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Groundwater Nitrogen: Behavior in Flatwoods and Gravel Soils Using Organic Amendments for Vegetable Production[1]

Sanjay Shukla, Edward A. Hanlon, Fouad H. Jaber, Peter J. Stoffella, Thomas A. Obreza, and Monica Ozores-Hampton[2]

Introduction

This document explores the use of several compost sources in vegetable production fields at Ft. Pierce and Homestead, Florida. Water quality measurements of three nitrogen forms (nitrate, ammonium, and total nitrogen) were used to identify any changes that would indicate potential nutrient losses from the composts compared with a traditional inorganic fertilizer treatment. The target audience for this publication includes Certified Crop Advisors, vegetable production managers, organic farm managers, compost producers, state and federal agency representatives, and those interested in nutrient management for agricultural and environmental purposes.

Vegetable production in southern Florida occurs on soils with low water-holding capacity that require active irrigation management and sufficient nutrient supply to satisfy crop nutrient requirements for a commercially marketable commodity. High soil hydraulic conductivity and shallow groundwater conditions in southern Florida can result in unintended nutrient movement from crop fields to groundwater and surface water. Balancing the production needs of the farm to be profitable and minimizing the environmental losses of nutrients is a challenge. One method that addresses both nutrient management and water control is the use of compost.

Compost can be produced from a variety of organic materials (feedstocks), such as: wastes produced by urban populations, including municipal solid waste; yard trash/trimmings; food wastes from restaurants and grocery stores; wood wastes from construction and/or demolition; wastewater (from water treatment plants); and biosolids (sewage sludge). Agriculture also produces organic wastes that can be composted: poultry, dairy, horse, feedlot, and swine manures; wastes from food processing

plants; spoiled feeds; harvest wastes; and mushroom media. These organic materials can be composted through a biological decomposition process aided by proper aeration and moisture conditions and assisted by some mechanical means to convert raw organic materials into relatively stable humus-like material which reduces the feedstock particle size. During decomposition, microorganisms assimilate complex organic substances and release inorganic nutrients. The process itself can take place using in-vessel (variety of forced aeration and mechanical turning techniques), static aerated pile (a blower to supply air to the composting materials without turning or agitating), or windrow (consists on placing the mixture of raw materials in long narrow piles, or windrows, which are agitated on a regular basis) composting methods. These organic materials are composted through normal microbial decomposition aided by proper aeration and moisture conditions and assisted by some mechanical means to reduce feedstock particle size. After composting, mature compost is relatively uniform in its characteristics, contains essential plant nutrients, and offers other advantages for commercial vegetable production, such as potentially improved water holding capacity and improved organic matter levels in the soil over time.

Nutrients within the compost are a function of the original feedstocks, production methods, and maturity. Some of these nutrients are available to the vegetable crop during the growing season. Thus, addition of compost may also reduce the amount of inorganic fertilizer required for a growing season. Not all nutrients within the compost may be plant-available immediately or even during a short-term growing season. The compost may act as a slow-release fertilizer source, releasing additional nutrient amounts as it further decays. Nutrients from the compost are not immediately soluble. Slow release of nutrients from compost exposes fewer nutrients to possible leaching from rainfall, as opposed to the use of pre-plant inorganic fertilizer that exposes most of the nutrients residing in the soil. This positive effect of nutrient retention is both beneficial for the vegetable crop and for reducing possible environmental concerns.

Many growers are aware of these environmental aspects and have taken positive actions through implementation of Best Management Practices (BMPs). While BMPs deal with a much wider range of management strategies than just water and nutrients, all BMPs are a result of the 1972 Clean Water Act that established the concept of Total Maximum Daily Loads (TMDLs). A TMDL is the maximum amount of a pollutant, such as N, that a waterbody can receive and still meet water quality standards. If the TMDL is exceeded, a water body might be impaired, i.e., could not be used for designated purpose(s), such as potable water, swimming, fishing, etc. Implementation of BMPs is a means of partly or fully achieving the TMDL for a waterbody such as a lake or river.

