Project report submitted to the Organic Farming Research Foundation:

Project Title:

On-farm nutrient budgets in organic cropping systems: A tool for soil fertility management

FINAL PROJECT REPORT

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FINAL REPORT:
On-Farm Nutrient Budgets in Organic Cropping Systems: A Tool for Soil Fertility Management

Summary

The long-term goal of this research is to develop tools that can be used by farmers to construct nutrient budgets for nitrogen, phosphorus and potassium in organic cash grain and vegetable production systems. An assessment of the quantity of nutrients entering, leaving and remaining on a farm is the starting point for understanding nutrient cycling. When these flows are documented for the entire rotation cycle, the resulting net balances can be used as a tool to help with soil management decisions and in the interpretation of soil tests. The first step in refining soil fertility management strategies in organic production systems involved interviewing farmers to document their soil fertility management practices and sampling of soil amendments and vegetable and grain crops at harvest for nutrient analysis, to assess the quantities of nutrients entering and leaving the farm. A series of databases were developed that can be used support nutrient management decisions. We also developed a prototype nutrient budgeting tool which would utilize these databases to construct multi-year budgets at the field and farm scale. This prototype budgeting tool currently exists in Excel spreadsheet format and is provided in electronic form. The sample budgets that we have developed for our study sites suggest that the majority of organic vegetable production systems are adding significant surpluses of the major nutrients, as much as 180-200 kg P and N ha^{-1} yr^{-1} in excess. While these surpluses have been viewed as necessary during the transition to organic management, they will clearly lead to environmental problems if they are continued on a long-term basis. We have also found a number of both grain and vegetable farms are achieving profitable yields without large surpluses of P and N supporting the idea that organic systems have the potential to operate with very high nutrient use efficiency.

Introduction and literature review

Soil fertility management in organic systems draws heavily from an ecological framework and seeks to manage plants, soil organic matter (SOM) and soil organisms to maintain internal cycling capacity. The system is managed with the aim of maintaining nutrients stored as SOM rather than supplying plant-available fertilizers directly to crops each growing season (Organic Farming Research Foundation, 2002). The intention is to manage the full range of soil organic and inorganic nutrient reservoirs, particularly those with relatively long mean residence times that are not susceptible to loss but can be accessed by crops and soil organisms (Figure 1).

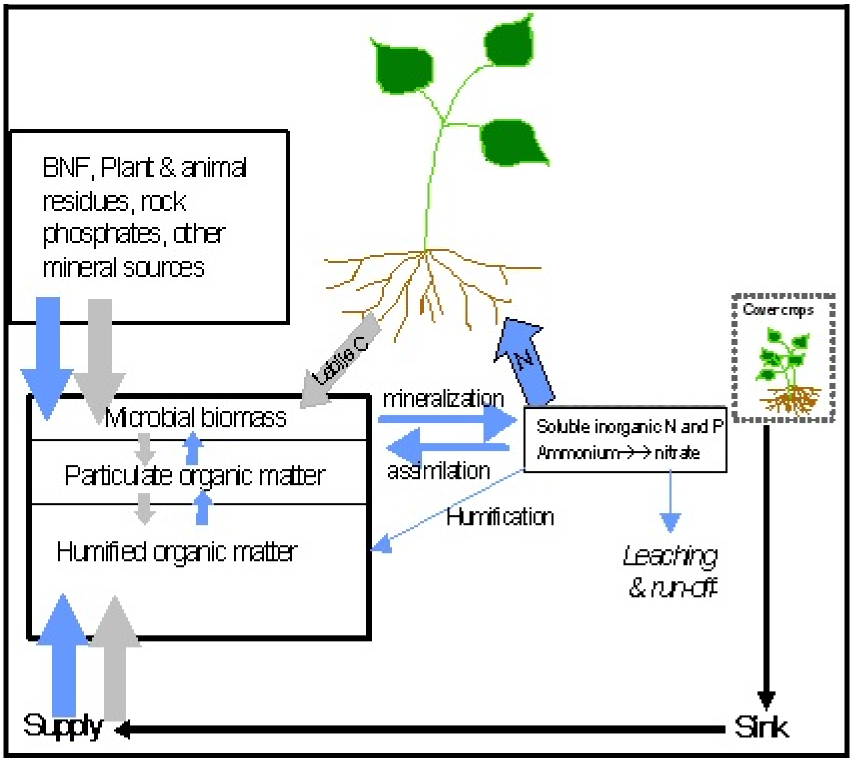

Figure 1. Conceptual model of nutrient additions, reservoirs and relative fluxes under organic management. Pools with longer mean residence times including the full range of SOM pools and sparingly-soluble, mineral pools (not shown) are managed leading to reduced standing pools of soluble inorganic N and P, increased microbially-mediated assimilation and mineralization and reduced nutrient losses. Newly added labile C released in the rhizosphere is exchanged to access recalcitrant soil reservoirs. Cover crops capture nutrients and return them to the SOM pools. Nutrient (dark grey) and carbon (light grey) flows are shown. Modified from Drinkwater and Snapp, in review).

