Organic fertility recommendations

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Fertility recommendations for organic farms have been difficult to establish but are critically needed. The high-priority need is to provide a framework for better prediction of the effects of fertilizer treatments on crop response, pollution risk and soil health on organic farms. Because the fertility treatments have diverse impacts on the production system in both the short and long term, a systemic and long-term approach is necessary.

Two issues make organic fertilizer response different from conventional ones. One is the yield response curve and the other is the fertilizer analysis. The yield response curve to added fertilizer tends to be flatter and displaced for organically managed soils. Fertilizer analysis labels report only soluble minerals, which reflects only a fraction of the long-term nutrient addition for many organic amendments. Applying these without considering this latent fertility could lead, over the long term, to over application and pollution risk.

I had the opportunity to collaborate with Klaas and Mary-Howell Martens on a project provides a systemic analysis of how crops respond to organic amendment on a farm that is fully transitioned organic management.

We went through a whole rotation of corn, soybeans and spelt with varying rates of organic fertilizers to determine crop response and the other factors of interest. We had five rates and three replications for statistical robustness. The experiment was field sized and all operations were conducted on the whole field. For instance, yield was measured by using the yield monitor on the combine. The results are directly applicable to real organic farms, and they also reflect the unpredictable events that happen in farming.

Organic fertility sources vary in how rapidly they become available. We did the whole trial with both a rapidly available and a slowly available source. That design allows makes it possible to use our results to predict how other fertility sources would respond.

The major conclusion from this study is

> *The best application rate for organic fertilizer was the one obtained using conventional soil tests, conventional fertilizer application rates, and using the nutrient analysis performed on the compost used as an amendment.*

This conclusion was certainly not what we expected to find, but many lines of evidence support it. First, adding more than the recommended amount of fertilizer never increased the yield. Second, adding more than the recommended amount of fertilizer increased the size of weeds, and caused a troubling rise in soil phosphorus into the excessive range without improving phosphorus availability.

When it comes to compost application, there are quite a few organic farmers who reason that is compost is good, then more compost is better. We found that reasoning to be wrong. What fits better is the Swedish concept of *lagom,* that overdoing is just as bad as not doing enough, and that satisfaction comes from finding the right balance. Fortunately, the right balance was easy to determine. With this site and with these composts (analysis about 4-5-2), the right amount was often modest, around a ton per acre.

The second important conclusion from this study is

> *Don't add N based on PSNT.*
> Nitrogen available from fall or spring applied organic amendments is not detected by mid-summer soil nitrate tests. This test is commonly used to determine side-dress nitrogen needs in field corn that has received manure. It will to be effective for many other organic nitrogen sources.

Specific questions we addressed, and the resulting data.

Do organic fertilizers reduce weed germination or growth by reducing the amount of nitrate available to the weeds?

The answer is No. Weeds germinate just fine, and applying compost to add nutrients beyond what the crop needs just makes them grow big.

How much compost is needed to meet crop demand?

PSNT did not show nitrogen in soil or predict crop performance. However, measuring how green the leaves were was effective. Nitrogen is required to make the proteins that fix carbon and that use the light energy captured by green chlorophyll. That is why even small nitrogen limitation makes the leaves yellow a little. One important difference between measuring leaf nitrogen and soil nitrogen is when it is measured. Soil nitrogen is measured just before the big vegetative growth spurt. Leaf nitrogen is measured just after it ends and the crop is about to use all that leaf area to fill the grain. Our data show that much nitrogen is made available to the plant in the intervening month.

Can organic fertilizers result in pollution problems?

Yes, overapplication of organic fertilizers causes phosphorus to build up. Simply doubling the recommended rate caused this field to go from low to very high P in just three seasons. The nitrogen in the compost is mostly consumed, but the P mostly builds up when it is added in amounts higher than the crop removes. Adding lots of compost each year can cause serious problems on a farm if the phosphorus levels are not managed carefully.

Establishing fertility recommendations for organic fertility applications on farms that have been under organic management for a long time.

In organic production systems, crop responses to fertility amendments have been difficult to predict. Conventional fertilizer recommendations are usually based on response curves generated using chemical fertilizer on conventionally managed soils. Many growers fertilize to equal crop use plus some extra for insurance. Consultants normally recommend applying the difference between the soil test results and an ideal target number they have balanced the soil. Recommendations of this kind are not appropriate for determining application rates of organic fertilizers to organically managed soils. Two issues make organic fertilizer response different from conventional ones. One is the response curve and the other is the fertilizer analysis. The response curve to added fertilizer tends to be flatter and displaced for organically managed soils, similar to that for corn after soybeans. Fertilizer analysis labels, by law, report only levels of soluble minerals but organic amendments contain varying amounts of mineralizable nutrients that contribute in subsequent seasons.

The experiment has five rates of fertilizer relative to the conventional recommendation for the next crop. Those rates are 0, 1/4x, 1/2x, 1 and 2x. Applications were made in Fall 2003 for the 2004 corn crop, in spring 2005 for the soybean crop, in spring 2006 for the spelt crop, and in spring 2007 in the maximal controls for the corn crop. The recommended amount in each year is in Table 1.