This document focuses on nitrogen (N), which is mostly supplied to vegetable crops via inorganic fertilizers. However, N can also be supplied from organic sources, such as compost, if it is added to the vegetable nutrient management plan. From a water quality standpoint, N is one of the most important nutrients since it can be easily transported off site in its nitrate form, possibly affecting surface and ground waters adversely.

When considering the quality of human drinking water, N is a primary contaminant of concern, and a limit of 10 parts per million (ppm) of N in the nitrate form has been set by the U.S. Environmental Protection Agency. Environmental loss of N should be considered when developing a nutrient management plan for commercial vegetable production, ensuring that both the crop nutrient requirement for N is satisfied and that N does not migrate from the field. It is important to make a distinction between potable groundwater, which is withdrawn from wells that are usually more than 50 times deeper than the shallow groundwater beneath a farm.

Keeping nutrients, especially N, in the field equates to reduced production costs and is smart economically. Compost use can help growers meet production goals and at the same time recycle both nutrients and organic matter that originate from urban communities. This recycling is, therefore, good for Florida, because it reuses residential organic

materials that would otherwise end up in a landfill or incinerator.

The practice of composting with subsequent application to vegetable fields results in a more sustainable system for both the urban and farming communities. An additional energy savings is realized by reducing inorganic N fertilizer use, because manufacturing inorganic N fertilizer requires considerable supplies of natural gas.

Best Management Practices

As defined by rule, BMPs must be economical and technologically implementable for the grower, as well as provide a positive environmental impact. In other words, the practice has to be practical, fit with the overall farm management capabilities, and provide the expected environmental effect(s). Use of compost to meet a portion of the crop nutrient requirement is considered a BMP. A list of BMPs designed for vegetable production can be found in the vegetable and row crop BMP manual at the following Web address: http://www.floridaagwaterpolicy.com/PDF/Bmps/Bmp_VeggieAgroCrops2005.pdf.

Nitrogen Mobility

Nitrogen can change its chemical form in several ways. These changes and resulting N forms are components of the N cycle. For the purpose of this document, the primary forms we considered are explained below.

1. **Nitrate-N** is an oxidized form of N (associated with oxygen), is readily taken up by plants, and is highly mobile in soils, often moving with water in the soil profile. Usually nitrate-N concentration in groundwater is higher than in surface water.

2. **Ammonium-N** is a reduced form of N (associated with hydrogen), is taken up by plants (often in lower amounts than nitrate), is much less mobile than nitrate, and can also be found in surface water and groundwater. Usually ammonium-N moves more slowly in soil compared with nitrate-N.

3. **Organic N** is the fraction of N associated with organic molecules. It is usually not directly plant available, but it can be present in surface and groundwater. Usually organic N moves much more slowly in soil compared with nitrate-N.

4. **Total N** is the sum of all N forms above.

In addition to N form, N mobility is controlled in part by the types of soil in which vegetable production occurs. In Florida, production areas are dominated by sandy soils, such as the sands found in the Ft. Pierce area on the eastern coast of Florida's peninsula. Winter production of vegetables is centered in extreme southern Florida around Homestead, which has calcareous, gravelly soils.

Both sandy and gravelly soils contain large pores, allowing water to move easily vertically and laterally. This soil property also means that nitrate-N can move readily. Since water is the carrier of nitrate-N, controlling its transport away from the field requires an active water management plan. For example, excessive irrigation or a large rainfall can move N below the root zone and into the shallow groundwater, making that N unavailable for the crop and possibly contributing nutrients to adjacent water bodies.

