Chapter 6
Organic Nitrogen Systems in the United States

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INTRODUCTION

Nitrogen (N) is one of the most important essential nutrients. Until the advent of the Haber-Bosch process for ammonia production, N was primarily managed by applying organic sources that added both carbon (C) and N to cropped land simultaneously. In this chapter, we review alternative approaches and uses of animal manures, inspecting selected case studies on organic N utilization and management in the US. For example, in the Mid-Atlantic region, employing compost optimized yields, improved soil quality and reduced N run-off. In the humid south, an Alabama study showed a doubling of sweet potato yield after receiving poultry litter as compared to recommended rates of inorganic fertilizer. In the drier, largely irrigated western US, positive results have been obtained using organic nutrient sources with irrigated vegetables. In a related study under semi-arid conditions, irrigated turf grass maintained its visual quality twice as long when compost was employed in contrast to recommended rates of inorganic fertilizers.

Coupling C and N cycles is seen as an appropriate approach to optimize soil fertility equilibrium over time and to improve N management (Delgado and Follett, 2002). Optimization of the C and N cycles is the most important management objective for ensuring high productivity and long-term environmental sustainability. Improving environmental resources of soil C regulates the biogeochemical cycling of N and other nutrients and provides a substrate for nutrient retention, well-known for its positive effects on soil and root ecosystems.

Applications of inorganic fertilizers beyond crop needs and their subsequent losses into the environment have resulted in serious environmental and health concerns in regard to pollution and eutrophication of surface water. In addition to surface water concerns, nitrate leaching can impact ground water sources. Organic amendments could serve as an effective and more environmentally friendly alternative when managed correctly. However, the success of this alternative depends on improved recycling of animal wastes and crop residues, crop rotation with legumes, and synchronization of N release from these organic N sources with periods of crop growth and N uptake. Compared to inorganic N fertilizers, which are quickly converted into soluble N forms susceptible to leaching, organic inputs release nutrients more slowly and continuously throughout the growing season. In addition, soil application of organic amendments enhances long-term soil productivity and quality by improving aggregate formation and stability, water infiltration, and the conditions for crop root growth. However, it is also important that organic N sources are not over applied, since they can contribute to significant NO_3^--N leaching losses and other reactive N losses to the environment as well (Kirchmann and Bergstrom, 2001).

MANURE

In the United States and throughout the world, animal manure is being generated in increasing amounts due to expanding demand for animal products. As animals are raised more and more in confined spaces, there is a burgeoning need for disposal and/or recycling of animal waste products. The most common means of manure disposal is through land application. Unlike N in inorganic fertilizers, the organic N in animal manures, crop residues, or other organic inputs must be mineralized to become available to plants.

Historically, manure application rates have been based on crop N requirements, N content of manure, and N availability in the source. However, because animal manure causes soil phosphorus (P) to build up when manure is applied according to N needs, the current tendency is to base application rates on P content of manure and soil when P runoff risk is high. Manure applications should consider both the P and N content and site-specific conditions.

Utilization of compost, manure, fertilizer, and cover cropping has different effects on soil N movement, and soil quality and fertility, depending on how long each has been implemented. While insufficient soluble N can curtail potential yield, excessive soluble N can result in serious ground- and surface-water contamination. While agricultural food production has doubled since 1965, N fertilization increased tenfold from 1950 to 1990 (Khush, 1999). Intensive use of N fertilization has contributed to heavy N leaching into the environment (Socolow, 1999). Scientists have suggested improving crop plant utilization of N as one way of reducing groundwater nitrate contamination. Using non-fertilizer approaches to supply crops with less-soluble N could also help reduce N losses to the environment.

ALTERNATIVES IN MANURE NITROGEN MANAGEMENT

Traditionally, animal manures are recycled either by direct land application or by land application after composting. With animal production on the rise in the US and worldwide, and with land area available for manure application at agronomic rates shrinking, farmers are faced with a serious disposal quandary. Confined livestock produces an estimated 1.23 million tons of recoverable N and 0.66 million tons of P (Gollehon et al., 2001). Confined animal operators control only 73 million acres of cropland and permanent pasture with an estimated capacity to assimilate only 40% and 20% of the N and P, respectively (Gollehon et al., 2001). Because of the problems associated with over-application to land surfaces, manure produced by confined livestock must be transported to other areas where it can be used. However, the cost of transporting manure can quickly become a limiting factor. Alternatives to manure land application can be broadly classified as output-use and source reduction technologies (Ribaudo et al., 2003).

Output-Use

With this approach, manure is collected at a farm level and redirected off-farm where it is used as input for treatment (Ribaudo et al., 2003). The industrial uses of manure include: manure homogenization and stabilization for production of fertilizers, such as composting, or incineration of low-moisture manure (typically broiler litter) for power production. Composting reduces manure mass, homogenizes its nutrient contents, stimulates humus formation, and reduces loads of pathogenic bacteria. Composting can be done at the farm level by an individual farmer or at a municipal level.

Perdue AgriRecycle and Harmony Farms in the Chesapeake Bay watershed transform manure into fertilizer products (Ribaudo et al., 2003). Perdue AgriRecycle became operational in 2001 and is located in the largest broiler-producing county in the US (Suffolk County, Delaware), with an annual capacity of 94,000 to 150,000 tons. Harmony Farms in Harrisonburg, Virginia, has an annual production of 60,000 tons of chicken litter, which is incorporated into organic fertilizer products.

For the past century, fossil fuels have been major sources of the world's energy. With continued growth of industrial economies and the rise of new economies such as those of China and India, these resources are expected to dwindle in the near future. Excess manure can be used to generate electricity, to heat homes and industrial facilities and fuel vehicles as an alternative to fossil fuels. In a case study conducted on an upstate New York dairy farm, Young and Pian (2003) showed that gasification of dairy wastes can provide for production of more than twice the energy required by the dairy farm producing the waste. Numerous studies confirm the potential to convert waste animal fat into ethyl and methyl esters (also called biodiesel). According to Tasthtoush et al. (2004), waste animal fat provides an excellent raw material for biodiesel production.