Organic materials applied as fertilizer take varying amounts of time to become available. We addressed that challenge by using a material the makes nutrients available quickly, and one that is on the slow end. By using the two extremes, it is possible to estimate how other materials might work. The rapidly available nutrients are from pure poultry manure that is composted. The slowly available nutrients are from poultry litter that is mixed with other organic matter in the laying house, then mixed with fine wood chips before composting. The nutrients are tied up in much more stable organic compounds. Both products have about 50% organic matter.

Table 1. Nominal nutrient application based on reported fertilizer analysis. Recommended amount was based on soil test and nutrient requirement. The two materials had different analyses, so the application rate was based on the likely limiting nutrient for that crop. The values are in tons of wet material applied and pounds of N-P_2O_5-K_2O per acre recommended.

	Year	2004	2005	2006	2007
Fertilizer	Crop	Corn	Soy	Spelt	Corn
Recommended (lb/ac)		120 N	37 P_2O_5	130 P_2O_5	33 N
Applied (T/ac)					
Rapidly available		3	0.6	1.25	0 (+N =1.0)
Slowly available		3	0.6	1.80	0

The crop needs to respond to the amendments in a way that can be analyzed effectively. The Mitscherlich curve is appropriate for interpreting the response to conventional fertilizer. The composts in this experiment also fit that curve well (Figure 1).

For corn in the first year of the trial, the expectation was that the rate of application to achieve the maximum rate would differ between the two materials. A slightly greater rate of the organic fertilizer is needed that the soluble one (~2.0 vs 1.5 T/ac), but they were very similar (Fig. 1). In both cases, they maximum yield came at less than the recommended application to meet crop needs.

Soybeans in the second year showed no significant response to fertilizer application (Fig. 2). Spelt in the third year responded, with the recommended amount being sufficient (Fig. 3). In the fourth year we used corn to see how much fertility the repeated compost applications provided in later years. Unfortunately, we cannot make any conclusion because the well-fertilized control had the same yield as the unfertilized plot (Fig. 4). Therefore, all the treatments had enough fertilizer to produce maximum yield.

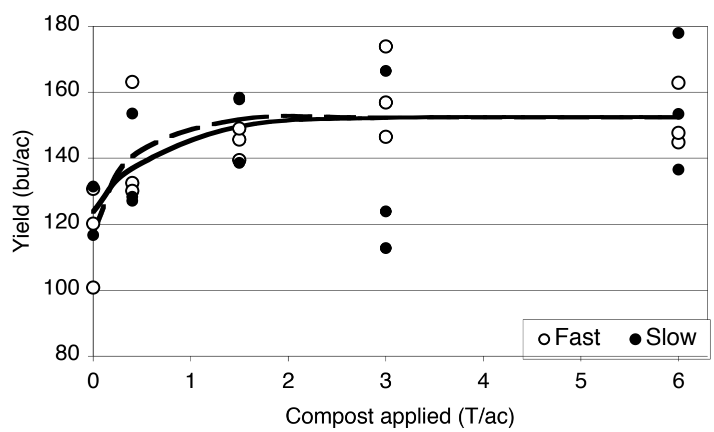

Figure 1. Response of corn yield to fertilizer supplied in a fall application of rapidly available(Soluble) or slowly available (Organic) fertilizer. Harvest was on November 30, 2004. The lines show the asymptotic fit. The recommended application was 2.5 T/ac for the rapidly available material and 4 T/ac for the slowly available.

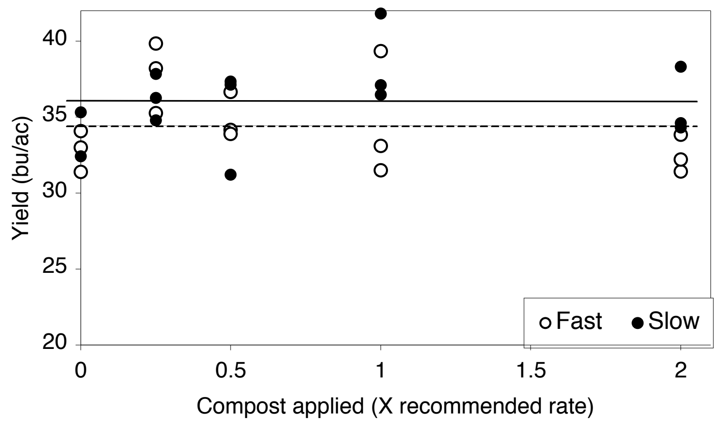

Figure 2. Response of soybean yield to fertilizer supplied in a spring application of compost with rapidly or slowly available nutrients. Harvest was on October 2, 2005. The Mitscherlich algorithm indicated that there was no response to the compost rate for either material.