How We Conducted the Tests and What We Measured

While many blends of various feedstocks can be composted together, we elected to use commercially prepared and readily available composts (Table 1) for the tests at both locations. No commercial names are used in this document to avoid recommending one product vs. another. Amendments and fertilizers were roto-tilled to a depth of 4 inches. Most of the amendment was contained in the 10-inch-high beds using a standard, raised-bed polyethylene mulch cultural practice. Seepage irrigation was used at Ft. Pierce (Figure 1), and micro (drip) irrigation was used at Homestead. Irrigation was scheduled based on tensiometer readings to keep optimum soil moisture in the root zone. Rainfall was recorded for both sites to characterize N movement to groundwater.
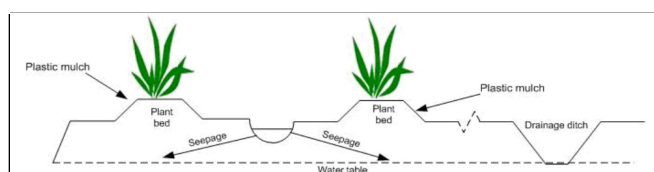
Figure 1. Layout of the beds and the seepage irrigation system at the Ft. Pierce site.

Groundwater Sampling at Ft. Pierce and Homestead

The soil at Ft. Pierce was Oldsmar sand, a typical flatwoods soil with restrictive Bh and Bt horizons (Figure 2). Water percolating through the soil is impeded by the restrictive horizon, creating a perched water table. A small portion of the water reaching the restrictive layer moves vertically through the layer, while the major portion moves laterally toward field drainage ditches. This hydrology necessitated the monitoring of groundwater above and below the restrictive layer. Two types of wells, shallow (above restrictive layer, depth = 3 ft) and deep (below restrictive layer, depth = 11 ft) were installed in each treatment (Figure 2).
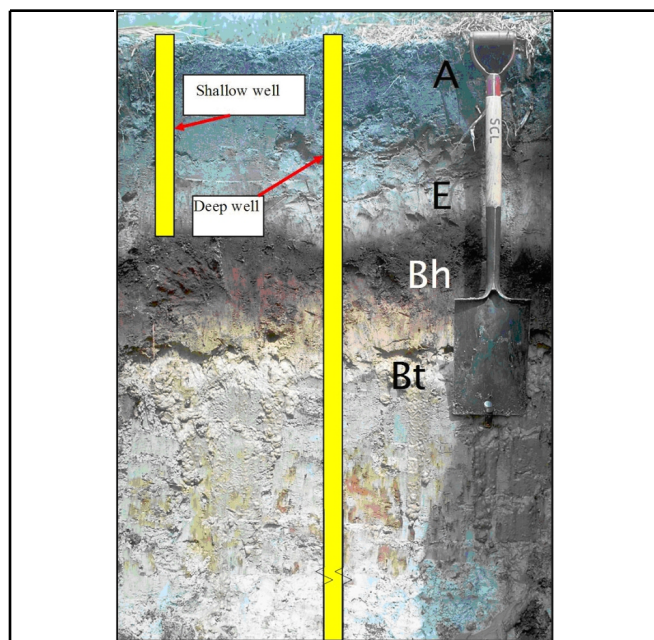
Figure 2. Oldsmar sand at the Ft. Pierce site showing soil diagnostic horizons and the location of sampling wells. Credits: Original photograph, courtesy of M. Bauer

The soil profile at Homestead contained no restrictive horizon (Figure 3), so only one well per treatment was used. The soil was Krome, a very gravelly loam, underlain by limestone rock.

Figure 3. The shallow profile of Krome very gravelly loam at Homestead. This soil is only 8 inches deep and is underlain by limestone rock (not shown). Credits: Original photograph, courtesy of Y. Li

To evaluate groundwater nutrient inflow and outflow from the study areas, wells were located outside of the areas along the hydraulic gradient found at both sites. A pair of wells was used at Ft. Pierce, and single wells were used at Homestead.

Amendment Rates

The soil amendment rate was calculated to deliver 175 lbs of N per acre (previous UF/IFAS recommendation for tomato), regardless of other nutrients found in the amendment. Soil testing was used to determine the recommended UF/IFAS rates of other nutrients.

The experiments were conducted according to typical grower practices in the two production areas (Table 2). A tomato-squash rotation was used at Ft. Pierce, while a tomato-calabaza rotation was imposed at Homestead. Amendment applications were made twice on the sandy soil and three times on the gravelly soil (Table 2). While additions of organic matter like the composts used in this demonstration project improve soil quality, a measurable increase in soil organic matter is quite slow due to the rapid decay processes given Florida's hot, humid climate. Therefore, any increases in soil organic matter usually

occur from repeated additions of organic matter, such as these annual additions.

