Soil Fertility Management on the Intensive Market Farm

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Introduction and project overview

Organic growers in general—and organic vegetable growers in particular—rate soil fertility as a significant challenge and top research priority. As an initial step to address organic vegetable growers' needs and concerns, the UW-Madison Center for Integrated Agricultural Systems gathered basic information about the fertility management practices on organic vegetable farms in Wisconsin and Illinois.

The purpose of this project was to document the soil fertility practices employed by organic vegetable growers in Wisconsin and Illinois while simultaneously gathering information about their research needs and priorities. The researchers collected this information through a survey, and generated a set of cases studies highlighting contrasting fertility management strategies. This publication highlights observations from the case study farms.

The vegetable industry in Wisconsin and Illinois features both significant processing vegetable acreage and a large and growing fresh market sector. In Wisconsin, there are over 1,500 fresh market vegetable growers that generate all or part of their income from the sale of vegetables. The 2007 Census of Agriculture found 214 organic vegetable and melon farms in Wisconsin covering 5,042 acres and generating $5,352,000 in sales. In Illinois, the census found 90 organic vegetable and melon farms covering 497 acres and generating $1,100,000 in sales.[1]

Organic vegetable growers face a common challenge regardless of the crops they grow, the scale of their farms or their marketing strategies. These growers export significant amounts of biomass and nutrients off their farms each year. To maintain or improve crop yields and quality—and uphold the soil building tenets of organic farming—organic growers endeavor to improve soil health and supply nutrients through a wide variety of strategies. These include short-term cover cropping, spreading compost or manure, rotating cash crops with long-term (sod) cover crops and applying fertility amendments approved for use on organic farms.

There has been some speculation about nutrient imbalances on organic farms. There is a lack of soil test data to confirm or refute the build up of available nutrients on organic farms, particularly those that might impair water quality, such as phosphorous and nitrogen. Heading into the project, it was perceived that few organic farmers test their soil because interpretation of soil test results and recommendations are geared toward conventional farmers.

This project also set out to document whether or not the USDA National Organic Program (NOP) is changing soil fertility management. Although the NOP has created a task force to develop new guidelines that will make composting easier on organic farms, some growers may no longer make compost due to standards that specify how many times compost must be turned, and internal temperature requirements for compost piles. Other growers may not be able to find NOP-acceptable compost off farm. Growers must treat any manure-containing compost that does

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[1] U.S. Department of Agriculture. *2007 Census of Agriculture*. Table 62. http://www.agcensus.usda.gov/Publications/2007/index.asp. Accessed 11/11/09.

not meet the NOP guidelines as manure; that is, they must apply the compost 90 or 120 days before harvesting crops intended for human consumption. .

There are no data showing the prevalence of different soil fertility practices on organic vegetable farms. Existing literature and communication with growers suggest that many organic vegetable farms rely on off-farm sources of manure and manure-based fertilizers, especially poultry litter. Some have questioned the sustainability of this practice due to nutrient runoff concerns and the desire of many organic farmers to reduce their reliance on off-farm inputs. New phosphorous management standards may prevent growers from applying enough manure to supply crop nitrogen needs.

A 1978 study entitled "Contradictions in organic soil management practices: Evidence from 31 farms in Maine," which was presented at the 2nd International IFOAM (International Federation of Organic Agriculture Movements) Conference in Montreal, Canada, found that the majority of organic farms in Maine at that time relied primarily on cheap off-farm chicken manure rather than on-farm fertility management strategies such as legume rotations and cover crops. The authors expressed concern that, with the Maine poultry industry in decline, most of these organic farmers were in an economically vulnerable partnership. The authors were also uneasy about the ecological consequences of most of Maine's organic farmers depending on heavy annual applications of poorly–composted and nutrient-rich poultry manure.

Organic agriculture has come a long way since 1978, but organic vegetable farmers may still depend on off-farm sources of manure for readily-available plant nitrogen. A 1993 survey revealed that over 70 percent of organic vegetable growers in Florida relied on chicken manure or bagged organic fertilizer made primarily from poultry manure. Anecdotal information from growers in Wisconsin suggests that poultry litter, combined with various annual cover crops, is a common source of fertility. On-farm integration of crops and livestock and complex rotations that include both cash crops and sod crops are thought to be relatively uncommon on most organic vegetable farms in Wisconsin.

Regardless of their fertility strategies, many organic vegetable growers question how well their practices provide fertility for subsequent crops. They also wonder whether they are meeting benchmarks such as increases in both biologically active and stable organic matter pools that would indicate improved soil health. In addition, many growers have expressed a desire to implement long-term, perennial cover crop rotations, but lack sufficient land or proof that these rotations make economic sense.

Soil fertility management survey

In order to gather basic information about growers' fertility management practices and research and education needs, the researchers mailed a survey to 181 vegetable farms during the winter of 2005/2006. These farms were either certified organic by the USDA-NOP or self-described, uncertified organic farms. Eighty-eight surveys were returned for a response rate of 49 percent.

The survey showed that cover crops are commonly used on organic vegetable farms. The most popular cover crops are winter rye, oats, clover and buckwheat. Vetch, sorghum-Sudangrass and wheat are also relatively common. Growers use these crops as needed throughout the growing season to keep soil covered, add organic matter, produce nitrogen, smother weeds, scavenge for nutrients, provide beneficial insect habitat and reduce erosion.

The use of uncomposted manure was reported by almost 50 percent of farms. Growers most frequently apply uncomposted manure in the fall in order to comply with the strict requirement of 90 or 120 days between manure application and harvest of crops that come in contact with the soil. Sixty-one percent of farms keep livestock as a farm business enterprise and 29 percent graze livestock as part of a larger crop rotation—meaning that the manure is applied directly to fields in perennial cover by the animals themselves. This contradicts the perception that integrated vegetable and livestock operations are scarce.

Compost use was reported on 69 percent of the farms. 70 percent of these farms that use compost incorporate it as an ingredient in greenhouse potting soil mixtures. However, even more of these farms (77 percent) apply compost to their fields. The most common rate of application was one to five tons per acre (65 percent) and the most common frequency was every year (48 percent). An impressive 82 percent make some compost on their farms, although 47 percent buy compost from commercial sources. Farms were more likely to use compost and less likely to use manure as the percentage of farm income from vegetable sales increased.

Most farms (73 percent) indicated that the USDA-NOP standards for certified organic compost have not affected their production. Anecdotal evidence, however, suggests that farms still making compost often treat it like fresh manure because they cannot always follow the NOP standards for compost production. Only seven farms (12 percent) indicated that they previously made compost but no longer do so. The challenge of following the NOP standards for compost was the most frequently cited reason for no longer making compost.

Case studies

From the pool of 88 respondents who returned the initial soil fertility management survey, 12 farms were selected for case studies. These case studies were designed to better understand fertility management knowledge, strategies, practices, costs and impacts at the farm level. The case study farms were not selected randomly; instead, a diverse group of farms was chosen in order to highlight different types of soil fertility management strategies. For example, some case study farms rely on extensive rotations with perennial cover cropping; others make and use significant amounts of compost, raise annual cover crops or apply purchased fertilizer products and amendments.