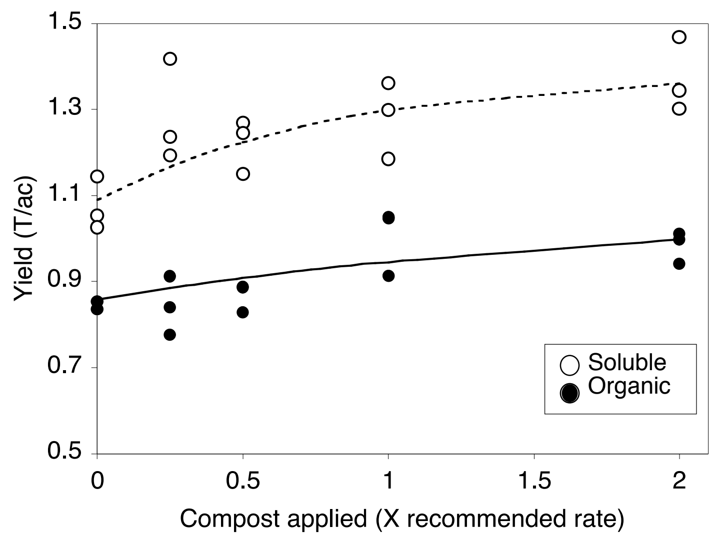

Figure 3. Response of spelt yield to fertilizer supplied in a spring application of rapidly available (soluble) amendment or a slowly available amendment (organic). Harvest was on July 26, 2006. The Mitschelich curve indicated that maximum yield was obtained with the recommended rate of nutrient application (based on the P requirement).

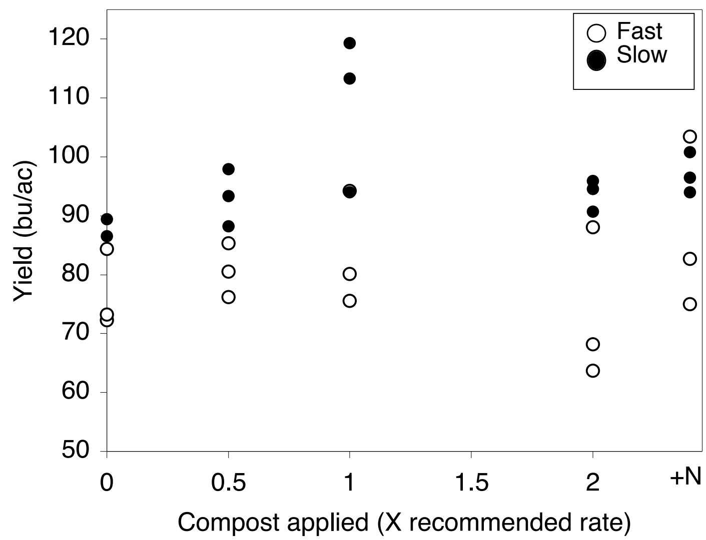

Figure 4. Residual fertility from fertilizer supplied in previous years. Corn was used as a highly responsive crop. A full-fertility control (+N) was used to determine maximum yield. The spring application to measure yield with saturating fertilizer was twice the recommended rate of rapidly available fertilizer. Harvest was on November 12, 2007. The fit showed no effect of residual nutrients from prior years application, or from nutrients applied in the current year.

How quickly are nutrients available following compost additions?

The organic fertilizer requires nitrification to provide nitrogen to the crop, while the soluble one is less limited by this process. We examined nitrogen availability using a pre-sidedress nitrogen test (PSNT) and a chlorophyll test.

Soil nitrate was measured when the concentration was near maximum. Most mineralization should be complete, but peak uptake by the crop had just begun. While the current year application was now detectable, there was not evidence of significant nitrate from previous year's compost applications (Fig. 5). The measured nitrate concentrations are below the conventional sidedressing threshold of 25 ppm despite the plowdown of a clover crop.

The nitrate data compare with those sampled in May (2006) or early June (2004), in which nitrate had not yet been released from the compost. We inferred that the release that produced a yield increase occurred later. Here we see that it is becoming available by mid-July.

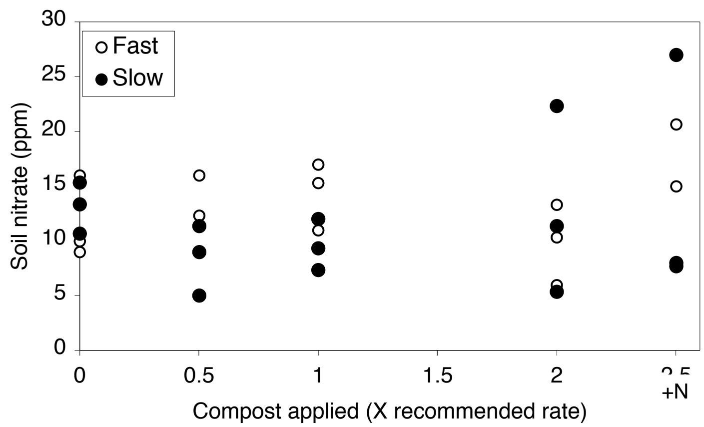

Figure 5. Effect of compost application on soil nitrate after prior years' application would have mineralized but before greatest crop uptake (July 17. 2007). The compost applications were in prior years, the +N treatment was applied in 2007. There was no evidence for residual nitrogen release.

