatments are presented in Tables 1 and 2. Values from before the start of the experiment (fall 2006) are contrasted with values obtained in late summer 2010. Values from conventional plots from 2010 are shown for comparison purposes.

Table 1. Selected characteristics of soil from two organic treatments and a conventional comparison before (2006) and after (2010) several years of amendments as discussed in the text. Conventional plots were added to the experimental design in 2008 and are in a field directly adjacent to the field containing the long-term organic fertility systems trial. Values shown are means of four replicates of each treatment. If no letters are present within a column, values in that column do not differ. If letters are present, values not sharing a lower-case letter are significantly different within each column by ANOVA and Tukey's HSD at the P = 0.05 level.[¶]

	Percent organic matter*		pH		P ppm		K ppm		Ca ppm		Mg ppm	
	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
Standard organic fertility	3.4	3.6	6.7	6.6	76	65	207	199 a	1629	1991 a	559	600 a
BCSR organic fertility	3.1	3.5	6.7	6.9	72	64	183	173 b	1598	2321 b	552	492 bc
Conventional fertility	N/A	3.6	N/A	6.7	N/A	74	N/A	329 b	N/A	1809 c	N/A	527 c

[¶] While these data meet assumptions for ANOVA, results represent preliminary analysis. Proper analysis may involve building models that incorporate a block effect for each variable within each year.

* Analytical methods used: organic matter, loss on ignition; pH, water (1:1); P, weak Bray (Bray 1); K, Ca, Mg, extracted with 1 *M* NH_4OAc at pH 7. Analyses performed Midwest Laboratories, Omaha, NE.

Statistical analysis across years within each treatment will likely prove informative (for example, both soil organic matter and total cation exchange capacity may have increased in both organic treatments), but these analyses have not been completed. Comparisons within years and across treatments are also preliminary and will need to be adjusted for block effects and other factors. However, at present it seems that the BCSR organic plots have significantly higher levels of exchangeable soil calcium than standard organic plots (an average of 2321 ppm Ca for BCSR in 2010 compared to 1991 ppm Ca for standard). At the same time, BCSR plots also have significantly lower levels of exchangeable Mg and K than standard plots (492 ppm Mg for BCSR in 2010 compared to 600 ppm Mg for standard, and 173 ppm K for BCSR compared to 199 ppm

K for standard). These results are consistent with the replacement of Mg and K by Ca on surfaces of soil clay and organic matter. In all treatments, however, quantities of Ca, Mg, and K are above deficiency ranges defined for Wisconsin according to the SLAN concept (Laboski et al., 2006).

Table 2. Cation-related characteristics of soil from two organic treatments and a conventional comparison before (2006) and after (2010) several years of amendments as discussed in the text. Conventional plots were added to the experimental design in 2008 and are in a field directly adjacent to the field containing the long-term organic fertility systems trial. Values shown are means of four replicates of each treatment. If no letters are present within a column, values in that column do not differ. If letters are present, values not sharing a lower-case letter are significantly different within each column by ANOVA and Tukey's HSD at the P = 0.05 level.¶

	Cation exchange capacity (cmol$_c$ per kg)		Percent saturation with Ca		Percent saturation with Mg		Percent saturation with K		Ratio of percent Ca saturation to percent Mg saturation	
	2006	2010	2006	2010	2006	2010	2006	2010	2006	2010
Standard organic fertility	13.9	16.4 a	58.9	61.0 a	33.6	30.6 a	3.8	3.1 a	1.75	2.00 a
BCSR organic fertility	13.6	16.4 a	58.7	70.7 b	33.9	25.0 b	3.4	2.7 a	1.74	2.84 b
Conventional fertility	N/A	14.5 b	N/A	62.3 a	N/A	30.3 a	N/A	5.8 b	N/A	2.06 a

¶ While these data meet assumptions for ANOVA, results represent preliminary analysis. Proper analysis will likely involve building models that incorporate a block effect for each variable within each year.

*Analytical methods used: K, Ca, Mg, and Na extracted with 1 *M* NH_4OAc at pH 7 (Na not shown; levels were very low), protons (H, not shown, present at low levels) estimated from buffer pH. Analyses performed Midwest Laboratories, Omaha, NE.