Under anaerobic storage conditions, manure produces methane (CH_4) gas, contributing to the greenhouse effect and global warming. Under controlled anaerobic conditions, however, the biogas emitted during manure degradation can be captured and used as a fuel resource. Recent investigations show that CH_4 productivity fluctuates widely among different animal manures studied. Sows showed the lowest methane productivity (165 m^3 CH_4 LU^{-1}) while other animals (dairy cattle and finishing pigs) range between 282 and 301 m^3 CH_4 LU^{-1} (Møller et al., 2004). Burning of poultry, dairy cow or pig manure can also generate energy (Reijnders and Huijbregts, 2005), and more potential remains to be tapped in this conversion strategy.

Biogas generated from manure has found application in fuel cell technology (Fuel Cells Tech., 2005). The Haubenschild family's farm near Princeton, Minnesota, serves as a demonstration project. The project is the first in the world to run a hydrogen fuel cell from biogas captured from dairy cows to generate electricity. The project is a cooperative venture between the Minnesota Department of Agriculture, Haubenschild Farms, the University of Minnesota's Department of Biosystems and Agricultural Engineering and the Minnesota Project (Fuel Cells Tech., 2005).

Source-Reduction

In the last two decades, scientists have increasingly focused on reducing N and P in livestock and poultry wastes. Tougher environmental regulations that set limits for nutrient discharge into waterways have forced livestock and poultry industries to adopt more innovative technologies that include using improved breeding, genetics and feed formulation to increase feed nutrient capture by farm animals. In this effort, new feed supplements have been introduced, and modified feeding systems have been developed. The use of synthetic amino acids, enzymes (e.g., phytase) and growth substances, reduced protein levels, and incorporation of highly digestible raw materials in chicken and pig rations have considerably reduced the amount of waste nutrients (Nahm, 2002).

Despite research progress, further challenges and public concern remain. Adoption of diet formulations closer to nutrient requirements have reduced the N content of chicken and pig wastes by 10% to 15%

(FEFANA, 1992). Incorporation of amino acids into chick and layer diets reduced N content of the wastes by 18% to 35% (Blair et al., 1999; Farrell, 2000). Following low-protein amino acid-supplementation of feed, Boisen et al. (1991) reported reduction in ammonia (NH_3) emissions by 49% to 79% in pig manure, while Aletor et al. (2000) observed a reduction of N excretion by 41%. Effects of grinding maize meal to a particle size <600 μm reduced daily N excretion from pigs by 27% (Wondra et al., 1995). The use of source-reduction technology has increased application of manure at rates that meet N- and/or P-standards and has decreased total costs of manure management, transport, and application (Ribaudo et al., 2003).

CASE SCENARIOS

The Organic Opportunity

According to the USDA (2009), organic acreage doubled from 1990 to 2002 and doubled again from 2002 to 2005. Organic food represents the fastest growing agricultural sector in the US. Organic agriculture depends on manures and legumes as the foundation for soil fertility and crop production. Transportation costs are one of the limiting factors for re-coupling livestock production with crop production through the recycling of manure nutrients. Organic agriculture provides the possibility of increasing manure transportation distances due to the higher value of the crops grown. In addition, composting manure enhances its value and hence also increases its potential transportation distance.

The management of organic sources of nutrients while considering environmental sustainability is key to the conservation of our biosphere. A holistic approach that considers the management of organic waste and looks for potential uses for this waste such as bioenergy, C sequestration and soil fertility has the potential to reduce environmental impact and even serve as a mitigation alternative for emerging issues related to global warming. The following case studies exemplify how organic sources of nutrients can be used in a viable way for different cropping systems across different regions in the US.

Mid Atlantic

From 1992 to 2001, the Rodale Institute conducted a compost utilization trial designed in collaboration with the USDA Agricultural Research Service (ARS). This trial compared the impact of compost, manures and synthetic chemical fertilizer on the productivity, soil quality and environmental impacts of a maize-vegetable-wheat rotation. Starting in 1998, hairy vetch (*Vicia villosa* Roth.) was used as an annual winter legume cover crop prior to maize production. The hairy vetch was plowed prior to planting maize. The decomposition of this green manure provides N needed for high maize crop production levels. Before 1998, red clover (*Trifolium pratense* L.) served as the green manure cover crop. The experiment was conducted using a split plot randomized complete block design with 4 large plot replications.

Site Description. The 2.0-ha experimental site was located at the Rodale Institute Experimental Farm in Kutztown, Berks County, Pennsylvania. The climate is continental sub-humid temperate. The location is situated at 40°22′N and 75°57′W. The soil type consists predominantly of Berks shaly silt loam (Typic Dystrochrepts) with some lesser amounts of Fogelsville silt loam (Utic Hapludalfs). The mean precipitation is 1,000 mm annually and is evenly distributed throughout the year. The mean maize growing degree units are approximately 2,950 per annum.

Treatment Descriptions and Experimental Design. The four treatments compared for the purpose of this book are described in Table 1. Starting in the spring of 1993, a three-year cash crop rotation of maize-vegetable-small grain was initiated. There were sixteen 21.3 x 18.3 m main plots (4 fertilizer treatments x 4 replications), with three 21.3 x 6.1 m subplots in each main plot.

Table 1. Crop rotations used in the Rodale compost utilization trial, 1993–2001. Entry points 1, 2, and 3 occurred each year for each treatment. Capital letters signify cash crops, while lowercase letters signify green manure cover crops. Legend codes: cc = crimson clover; hv = hairy vetch; M = maize; O = oat; P = pepper; r = rye; rc = red clover; S = spinach; sg = sorghum-Sudan grass; W/w = wheat. In 1995, the rotation was changed to include legume green manure after wheat, and in 1996, a rye cover crop was added after maize. The crimson clover planted the fall of 1995 did not overwinter.