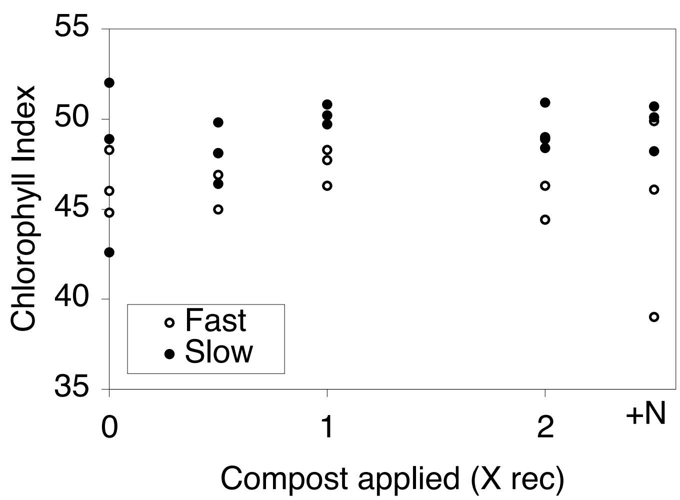

Figure 6. Effect of residual applied compost on nitrogen limitation as measured by the Leaf Chlorophyll Index. Measured July 18, 2007 on recently expanded leaf six. +N received maximal fertilizer in 2007.

Leaf greenness was measured using a SPAD meter, with the resulting Leaf Chlorophyll Index (LCI) in arbitrary units. The measurement was made on July 18, during peak nitrogen demand. Nitrogen limitation would be most likely to be observed at this time. The results indicate that either there was no effect of the fertilizer or there was no nitrogen limitation to the corn (Fig. 6). In the past, unlimited fertilizer produced an LCI between 50 and 55.

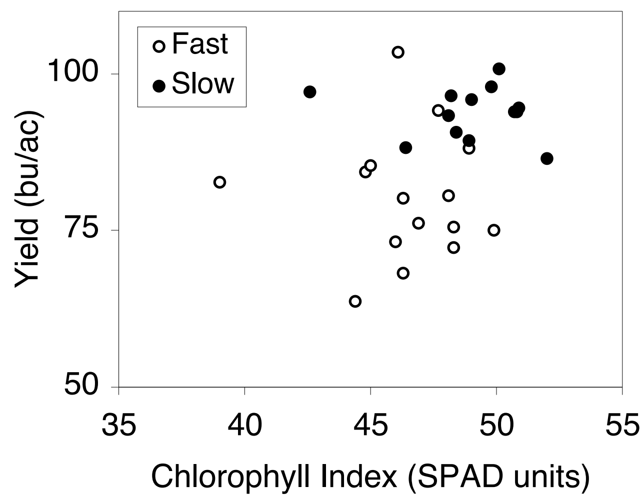

Figure 7. Effect of plant nitrogen content, as determined by Leaf Chlorophyll Index on July 18, on yield at harvest on November.

Leaf greenness was a moderate predictor of yield (Fig. 7). Again, this result reflects that nitrogen supply is a determinant of yield, but the variation in leaf greenness was not related to the amount of fertilizer applied in previous years. In earlier years' trials there was a strong association between the Chlorophyll Index and yield for all the crops grown.

How does organic fertilizer type and application rate improve soil health?

Soil health is what underlies the organic philosophy of agriculture, and is therefore of prime interest on organic farms. A common experience after the transition to organic production is an increase in the tilth of the soil. That change is frequently attributed to the elimination of soluble fertilizers. A corollary of that assertion is that high application rates of soluble minerals in the form of composted pure poultry litter will fail to improve the tilth.

We found that the benefits of compost that are attributed to the input of organic matter were not significant with these high-analysis composts. Applying the necessary amount of nutrients was associated with modest inputs of organic matter. Low-analysis composts applied at rates that supply the recommended amount of nitrogen or phosphorus would supply substantially more organic matter, and may have an effect.

We found that the effects of compost attributed to phosphorus were easily detected. In this case, the recommended rate resulted in good phosphorus nutrition of the crop without undesirable side effects. Overapplication stimulated weed growth, not crop growth, even in future years. The result could be greater difficulty in controlling weeds through cultivation. Furthermore overapplication resulted in a progressive rise in soil test phosphorus that could result in a pollution problem within a few years if it is an annual practice.

Effect of fertility on weeds

Our model is that different fertility treatment will affect the weed population. Specifically, excess mineral nutrients are expected to raise the populations of non-mycorrhizal weeds such as pigweed, lambsquarters, and velvetleaf. We tested whether the number or vigor of these weeds is greater in high-rate plots that also have high soluble nitrate and phosphate.

Over the years, we never saw much effect of compost on the population. If nitrate were stimulating nitrate-sensitive weeds to germinate, it would have been apparent in pigweed in the 2X rate of the compost with rapidly available nutrients. We did not see that.

If the compost were having an impact on reproduction in the long term, we would have seen a shift in the number of seedlings of the successful weed species over the years. We did not see that (Fig 8). Overall, compost application had essentially no effect of weed population.

We consistently saw an effect of compost application rate on weed size.