This holistic view is the basis for identifying the soil fertility management practices used in organic agriculture. There are four soil fertility management practices typically used in organic cropping systems that determine the cycling and availability of nutrients in the soil: 1) use of organic residues as soil amendments or sparingly soluble minerals, 2) use biological N-fixation as the major N source, 3) the soil is kept in active plants as much as possible, i.e a green cover is maintained with cover crops, relay cropping, and intercropping, 4) plant species are diversified in space and time to fulfill a variety of functions. Ideally, N inputs from N-fixing crops balance N removed as harvested exports. Use of all of these practices as an integrated approach to soil fertility management is unique to organic cropping systems.

As a result, the conventional method used for managing soil fertility in systems based on soluble, inorganic nutrient sources cannot be transferred to organic farms. This conventional framework is based on targeting fertilizer additions of plant-available forms for the immediate cropping season. Fertilizer management guidelines hinge upon assessments of plant-available N and P combined with empirical fertilizer addition studies that are able to provide estimates of the amount of fertilizer required to achieve yield goals (Balasubramanian et al. 2004, Havlin 2004, Dobermann and Cassman 2004). This approach is unlikely to be successful in organic production systems given the wide array of soil amendments and the range of soil nutrient reservoirs that support plant growth. The soil amendments vary in terms of composition (carbon and nutrient content, i.e. C:N, C:P), quality (carbohydrate versus lignin) and stage of decomposition (fresh plant residues versus composts which contain mainly products of decomposition). Endogenous nutrient stores are highly variable due to management history and soil type. Newly added residues interact with SOM and the community of decomposers that are present (Drinkwater and Snapp, in review). As a result, the outcome in terms of nutrient availability in the short term can be extremely variable.

The limited research that has been conducted on organic soil fertility management as well as farmer experience confirm these ideas. Nitrogen release curves for composts and animal manures that have been developed using conventionally managed soil as a background do not seem to be directly transferable to organically-managed systems, probably due to interactions with organic matter in the soil (Reider et al., 2000). Although many organic producers do use soil testing to assess soil nutrient levels, they report that while these tests often indicate that plant-available N or P may be limiting, their yields do not reflect these soil test results (Spray, Martens, personal communication, Morris, unpublished). The prospect of developing soil tests to serve as indicators of bioavailability is particularly challenging for nutrients like N and P that are converted to plant-available forms by soil biological processes which reflect environmental conditions, plant-microbe interactions and soil food web dynamics (Drinkwater and Snapp, in review). In addition to these soil processes, plants also mediate decomposition and food-web dynamics so the crop itself also plays a role in regulating N and P mineralization (Hamilton and Frank, 2000).

Mass balance approach

All of these factors make it extremely challenging for organic producers to manage soil fertility so that the correct balance of nutrients is applied to maintain food quality and yield while avoiding over-application. One strategy that could contribute to organic nutrient management is application of a mass balance approach to budgeting nutrients. This kind of budgeting, which is illustrated in Figure 2, is not typically used in soil fertility management in conventional agricultural systems. However aggregate budgets at regional and watershed scales indicate that in the US and Europe, annual N and P inputs consistently exceed the amounts exported as harvested crops (Van der Molen et al., 1999, David and Gentry, 2000). As a result, the majority of lands under conventional management in industrialized countries tend to have nutrient surpluses.

The consequences of nutrient surpluses are not as immediately apparent as are nutrient deficiencies. *Any* ecosystem subjected to additions of more nutrients than can be used by plants and microbes will become saturated and show increased nutrient losses to the environment. This has been documented for temperate deciduous and pine forests (Fenn et al., 1998), other natural terrestrial ecosystems (Neff et al. 2002) and conventional (David and Gentry, 2000) and organic agricultural systems (Oelson et al., 2004). Nutrients lost from agriculture contribute to a myriad of environmental and health risks. In addition to these environmental impacts, surplus nutrients can alter microbial community structure and function, increase plant susceptibility to pathogens (Abawi and Widmer 2000) and arthropod pests (Lewis et al. 1997) and can also lead to increased weed competition (Gallandt et al. 1999). In forests receiving atmospheric N deposition, microbially-mediated processes that contribute to N losses, such as nitrification and denitrification increase (Aber et al., 1998, Fenn et al., 1998).