Entry	1993	1994	1995	1996	1997	1998	1999	2000	2001
1	M	P-w	W-sg-cc	cc-M-r	r-P-w	W-hv	hv-M-r	r-P-w	W-hv
2	O-sg	M	P-w	W-rc	rc-M-r	r-P-w	W-hv	hv-M	r-P-w
3	S-P-w	W-sg	M	P-w	W-rc	rc-M-r	r-P-w	W-hv	hv-M

In the fall 1993 trial, lysimeters were installed. In 1993, spinach (*Spinacea oleraceae* L.) preceded bell pepper (*Capsicum annuum* L.); thereafter, the vegetable crop was always bell pepper. In 1993, the small grain rotation was initiated with oats (*Avena sativa* L. cv. Ogle), but from 1994 to 2001, winter wheat was used (*Triticum aestivum* L. cv. 'Wilkens'). From 1993 to 1995, sorghum-Sudan grass (*Sorghum bicolor* (L.) Moench.) was planted after small grain harvest to serve as a nitrate-scavenging catch crop.

In these trials, wheat depended completely on residual nutrients from the previous crop/nutrient sources used on maize and bell peppers. Green manure was used for maize, though vegetables received compost, manure, or synthetic fertilizer. Nitrogen applications were designed to give equal available N across the treatments. To optimize maize and vegetable production, the available N target rates were 130 and 100 kg N ha^{-1}, respectively. Nitrogen availabilities in fertilizer, manure, and compost were calculated as 100%, 50%, and 40%, respectively.

In the initial red clover cover crop stage (1994 to 1997), raw dairy manure produced the highest mean maize yields with 7.3 Mg ha^{-1} (approximately 134 bushels per acre at 15.5% moisture. This exceeds the Berk County mean yield (approximately 120 bushels per acre) by about 12%). Maize yields in all treatments from 1998 to 2001, which followed hairy vetch green manure crops, increased (P = 0.05 FLSD) by about 8.9% (approximately 580 kg ha^{-1} y^{-1} or 10.6 bushels acre^{-1}) compared to the previous management scenario (1992 to 1997), in which maize crops followed red clover green manure crops. From 1998 to 2001, yields resulting from conventional synthetic fertilization were about 9% to 16% lower than treatments employing raw manure or compost. Besides the crop yield increases for maize and wheat with organic amendments and cover cropping in these trials (Table 2), results from long term studies at the Rodale Institute show organic systems can increase yields (Tables 2 and 3) and increase C and N sequestration in soils (Table 4).

Not all treatments show a yield response. Pepper fruit yields were not responsive to the cover crop and/or amendment treatments. Wheat yields were higher (8% to 14%) under residual composts (4,020 kg ha^{-1}, 71.8 bu acre^{-1}), and raw dairy manure (3,805 kg ha^{-1}, 67.9 bu acre^{-1}) than under residual synthetic fertilizer (3,386 kg ha^{-1}, 60.5 bu acre^{-1}) and substantially higher (13% to 27%) than the Berk County mean wheat yield of about 3,000 kg ha^{-1}, 52 bu acre^{-1}. Hairy vetch winter cover cropping before maize production resulted in an 8.8% increase in wheat yields compared to clover cover crop in the years prior. Hairy vetch as green manure crop increased both maize and wheat seed N contents by about 16% to 17%.

Selecting the right cover crop is important in reducing nitrate leaching. Cover crops have been reported to reduce nitrate leaching and even mine nitrates from underground water while contributing to increases in vegetable yields (Delgado, 1998; Delgado et al. 2001a, 2007). In these Rodale Institute compost utilization trials, although nitrate leaching was low (<13 kg N ha^{-1}) for both cover crops, the hairy vetch cover crop resulted in nitrate-N leaching greater than leaching under a red clover cover crop (Table 5). September was the month with the most nitrate leaching. This was the result of high amounts of rainfall in the absence of an active cash crop and/or scavenging cover crop to intercept residual N. Providing better early cover crop development during the maize crop could prevent this loss. This would ideally be accomplished by seeding the cover crop after the critical periods for crop competition and interference but before stages of maize root senescence in order to ensure that the cover crop intercepts N, minimizing losses during the critical September timeframe.

Table 2. Crop yields (dry weight in kg ha^{-1}) in red clover and hairy vetch stages of the Rodale Institute compost utilization trial 1992 to 2001 Kutztown, Pennsylvania. Within the same stages, treatments possessing a common lower case letter are not statistically different at p = 0.05. BLLC = broiler litter leaf compost; CNV = conventional mineral fertilizer; DMLC = dairy manure leaf compost; RDM = raw dairy manure; Grand mean = average of all amendment treatments.

Crop	Treatment	Yield (kg ha^{-1} y^{-1})	
		Red clover stage	Hairy vetch stage
Maize grain	BLLC	5,932 a	7,224 ab
	CNV	6,333 b	6,847 b
	DMLC	6,891 ab	7,927 a
	RDM	7,563 a	7,076 b
	Grand mean	6,679	7,275
Wheat grain	BLLC	3,069 c	3,829 a
	CNV	3,362 b	3,386 a
	DMLC	3,673 ab	4,020 a
	RDM	3,715 a	3,805 a
	Grand mean	3,455	3,760
Pepper fruit	BLLC	1,455 b	1,549 a
	CNV	1,686 a	1,529 a
	DMLC	1,754 a	1,564 a
	RDM	1,825 a	1,561 a
	Grand mean	1,680	1,551

Table 3. Yield, plant height, and grain protein content for 2004 maize crop in organic and conventional farming systems in the Rodale Institute Farming Systems trial. Different letters indicate statistically significant differences (p = 0.05) between the farming systems for yield and height and a tendency of higher crude and available protein levels, which did not reach statistical significance.