First we tested whether nonmycorrhizal weeds would be less competitive on organic farms than they are on conventional farms with abundant phosphorus. Three species were present in sufficient number and in most plots to permit statistical analysis. These were common lambsquarters, common pigweed and giant foxtail. Of these, giant foxtail is mycorrhizal, and would be expected to respond less to the high rate of fast compost under the model we are testing. All three species grew larger at the higher rate, with pigweed having the greatest response. The lower response of mycorrhizal foxtail (also seen in 2006) lends some weak support for the model that such weeds will have a competitive advantage in organic farms where modest application of compost is used. However, that observation may have little practical importance. Application of manure and compost can easily raise the soil phosphorus to a range where nonmycorrhizal weeds are substantially stimulated.

The response of weed size in 2007, when no compost was applied, indicates that the residual effect of these composts is to promote weed growth even when they do not promote crop growth. In this case, overapplication of compost results in worse weeds, but not better crops. Again, using the conventionally calculated application rate was good but overapplication caused problems with no benefit.

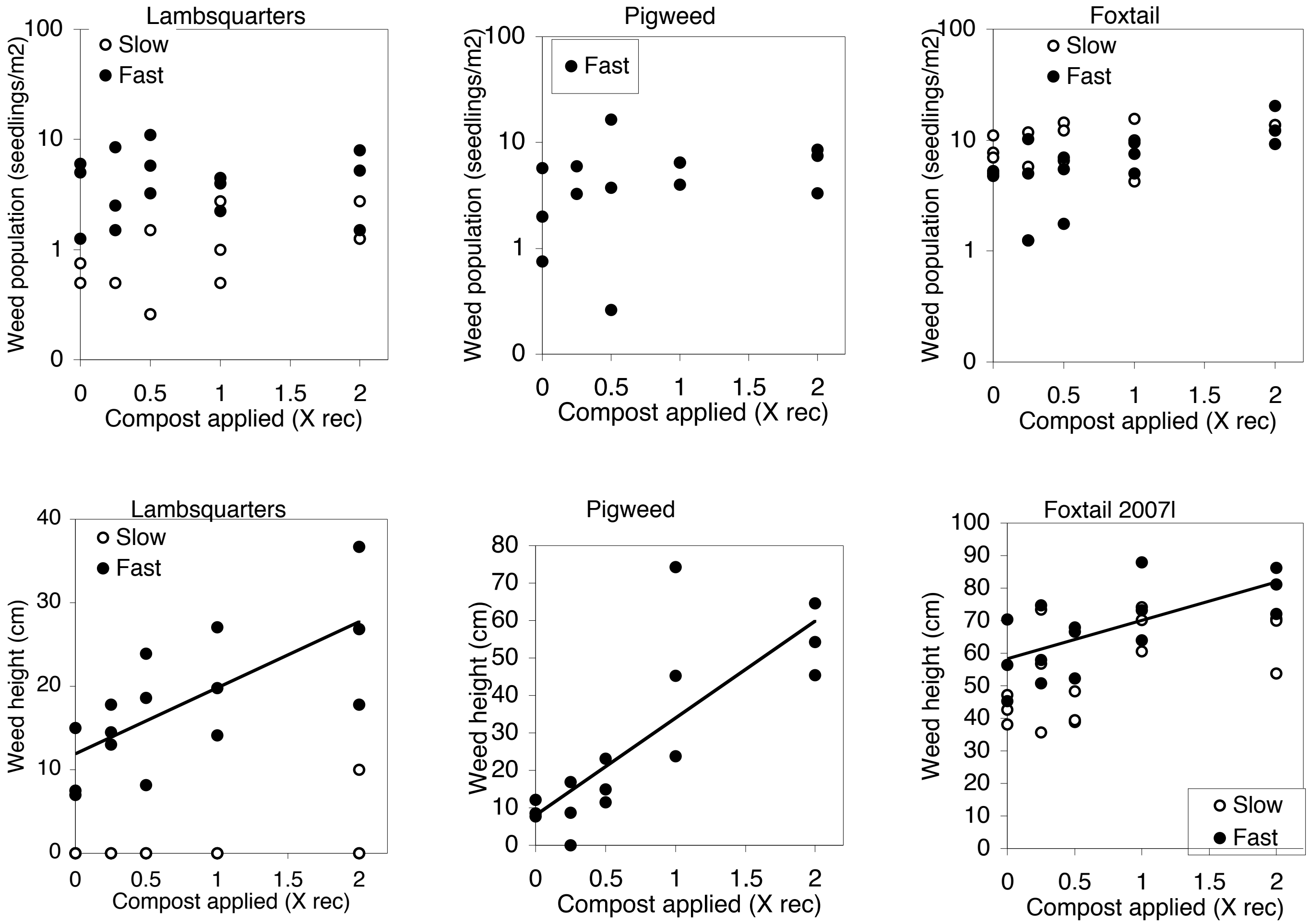

Figure 8. The change weed population in four years of compost amendment (Top row) and growth (bottom row) in corn in August 2007 when the corn had filled in between the rows.