What We Found

Rainfall

Rainfall amounts at both locations followed typical patterns for peninsular Florida with a distinct dry period during the winter and early spring, followed by a wet season. As expected, Ft. Pierce received 2 inches less rainfall compared with Homestead, which often receives additional moisture from the Gulf of Mexico and Caribbean.

### *Wells Located Up and Down Slope of the Study Areas*

Information from these wells indicated that nutrients were entering the site at Ft. Pierce from adjacent land, but not at Homestead. Concentrations were not a concern at either site. Concentrations were generally lower in water exiting the sites, indicating that the amendments as a group did not have an impact on water quality.

Nitrates

Nitrate-N concentration was less affected by rainfall at the Ft. Pierce site than at the Homestead site. This finding agrees with the relatively slower water movement that occurred in the sandy soil compared with the more rapid water infiltration in the gravelly soil.

At Ft. Pierce, the mean nitrate-N concentration in shallow wells was consistently less than 0.5 mg/L (Figure 4). On only one sampling date did the inorganic fertilizer (Fert) and the biosolid (BS) treatments have higher nitrate-N concentrations than the rest of the treatments (Figure 4). There was no difference in nitrate-N concentrations in deep wells as a result of treatments, which mirrored shallow well findings and concentrations.

The Homestead site showed more erratic fluctuations in groundwater nitrate-N (Figure 5). This result was expected due to the much higher water movement rate through the gravelly soil. However, concentrations did not exceed the maximum contamination limit of 10 ppm of nitrate-N, except by
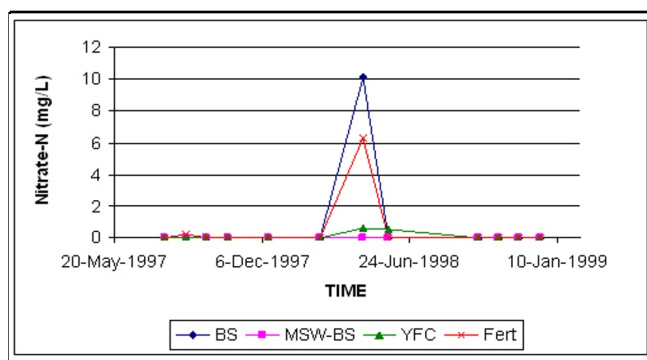
Figure 4. Mean groundwater nitrate-N concentrations in shallow wells at the sandy soil site (each point is an average of four replications). BS is biosolids; MSW-BS is municipal solid waste-biosolids; YFC is yard and food waste compost; Fert is inorganic fertilizer.

the MSW-BS treatment at the beginning of the rainy season.
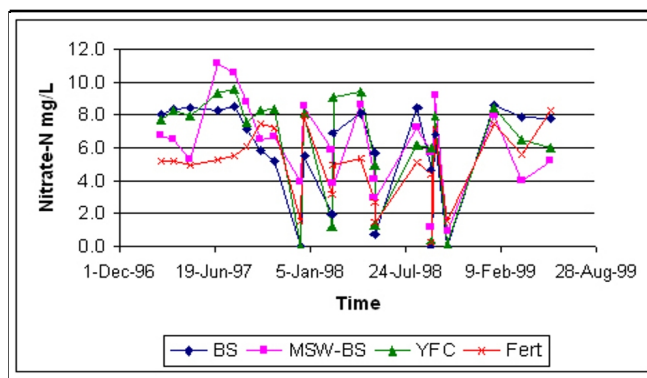
Figure 5. Mean groundwater nitrate (NO_3-N) concentrations at the calcareous soil site (each point is an average of four replications).

The C:N ratio of these organic amendments varied between 6 and 29 (Table 1). The amendment with the smallest C:N ratio would be expected to contribute more N earlier in the season than amendments with higher ratios. The single, unusually high nitrate-N concentration observed in the FERT and BS treatments at Ft. Pierce (Figure 4) was probably due to the lower C:N ratio of BS.