Farming system	Yield (kg ha^{-1})	Height (cm)	Crude protein (%)	Available protein (%)
Organic	7,902 b	242 b	8.2	7.7
Conventional	6,844 a	207 a	7.2	6.7

Table 4. Soil C and N accumulation in kg ha^{-1} y^{-1} between 1981 and 2002. Different letters indicate statistically significant differences for that element (p = 0.05).

Farming system	Soil nutrient increase (kg ha^{-1} y^{-1})	
	Carbon	Nitrogen
Manure	981 b	86 b
Legume	574 b	41 b
Conventional	293 a	–2 a

Table 5. Influence of cover crop and amendment treatments on the leaching of nitrogen in the Rodale Institute compost utilization trial from 1994 to 2001 in Kutztown, Pennsylvania. BLLC = broiler litter leaf compost; CNV = conventional mineral fertilizer; DMLC = dairy manure leaf compost; RDM = raw dairy manure; Grand mean = average of all amendment treatments. Treatments with different letters are significantly different within column (p < 0.05).

Amendment	Red clover 1994–1998	Hairy vetch 1999–2001	Percent change
Nitrate N leached (kg ha^{-1})			
BLLC	1.3 a	5.7 a	226
CNV	2.8 b	10.5 b	262
DMLC	2.3 ab	12.6 b	425
RDM	4.3 c	12.7 b	189
Grand mean	2.68	10.38	275.5
Ratio of input N to leached N			
BLLC	87 a	20 a	77
CNV	25 b	7 b	72
DMLC	63 a	7 b	89
RDM	34 b	8 b	76
Grand mean	52.3	10.5	78.5

Among the organic amendments, broiler litter leaf compost (BLLC) showed the lowest (P = 0.05) nitrate leaching, and raw dairy manure showed the greatest leaching. Nitrate leaching using conventional fertilizer was similar to raw manure when combined with hairy vetch cover cropping. Leaching under red clover and dairy manure leaf compost tended to be lower than with either fertilizer or raw manure but more than with broiler litter leaf compost (Table 5).

Compost can be superior to conventional synthetic fertilizer and raw dairy manure for (1) building soil nutrient levels, (2) providing residual support to wheat production, and (3) reducing nutrient losses to ground and surface waters without lowering yield potential of grain crops such as maize or wheat. Using organic N sources to build up soil fertility has environmental advantages that can be combined with competitive yields and crop quality. Raw manures can constitute a greater environmental and health risk than synthetic fertilizers when used improperly. As such, for reducing the pathogen load in manure generated by concentrated animal feeding operations, composting should be considered a best management practice versus disposal of raw manure waste without composting.

Humid South

Climate and hydrology. The experiments described below were carried out at the George Washington Carver Agricultural Experiment Station at Tuskegee University, Tuskegee, Alabama. The study site is located at 32°26′N, 85°45′W, with a 400-foot elevation. The soil is a loamy sand of the Marvyn series (fine-loamy, siliceous, thermic, Typic Kanhapludults) with shallow underground water.

For the last 100 years, the average maximum air temperature in Alabama has varied between 15ºC and 35ºC (Figure 1) with highest peaks in the months of June–August. During the same period, the average minimum air temperatures ranged between 2ºC and 22ºC (Figure 1). The average total monthly rainfall in Alabama between 1906 and 2006 is shown in Figure 2. March and July are typically the wettest months. In 2003, a nearby weather station at the E.V. Smith Agricultural Experiment Station, Shorter, Alabama, was used to record ambient temperatures and rainfall in 2003 (Figures 1 and 2).

Tuskegee is located in east-central Macon County, Alabama, in the coastal plain hydro-geologic region. The experimental site is underlain by unconsolidated (undifferentiated) rocks of the upper Selma group. The soils in the study area are formed from sedimentary rocks underlain by impermeable igneous, metamorphic, and sedimentary rocks that form the floor of the coastal plain (Miller, 1992). These coastal plain sediments were deposited during a series of sea retreats. In Macon County, the Tuscaloosa group and the Eutaw formation are the main sources of ground water. The county is drained by Uphapee, Calebee, Cubahatchee, and Line Creeks, and their tributaries, all of which discharge into the Tallapoosa River.

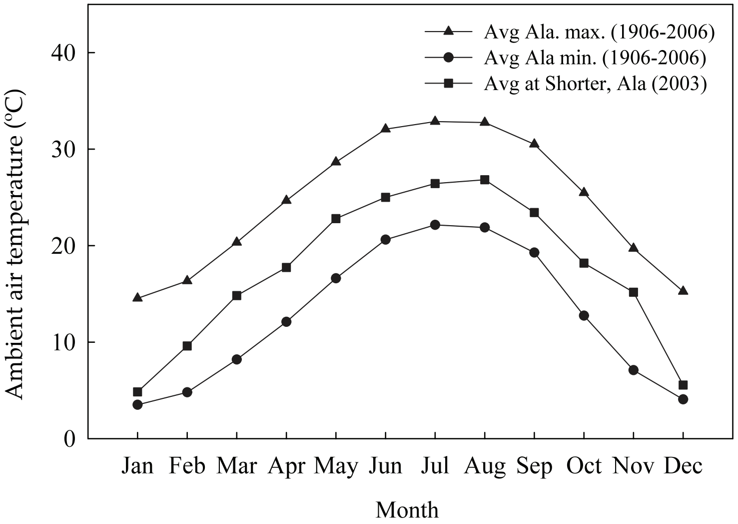

Figure 1. Average maximum and minimum monthly ambient air temperature in Alabama (1906–2006) and average 2003 monthly temperatures at E.V. Smith Agricultural Station, Shorter, Alabama. Source: www.srh.noaa.gov/bmx.