Effect of fertility on soil microbes

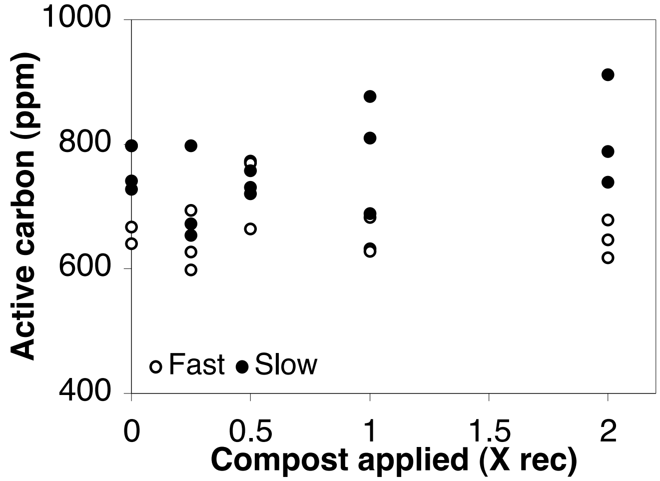

Figure 9. Active carbon. In soils of this type values below 500 are poor, 600-700 is normal, and over 700 is good.

Active soil carbon is an important source of energy for the soil microbes that are so important in organic production. Most active carbon is provided by crop exudates and residue, but all organic amendments can contribute. Since this field has been managed organically for some time, it is no surprise that it is very high in active carbon. The amount of carbon in the compost applied in this trial was not sufficient to raise the measured active carbon further (Fig. 9). Applying larger amounts of a low-analysis compost to soils that have insufficient active carbon might have an effect. That response would be worth investigating because the present test does not provide insight one way or the other.

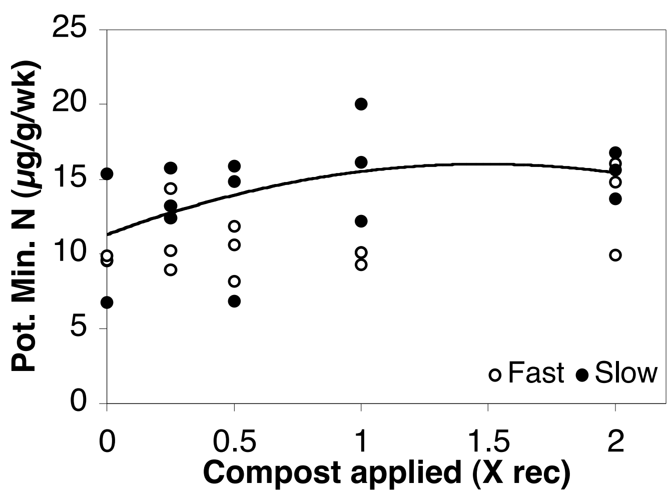

Figure 10. Effect of compost additions on Potentially Mineralizable Nitrogen. Values above 5 are fair, and above 7 good.

Microbial release of organic nitrogen is important for nitrogen nutrition in organic production. Potentially mineralizable nitrogen is a measure of the combined effect of organic matter to feed microbes, nitrogen-containing organic compounds, and the population of microbes. This soil had extremely high levels of PMN, about double the amount considered good. The 1X and 2X rates of the slow-release compost increased PMN by about 20% (Fig. 10), presumably by increasing the amount of nitrogen-containing substrate.

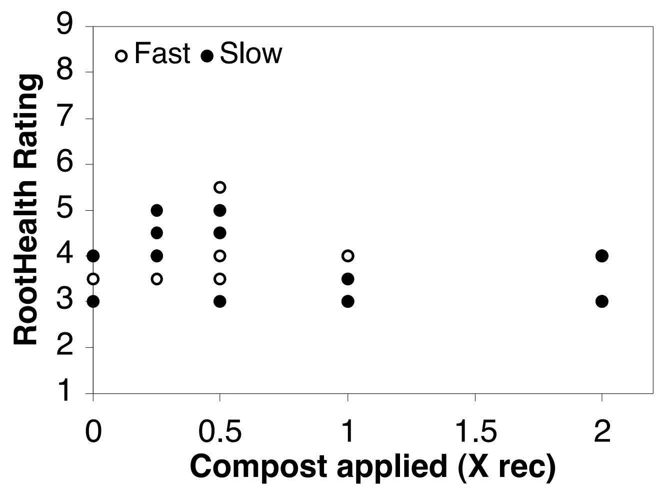

Figure 11. Effect of compost additions on the Root Health Rating. The assay involves raising snap beans in the soil under controlled conditions and measuring the amount of root rot. Values below 4 are good, and below 5.5 are fair.

There are both good and bad microbes in the soil. Organic production strives to create soil conditions that favor the good microbes and disfavors the pathogens. Some composts help suppress pathogens, but that is not one of the expectations of poultry manure compost. The root health rating was unaffected by either compost (Fig. 11). As with some other measures, the soil was in good enough shape that further treatments don't show much effect.