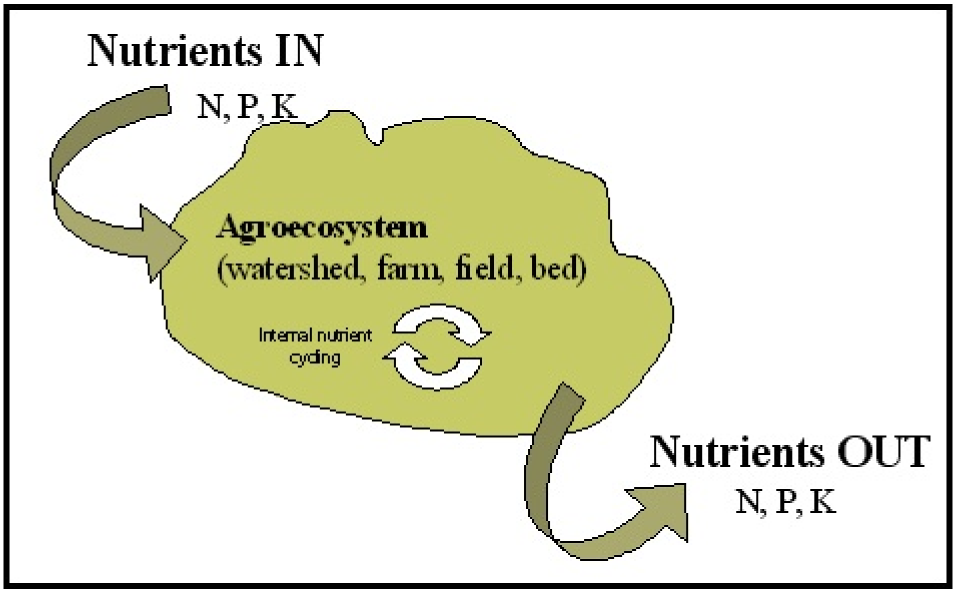

Figure 2. Mass balance concept involves defining the management unit and measuring nutrient additions and harvested nutrient exports.

Construction of simple mass-balance budgets at the management-unit (field or farm) scale involves quantifying inputs and harvested exports. Typically, N, P and potassium (K), and other nutrients are brought into the farm in purchased soil amendments or feed for livestock. Additionally, N is imported from two other sources: N fixation by legumes, and to a lesser extent, from atmospheric deposition in the form of precipitation. Nutrients that originate from mineral sources (i.e. soil mineral constituents) such as P and K are also made available by the process of weathering or mineral solubilization. In soils with greater biological activity the rate of biological weathering of soil mineral components is accelerated, increasing the availability of soil-derived nutrients. (Bormann et al., 1998). Measurements of weathering rates are beyond the scope of the proposed work, however, farmer experience suggests that this may be a significant source of nutrients in organic production systems. If our mass balances show consistent deficits for mineral-derived nutrients, this will support the idea that biological weathering is important and should be studied in organic production systems.

Nutrients leave the farm in harvested crops and through unintended losses such as leaching and soil erosion. Nitrogen is also lost to the atmosphere through ammonification and denitrification. The amount of nutrients leaving the farm as unintended losses is determined by the size of the surplus and the capacity of the agroecosystem to store surplus nutrients. In other words, excessive applications of nutrients, particularly nitrogen, tend to increase the size of nutrient losses.

Long-term studies of organically managed cropping systems indicate that yields comparable to conventionally managed systems can be achieved under organic management while N surpluses are very small and N losses are significantly reduced (Drinkwater et al. 1998). In these studies, under conditions of surplus N additions, a greater proportion of total N inputs was retained in the soil (Drinkwater et al., 1998, Clark et al. 1998). Thus, organic production systems clearly have the capacity to operate close to a balanced state, something which has not been achieved in fertilizer-driven systems. Understanding the underlying mechanisms which enable some organically-managed cropping systems to achieve high yields while maintaining balances with very small surpluses will be key in fine-tuning organic soil fertility management.

While these simulated research based systems demonstrate the potential for organic management to meet yield goals without surplus nutrient additions, studies of organic farms indicate that the balance between nutrient additions and nutrients harvested in the crop varies tremendously due to large variations in nutrient additions (Watson et al. 2002, Drinkwater et al., unpublished). Studies of European organically-managed commercial farms, found that grain systems operate with smaller N surpluses (2 to 50 kg N ha^{-1} yr^{-1}) compared to horticultural crops with surpluses of 90 to 400 kg N ha^{-1} yr (Watson et al. 2002). Nutrient budgets constructed for multiple years that reflect rotation cycles for organic management units will provide a foundation for soil management recommendations that will improve efficiency, reduce costs and reduce the potential for environmental losses of nutrients. We also consider this information on nutrient balances as providing a necessary context for interpreting soil tests and for conducting fundamental research on the relationship between management and nutrient cycling in these systems.

Methods

We began working with local organic farmers to develop nutrient management tools in 2001 with a small seed grant. Figure 3 illustrates the approach we used to develop the nutrient budgeting tool and supporting databases. A key component of the nutrient budgeting tool is the supporting databases that were tailored to the farming systems. These databases are useful in conjunction with the nutrient budgeting tool or on their own as aids in soil fertility decisions. The three supporting databases are as follows: 1) The Green Manure Database is a set of conversion tables for green manures and their N content which will be based on green manure stand size, 2) The Soil Amendment Database is a compilation of the nutrient content of external nutrient sources commonly used by organic farmers in the Northeast and, 3) The Grain and Vegetable Crop Database which contains nutrient content for grain and vegetable crops.