In addition to collecting more detailed fertility management information from these farms through farm visits and interviews, soil samples were taken from the case study farms twice over two years. Given the time constraints of this study, this soil test data can only be used as descriptive, supplemental information rather than evidence of the impacts of different fertility management practices. It can take many years, for example, for soil to register changes in organic matter. Likewise, it can take many years for high phosphorous levels associated with historical, non-vegetable production practices to diminish.

The following summaries of six case study farms reflect a diverse set of approaches and practices, as well as some of the more common overall fertility management strategies used by organic vegetable growers. The farm names and the names of the growers have been changed.

Cover crops and composted poultry manure fertilizer

Fox Hollow Farm	*Strategy:* Poultry litter fertilizer and cover crops
Farm: 80 acres total; vegetables: 5 acres	
20 years in business	
Silt loam soil	
Soil fertility-related labor expenditures: 85 to 100 hours per year	
Soil fertility-related direct costs: $3,200[2]	

Overview

Patrick and Denise have operated Fox Hollow Farm in northern Wisconsin since 1989. They grow a full compliment of vegetables for CSA farm members on about five acres each year, with about three additional acres of fallow land in cover crops. The entire farm is 80 acres; most of the remaining land is wooded. The farm lies in a shallow valley and features moderately well-drained, silt loam soils. Given the sloping land, vegetable fields are planted on the contour and alternated with sod field roads and berms to reduce erosion. Vegetable fields are irrigated from a spring-fed pond.

Patrick and Denise's soil fertility strategy emphasizes annual cover crops and mulch to build organic matter coupled with pelleted poultry manure fertilizers to supply annual nitrogen needs. Compost is used in the greenhouse potting mix and is applied every other year at a rate of at least 40 tons per acre in three 16' by 96' hoophouses, which are primarily used to grow tomatoes.

The farm follows organic practices but is not USDA-NOP certified. With essentially 100 percent of their produce going to CSA farm members, Patrick and Denise have not felt a need to become certified. They earn most of their $60,000 to $100,000 gross farm income from the sale of vegetables. Seventy-five percent of their household income is earned from the farming operation.

Fertility management

Cover crop regimens vary at Fox Hollow. Patrick and Denise seed quite a bit of land to rye each fall. Some of this land is kept fallow the following year by rolling down the rye in June and then allowing it to re-sprout. Patrick clips fallow fields throughout the summer to control weeds. In September, he rotovates at a shallow depth to kill any persistent weeds and make the soil easier to work the following spring.

Buckwheat and sorghum-Sudangrass are planted during the summer to provide quick cover and smother weeds—especially purslane, which is one of the farm's most troublesome weeds. Both of these cover crops are often left to winterkill. Oats and peas are frequently planted after early summer crops such as spring Brassicas and salad greens that are out of the field by August.

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[2] Direct costs in this study include fertility inputs (compost, fertilizers, etc.), including shipping or hauling fees, and cover crop seed. Labor costs, tractor use and fuel are not included.

At the end of a typical growing season, Patrick estimates that 25 percent of his cropland is planted to hardy cover crops that will overwinter, while 45 percent is planted to cover crops that will winterkill. Twenty to 30 percent of his cropland is left in vegetable crop stubble until the following spring, and zero to ten percent is tilled and left open.

About ten percent of the farm's annual seed bill—about $200— goes to cover crops. Patrick estimates that he spends about 35 to 50 hours per year planting, mowing and tilling cover crops.

Organic mulch is used extensively at Fox Hollow. Hay is applied to many different crops, but especially to vine crops. Patrick and Denise roll out 4'-by-4' round bales between rows of squash, melons and cucumbers. Other crops, such as peppers, are mulched by hand using small square bales. Patrick and Denise have reaped many benefits from mulching including adding organic matter to their soils, inhibiting weeds and reducing erosion on their sloping fields.

Patrick and Denise regularly apply organic-approved, pelleted chicken manure fertilizers to all of their vegetable crops to supply necessary nitrogen. Application rates vary by crop and are based on soil test results and crop needs. In the past, Patrick and Denise simply applied these products by hand using buckets and plastic watering cans. The farm now has a three-point cone spreader that can be accurately calibrated based on tractor speed. For direct seeded crops, the fertilizer is applied to beds prior to final soil prep with a rotovator. For transplanted crops, fertilizer is banded pre-plant or in holes at transplant time. Some crops—such as Brassicas and potatoes—receive half their fertilizer allotment pre-plant and half as side dressing a few weeks after transplanting.

Patrick and Denise have used several different fertilizers including Sustain, a 5-2-4 (NPK) rated feather meal-turkey litter combination, and another brand that is rated at 4-5-3. They order a pallet or two of fertilizer each year to have plenty on hand and to get a price break. They spend about $3,000 annually on bagged fertilizer. Applying the fertilizer requires about 50 hours of labor per year.

In the farm's early years, turkey manure was applied by a local processing company at a rate of five tons per acre every three years. This is no longer allowed due to excessive soil test phosphorus levels based on a Wisconsin DNR ruling. Patrick and Denise hesitate to use raw manure any more, even if it were an option, because of pathogen concerns.

Crop rotation

Fox Hollow is similar to many farms in that Patrick and Denise do not follow a specific rotation plan for vegetable crops. Says Patrick, "We attempted to follow rotation plans in the past, but complexity—so many crops—made this difficult. Regular expansion made it impossible to follow a coherent system. Also, we were never sure which rotation paradigm to follow. This led us to think about moving to the 1:1 vegetable-to-fallow ratio, and think less about the individual vegetables and more about a long-term view of soil building and soil health."

Vegetables, sod-forming cover crops and annual cover crops, rather than specific vegetable crops, are now the basic rotation planning units. Patrick and Denise record where vegetables are grown, however, so that they have a bed-by-bed cropping history and can avoid growing crops from the same family too often in the same area. “Prior to this,” Patrick admits, “it was catch as catch can in terms of planning and execution.”

The 1:1 ratio that Patrick envisions would put half their cropland in vegetables with various annual cover crops, and the other half of their cropland in perennial, sod-forming cover crops. For a few years, their vision included a shift toward no-till production, primarily due to concerns about erosion on their sloping land. Patrick experimented with rolling down rye and transplanting vine crops such as winter squash. While results were initially favorable, after a few seasons he became convinced that their short growing season and climate do not lend themselves well to organic, no-till vegetable production in most cases. Applying plastic, straw and hay mulch is now a key emphasis for Patrick and Denise to minimize erosion.

Observations

Patrick and Denise, who did not have farming backgrounds prior to starting their operation, work closely with one of their CSA farm members who has a soil science degree to collect and analyze soil samples, determine fertilizer rates, set goals and evaluate progress toward those goals. At Fox Hollow, soil samples are taken every other year and tested by the University of Minnesota. Patrick admits that, without their CSA member consultant, the information and recommendations he receives from the university would be difficult to apply to their farming system.

Their goals are to produce more of their own nitrogen through legume cover crops and build soil organic matter over time. Their soil test results show that they have close to five percent organic matter, a solid value for a silt loam soil. Patrick and Denise would like to use more compost and nitrogen-fixing cover crops in place of pelleted fertilizer products, which have increased in price significantly in recent years. They do not have a local source of good-quality compost, however.