Ammonium

While there is no set maximum contamination limit for ammonium-N concentration in drinking water, values remained less than 0.5 ppm for all organic amendments. As with nitrate-N, a higher C:N ratio proved to be an indicator of how slowly ammonium-N would be released (larger ratio implies slower release). Both FERT and BS released more

ammonium-N soon after application compared with other organic sources.

Ammonium-N, a positively charged ion, can also be held within the soil by charged particles (Cation Exchange Capacity, or CEC). Both soils have relatively low cation exchange capacities, and when coupled with the coarse textures of these soils, little ammonium-N would be retained by this mechanism. As is the case with nitrates, controlling water movement will also contribute greatly to slowing the loss of ammonium from the root zone. No difference in ammonium-N due to amendments was detected in the deep wells at Ft. Pierce, indicating that this N form was either utilized by the plant, converted to nitrate (nitrogen cycle), or moved laterally above the restrictive horizons. The inorganic N source (FERT) had one slightly elevated concentration early in the season, but did not exceed 1.5 ppm ammonium-N.

Total Nitrogen

Total N concentrations in shallow groundwater were similar at both locations, regardless of amendment treatment (Figures 6 and 7). Total N at both sites was dominated by fluctuations of nitrate-N.
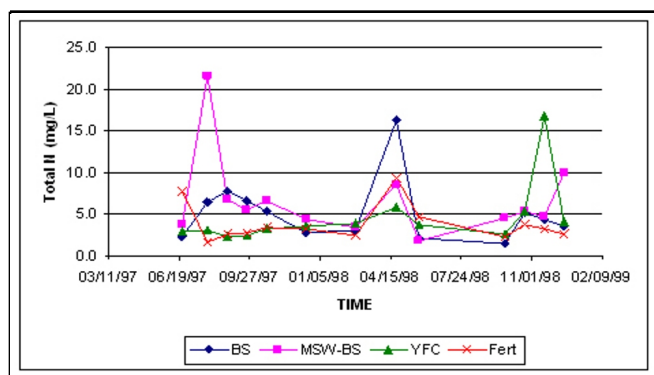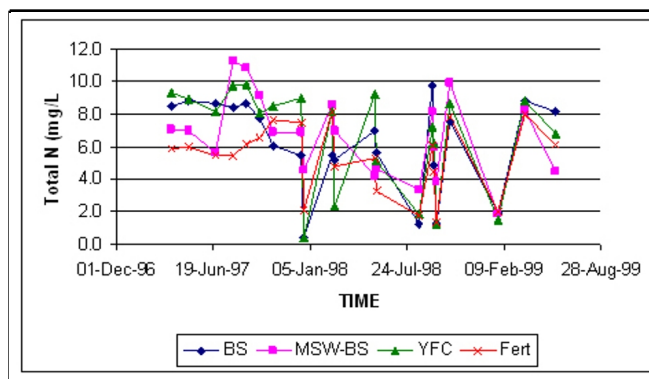

Figure 6. Mean groundwater total N concentrations in shallow wells at the Ft. Pierce site (each point is an average of four replications).

Crop Yields

Vegetable yield data from the sandy soil site showed similar yields of both organic and inorganic nitrogen sources, indicating that either source was effective in providing available N to commercially grown vegetables. Tomato yield data at Ft. Pierce were not collected for the second year of the experiment. The yield data suggested that compost

not only resulted in similar or higher yields than the inorganic fertilizer but also did not increase the N concentration in the groundwater compared with the inorganic fertilizer. Yield data from the Homestead site was not available.

Figure 7. Mean groundwater total N concentrations at the Homestead site (each point is an average of four replications).

Conclusions

1. Composts supplied available N at sufficient amounts and rates to satisfy the crop N requirement of tomato and squash at the sandy soil site. While these field trials addressed only two crops, similar yield performance is possible for other commercially produced vegetables.