Effect of fertility on tilth

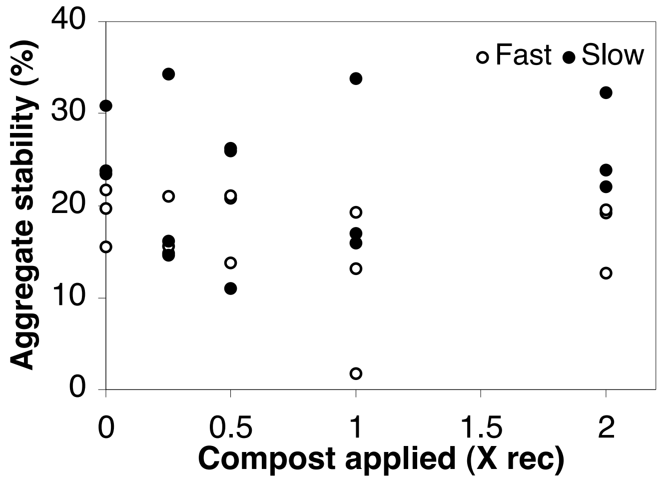

Figure 12. Effect of fertility amendment on soil aggregate stability. A key tilth measure, the stability of aggregates maintains the pores essential to drainage, air circulation, root growth and activity. Values below 20 are poor, over 35 are good.

Maintaining good tilth is at the heart of organic production. The Soil Health Test provides several measures related to tilth. The first is aggregate stability, a measure of how good the crumb is in the soil and how resistant it is to tillage. This field had intermediate and variable aggregate stability (Fig. 12). The main remedy for low aggregate stability is actively growing roots. Compost amendment of any kind tends to have only slight effects. Here, adding high-analysis compost for nutrients did not affect the aggregate stability. These results support the convention that aggregate stability is best addressed with a rotation of crops and cover crops that results in a lot of root growth.

When aggregates collapse or are deformed as a result of tillage, cultivation and traffic, they press together to make the soil hard. As with aggregate stability, the surface hardness was intermediate and variable, with compost additions having no effect (Fig. 13). Overall, the surface soil in this field was not compacted.

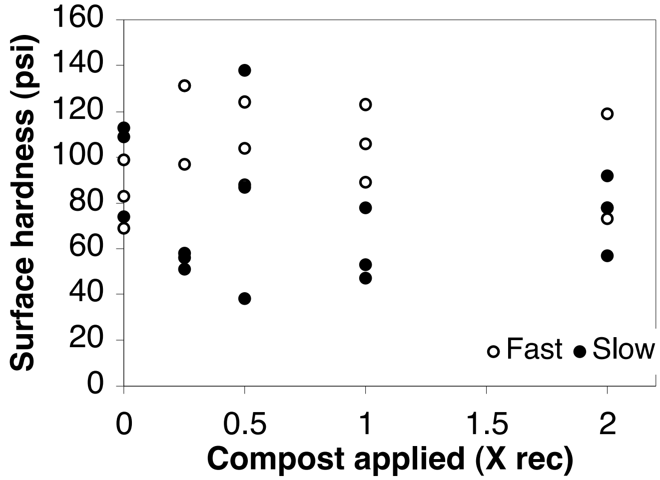

Figure 13. Effect of amendments on surface hardness, a measure of the ability to penetrate the upper several inches of soil. Surface hardness below 160 psi is fair, and below 110 psi is good.

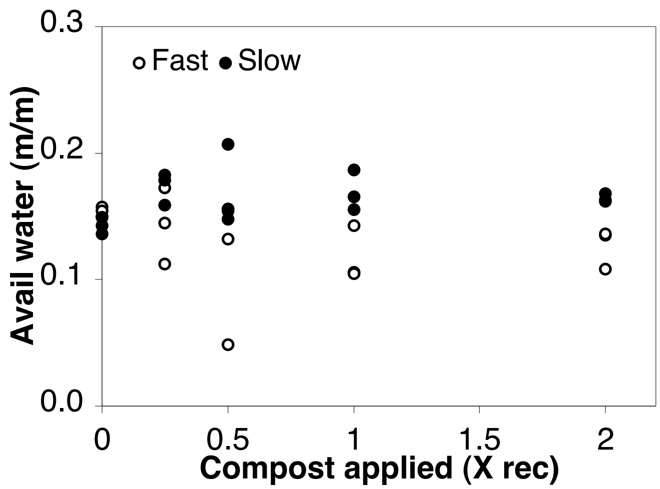

Figure 14. Effect of amendments on available water, a measure of the mesoporosity in the soil, and a consequence of organic compounds that affect the structure and sorbtion of soil aggregates.

The organic matter contributed by the compost is expected to contribute to the internal makeup of aggregates in a way that increases water holding capacity. In the Soil Health Test that was launched by Cornell this year, the prescription for low available water is to use compost. However this measure was unresponsive to the compost additions.

We found that four years of applying nutrient with poultry-manure compost did not provide enough carbon to affect available water (Fig. 12), aggregate stability (Fig. 13) or surface hardness (Fig. 14).

The rates used in this trial were not sufficient to have a measurable impact on these tilth parameters, but composts with substantially lower nutrient content would contain much more carbon. Therefore, using composts that are based on straw, with nutrient analyses of 0.5% or less of each mineral macronutrient, may be effective for this purpose.