Soil test results from 2008 indicate excessive phosphorous and optimal to excessive potassium. This may partly be a consequence of the turkey manure applications that were halted more than ten years ago. Furthermore, as the farm was previously a dairy and a cow-calf operation, Patrick and Denise inherited heavily manured land with high phosphorous levels. Their plan to switch to compost and nitrogen-fixing cover crops is a good one, given current phosphorous levels and the NPK rating of many poultry-based fertilizers.

To achieve their goals, Patrick and Denise say they need a better grain drill for establishing good stands of cover crops, a flail mower for management and a chisel plow and disk to incorporate cover crop residues. In addition to requiring more and better tools, Patrick recognizes that he needs better information about when and how to use cover crops to produce nitrogen on farm. Finally, he wonders how, on a “vegetarian farm,” he can effectively make use of the vegetable waste generated on the farm. “How do I effectively compost all the trimmings and culled vegetables and turn it into a resource? Other farms can cycle vegetable waste through hogs or chickens and then use the manure. At my scale, it is not practical to invest in composting equipment.” He wonders if worm composting might be the answer.

Ultimately, Patrick feels that their soil fertility management is improving, but that they have a long way to go: “I am not yet satisfied with our system, and I do not feel I have an adequate understanding of soils to make sounds decisions.”

Long-term rotation with sod-forming cover crops

Clover Leaf Farm	*Strategy:* Long term rotation with sod-forming cover crops
Farm: 15 acres owned, 10 acres rented; Vegetables: 10 acres	
17 years in business	
Silt loam to clay loam soil	
Soil fertility-related labor expenditures: 40 hours per year	
Soil fertility-related direct costs: $660 to $1400	

Overview

Jay farms in central Illinois. He sells vegetables at local farmers' markets and through a CSA program. He has approximately 20 acres of tillable land and five acres that are not tillable, with ten acres in vegetables each year. He rotates land into and out of vegetables every two years. Most of his farm is deep, rich river bottom land. Soil types on Clover Leaf Farm range from silt loam on the bottom land to clay loam on the upper fields. All are moderately well drained, and he only irrigates in emergencies.

Jay began farming in 1993 with one or two acres in production. He quickly expanded to ten acres of production by 1995. He rents 10 acres and owns 15 acres. He uses organic farming techniques and materials, but has avoided certification because he sells directly to the public and has philosophical differences with the USDA-NOP. All farm income is from vegetable sales, and the farm supplies 91 to 100 percent of household income for Jay and his family. Gross sales are over $200,000 per year.

Fertility management and crop rotation

Even with his commitment to sustainable practices, Jay believes that all farming is inherently destructive of the soil. Because he feels that soil structure is one of the most important elements of soil health, he has always rested 50 percent of his land by having it in perennial cover crops for two years before returning to grow vegetables for two years. He believes that this rotation maintains and improves soil structure, as well as supplying the necessary nutrients for healthy crops and good harvests.

This two-year cycle, detailed below in Table 1, is the foundation of Jay's fertility management program. When idle, his land is in a mixture of alfalfa, clover and grass. He does not purchase fertilizer. He grazes a small herd of cattle on cover-cropped fields as part of his rotation, but otherwise applies no manure or other amendments. Annual cover crops are used primarily in the fall on land currently in vegetables, to provide winter cover.

Table 1. 1:1 Fallow rotation at Clover Leaf Farm

	Spring	Spring – Fall	Late summer – Fall
Year 1	Till in cover crops as beds are needed for planting	Mixed vegetables	Sow wheat and vetch as crops are harvested
Year 2	Till in wheat/vetch cover as beds are needed for planting	Mixed vegetables	Sow oats as crops are harvested
Year 3	Disk winter-killed oats and vegetable residue and sow alfalfa, red clover, orchard grass (at 15#:15#:3# per acre rates) with oats nurse crop	Cut oats for hay in early June; use as mulch on vegetable beds Take one or two more cuttings of hay for mulch and cattle feed	
Year 4	Take two or three cuttings of hay for mulch and cattle feed	If many weeds went to seed during the fallow period, disc or plow in the fall and sow wheat and hairy vetch; if weed pressure is minimal, leave as is and till as needed the following spring	

In addition to the cover crops described in Table 1, Jay sometimes plants sorghum-Sudangrass, peas and buckwheat. About 80 percent of all cropland is in cover crops heading into the winter, with 15 percent covered with crop residue and the remaining five percent plowed and left open for the earliest plantings the following spring.

Jay generally incorporates his cover crops with a tiller, although he may use a moldboard plow if the land is exceptionally weedy. Two passes are made to prepare land for planting: a rough pass to incorporate a cover crop or other residue, and a second pass two to three weeks later to prepare a seed bed. Jay keeps track of his labor and spends about 40 hours a year planting, clipping and tilling cover crops.

His expenses for cover crop seed vary. If he is seeding down 10 acres for the 2-year fallow period, he spends as much as $1,400. In years when he is only buying seed for annual cover cropping, the bill comes to about $660.

Jay uses compost in his greenhouse and hoophouse. The compost is made on farm using cow and various other manures, hay, and brush and wood chips. He windrows the material and turns it occasionally. He wishes he had more compost available for field application. His grazing cattle leave raw manure in the vegetable fields during the two-year fallow period, especially in the winter.

Observations

Jay's long-term rotation is relatively unique among the vegetable growers who returned the written survey. Most growers either do not have enough land to put half of their cropland in cover crops, need their additional land for other enterprises such as cash grain or hay, or feel they cannot afford to take land out of production for two years. Jay feels that his two-year fallow cycle helps build soil organic matter and returns soil structure to a more "undisturbed state." He adds organic matter whenever he can and places a high value on keeping soil covered with cash crops or cover crops as much as possible.

Jay tests his soil every three to five years, but he is often unsure what to do with the information beyond making sure his soils are the proper pH and keeping track of soil organic matter. The fertilizer recommendations, which are geared toward conventional growers, do not seem all that helpful to him.

Ideally, Jay would like to use more composted animal manure in his system but has limited access to this resource. He would move to a three-year fallow period if he had more land and the third year proved to enhance his soil. He would also like to reduce tillage and is interested in no-till systems where he could plant directly into cover crop residue.

Based on an initial 2008 soil test, Jay does an excellent job of managing for phosphorous. Interestingly, the farm's lower field showed high levels of organic matter but a low aggregate stability percentage[3]. Meanwhile, the upper field had a low organic matter reading but better aggregate stability. The low aggregate stability with high organic matter is attributed to the fine, silty texture of the soil on the lower field, which floods nearly every year.

Cover crops, bulky organic materials and fertility amendments

Green River Organics *Strategy:* Bulky organic materials, cover crops and fertilizers
Farm: 76 acres total; Vegetables: 38 acres
33 years in business
Sandy loam soil
Soil fertility-related direct costs: $11,000

Overview
Green River Organics sells directly to retail stores, wholesale outlets and a large CSA membership. In business for over 30 years, Carl is now on his third piece of land, having owned and rented other farms previously. Carl and his partner, Sally, have worked their current 76-acre farm for six years. They continue to hone a system involving cover crops, bulky organic materials and fertilizer inputs. Thirty-six acres are in vegetables with another two in cover crops and nine comprising headlands and field roads. Another large area is in alfalfa for on-farm fertility production. With gross sales income over $550,000, Carl and Sally earn all of their household income from the sale of vegetables and strawberries grown on the farm.