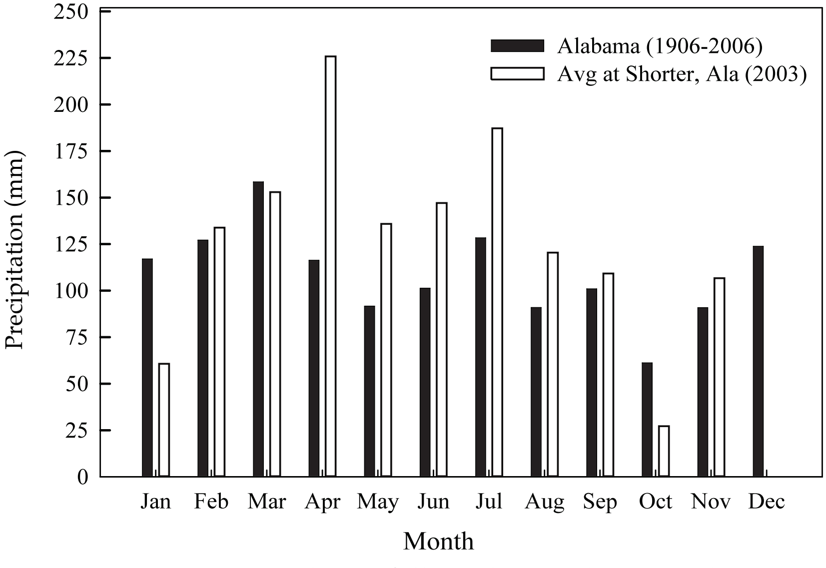

Figure 2. Average monthly rainfall in Alabama (1906–2006) and 2003 rainfall at E.V. Smith Agricultural Station, Shorter, Alabama. Source: www.srh.noaa.gov/bmx.

Research site. In spring 2001, a field study was initiated at Tuskegee University to investigate the use of organic amendments as nutrient sources. The studies evaluated different sweet potato cultivars using crimson clover, broiler litter, or NPK fertilization to determine how the factors of cultivar and soil amendment influenced sweet potato yield and water quality.

A split plot randomized complete block design was employed. The main plots were three sweet potato cultivars, and the subplots were four soil amendments: (1) non-amended control, i.e., weed fallow with no fertilizer; (2) crimson clover cover crop with broiler litter amendment; (3) crimson clover cover crop alone; and (4) crimson clover cover crop plus commercial NPK fertilizers. Each treatment was replicated four times in a randomized complete block design, resulting in 48 total experimental units. Porous ceramic suction lysimeters were installed under each "Nugget" sweet potato cultivar at 30, 60, and 90 cm.

In fall 2001, each experimental unit was planted with crimson clover (*Trifolium incarnatum* L) at a seeding rate of 45 kg ha^{-1}, with the exception of the non-amended control weed fallow treatment. Before planting, the crimson clover seeds were inoculated with *Rhizobium leguminosarum biovar trifolii* by moistening the seeds with water (18 mL kg^{-1} seeds) and combining seed with inoculum at the rate of 2 g inoculum kg^{-1} seed. In the control plots, no cover crop or fertilizer was applied and weeds grew freely. In spring, before planting sweet potato slips, the crimson clover tops were mowed and incorporated into the soil by plowing. Nutrients were applied as follows: broiler litter at a rate of 4 Mg ha^{-1} and ammonium nitrate and triple super phosphate at rates of 120 kg N ha^{-1} (in two split applications) and 120 kg P_2O_5 ha^{-1}, respectively. Potassium was applied as potassium chloride at a rate of 170 kg K_2O ha^{-1} to the NPK treatment plots according to soil testing recommendations.

Biomass. The biomass of leaves and vines for all sweet potato cultivars grown on the broiler litter-amended treatment were significantly higher ($P < 0.05$) than those grown on the crimson clover alone or the weed fallow control. However, there was no significant difference between the broiler litter-amended plots and the NPK treatments in terms of foliar biomass.

Cutlivars. "Beauregard" is a rapidly growing cultivar and provided fuller ground coverage and higher yield than "Nugget" or "Porto Rico." In organic farming, rapid ground coverage is especially important for weed control. The sweet potato biomass on broiler litter-amended plots was 7.1, 6.3, and 5.4 t ha^{-1} for "Beauregard," "Nugget," and "Porto Rico," respectively. No significant differences were recorded in sweet potato nutrient (C, N, and S) contents among the cultivars under the different treatments (Figure 3). The average nutrient contents across all cultivars and treatments were 41.7%, 1.5%, and 0.3% organic C, N, and S, respectively. Although the nutrient contents of the cultivars did not vary significantly, nutrient uptake under different treatments within cultivars varied significantly.

Amendment. Across all cultivars, the broiler litter-amended plots removed the largest amounts of C, N, and S (although N and S differences were not significant), and the control weed plots removed the least. Beauregard amended with broiler litter yielded 2.9 Mg C ha^{-1}, while the control plot yielded only 0.9 Mg C ha^{-1} (Figure 3). Nitrogen and S also tended to be higher under broiler litter-amended plots than under the control, the crimson clover alone, or the NPK plots (Figure 3).

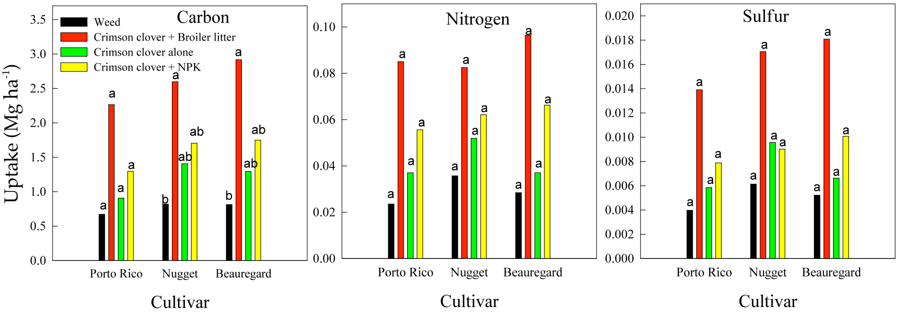

Figure 3. Carbon, nitrogen and sulfur contents of leaves and vines for three sweet potato cultivars grown on organic farming plots (Mathews, 2005). Treatments with different letters are significantly different within cultivar ($p < 0.05$).