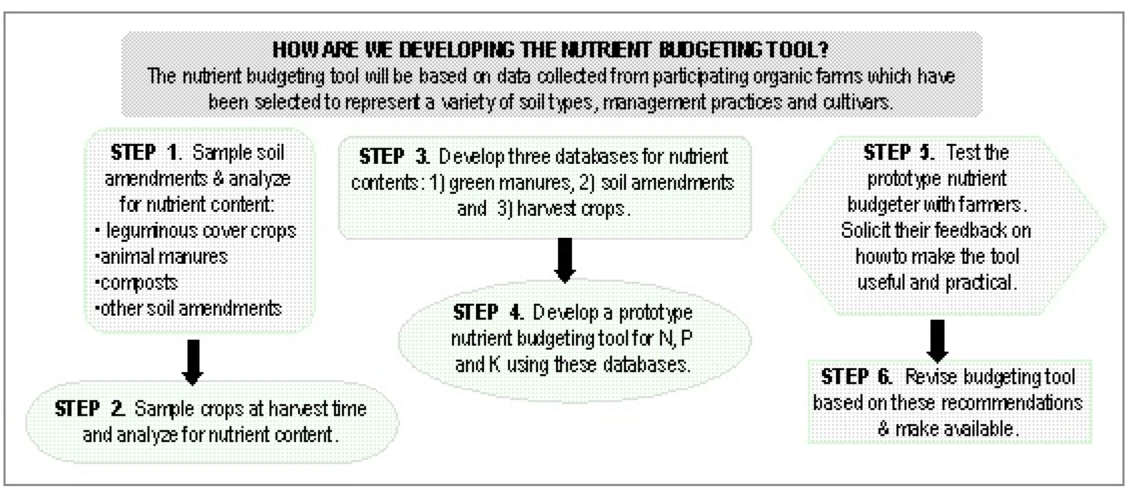

Figure 3. Diagram of the steps involved in developing the nutrient budgeting tool and supporting databases.

Green manure database

Cover crop and green manure samples were collected over three years (2002-2004) on twelve farms. The objectives of this data collection were two-fold. First, we wanted to collect quantitative data that could be used to estimate N inputs from biological N fixation in fields where green manures were being used for our budget calculations. Secondly, by collecting information on aboveground biomass in conjunction with simple measurements of height and density, we were able to determine the feasibility of developing simple tables that could be used by growers to estimate green manure N content.

Samples were taken in sets of four on large fields (as on grain farms), and in sets of three for small beds (as on vegetable farms). For each sample, cover crop plants were clipped at the soil surface within a 4 ft^2 quadrant and the fresh weight was measured. In the case of a mixed cover crop, all plants were clipped and species were separated before weighing. Percent cover was estimated visually within the quadrant and measured twice along each transect using a 30 ft beaded string. Height was measured eight times within each transect. Green manure samples were then dried at 60 degrees C for one week and ground with a Wiley mill grinder for nutrient analyses.

Soil amendment database

Our objectives here were similar to those of the green manure data collection in that the data was needed for budget construction but was also collected so that the variability in nutrient contents by source and year of production could be evaluated. Compost and manure samples were collected from 16 farms over two years (2003-2004). A total of 23 compost or manure samples were taken in triplicate. With the exception of two liquid manure samples which were taken from on-farm storage vats, input samples were taken from large on-farm piles. For each of these samplings, the outer crust of the pile was removed and samples were taken with a shovel from three to four spots inside the pile to fill a five gallon bucket. The sample was then mixed in the bucket and a sub-sample was taken from the bucket. Compost and manure samples were weighed in the field. Compost samples were then air dried in a greenhouse for one week. Once dry, samples were weighed and ground for nutrient analysis. Raw manure samples were frozen prior to analysis.

Crops databases

Vegetable samples were collected during four growing seasons (2001-2004) from 41 fields on seven vegetable farms in New York and Pennsylvania. Twenty-five types of vegetables were collected, which included approximately 150 different varieties. Vegetables collected included: beet greens, beets, broccoli, cabbage, carrots, carrot greens, chard, collards, cucumber, eggplant, green beans, kale, leeks, lettuce, onions, peppers, potatoes, scallions, snap beans, spinach, summer squash, sweet corn, tomatoes, winter squash, and zucchini. Vegetables were weighed in the field to obtain fresh weight and then stored in coolers for transport back to the laboratory. Vegetable samples were then triple washed, first in tap water and then twice in distilled water and chopped into smaller pieces for drying. Most vegetables were then oven dried at 60 degrees C for approximately three days. Because of their high sugar content, beet and tomato samples were freeze-dried. After drying, vegetable samples were again weighed and then ground into a powder using a wiley mill grinder.

Grain samples were collected over two years (2002-2003) from 51 fields on eight farms in New York. Grain crops collected included: corn, soybean, wheat, oats, spelt, barley and triticale. Samples were randomly collected from within four transects across each field, for a total of four samples per field. Three meters of two rows were sampled for each corn sample and two meters of one row were sampled for soybean samples. Cereal samples were collected by clipping grain heads six to eight times along the transect to fill a paper grocery bag. Grain samples were oven dried at 60 degrees C for one week. After drying, grain was threshed either by hand (for soybeans) or with a mechanical thresher (for corn and cereals). Grains were then ground using a Wiley mill grinder.

Analytical methods

Nutrient analysis of manure samples was also conducted by the forage lab at Dairy One (Ithaca, NY). Total nitrogen and total carbon were measured by combustion for all samples using a LECO CN-2000 autoanalyzer (LECO Corporation, St. Joseph, MI). Other nutrients, including P, K, Ca, Mg, Mn, Fe, Cu, B, Al, Zn and Na, were measured by the Agricultural Analytical Services Laboratory at Penn State University, using a dry-ash digestion procedure and inductively coupled plasma (ICP) analysis.

Nutrient Budgeter

A prototype nutrient budgeting tool was developed and linked to the databases described above. The original tool, in Excel spreadsheet format, was tested with farmers in January, 2004. Farmers' suggestions were then used to revise the budgeter. Nutrient budgets were constructed for two fields at Martens' Organic Grain Farm, one field at Myer's Organic Grain Farm, and sample rotations at Beech Grove Farm and Blue Heron Farm. A description of these farms is found in Table 1.