The irrigated farm is located on extremely well-drained loam and sandy loam soils in southern Wisconsin. Half of the farm was previously owned by Amish farmers, and the other half was in continuous corn as part of a dairy and hog operation. As a result, the land was heavily manured before Carl and Sally came onto the scene.

[3] Aggregate stability is a measure of the ability of soil aggregates (soil particles bound together more strongly than to other, adjacent particles) to resist disruption by outside forces, especially water. The stability of aggregates is affected by several factors including soil texture, the amount and type of organic matter present and the type and size of the microbial population.

Fertility management

Carl and Sally's fertility management practices include applying bulky organic materials such as leaves, compost and chopped alfalfa, growing cover crops and applying various fertilizers. They receive free, uncomposted leaves from their local town and purchase yard debris-based compost from White Oak Farm in Oconomowoc, Wisconsin. In addition, they receive dairy manure-leaf compost from the University of Wisconsin West Madison Agricultural Research Station. They do not make any compost on the farm themselves.

Carl and Sally feel that applying these bulky organic materials helps build biologically active soil that can readily release nutrients to their vegetable crops. These materials are applied every year, but not to every field. Compost is applied at rates between six to ten tons per acre in the spring and summer. Application rates are based on experience and the nutrient content of tested compost. Compost is sometimes side dressed. Carl and Sally would apply more compost more often if it were available and economical. They do not use uncomposted manure due to food safety concerns.

Cover crops, especially winter rye and vetch, are used extensively between cash crops. These are typically planted in the fall after vegetable crops are harvested. Overwintering cover crops such as rye and vetch are chopped and disked in the spring before fields are planted to main season or fall crops. Fields planted to cover crops that winterkill, such as oats and peas, are used for early spring-planted crops such as lettuce, onions and Brassicas.

To prepare land for seeding after a cover crop, Carl typically works the soil with a moldboard plow followed by a field cultivator or a disk and field cultivator. If he is seeding to a small-seeded crop and there is a fair amount of residue left from the cover crop, he will likely work the soil with a rotovator. If there is not much residue, a chisel plow and field cultivator may suffice. In areas that need to be prepared for transplanting, cover crops are flail chopped, disked, given time to break down and then disked again. If the area intended for transplanting was not planted to a cover crop, a chisel plow may again suffice. Carl aims to minimize tillage in order to keep as coarse a transplant or seed bed as is practical.

As for fertilizer, Carl and Sally use Sustain—a turkey litter and straw peletized product—and composted chicken manure from Pearl Valley Organics in northern Illinois. They also sometimes apply soybean meal to their vegetables.

Applying chopped alfalfa to vegetable fields is a unique fertility management practice used at Green River Organics. Carl and Sally grow 14 acres of alfalfa on a sandy knoll and hillsides that are too steep to cultivate. They chop this alfalfa and apply it with a side discharging spreader to vegetable fields before planting. They figure that for every acre of alfalfa they grow, they can fertilize a half acre of vegetables for a year. "When we bought the farm, we had to take the hills as well as the flat land, and we figure this is a way to stabilize the hills but keep them productive," Sally explains.

"We feel this is a great way to supply nutrients and organic matter." continues Carl. "Cut and chopped alfalfa has a perfect carbon-to-nitrogen ratio, so it decomposes quickly." Carl thinks that growers are better off buying alfalfa from neighbors rather than bagged fertilizer. The caveat is that bagged products are easier to handle, especially for smaller scale producers. "But if you have the machinery," Carl says, "I think you're better off buying the bulky material; it's worth a lot to you as a vegetable grower."

Crop rotation

Due to the diversity of crops grown and recent expansion, the farm does not follow a set rotation. However, plantings of crops from the same family are spaced at least three to four years apart in any given area. Most often, crop rotations are based on timing—whether a crop is planted early or late. For example, fall carrots are typically followed by onions in the early spring, and late Brassicas might follow an overwintered rye cover crop.

Observations

Rather than think in terms of NPK, Carl and Sally emphasize feeding the soil through cover crops and bulky organic materials. As an established, relatively large farm, they have a wide variety of equipment and pool of labor available to accomplish this strategy. They have seen impressive results: biologically active soils that process nutrients rapidly and grow crops quickly.

Carl, Sally and their work crew spend an average of two hours per acre spreading leaves and compost. "Compost spreading is pretty fast—less than one hour per acre," says Carl. As for their compost application rates, he notes, "For chicken manure-based composts, one spreader load (six to eight cubic yards) covers about one acre. For less concentrated composts, it usually takes about two loads per acre." They usually spread four loads of bulky, loose leaves per acre, and these take longer to load. Carl estimates machinery costs at $50.00 per acre and labor costs at $30.00 per acre for spreading.

Cover crop costs at Green River Organics are extremely variable, depending on the crop. Carl says, "It takes us about one and a half hours per acre to prepare the ground and seed a cover crop after a crop is finished," and plastic mulch and drip tape are removed. The exact amount of time required depends on the vegetable crop being plowed down. Carl estimates machinery costs of $35.00 per acre and labor costs of $25.00 per acre for these tasks. He notes that, "The cost of handling a grown cover crop range from essentially zero—if the cover crop is small and succulent, or if winterkilled and all we're doing is normal, pre-plant tillage—to as much as $80 or more per acre if we must chop, disc and moldboard plow," as is the case with a mature stand of rye and vetch.

Carl does not test his soils regularly, although he feels that testing every three years would be a good idea. In the past, he did not actively use the information provided by the labs and thus has not tested in recent years. In general, Carl does not feel that soil test results are all that useful, given the differences between organic and conventional practices. Unlike many other growers surveyed as part of this project, Carl is confident of his soil fertility management and knowledge.

Carl believes his system of cover cropping combined with applications of composts and other organic materials minimizes nutrient leaching and runoff, because these materials tend to release nutrients slowly. "I always want something decomposing in the soil, and so I try to add as much carbon as possible," he says. "We choose to spend our money on bulky organic materials while using concentrated fertility inputs like pelleted poultry litter judiciously."

Soil test data from 2008 reveal excessive phosphorous and optimal potassium on this farm. Application of manure by the previous farm owners is an obvious factor, but the current practice of using poultry manure products is likely contributing to high phosphorous levels. The farm's aggregate stability score was quite good, considering its sandy loam soils. It is likely that adding leaf compost and other bulky organic material to the soil is contributing to aggregate stability, although direct attribution of soil test results to current farming practices is not possible, given the limits of this study.

Ideally, Carl and Sally would like to expand the amount of chopped alfalfa they apply, use some compost and grow lots of cover crops. Over time, they hope to continue to reduce tillage by transplanting as often as possible.

Cover crops, compost and foliar feeding

Tom's Farm	*Strategy:* Compost, cover crops and foliar feeding
Farm: 10 acres owned, 20 rented; Vegetables: 12 acres	
10 years in business	
Silt loam soil	
Soil fertility-related labor expenditures: 130 hours per year	
Soil fertility-related direct costs: $1,100	

Overview

Tom farms in Illinois on 30 acres, 20 of which are rented. Approximately 12 acres are planted in vegetables each year. Part of the farm was a conventional hog operation until the 1970s. The other portion belonged to Tom's grandfather who avoided pesticides and conventional fertilizers. Tom continues the family tradition of farming organically, although he has chosen to be Certified Naturally Grown (CNG). CNG is a farmer-based program that follows the USDA-NOP organic rules, but inspections are conducted by fellow program participants rather than a third party agency.