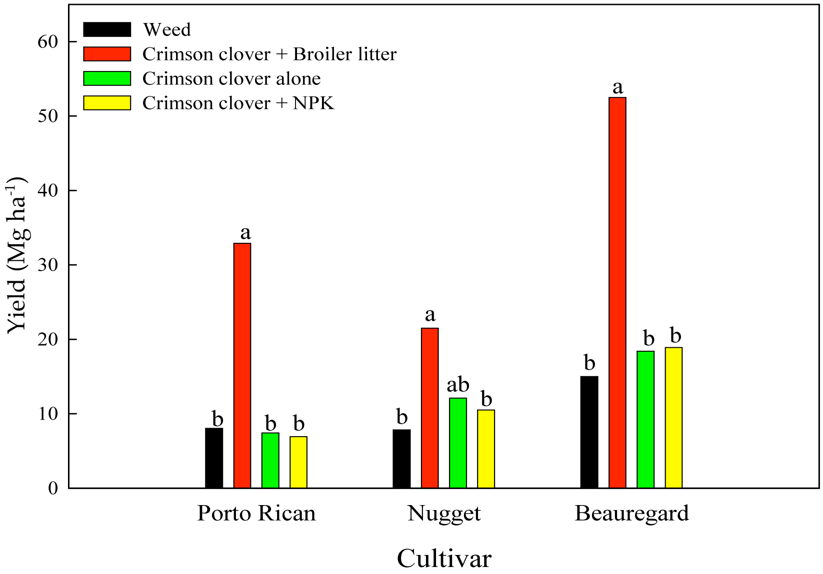

Figure 4. Sweet potato storage root yields of three cultivars grown on organic farming plots (Mathews, 2005). Treatments with different letters are significantly different within cultivar ($p < 0.05$).

Sweet potato storage root yields. Application of broiler litter significantly ($P = 0.05$) increased sweet potato storage root yields compared to other amendment treatments tested (Figure 4). There was a significant difference ($P < 0.001$) in storage root yields between Beauregard and the other cultivars. Sweet potato storage root yields on broiler litter-amended plots were 52.5, 32.9, and 21.5 Mg ha^{-1} for "Beauregard," "Porto Rico," and "Nugget," respectively (Figure 4).

The storage root yields of "Beauregard" and "Nugget" amended with broiler litter were much higher than that of "Porto Rico." "Beauregard" is a high-yielding cultivar, requiring lesser amounts of nitrogenous fertilizers than other cultivars (J. Schultheis, personal communication). Beauregard yields in North Carolina vary from 25 to 43 t ha^{-1} in sandy loam soils. Our results suggest that Beauregard may be very well suited for profitable production under organic farming systems.

The storage root yield data showed that Beauregard amended with broiler litter had a significantly higher yield than when using crimson clover alone (18.4 Mg ha^{-1}), crimson clover fertilized with inorganic NPK fertilizers (18.9 Mg ha^{-1}), or with no fertilizer (15.0 Mg ha^{-1}). Under similar environmental conditions, sweet potato storage root yields of 13.0 and 21.0 t ha^{-1} were measured for "Georgia Jet" and "Rojo Blanco," respectively, both fertilized with NPK fertilizers (Ankumah et al., 2003). These results point to a significant potential response to organic fertilization by sweet potato grown in low fertility soil on the coastal plain of the southeast.

Total dissolved organic N. Total dissolved organic N in the soil water before fertilizer application ranged from 1.3 g L^{-1} in the weed control plot to 1.7 g L^{-1} in the crimson clover at the 30 cm depth, from 1.4 g L^{-1} in the NPK plots to 1.6 g L^{-1} in the crimson clover at the 60 cm depth, and from 0.9 g L^{-1} in the NPK plots to 1.7 g L^{-1} in the weed control plots. No significant differences were found in the total dissolved organic N concentrations the first 10 weeks of the experiment. However, concentrations of the total dissolved organic N leached under the broiler litter-amended plots were higher ($p < 0.05$) than those under all other treatments at 30 cm depth, those under crimson clover alone at 60 cm depth, and those under crimson clover and NPK at 90 cm depth.

Nitrate-N. Prior to fertilizer applications, soil water NO_3^--N concentrations were low (below 5 mg L^{-1}) at all depths except in the broiler litter-amended plots, where the concentrations were close to 5 mg L^{-1}. Following fertilizer applications, significant amounts of NO_3^--N in the topsoil (0 to 30 cm) remained unconsumed by the sweet potato plants, still in an early stage of growth and development. As a consequence, the unconsumed NO_3^--N moved downward in the soil profile with percolating water. At the 30 cm depth, NO_3^--N concentrations ranged from 1.8 mg L^{-1} in the crimson clover plots to 5.0 mg L^{-1} in the broiler litter-amended plots. Concentrations of NO_3^--N at the 30 cm depth in the broiler litter-amended plots reached 33 and 30 mg L^{-1} at four- and six-week sampling times, respectively. At the same sample times, NO_3^--N concentrations in the NPK plots were 24 and 23 mg L^{-1}. After six weeks of water sampling, the NO_3^--N concentrations gradually decreased to below 5 mg L^{-1} and remained low for the rest of the season. The peak in NO_3^--N concentrations (19 mg L^{-1}), observed at six-weeks in the weed control plots, may be attributed to the fact that the plant root systems were not fully developed to take up nutrients that had accumulated in the soil as a result of residual plant material decomposition.

Nitrate-N concentrations never exceeded 15 mg L^{-1} at the 60 and 90 cm depths at four- and six-week sampling times (when their concentrations exceeded 15 mg L^{-1} at 30 cm depth). Nitrate movement in the soil could have been restricted by a heavy clay layer below 30 cm. A heavy clay pan is usually found at 60 cm depth in this soil. Presence of NO_3^--N at the 60 and 90 cm depths at concentrations exceeding the safe drinking water limit of 10 mg L^{-1} may be of concern, depending on drinking water well depths. A high nitrification rate, exceeding crop uptake at that stage of growth and development is a probable cause for the high concentrations at these depths in the weed control and crimson clover plots.