Does generous application of organic fertilizer result in pollution risk?

Excessive fertilizer application leads to problems with nitrogen and phosphorus pollution. The latent availability of these nutrients in organic fertilizers and the high application rates sometimes employed make this a pressing issue for organic growers. The farmer's commitment is usually strong, but the information to act according to that commitment is not available.

We assessed over-winter phosphorus leaching risk by measuring water-soluble phosphate. In soils of this type, leaching is unlikely to be a concern if the value is under 10 mg P/kg soil.

For the first time, there appears to be enough P accumulation from the double rate of slowly available phosphate to indicate some caution (Fig. 15 and 16). These data fit the model found in local soils that if the Soil Test P is in the very high range, it is more difficult for the soil to bind the P, and the water soluble phosphate rises more quickly. In general, this site does not represent a phosphate pollution risk with current management. Over the years, the water-extractable P has been variable and low enough that leaching has not been an acute concern.

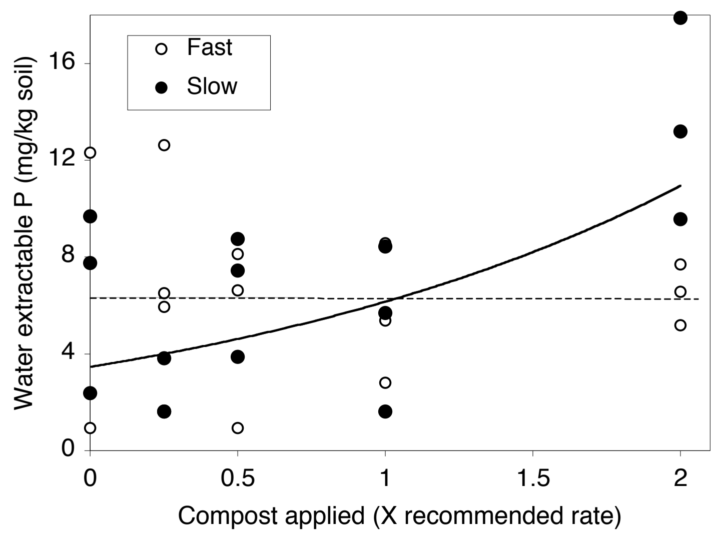

Figure 15. Effect of applied compost on phosphorus pollution potential. Water extractable phosphorus is immediately soluble and reflects leaching potential. The risk level is >10 mg P/kg soil.

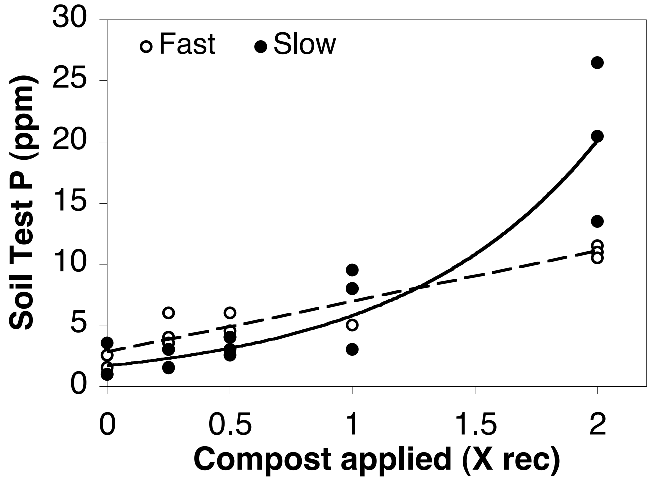

Figure 16. Effect of applies compost on plant-available soil phosphorus as measured by the Morgan extraction. Runoff risk occurs when the soil test phosphorus exceeds 180 mg P/kg soil. The desirable range is 4 to 21.

Long term use of compost and manure for fertility can lead to buildup of undesirably high soil phosphorus levels. Soil that runs off fields into fresh water contains enough phosphorus to stimulate algal blooms and other ecological damage. The 1X application rate moved the soil phosphorus from low to the desirable range (Fig. 16). The 2X rate is threatening to move it beyond the desirable range. We do not anticipate approaching runoff risk values because the starting values were low and because the high additions will not continue. However, this response demonstrates how quickly soils can go from P deficiency to excess if more compost is applied than what the crops need.

Nitrate leaching was not a concern because soil nitrate values before crop uptake were moderate. It appears that mineralization does not substantially precede crop demand. Therefore the risk window that had been identified for manure application before corn is not appearing with these amendments.

Is there a threshold initial application rate for enhancing mineralization?

We tested Kinsey's model that a large single dose of organic phosphorus will stimulate microbial mineralization that persists over several years to supply adequate available phosphorus. This soil has low available phosphorus, which is necessary to test Kinsey's model. The model was tested in the 2005 soybean crop.There was no carryover response to the initial application of P, indicating that Kinsey's model is not applicable to this site.

This project was funded by the Toward Sustainability Foundation of Marblehead, MA. It involved close teamwork with Klaas and Mary-Howell Martens, the Cornell Soil Health Team (George Abawi and Carol MacNeil) and the Cornell Organic Transitions Project (Chuck Mohler)