Soils on Tom's Farm vary from clay loam to silt loam to loam, with silt loam being the predominant type. All are moderately well drained. Tom does not irrigate.

Tom grows a wide variety of vegetables, with a major focus on solanaceous crops (tomatoes, peppers and potatoes), cucurbits (melons, cucumbers and squash) and sweet corn. He sells most of his product at farmers' markets and a farm stand. Farm income is 51 to 75 percent of all household income. Most of this comes from the sale of vegetables, although the farm also sells flowers, bedding plants and strawberries. Tom has been in business for ten years.

Fertility management

Tom uses cover crops and compost with the goal of increasing organic matter. He also uses kelp meal and fish emulsion to foliar feed crops such as melons and eggplants. He makes his own compost from municipal leaves and horse barn bedding that he receives by the semi-load from stables on the north side of Chicago. The bedding is sawdust mixed with urine and small amounts of manure. Both the leaves and bedding are free of charge. Tom sheet composts both the leaves and horse barn bedding over the winter before using them; he spreads out the semi loads and occasionally uses a chisel plow to aerate the piles. He makes his own potting soil from leaves and horse bedding that have composted longer than his field compost.

Tom applies leaf compost to his fields at rates of 11 to 20 tons per acre. He often applies compost on top of an existing cover crop in the summer or winter, and targets areas where he will grow heavy-feeding crops such as tomatoes. One of Tom's primary uses of compost is as mulch, at application rates of 21 to 40 tons per acre. Tom mulches crops such as tomatoes, zucchini and cucumbers with the horse bedding compost. He considers soil and compost test results when applying compost, but acknowledges that his application rates are influenced by the amount of compost available and field size.

Tom applies dry fish and kelp products as foliar feed using a pull-behind 150 gallon sprayer. The spray also includes diatomaceous earth, with an eye toward pest management. The NPK rating of the fish product is 12-0-0. Application rates are one to two tablespoons of fish per gallon of water; 75 gallons treats one acre. According to Tom, this translates to about two lbs. of fish per acre. Tom spends less than $100 per year on fish and kelp.

Tom targets his foliar feeding to watermelons and eggplant, which are crops that he struggled with until he began the foliar feeding regimen. He explains, "I've been dealing with relatively high pH soil: 7.1 to 7.3. These plants can't absorb N at a higher pH. Applying compost has helped to bring down the pH levels, but the foliar sprays really help. The difference has been like night and day. The day after spraying, the plants go from looking sad to thriving."

Tom mainly uses oats, winter rye, sorghum-Sudangrass and buckwheat cover crops; he also plants alfalfa, clover, beans, peas, vetch and millet. Oats are often used in the fall in areas that will be planted to the earliest spring crops the following year. Approximately 70 percent of Tom's vegetable fields are planted to winter hardy cover crops while 30 percent are planted to cover crops that will winterkill. Recently, he has begun experimenting with buckwheat and sorghum-Sudangrass to control weeds such as Canadian thistle and foxtail. Tom uses an offset disc to incorporate cover crops and prepare fields for planting. The annual cover crop seed bill for the farm is around $1,000.

Observations

Tom feels strongly about improving soil health and has observed improvements over the years. He notes that his soil is "fluffier and no longer sticks to my boots." He feels confident that he has an adequate working knowledge of soil fertility management.

Tom tests his soil every year; his samples are analyzed by an Ohio laboratory. He has seen his organic matter increase from around 2.5 percent to around 4.0 percent in the ten years he has been farming. Based on the Ohio lab tests, Tom has been under the impression that his soils are low in phosphorous. The tests conducted for the case study suggest that phosphorous is excessive on his farm, however.

The fields that belonged to Tom's father were historically managed quite differently than the acres he rents, which may contribute to different levels of phosphorous on his farm. His father avoided phosphate, while the rented land was part of a conventional hog farm. Furthermore, Tom used to spread cow manure that he got from a neighbor. While he no longer applies uncomposted manure to his fields, past applications might contribute to his current high phosphorous levels.

Fish and foliar feeding have not only improved Tom's plant health dramatically; the fish, with a 12-0-0 NPK rating, provides nitrogen without contributing phosphorous or potassium. This is a possible alternative for organic vegetable farmers who have high levels of these nutrients in their soil. Foliar feeding, however, does not improve soil organic matter, structure or bulk density, all of which are important measures of overall soil quality. If these are to be improved, a grower using foliar feeding might want to find a source of carbon such as leaves or yard-debris-based compost.

Tom's use of the horse-bedding compost as a mulch is admittedly labor intensive. He works with a crew of four to accomplish this task each spring after the tomatoes and cucumbers are transplanted. This takes around 60 hours at a time of the year when labor demands are extremely high. Spreading out the leaves and horse barn bedding for sheet composting takes about 40 hours during the late fall and early winter. Tom also spends about 40 hours a year working with cover crops and another 30 hours applying foliar sprays.

Tom's aggregate stability scores were lower than most of the other case study farms, possibly as a result of his tillage and fertility management practices.

Compost and cover crops

Second Nature CSA	*Strategy:* Heavy compost and cover crops
Farm: 25 acres total; Vegetables: 15 acres	
21 years in business	
Silt loam soil	
Soil fertility-related labor expenditures: 285 hours per year	
Soil fertility-related direct costs: $1,900	

Overview
Second Nature CSA is owned and operated by Randy and Sue. They started the farm in 1988 on 25 acres. They have farmed organically since then, although their farm has never been certified. They raise 15 acres of vegetables, which provide most of their farm and household income. They earn additional income from the sale of eggs and turkeys. The farm has gravelly silt loam soil that is well drained and tiled. Formerly, the farm was a dairy.

Fertility management
Compost is the core of the fertility management scheme at Second Nature CSA. Randy and Sue make close to 500 tons of their own compost each year using a compost turner. Feedstocks for the compost include leaves, hay, straw, culled fruits and vegetables, food processing waste and cow, horse and chicken manure. These materials are windrowed in huge piles and turned at least five times. In addition, Randy and Sue purchased a manure-based compost from Vermont that is used exclusively in the greenhouse.

Compost is applied every year at rates between 11 and 20 tons per acre. Application normally occurs on bare ground in the spring or fall before planting vegetables or cover crops. Occasionally, the compost is applied on top of an existing cover crop. Randy applies the compost on all fields and does not target applications to specific crops. He has been applying compost to his fields for 20 years and has seen improvements in soil tilth, organic matter and fertility.

The feedstocks for the farm-produced compost are usually obtained free of charge, although Randy often pays to have someone haul these materials or hauls them himself. The food processing waste, obtained from local canning companies, costs $10 per ton. Much of the hay and straw used is spoiled, so it is free for the hauling.

Randy and Sue rarely use uncomposted animal manure. Sometimes, they apply compost that is not completely finished in the fall to get a jump start the following spring. They treat unfinished compost like manure to address concerns about food safety and follow organic rules (even though the farm is not certified).