Semi-arid West

In semi-arid climates, such as those found in the western US, organic N sources can have additional benefits compared to the use of inorganic N sources. Under semi-arid environments, water availability is of paramount concern; therefore, the impacts of organic N source on water retention and conservation present added value that is not always recognized beyond the fertilizer value of soil amendments. Soil amendment impacts on water cycling and availability must be taken into account when assessing production options.

Turf. For example, in a study evaluating the use of composted dairy manure as a topdressing for Kentucky bluegrass turf grown on a Nunn clay loam (fine, smectitic, mesic Aridic Argiustolls) with an annual precipitation of about 400 mm, Johnson et al. (2006a, 2006b) found that moderate to high rates of compost application (66 and 99 m^3 ha^{-1}) resulted in increased soil water retention at saturation and field capacity, delayed water stress, and improved turf quality. These results demonstrate the ability of organic amendments to modify crop-soil-water dynamics. Johnson et al. (2009) also reported that compost application increased infiltration rate and improved drought tolerance of Kentucky bluegrass (evaluated through canopy temperature measurements and turf quality rankings during a 10-day dry down period) (Figure 5). Turf quality dropped below 6 (the threshold for acceptable turf quality) on the seventh day of the dry down period in the plots with no compost applied and on the eighth day in the plots receiving the low compost application rate (33 m^3 ha^{-1}). However, the turf quality of the plots receiving moderate and high compost application rates remained above 6 throughout the entire 10-day dry down period. Application of manures and composts has been shown to increase soil water retention in other studies, as well (Aggelides and Londra, 2000; Celik et al., 2004; Nyamangara et al., 2001; Miller et al., 2002).

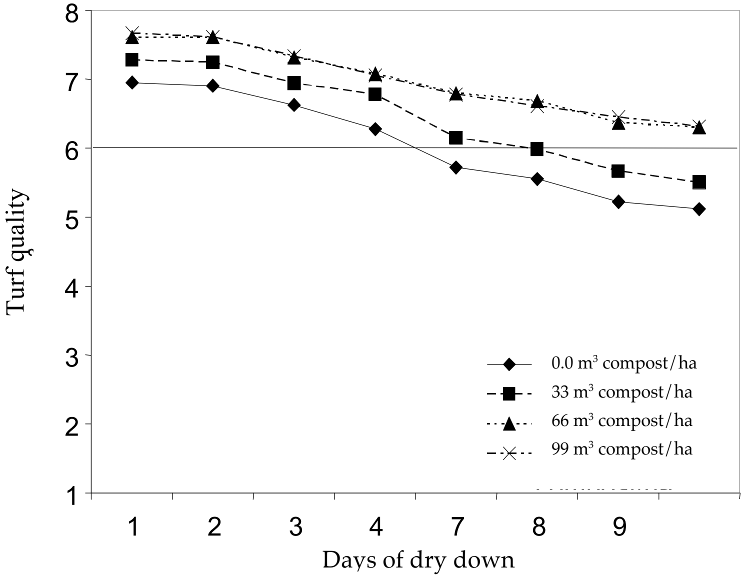

Figure 5. Decline in turf quality ratings after irrigation withdrawal for three Kentucky bluegrass cultivars. Turf quality rating was based on a combined evaluation of color, uniformity, density, and texture. A rating below 6 indicates unacceptably low quality. Based on Johnson et al. (2009).

Fruit trees. The challenge of optimizing the mineralization of N from organic sources to match crop needs was demonstrated in an on-farm study on the use of chicken manure or composted chicken manure in organic apple orchards in the Rogers Mesa area of Colorado, a region with an annual precipitation of 380 mm.

Two orchards were chosen for this three-year study: a certified organic orchard and a transitional orchard (one in the process of conversion to organic). Both orchards had initial pH levels of 7.6–7.7, 0.7 mmhos cm^{-1} soluble salts, and 2.0% OM. Treatments were 2.2 Mg compost ha^{-1}, 11 Mg chicken manure ha^{-1} (50% sawdust bedding), 22 Mg chicken manure ha^{-1} (50% sawdust bedding), and a control. There were five replicates at each site, laid out in a randomized complete block design, and treatments were applied annually in April in 1-m wide strips within the tree rows.

Climate has a very large effect on mineralization and nitrification rates, and the trends were similar across treatments. In general, early in the spring and shortly after compost or manure application, soil NH_4^+-N levels rose as a result of ammonification of the organic N. About a month later, soil NO_3^--N levels increased, apparently due to nitrification of the ammonium. When soil inorganic N levels were evaluated across time (averaged over the three-year study period), treatment effects were evident. Whether N was applied as compost or manure, as the total N application increased, so did the average soil NH_4^+-N and NO_3^--N levels. In addition, this study illuminates a common problem associated with organic soil amendments: the inadvertent buildup of soil P levels. The initial soil P (Olsen P) levels of the transitional and organic orchards were 42 and 95 mg kg^{-1}, respectively. At the end of the third year of the study, the soil test P levels in the transitional orchard had increased to 86, 98, and 148 mg kg^{-1} in the 2.2 Mg ha^{-1} compost, 11 Mg ha^{-1} manure, and 22 Mg ha^{-1} manure treatments, respectively. In the organic orchard, soil test P increased to 215, 239, and 337 mg kg^{-1} with application of 2.2 Mg ha^{-1} compost, 11 Mg ha^{-1} manure, and 22 Mg ha^{-1} manure treatments, respectively. In Colorado, a level of extractable soil P (Olsen) greater than 100 mg kg^{-1} presents a risk of P contamination of surface water from runoff that could lead to surface water quality degradation.