Table 1. Site descriptions of initial four farms for which nutrient budgets were developed.

Site	Crops Grown	Soil Series	Texture	Farm Size	Input Level
Beech Grove Farm, Trout Run PA	Vegetables	Leck kill	silt loam	6 ac	low
Blue Heron Farm, Lodi, NY	Vegetables	Honeoye, Kendaia	loam/ silt loam	154 ac (13 ac in vegetables)	high
Martens Farm, Penn Yan, NY	Grains	Honeoye, Lima , Lansing	loam/ silt loam	1300 ac	low
Myer Farm, Ovid, NY	Grains	Lima, Cazenovia	loam/ silt loam	900 ac	low

Results &Discussion

The OFRF project was conducted in conjunction with a larger project with multiple funding sources. In the course of these 3 years, we have analyzed three composite samples from more than 400 crops, including the 24 most commonly grown vegetables and 7 widely grown grain crops collected from a core group of 20 farms. We have also analyzed samples from 86 green manure stands and 34 soil amendments. These samples have been analyzed for C, N, P, K, calcium (Ca), magnesium (Mg) and micronutrients. We are emphasizing carbon management and the major nutrients at this stage, however we intend to examine the balances and soil levels of other nutrients at a later date. Micronutrients interact with macronutrient nutrition (Marschner, 1986) and can also impact weed competition (Gallandt et al., 1999) so it is important to also consider these elements. We have also collected detailed information on the farming practices used to manage these farms.

We are currently engaged in analyzing and synthesizing all of the data collected in the course of this project. This synthesis will be reported in two publications which we are in the process of writing. We will provide OFRF with electronic copies of these manuscripts as they are submitted to journals. Here we report a brief sampling of our results.

Green manures

Obtaining reasonable estimates of N inputs from biological N fixation (BNF) is one of the most challenging aspects of managing organic soil fertility. It is well-known that as N fertility increases, the proportion of N-fixed decreases as the plant is able to acquire increasing amounts of N from soil pools. Some of the farmers we are working with have reported decreases in nodulation in leguminous cover crops. However, the quantitative nature of this relationship remains undefined. The effects of soil nitrogen supply on BNF in legumes have been studied almost exclusively using inorganic nitrogen fertilizers to create a fertility gradient primarily in greenhouse pot studies (Atkins et al., 1980; Butler and Ladd, 1985) or in a small number of field studies (Voisin, 2002). Greenhouse pot studies do not simulate biogeochemical processes that drive nutrient cycling in the field. There are many reasons to expect that the use of inorganic N fertilizer does not simulate the responses that would occur in an ecosystem where fertility is driven by soil organic matter dynamics (Drinkwater and Snapp, in review), and that the dynamics of BNF differ between organic and conventionally managed systems (Drinkwater et al., 1998).

This lack of quantitative information on the contribution of green manures to total N additions has been identified as a critical knowledge gap by a majority of growers participating in this effort. For this reason, and because of the promising results from this OFRF funded work, we are continuing our efforts to develop farmer-friendly methods of assessing cover crop biomass N contents. In addition, as part of a different project funded by USDA we (LED and students) are currently conducting studies to quantify biological N-fixation in organically-managed grain systems for three important legume species (USDA/NRI-CGP grant number 2003-35101-12932 to LED). This mechanistic work can be used to improve the accuracy of simple, farmer-friendly N-fixation estimates that are based on aboveground biomass determinations thus permitting rapid assessments of a major N source in organic systems.

There was an acceptably strong relationship between height x density and aboveground biomass (r^2=0.7, n=180) despite the fact that all legume species were lumped together for this preliminary analysis. We believe that we can use this relationship to develop species specific tables that can be used to estimate N inputs from green manures. We intend to continue work in this area in order to produce a set of conversion tables for green manures and their N content which will be based on a simple, visual method of assessing green manure stand size. We plan to test and calibrate several quick, visual methods for quantifying legume biomass stands, in addition to the knotted rope method, including a modified version of the forage disk (Barnhart,

1998) and a visual method that is calibrated based on % light penetrating the canopy.

Soil Amendments Database

Organic soil amendments are notoriously variable in terms of nutrient contents. Our study confirmed that these amendments vary significantly, depending on the feedstocks used and the management of the composting process. We anticipate that this database can provide growers with some useful information about the variability of nutrient contents for these amendments, however we expect that growers will need to invest in some nutrient analyses themselves when they are purchasing composts or manures. To that end, we have put some effort toward compiling nutrient contents for a wide range of amendments which are used in the Northeast and have incorporated those values into the Prototype Nutrient Budgeting Tool. We have also devised a simple method for collecting representative samples and determining bulk density that can be used by growers and will assist them in interpreting the data they receive from lab nutrient tests.

Vegetable and grain crop databases

Our preliminary analysis indicates that most vegetables can be grouped without regard to variety with a few notable exceptions. Examples of average N and K concentrations for several of the most commonly grown vegetables are shown in Figure 4. Some vegetables had greater than 25% variability in nutrient contents by variety and will require more analysis to determine whether or not this variability is consistent and needs to be accounted for in constructing budgets. For example, potatoes and eggplants may need to be separated out by major varietal types. Figure 5 gives N contents for eggplant varieties. Vegetable water content varies with time of harvest for some vegetables such as lettuce, potatoes and chard. In these cases, vegetables harvested early in the growing season tend to have higher water contents than those harvested in mid- or late-season. We believe that this variation will not need to be accounted for in constructing budgets for most farming systems.