Because his farm is diversified, Randy has many opportunities to plant cover crops during the growing season. “If there is bare soil, I try to get something growing there,” he says. He plants a wide variety of cover crops including peas, vetch, clover, oats, wheat, rye, sorghum-Sudangrass and buckwheat. Winter rye is the cover crop he uses most often. He estimates that 50 percent of his cropland is planted to winter-hardy cover crops each fall, usually winter rye. Another ten percent might be in a cover crop that will winterkill. The remaining 40 percent is either covered with vegetable crop stubble or plowed and left open until spring.

Randy uses a moldboard plow and a heavy disk to incorporate cover crops, and a reverse tine tiller and a field cultivator to prepare ground for planting vegetables. For large-seeded crops and transplants, the field cultivator is often all that is needed. Randy spends $300 to $400 a year on cover crop seed. He spends 35 hours a year managing cover crops.

Crop rotation
Randy does not have an established rotation, but he does move plant families in groups so that related crops are planted in any given area three to four years apart. He notes that it is virtually impossible not to have some crops repeat in the same area within three years, given the limited amount of land he has available for vegetable production.

Observations
In order to make his own high-quality compost, Randy bought a self-propelled compost turner. With this $10,000 piece of machinery, he can turn a 300- to 400-foot windrow in five to ten minutes. Randy estimates that it takes about 230 labor hours a year to produce and apply his compost. This includes time to haul materials to the farm, assemble the windrows, turn them and apply the finished compost to the fields.

Randy has his soil tested every three to five years. He expressed some frustration with the variability of test results from lab to lab, and he does not feel that the labs provide useful interpretations of these results. He would sample his soils more often if he had faith in the results and obtained useful recommendations. Not surprisingly, in the written survey and interviews, Randy described soil fertility management as an area of uncertainty.

The soil test results from 2008 reveal that Second Nature CSA had the highest C/N ratio and total Particulate Organic Matter (POM) value of all of the case study farms. In addition, this farm's soils showed very good aggregate stability. These findings likely result from years of compost application. On the downside, the soil test revealed excessively high levels of phosphorous and potassium. The farm's history as a dairy operation is certainly part of the equation, but the current manure-based compost regime is likely contributing to the problem.

In addition, this farm had pH readings of 7.5 to 7.8, which are considered high for vegetable crops. This is likely due to the use of large amounts of composted animal manure. At pH levels in this range, plants are unable to take up many micronutrients such as zinc and boron.

Randy's goals are to build a biologically active soil, keep it on the farm and mimic nature as much as possible. His ideal system would involve grass-based pastures that he would convert to vegetables every few years in order to generate fertility on-farm and minimize tillage.

Integrated vegetables and livestock with cover crops

Rolling Acres Farm	*Strategy:* Rotation with pastured poultry and cover crops
Farm: 109 acres total; Vegetables: 25 acres	
12 years in business	
Silt loam soil	

Overview

Matt and Kristen manage Rolling Acres Farm, which is located in southern Wisconsin on gently rolling, well-drained, silt loam soils. The farm totals 109 acres; Matt and Kristen use 50 acres of this land for their vegetable and livestock operation. They plant half of this area to vegetables while the other half is in pasture for their movable poultry pens. Some of the fields are tile drained, and all are irrigated.

The farm sells to retail stores, restaurants, wholesalers, farmers' markets and CSA members. Vegetables make up 76 to 90 percent of the farm's sales, with the remaining sales coming from strawberries and poultry. Farm income comprises 91 to 100 percent of all household income.

Matt and Kristen have been farming since 1997 and have been certified organic for five years. The farm was previously used for corn and soybean production. Matt seeded the farm to alfalfa and clover three years before beginning to grow vegetables.

Fertility management

The integration of vegetables and poultry is the foundation for fertility management at Rolling Acres. The land is planted with red and ladino clovers for three years, which serves as poultry pasture in the second and third years. Poultry feed on the clover and fertilize the fields with their manure. The land is then planted to vegetables for two years. Vegetables needing large amounts of nitrogen are grown the year a field comes out of poultry pasture; crops needing less nitrogen are grown the second year. The land is then put back into clover following a winterkilled oat crop.

This rotation is supplemented with annual cover crops such as wheat, barley, sorghum-Sudangrass and winter rye during the vegetable years. Matt always leaves cover crop or cash crop residue on his fields heading into the winter to prevent erosion, and he plants on the contour. To minimize nutrient loss and leaching, he avoids fall tillage and fall or winter nutrient applications. He maintains clover and grass borders around all fields, grass buffers around drainage ditches and grass waterways through sloping fields.

Matt's tillage practices reflect his concern for healthy soils. He uses a moldboard plow but keeps rotovator tillage to an absolute minimum. While the rotovator makes a nice seed bed, Matt believes that it harms soil structure and earthworms. Matt uses the rotovator in the fall to roughly till his clover pastures that will be used for vegetables the following year. "With the shield up at the back of the rotovator," explains Matt, "this shallow tillage is designed to kill the clover, or allow winter to kill it, while leaving as much residue on the surface as possible." In the spring, Matt plows with the moldboard and prepares his beds with a cultimulcher before planting.

Matt uses a rotovator to work in cover crops that are less than four inches tall. Rye, which can be very persistent, is usually rotovated twice before it is worked into the soil with a field cultivator. Matt uses a chisel plow once a year in the fall on any land that does not have a cover crop. If possible, he prefers to prepare open land in the spring using only a field cultivator.

Matt applies additional inputs such as eggshells, lime and other amendments based on soil test results and consultant recommendations. He works with a consulting company to monitor and manage calcium levels and micronutrients in his soils.

Observations

Matt and Kristen's integrated farming system reflects their Holistic Management training. Holistic Management is a planning process that engages the whole farm system, including all biological, social and economic elements of the farm and farm family. As a result of this training, they firmly believe, as do many organic and sustainable growers, that their first concern is to feed the soil. Matt and Kristen put their energy into creating healthy soil, then let the soil feed the plants. Matt believes that he needs to listen to the land and have a relationship with it in order to make good decisions and hone his farming system.

Kristen and Matt also believe that animal agriculture is important for vegetable production. Farms that combine livestock and vegetable enterprises are generally perceived as uncommon. The survey done by this project, however, revealed that a significant number of vegetable growers in Wisconsin and Illinois also raise animals (see pages 2-3). The extent to which these farms integrate their animal and vegetable enterprises varies. The prevalence of combined vegetable and livestock farms in these states—particularly Wisconsin—is partially due to the number of Amish farms that raise vegetables and livestock, and keep horses for field work.

Other growers, like Kristen and Matt, have chosen to combine vegetables with a pastured poultry enterprise.

Integrating crops and livestock minimizes the need for off-farm inputs such as fuel and fertilizer, as the animals produce and spread the nutrients needed for crop production. It also mimics natural ecosystems. As a result, many sustainable and organic farmers consider this kind of integrated approach to fertility management an ideal farming system. Current and future food safety concerns and legislation, however, may make it extremely difficult to grow fresh fruits and vegetables on farms that integrate crops and livestock. While beyond the scope of this research project and publication, clearly there is a disconnect between the trajectory of food safety regulations and the goal of the sustainable agriculture community to create diversified farming systems that integrate plants and animals.

Soil test data

Soil samples were taken from the case study farms twice over two years. The results reported in Table 2 are from the first year's soil tests. Test results from Rolling Acres Farm were not available.