2. Nitrogen was supplied through compost addition without increasing groundwater N concentrations compared with inorganic fertilizers.

3. Composts with high C:N ratios supplied N with somewhat decreased N leaching potential compared with composts with a low C:N ratio or inorganic fertilizer sources.

4. Using N from composts also recycles other nutrients and provides for an environment-friendly means of waste disposal. At the same time, soil quality can be improved and/or maintained.

How Do We Use This Information

We conducted this study in two of Florida's important vegetable growing regions. From a groundwater N standpoint, we found that use of organic amendments did not adversely impact water quality compared to traditionally used inorganic N

fertilizer. From a fertility standpoint, organic amendments at the sandy soil site provided similar crop yields to those obtained from inorganic fertilizer, demonstrating that they are a viable source of nutrition. In certain areas of Florida where P is the main water quality concern, the rate of compost application should be based on the plant requirement of P and not N. The fertilizer P requirement for vegetables can be obtained from UF/IFAS fertilizer recommendations. In addition to satisfying the nutritional requirement of these vegetables, use of organic amendments also has other potential benefits, such as increasing the water-holding capacity of Florida's sandy soil and recycling urban by-products in an environmentally safe manner. Use of organic compost should be expanded for vegetable production in Florida where it is economically feasible.

For More Information

Farming for Clean Water in South Carolina: A Handbook of Conservation Practices.

Cage Layer Manure: An Important Resource for Land Use. http://edis.ifas.ufl.edu/PS005.

Poultry Manure as a Fertilizer. http://edis.ifas.ufl.edu/AA205.

Soil Organic Matter, Green Manures and Cover Crops for Nematode Management. http://edis.ifas.ufl.edu/VH037.

Utilization of Organic Wastes in Florida Agriculture. http://edis.ifas.ufl.edu/AG113.

Soil and Fertilizer Management for Vegetable Production in Florida. http://edis.ifas.ufl.edu/CV101.

University of Florida North Florida Research Center – Suwannee Valley. http://nfrec-sv.ifas.ufl.edu/.

Sampling Guide from North Florida Research and Education Center Animal Waste Testing Laboratory. http://nfrec-sv.ifas.ufl.edu/lwtl1.htm.

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Table 1. Compost properties and application rates.

Amendments[1]	Source	pH	EC[2] (ds/m)	C:N Ratio	Mineralization Rate[3] (%)	Amendment Rate[4] (Tons/acre)
MSW-BS	75% MSW and 25% Biosolids	7.7	10.4	29:1	16	37
Biosolids (BS)	Wastewater	6.0	17.6	6:1	20	7.1
Yard and Food Compost (YFC)	Yard and food waste	8.0	4.2	17:1	15	32

[1]MSW-BS compost is a blend of municipal solid waste with biosolids; BS is a biosolid compost produced from wastewater treatment residuals; YFC compost is a blend of yard trash and food wastes, [2] Electrical conductivity, [3] Estimated from the literature and observed C:N ratio, and [4] Target was 175 lbs N/acre based on UF/IFAS recommendations.

Table 2. Field activities timeline for the two sites.

Sandy Soil		Calcareous Soil	
Date	**Activity**	**Date**	**Activity**
14 Mar 1977	Apply treatments	12 Dec 1996	Apply treatments
17 Mar 1997	Plant tomato	24 Apr 1997	Plant calabaza
28 May-4 Jun 1997	Harvest tomato	8 Jul 1997	Harvest calabaza
7 Jul 1997	Plant squash	24 Nov 1997	Apply treatments
25 Sep 1997	Harvest squash	2 Dec 1997	Plant tomato
26 Feb 1997	Apply treatments	6-24 Mar 1998	Harvest tomato
9 Mar 1998	Plant tomato	9 Jun 1998	Plant calabaza
21 May-2 Jun 1998	Harvest tomato	26 Aug 1998	Harvest calabaza
17 Jun 1998	Plant squash	30 Nov 1998	Apply treatments
18 Aug 1998	Harvest squash	28 Dec 1998	Plant tomato
		6-20 Apr 1999	Harvest tomato