The ratio of percent saturation with Ca to percent saturation with Mg appears to be significantly higher for the BCSR organic soil than for the standard organic soil (2.84 compared to 2.00 in 2010). The BCSR plots have significantly higher percent saturation with Ca than the standard plots (70.7% compared to 61.0% for the standard plots in 2010), and this percentage brings the soil into the range suggested by advocates of the BCSR approach.

Despite approaching the target cation ratios in the field BCSR organic plots, few measures of yield or insect pest response have differed significantly by treatment thus far. Yields of corn in 2010, for example, averaged 192 bushels per acre for all treatments, while soybean yields ranged insignificantly between 63 and 65 bushels per acre for the three treatments (soil balance, standard organic, conventional). Data on grain quality and forage quality have been collected and statistical analyses of these data are underway.

One representative set of insect data is the graph of soybean aphid population growth shown in Figure 1. As with a similar set of data from 2008 (not shown), aphid populations appeared to diverge between the three treatments near the end of the season, with populations lowest in the BCSR organic plots, next lowest in the standard organic plots, and highest in the conventional plots. However, due to wide variation in aphid counts between plants, populations did not differ significantly by treatment except on the final sampling date, when plants in conventional plots harbored significantly more aphids than plants in either of the two organic treatments. We have not yet analyzed the analogous 2010 data, but preliminary summaries suggest that the pattern of data is the same as in the previous two years. We are now analyzing a corresponding set of plant tissue data for each pest (mineral content of soybean leaves at R1-R2, in the case of soybean aphids) that may allow us to establish soil-plant-insect interaction effects.

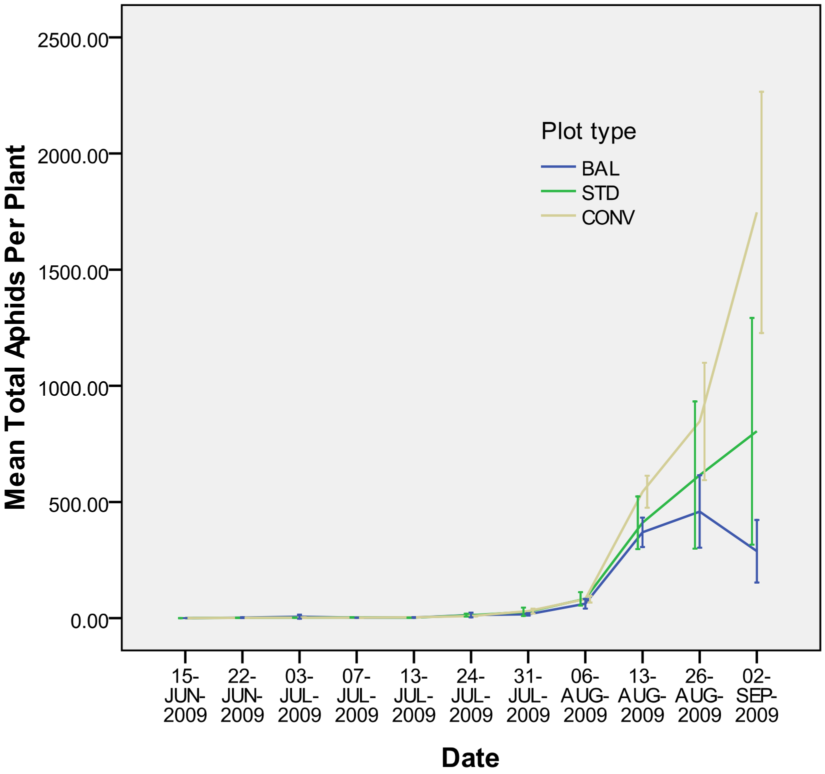

Figure 1. Aphid populations in plots of three treatments (BAL = BCSR organic, STD = Standard organic, CONV = Conventional) in summer 2009. Error bars represent +/- 2 SE.

Research results from the greenhouse largely mirror those obtained in the field. Using methods modified from Favoretto et al. (2006), we did successfully create soils with ratios of exchangeable Ca:Mg as high as 4.65:1. There was a significant difference between soil treatments in the length of time it took for beet armyworm larvae to reach pupation, with the larvae on plants grown in 4.65:1 soil pupating slightly faster than larvae in other treatments. However, weight gain and final pupal weight do not appear to have been significantly affected by feeding on soybeans grown in soils of different cation ratios. Soybean aphids feeding on similar soybean plants similarly did not differ in lifespan or total lifetime reproduction.