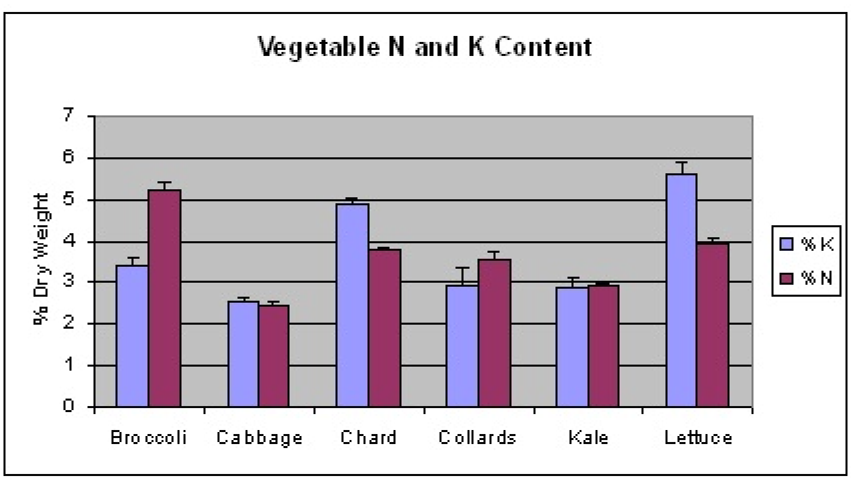

Figure 4. Nitrogen and potassium contents of brassicas and lettuce. We have been able to sample several varieties across farm sites enabling us to eliminate variety as a significant source of variability for many (but not all) vegetables.

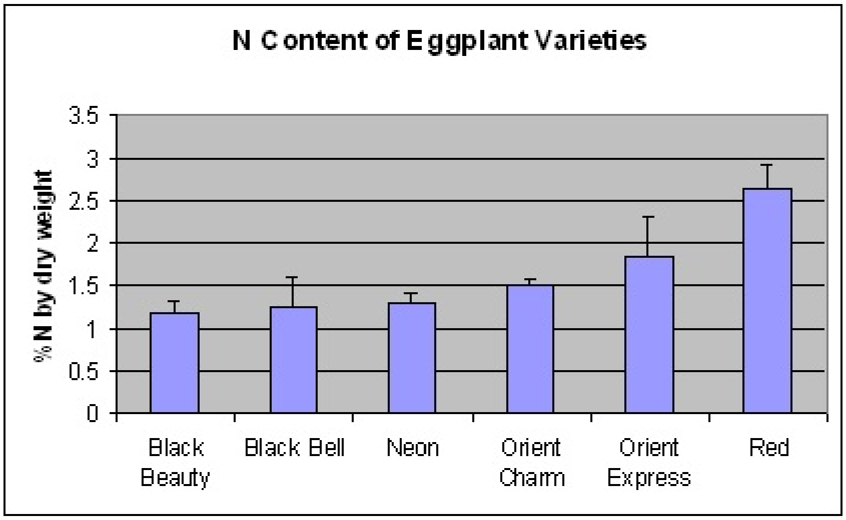

Figure 5. Nitrogen content by eggplant variety.

Grain nutrient contents were much more consistent than are vegetables, although there is some year to year variability. This is not surprising given that grains have been selected to have more consistent contents of N and P reflecting the influence of the animal feed industry. Our comparisons of nutrient contents relative to literature values are in progress at this point. Some literature values are in close agreement with our data whereas others differ by as much as 2-fold. We will continue with this analysis and present our findings in the journal article we are preparing.

Prototype Budgeting Tool

The prototype budgeting tool was subjected to evaluations by several participating farmers in January, 2004. The farmers' responses were very favorable. They seemed to like the flexibility of the tool in terms of being able to try out different rotations and combinations of amendments to evaluate nutrient budgets. Based on our experience with these growers we recommend that introduction to the tool should be carried out as part of a workshop. The prototype tool will be used this winter in a SARE-sponsored workshop aimed at training extension educators in organic management practices. The attached prototype budgeting tool is the version we are currently working with.

Nutrient Budgets Developed

We constructed sample single-year budgets for 11 farms using the budgeting tool and supporting databases. Nutrient balances in these organic systems are highly variable but we found that it is more common for vegetable production systems to be managed with large surplus additions of P and N due to the heavy reliance on compost for nutrients. Figures 6 and 7 show the average annual rate of accumulation or depletion for N and P for model nutrient budgets for the 11 farms which were studied in conjunction with the NEON project. Nutrient budgets showing annual changes in mass balances during a 5-year rotation for a sample vegetable and a grain farm are presented in Tables 2 and 3.