When manure is applied to meet crop N requirements, excessive amounts of P are often co-applied, leading to increased soil P and the potential for increased P runoff concentrations (Davis et al., 2004; Schoenau and Davis, 2006). Therefore, when using organic N sources, it is critically important not to focus on N alone when determining rates, but to consider all potential water quality problems related to those sources, including P. Use of legume cover crops is a way to provide N without adding P, and another option is to apply manure or compost at P-based rates and supply the rest of the needed N through other sources. These options help farmers deal with the N-P imbalance and allow application of organic amendments to larger acreages at lower rates, creating better overall results.

Vegetables. When utilizing organic sources of plant nutrients, it is impossible to separate impacts of single nutrients on crop productivity. Nonetheless, we have documented changes in soil fertility in a long-term study on Grant Family Farms (the largest organic farm in Colorado). The farm is located just east of the foothills of the Rocky Mountains in northern Colorado and has clay to clay loam soils and a semi-arid climate averaging about 440 mm of precipitation annually. The soil fertility program that Grant Family Farms uses is based on dairy manure application every three years with green manures used during the other two years.

Low available soil P levels are a common problem in organically managed fields in the western US. This is due to low solubility of rock phosphate in alkaline and calcareous soils common in semi-arid areas. Phosphorus sources such as manure and compost are essential in organic farming systems on these soils. We evaluated 12 fields at Grant Family Farms with a range of five to 12 years of soil test data and recorded significant increases in soil test P in 11 out of the 12 fields (Figure 6). Slopes were calculated for these 11 fields in order to quantify the increase in soil P (AB-DTPA extractable P) per year; the average slope was +2.0 mg P kg^{-1} y^{-1} since the fields were converted to organic management. This translates into an increase of about 4.0 mg P kg^{-1} per year for Olsen or $NaHCO_3$- extractable P.

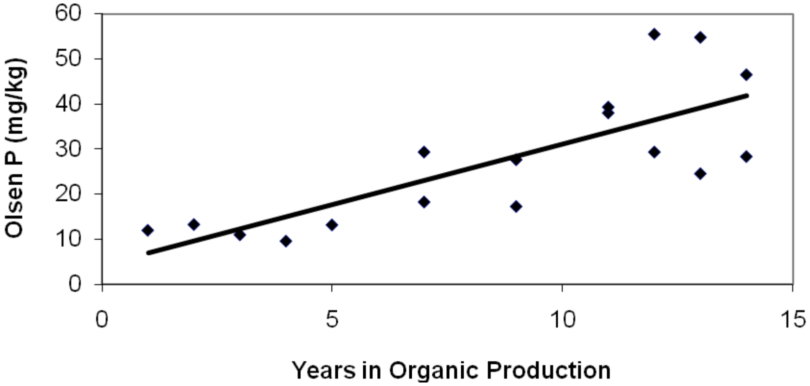

Figure 6. Soil test phosphorus (AB-DTPA) levels as a function of time under organic production. Based on a representative field from Grant Family Farms and adapted from Daniel (2002).

Annual soil testing, however, was not able to detect a significant soil NO_3-N difference in any of the 12 fields. In addition, soil organic matter significantly ($p = 0.05$) increased in four of the 12 fields (33% of fields). It is common in the semi-arid western US. that a history of manure or compost primarily impacts soil P levels, yet does not impact soil NO_3^--N concentrations. Nitrate is either taken up by plants, leached below the root zone in irrigated systems, or denitrified. Because of these soil reactions, high NO_3^--N concentrations do not typically persist in the topsoil under prevailing western conditions.

However, for traditional non-organic systems in the semi-arid western US that receive high N fertilizer inputs, NO_3-N accumulations in the surface soil can be very high (Delgado 1998, 2001). It has been reported that for irrigated vegetable systems of the semi-arid western US, the NO_3-N accumulation in the top 0–0.9 m of soil can be as high as 250 kg N ha^{-1} (Delgado 1998; Delgado et al. 2001a, 2001b). When intensively grown vegetables are grown without rotating with deeper rooted crops, the NO_3-N can be up to 800 kg NO_3-N ha^{-1} top 0–0.9 m horizon (Dabney et al., 2001). Delgado et al. (2010) conducted ^{15}N crop residue studies and reported that cover crops and deep rooted crops increase the efficiency of N cycled from organic cover crop residues, resulting in much higher N efficiencies than those obtained with inorganic N fertilizer. Therefore, cover crops and rotations with deeper rooted crops can be used as mining systems to minimize residual soil NO_3-N levels, increase N use efficiency, and reduce NO_3-N leaching in vegetable systems of the irrigated West (Delgado 1998, 2001; Delgado et al. 2000, 2001b, 2004).

CONCLUSIONS

Organic C has a significant ability to improve soil structure and increase soil water holding capacity. Studies at the Rodale Institute showed increased productivity of organic systems mainly under summer drought years. In addition, research in low organic matter soils of the southeastern US shows a positive response in organically amended sweet potato plots over those receiving only recommended inorganic fertilizer applications, and increased infiltration and water retention have been demonstrated even when compost was top-dressed in turf systems in the West.

Long-term studies have shown that enhancement of soil organic matter results in predictable increases in soil N and soil N recycling, which are associated with increased soil C levels. When soil N content increases jointly with soil organic matter (soil C) the entire crop system receives multiple benefits. This mechanism drives both the sustainability and productivity of diversified farming systems using manure, compost, legume cover crops, and rotations. Benefits of diversified farming for the improvement of soil productivity include competitive crop performance based on yield and quality. The Rodale Institute studies report that during drought years, maize and soybean performance were superior in the diversified farming system due to high soil organic matter, which conserves soil and water resources, thereby stabilizing yields for warm season crops.

Cover cropping and rotation typical of diversified organic agriculture improves aggregate stability and increases infiltration rates. With the increasing importance of C sequestration, soil organic amendments and C management should be part of nutrient management plans (Delgado and Follett, 2002). Organic systems are increasing in area, and optimization of C and N will be key to the sustainability and viability of these organic systems and of agriculture in general.

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