Though there was no apparent response by insects to the cation ratios in which their soybean host plants were grown, leaf tissue from the plants themselves did vary in content of calcium oxalate (see Fig. 2). Plants grown in soil modified to Ca:Mg ratios of either 2.95:1 or

4.65:1 contained significantly more calcium oxalate than plants grown in unmodified control soil with a Ca:Mg ratio of 2.0:1. Plants grown in soil of the 2.95:1 ratio also had more calcium oxalate than plants from a second control group grown in soil rinsed with water in a way that mimicked the cation ratio modification process, though this was not true of plants grown in soil with a 4.65:1 ratio.

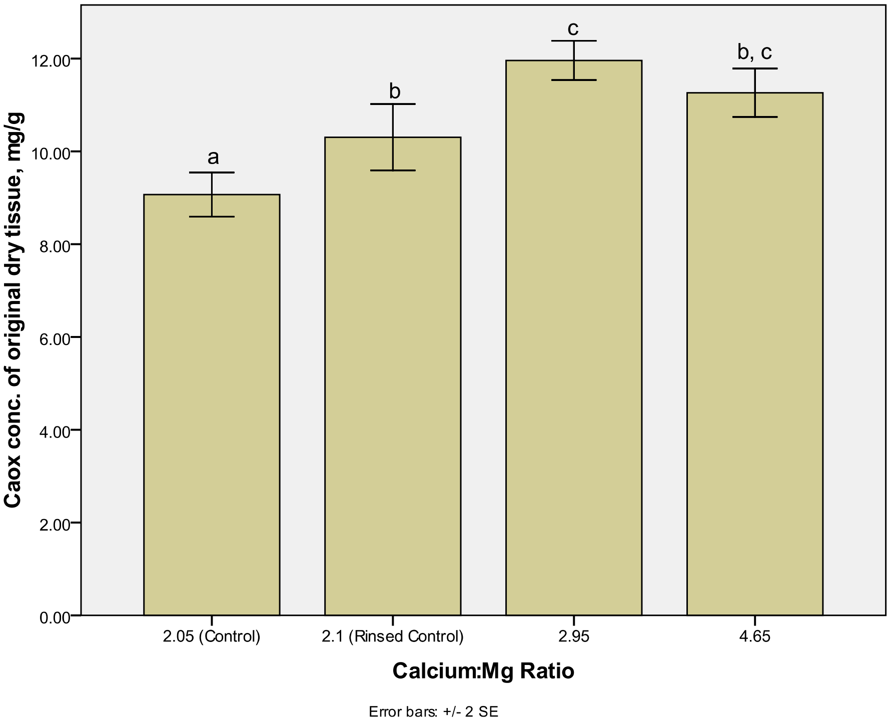

Figure 2. Calcium oxalate content of dry leaf tissue from soybean plants grown in soil of varying cation ratios. The "rinsed control" treatment involved soil that had been repeatedly saturated with water in a way that mimicked the modification process but did not involve concentrated calcium and magnesium salts. Columns not sharing a letter are significantly different by ANOVA and Tukey's HSD at the P = 0.05 level. Calcium oxalate levels were determined using a kit and protocol (available from Trinity Biotech, Dublin, Ireland).

BCSR, Plants, and Insects – Take-Home Points

- Changing cation ratios on a field scale appears possible, but the amounts of inputs required are large.
- In greenhouse experiments, use of the BCSR approach does not appear to have had significant effects on insect pests.
- Though aphid data hints at a possible difference in insect response between the two organic treatments, the BCSR approach has overall not shown significant effects on either crop yield or insect pest populations in four years of a large-scale field trial. However, the high Ca:Mg ratios advocated by BCSR proponents have only been achieved recently and may not yet have had time to affect plants or insects.

- By comparison with adjacent conventional plots, there is suggestive evidence that organic fertility management (with or without BCSR-related inputs) might result in lower pest populations than a conventional fertility system without insecticides.
- Our goal is to develop research-based information on how different organic fertility management practices affect crop resistance to insect pests, and what (if any) particular soil fertility management practices are most helpful. The practices described here represent only one possible fertility management variant with one set of crops and pests on a particular soil type and should not be interpreted as conclusive for any other production system.

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