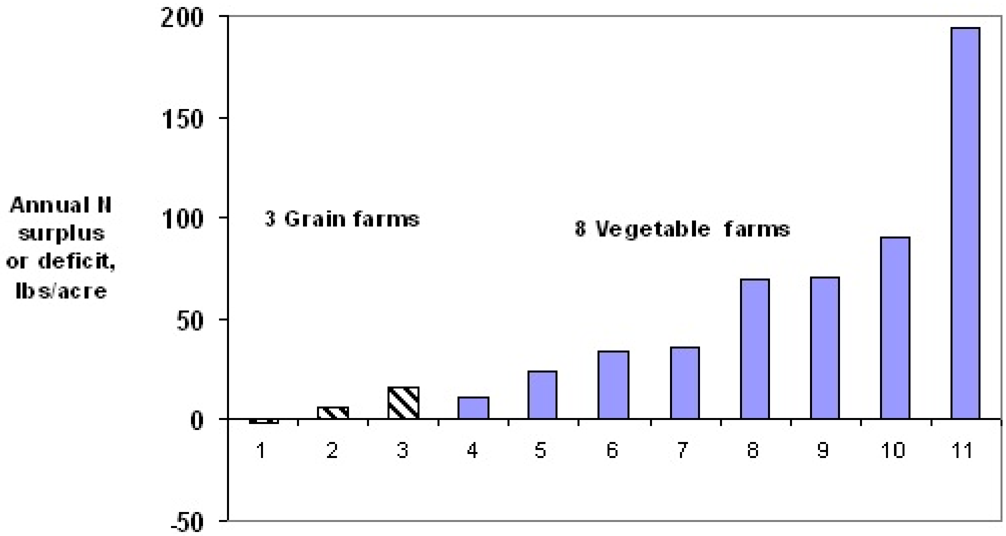

Figure 6. Nitrogen mass balances for sample fields in three grain farms (striped bars) and seven vegetable farms (solid bars). These were calculated by dividing the final nutrient balance of the estimated budget by the number of modeled years (usually between 5 and 7 years). A given farm usually did not rank the same way for different nutrients (i.e. "farm 9" for N is not the same farm as "farm 9" for P).

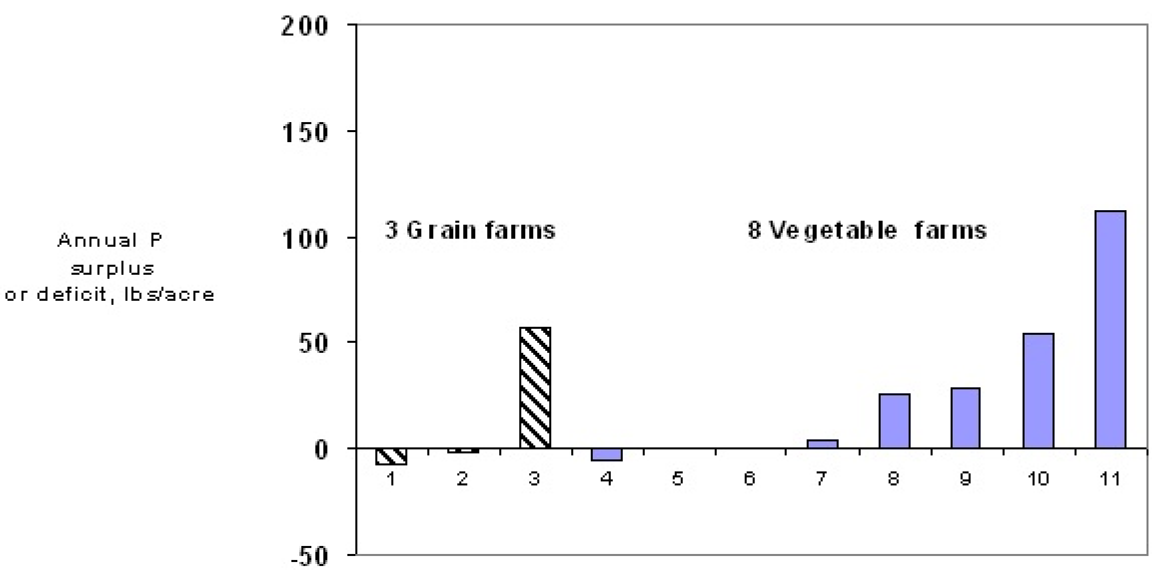

Figure 7. Phosphorus mass balances for sample fields in three grain farms (striped bars) and seven vegetable farms (solid bars)ranked within category.

We found some striking differences between vegetable and grain systems in terms of farm and field-scale nutrient balances. The tendency for small surpluses or deficits in grain farms compared to significant surpluses of varying sizes for vegetable farms is consistent with the findings of the European study conducted by Watson et al. (2002; see Fig. 6, Tables 2 & 3). Nitrogen was applied in the highest surpluses on vegetable farms with 50% of the farms exhibiting N excesses averaging 50 lbs/year or more. Although the analysis of nutrient balances always involves uncertainties, these quantities of N are almost surely well beyond crop needs. We expect that, while a portion of this surplus N remains in the soil for use by crops in subsequent field seasons, it is also likely that a significant amount is being lost to the environment either through denitrification or nitrate leaching. The major driver in determining the amount of N lost from an ecosystem is magnitude of the surplus (Aber et al., 1998). Given surplus N in the soil system, the dominant pathways of loss are determined by a complex set of environmental and biological factors including climate, soil type and texture, composition of the added soil amendment and endogenous soil organic N reserves, and microbial community structure and function. Some ongoing leaching and gaseous losses are inevitable given current techniques of tillage and amendment application and weather in the Northeast U.S. that includes heavy rains and other nitrogen-leaching events, but we expect that the extent of these losses can be greatly reduced by avoiding chronic over-application of nitrogen.