In general, the soil pH of most of the case study farms was close to neutral (pH=7.0). However, the two farms with pH values greater than 7.0 both applied bulky organic amendments, particularly animal manure based composts, at high rates. Such composts are inherently alkaline and, if amended to soils at high rates, will raise the soil pH. If the soil pH values exceed 7.5, certain micronutrients like Boron or Zinc may not be in forms available for plant uptake and could result in micronutrient deficiencies.

The organic matter values indicate good soil building practices, particularly on Second Nature Farm. The overall range of organic matter (OM) for the heavier-textured soils like silt and clay loams is considered ideal (4-5 percent OM for 20-30 percent clay content). It confirms that these farms uphold the soil organic matter-building tenets of organic agriculture. In contrast, the plant available phosphorus (Bray P) and potassium (K) are mostly high to excessive, except for Clover Leaf Farm. Clover Leaf Farm is the only case study farm that incorporates a long (two year) fallow period with cattle grazing. This farm uses no purchased, manure-based fertilizers or compost. The other case study farms either have historically high soil test P and K values and/or they exacerbate the historical values by continuing to use manure-based fertilizers or composts.

With regard to measures of biologically active organic matter (or carbon), the results for percent of total carbon that is particulate organic matter carbon (%C as POM-C) are considered optimal for all but Second Nature Farm and Tom's Farm. The high values for these two farms (>50 percent for the most part) indicate over-application of composts or other organic amendments. This is corroborated by the total soil C:N and POM C:N ratios of these farms. The ideal range for total soil C:N ratios is 10-12:1; values greater than 15:1 indicate that either there is a large amount of stable organic matter in the soils (less biologically active) or that decomposition of fresh organic matter will be slower than in soils with lower C:N ratios. For the POM C:N ratios, most of the farms fall within the ideal range (10-20:1); however, Second Nature Farm's higher POM C:N ratios (>18:1) indicate a greater amount of stable organic matter.

Given the critical role of the active fraction of organic matter in the formation of the stable aggregates that form the structural integrity of a soil, it is no surprise that most of the case study farms have percent wet stable aggregates (%WAS) greater than 30 percent. The low value for one field on Clover Leaf Farm (~8 percent) may be attributed to the location of this field in a flood plain that is flooded annually. Silty soils exposed to frequent flooding don't have the same opportunity to form stable aggregates as soils exposed to more "normal" wetting and drying cycles. Despite the high applications of leaves, horse bedding and other organic amendments on Tom's Farm, the %WAS is low (16-30%). This may be related to the use of these organic amendments as mulch rather than incorporating them into the soil.

Table 2: Soil test results from five case study farms

Farm	Soil Type	Strategy	pH	% OM	P (ppm)	K (ppm)	C/N Ratio	POM C/N	% WAS
Fox Hollow	Silt loam	Poultry manure fertilizer and cover crops	6.6 6.9	4.9 4.9	139 188	117 305	13.2 14.2	12.4 12.9	47.84 35.34
Clover Leaf	Silt loam Clay loam	Long term rotation with N-fixing cover crops	6.8 7.3	3.1 5.5	34 14	101 69	10.9 13.6	11.7 14.0	45.29 7.97
Green River	Sandy loam	Bulky organic amendments, cover crops, fertilizers	7.3 7.3	1.7 1.8	206 144	166 145	13.2 12.0	13.2 16.3	37.20 26.19
Second Nature	Silt loam	Heavy compost applications and cover crops	7.5 7.8	4.8 7.1	196 331	271 405	16.2 16.9	18.2 22.0	41.15 36.24
Tom's Farm	Silt loam	Leaves, horse bedding compost, cover crops, and targetted foliar feeding	6.9 7.0	3.7 4.2	91 102	198 185	14.4 15.7	16.4 17.4	29.96 15.90

Table key

pH: A measure of acidity or alkalinity. pH is expressed in a log10 scale with 7.0 being neutral; values less than 7.0 are considered acid and values greater than 7.0 are considered alkaline. The range of pH values found in all soils is roughly 4.5-8.0. The optimal range for vegetables is 6.5-6.8.

% OM: Percent Organic Matter. Organic matter influences soils physical, chemical and biological fertility values in mineral soils and varies with texture classification (loam, silt, clay). As the percentage of clay increases, so should organic matter. For example, below are some optimal values based on clay content:

% Clay	%OM
10	3
20	4
40	7
50	9

P ppm: Phosphorous parts per million using a Bray P weak acid extraction test. This is a measure of phosphorus that plants can readily take up. Bray P typically underestimates P levels if pH is high, as was the case for some of the samples in this study. Optimal values for Bray P are 25-40PPM for most crops; values greater than 150ppm are considered excessive and could be lost to surface or ground water, leading to nutrient pollution.

K ppm: A measure of plant available potassium. For most soils, 100-140 ppm would be optimum for plant growth; values above 240 ppm are considered excessive and could lead to nutrient imbalances in plants.

g POM-C per kg soil: Grams of particulate organic matter carbon. Particulate organic matter is an index of young or labile (biologically active) organic matter that is associated with nutrient supply and the physical quality of soils.

Percent C as POM: The percent of carbon in the soil that is particulate organic matter; this is considered an index of soil organic matter building status. Values between 5-7 percent indicate highly–worked, arable soils; values between 10-20 percent indicate good replenishment of biologically active soil organic matter. Values greater than 40-50 percent suggest over-application of organic materials like composts, leaves or manure.

Total C/N Ratio: The ratio of total carbon to total nitrogen in the soil. A C:N ratio of 10:1 is ideal for maintaining soil biological functions.

POM C/N: The ratio of POM carbon to POM nitrogen. This reflects the extent of decay and is influenced by the types of organic inputs. Values between 10-20 percent are desirable for well managed soils.

WAS %: Wet Aggregate Stability. This is a measure of soil resistance to dispersion or physical degradation using a wet sieving technique. Aggregation is a dynamic property; tillage or incorporation of N rich cover crops will lower aggregate stability will be lower. Values <20-30 percent are low for silty and clay textured soils.

The present picture, and future research and education needs

The farms and practices described in this report provide a glimpse into the diverse production systems used by organic vegetable growers in Wisconsin and Illinois. While cover crops are used widely, many of these growers feel the need to use compost, pelleted chicken manure and other inputs to provide nutrients to their crops. This confirms the observation that many organic vegetable farms rely on off-farm sources of fertility.

Given the goals and time constraints of this study, it is not possible to directly attribute the results of the soil tests taken on the case study farms to specific farming practices. The soil tests described in this report provide a single snapshot taken at one point in time. In can take years for the benefits of soil fertility management practices like cover cropping to show up in soil test results. It is clear, however, that many of the vegetable farms profiled in this report have high phosphorous levels, especially in Wisconsin with its long history of dairy and livestock farming. High phosphorous levels are not uncommon on Wisconsin farms, where an estimated 1.4 million kilograms of phosphorous are lost statewide each year due to erosion and runoff.[4] A study published in 2000 reported that Wisconsin farmers, on average, applied 83 kg/ha more phosphorous than recommended by the University of Wisconsin for corn production.[5] Farms with high phosphorous levels should monitor this issue through annual soil testing. Organic vegetable farms with high phosphorous levels should look to sources of nitrogen other than manure and manure-based compost, such as nitrogen-fixing cover crops, and target applications of manure-based fertility amendments to specific crops and soils where excess phosphorous is not a problem.

The survey and case studies suggest that it is relatively common for highly diversified, organic vegetable farms to not have a sharply defined crop rotation. As many farmers noted on their surveys or in interviews, with 40 or more crops to manage, it becomes next to impossible to develop—and follow—a precise rotation plan. Nearly all farms, however, made efforts to ensure that crop families were rotated to minimize disease issues. Many also sequenced their crops based on nutrient needs; for example, a legume cover crop plow down might be followed by a crop with high nitrogen needs, which would then be followed by a lighter feeding crop.

Project leaders initially hypothesized that most organic vegetable growers farm intensively on relatively small acreages, without much land to devote to perennial cover crops as part of a fallow rotation. While 36 percent of the survey respondents farmed less than three acres and 53 percent farmed less than six acres of vegetables, 47 percent had over seven acres in production and 19 percent farmed over 25 acres. Although nearly 46 percent of farms used 75 to 100 percent of their cropland for vegetables, a robust 55 percent used less than 75 percent of their land and 40 percent used less than half of their land each growing season.

Small farms tended to have less land available for cover cropping and crop rotations, however. Sixty-eight percent of farms with less than three acres of cropland and fifty-three percent of farms with three to six acres of cropland used 75 percent to 100 percent of their land for vegetables in a given year. In contrast, larger farms frequently had ample land for fallow rotations and cover cropping. Thirty-seven percent of farms with seven or more acres of cropland used less than 50 percent of that land for vegetables in a given year.

Additionally, over half of the farms that responded to the survey incorporated perennial vegetation that stayed in place for more than a year into their rotations. Smaller farms were

[4] Bundy, L. and S.J. Sturgul. 2001. A phosphorous budget for Wisconsin cropland. Journal of Soil and Water Conservation, vol. 56, no. 3, 243-249.
[5] Shepard, R. 2000. "Nitrogen and phosphorous management on Wisconsin farms: Lessons learned for agricultural water quality programs." *Journal of Soil and Water Conservation*, vol. 55, no. 1, 63-68.

just as likely to maintain land in perennial cover as larger farms. The length of growers' rotation plans was not significantly affected by farm size.

The costs and labor associated with the different soil fertility management strategies varied widely from farm to farm (Table 3). Data was not available from Rolling Acres Farm. The costs reported here represent only the direct costs for purchased inputs such as fertilizers, compost, and cover crop seed. Growers reported labor hours for fertility management activities such as planting and managing cover crops, spreading fertilizers and making and applying compost.

The smallest of the case study farms discussed here—Fox Hollow— had the highest direct costs per acre. This can be attributed to their extensive use of relatively expensive, pelleted poultry fertilizers. Their labor hours per acre were also high—primarily because when the data was collected, they still applied most fertilizer by hand. They have since mechanized and improved the efficiency of fertilization. The farm that makes and applies large amounts of compost—Green River—had the highest labor inputs. Given the time it takes to make compost, it is not surprising that many farms make very limited amounts of compost themselves and instead import it from off-farm sources. Clover Leaf Farm, which obtains all of its fertility from cover crops and observes a two-year fallow period, had very low labor inputs and costs. The cattle that graze the fallow land at Clover Leaf Farm are managed by one of the grower's family members, so animal husbandry does not add to his labor demands.

Table 3: Labor hours and costs associated with soil fertility management

Farm	Total acres	Veg Acres	Hours	Costs	Hours per acre	Direct costs per acre
Fox Hollow	8	5	100	$ 3,200	12.5	$ 400
Clover Leaf	20	10	40	$ 400	2.0	$ 20
Green River	47	36	300	$ 11,000	6.4	$ 234
Second Nature	15	15	285	$ 1,900	19.0	$ 127
Tom's Farm	30	12	130	$ 1,100	4.3	$ 37

This project sought to learn whether the USDA National Organic Program rules are affecting compost production and use on organic vegetable farms. Anecdotal evidence suggested that some growers feel that they can not devote labor or management time to making USDA-NOP approved compost, given the recordkeeping requirements regarding compost turning and compost pile temperature readings. Are these relatively new and prescriptive rules discouraging growers from making compost, or limiting the availability of compost approved for use on organic farms?

An impressive 82 percent of the survey respondents who use compost reported that they made some compost on their farms, although 47 percent bought compost from commercial sources.

Most farms (73 percent) indicated that the USDA-NOP standards for certified organic compost had not affected their compost production. However, anecdotal evidence suggests that farms making compost often apply it to their fields 90 or 120 days before planting vegetables, which is what the NOP rule requires for uncomposted manures, because they are not following the strict NOP standards for compost production.

This project revealed many opportunities for future research. One clear need is an examination of specific fertility management practices and their impacts on soil nutrients, especially phosphorous. Many growers would benefit from an evaluation of alternative nitrogen sources such as legume cover crops, fish emulsion and kelp products, including an economic comparison. Long-term studies of different rotation systems, including those that involve perennial cover crops, could enhance soil quality on organic vegetable farms. Such research should compare the ability of different management strategies to maintain and increase soil organic matter, which is a primary goal and concern for most organic vegetable growers.

But research is not the only need. Given the number of growers who expressed doubt or uncertainty about fertility management, there is a clear need for education and outreach on this topic. The survey revealed that many growers do not have soil samples analyzed often. Even if they do test their soil regularly, many are skeptical of, or frustrated by, the interpretations of test results and recommendations they receive. At a minimum, growers should understand the importance of monitoring soil pH, nutrient levels and organic matter. Organic growers may need assistance translating test results into fertility management strategies for their farms. Even better, soil testing labs that do not already work closely with organic growers should develop recommendations that meet the needs of organic farmers. These recommendations might include strategies for building soil organic matter and enhancing soil health over the long term, in addition to the individual nutrients needed to correct an immediate imbalance.

All of the case study growers and survey respondents expressed a desire to make their farming systems more productive, efficient and sustainable. The on-farm field days conducted as part of this project were well attended. This reflects growers' desire to learn more about organic soil fertility management, and shows that on-farm field days where farmers learn from experienced peers can be an appropriate and popular outreach strategy. Participants at the field days appreciated learning from experienced growers about their fertility management practices, as well as seeing cover crops in the field and equipment such as seeders, mowers, tillers and spreaders. Equally important was having knowledgeable university faculty and staff present to answer questions and share information and resources.

Soil fertility management is a complex issue, and there are a multitude of ways that organic vegetable growers can achieve healthy soils, healthy crops and productive yields. Growers involved in the cases studies made it clear, however, that it pays to have goals and a plan in place. Organic vegetable farmers work at an intense pace during the growing season. To ensure that good soil management practices are followed, growers should have the required materials, equipment and labor on hand before spring planting commences. Recordkeeping is a vital step in documenting how various practices and inputs affect soils and crops. While growers are often adept at observing and performing some tests on their own soils, on many farms it is important to have soil tests conducted on a regular basis.

While none of the growers in this study would suggest that their farming practices are ideal or that they achieve all of their soil quality goals every year, the case studies presented here will hopefully inspire growers, researchers and consultants to improve soil management practices on organic vegetable farms. High-quality soil will not only produce healthy crops today; it will feed future generations as well.