Phosphorus also showed a tendency towards excess on vegetable farms, again especially among farms applying high rates of compost. Four vegetable farms as well as two of the grain farms achieved average annual P balances near zero, which probably reduces these farms' impact on local watersheds and may have additional benefits for the production system such as reduced susceptibility to diseases and weeds. Interestingly, one grain farm also had a high annual rate of accumulation of phosphorus, traceable to the large amounts of dairy manure with an especially low N:P ratio that are available to this farm from local sources.

While land application of composted organic manures and wastes remains an excellent use of local resources for organic farmers, our simple mass balance analysis of the nutrient flows for a sample of leading organic farms points to the need to educate farmers and extension staff about appropriate and strategic use of such amendments, as well as risks of over applying nutrients that are mobile and can pollute local watersheds. The fact that a number of both grain and vegetable farms are achieving profitable yields without large surpluses of P and N supports the idea that organic systems have the potential to operate with very high nutrient use efficiency.The budgeting tool is most useful in identifying farming systems with significant imbalances and can be used in making decisions about the quantities of soil amendments that should be added to a rotation to replace exported nutrients. Farming systems that are generating small surpluses or deficits will need to combine budgeting with soil tests and crop performance considerations in order to accurately assess whether or not adjustments are needed. We conclude that using the mass balance approach can be an extremely useful and cost effective tool in conducting a first assessment of nutrient status of crop production system.

Table 2. Sample budget for one typical field in a vegetable farm. This farm is representative of typical soil fertility management practices that rely on significant compost inputs and generate large surpluses of nutrients. About half the vegetable farms showed signs of chronic over-application of nutrients relative to harvested exports.

Year	Crop	Input source	N export (lb/ac)	N input (lb/ac)	N balance (lb/ac)	P export (lb/ac)	P input (lb/ac)	P balance (lb/ac)
1	winter squash	poultry litter compost	39	336	297	18	416	398
2	potato	vetch + poultry litter compost	107	7 + 336	236	29	416	387
3	lettuce	buckwheat	32	0	-32	5	0	-5
4	beets	vetch + poultry litter compost	53	7 + 336	290	9	416	407
5	broccoli	vetch	**83**	7	-76	11	0	-11
5-YEAR BALANCE					**+715**			**+ 1176**

Table 3. Sample budget for a typical field from one of the grain farms showing that the N balances shift from positive to negative throughout the rotation cycle.

Year	Crop	Input source	N export (lb/ac)	N input (lb/ac)	N balance (lb/ac)	P export (lb/ac)	P input (lb/ac)	P balance (lb/ac)
1	corn	Fertrell GSS + poultry litter compost	96	4 + 34	-59	25	4 + 14	-7
2	soy	Fertrell Blue High K	0	1	1	8	0	-8
3	spelt	No inputs	55	0	-55	10	0	-10
4	corn	clover	65	111 + 4	50	17	4	-13
5	soy	Fertrell Blue High K	0	1	1	9	0	-8
5-YEAR BALANCE					**-62**			**-46**

Outcomes resulting from this funding

Extension presentations

Introduction to soil organic matter management. Department of Horticulture, Garden Day. March 2004, Canandaigua, NY.

On-farm research with Northeast Organic Network (NEON)," PASA's Annual Farming for the Future Conference, State College, PA, February 2004

Nutrient budgeting for soil fertility management. Northeast Organic Network.Conference. Poughkeepsie, NY. Jan 2004.

Farmer feedback from prototype nutrient budgeting tool, NEON Team Meeting, Poughkeepsie, NY, January 2004

Research approaches in organic agriculture: How best to study organic production systems? Symposium presentation at the Annual Meetings of the Agronomy Society of America. Denver, CO. November 2003.

Progress report: nutrient budgeting tool, NEON Team Meeting, Latham, NY, November 2003

Findings of on_farm research in nutrient budgeting, PASA/NEON Field Day, Beech Grove Farm, Trout Run, PA, October 2003

Nitrogen inputs from a clover cover crop: on_farm research in nutrient budgeting, NOFA Organic Crops and Soil Field Day, Geneva, NY, August 2003

Nutrient management in organic cropping systems. New York Certified Organic., Geneva, New York. March 2003.

Getting the most out of winter cover crops. New York State Vegetable Conference. Syracuse, NY. Feb 2003.

Development of a nutrient management tool for organic farmers. Farm Field Day. Martens Farm, Penn Yam, NY. Aug 2002.

Extension materials

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Drinkwater, L.E., S. Vanek, S. Williams, B. Caldwell and A. Rangarajan. 2004. Prototype nutrient budgeting tool for organic production systems. Electronic version provided.

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Drinkwater, L.E. and S.S. Snapp. In review. Nutrients in agriculture: Rethinking the management paradigm. Submitted to Ecosystems.

Vanek, S., S. Williams, A. Rangarajan and L.E. Drinkwater. *Forthcoming.* Nutrient budgets for organic production systems in the northeastern USA: Balancing production with environmental goals. To be submitted to Agriculture, Ecosystems and Environment. Feb 2005.

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