Nutrient inputs and cycling in conventionally and organically farmed, and abandoned cranberry bogs

Tabea Zimmermann

Dr. Jimmy Nelson

Collaborator: Nick Pagan

1Dickinson College, 28 N. College St., Carlisle PA 17013
2Marine Biological Laboratory, 7 MBL St, Woods Hole MA 02543
3Clark University, 950 Main St., Worcester MA 01610

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Abstract

Organic agriculture has arisen as an alternative to conventional methods and studies have shown that while organic farming has lower yields than conventional agriculture, it uses fewer fertilizer and chemical inputs and is more efficient. This study compared nutrient cycling in a conventional and organic cranberry bog. Soil and water samples were analyzed for their nutrients (ammonium and nitrate). The sandy soils on the farmed bogs had lower organic material than the control site, and therefore less ability to nitrify and mineralize nitrogen into inorganic forms usable by cranberry plants. The organic bog had greater nitrate losses in its outflow stream, although it retained 60% of the nitrate within the bog site, demonstrating this bog’s ability to retain and recycle nutrients. The conventional bog on the other hand, had the highest concentration of ammonium found directly after the bog. This study showed that agricultural disturbance on both the organic and conventional cranberry bogs resulted in soil property differences compared with the abandoned site. Overall, the organic bog used nitrogen more efficiently within the site and did not lose as many nutrients to the outflow stream as the conventional bog. If the fertilizer application rates and efficient nutrient use on the organic cranberry bog result in only a 20% decrease in crop yields, this may be a viable option for agriculture in general, as it becomes more imperative to move away from the high-input and ecologically-damaging practices used in conventional agriculture.

Key words: cranberry bogs, conventional agriculture, organic agriculture, fertilizer inputs, nitrogen cycling, stream water, nitrogen leaching, soils
Introduction

The intensification of agricultural use of synthetic fertilizers and pesticides has caused increased environmental degradation (Pimentel et al 2005, Environmental Biology). Nutrient runoff from agriculture causes algal blooms and eutrophication, which pollute aquatic ecosystems such as the “dead zone” in the Gulf of Mexico (Beman et al 2005, Frankenberger & Turco 2003, Galloway et al. 2003). Organic agriculture has become a widely-used alternative to conventional farming practices (Pimentel et al 2005, BioScience). Organic farming is defined by the National Organic Standards Program as agriculture that does not use synthetic fertilizers or chemicals, genetically modified organisms, or sewage sludge (National Organic Program 2013). In 2011, organic food sales surpassed $25 million, more than double from purchases in 2004 (Osteen et al 2012). As consumer environmental and health concerns increase, organic food sales and therefore organic production is projected to increase (Dimitri and Green 2002).

Organic farming has been shown to have fewer negative impacts on the environment than conventional agriculture. Organic farms in Central Europe reduced their fertilizer and energy inputs by 35-53% and pesticide use by 97% while only observing a 20% decrease in crop yield, indicating that overall organic production is more efficient than conventional production (Mäder et al 2002). While organic production has been shown to be less environmentally harmful than conventional practices because it uses fewer fertilizer, pesticide, and herbicide inputs that are not synthetically-produced (Mäder et al 2002), it is still a form of agriculture, which is considered the largest human alteration of earth’s natural ecosystems (Tilman et al 2002). Many consumers have perceptions of organic agriculture that do not align with official definitions of the term, such that “organic” refers to the absence of chemicals and pesticides, artificial fertilizers, and growth hormones (Bonti-Ankomah & Yiridoe 2006). Modern consumers’ opinions of organic agriculture is that it is free of ecological consequences, but all forms of agriculture result in the loss of previously undisturbed land, including the addition of concentrated substances not naturally found in those ecosystems (Tilman et al 2002).

Cranberry production in Massachusetts covered 13,000 acres of the state in 2012 and was valued at over $100 million (New England Agricultural Statistics 2013). Because of pest, disease, and weed pressures, it is easier for cranberry growers to manage their bogs conventionally, using synthetic fertilizers and pesticides (Zeldin 2008). As of 2008, only 30 acres of cranberry bogs in Massachusetts are organically grown (Zeldin 2008). With the rise in national interest in organic farming however, more growers may begin transitioning their bogs to organic management.

Cranberry growing relies on large volumes of water for yearly flooding to harvest berries and purge bogs of pests and weeds. Typically, each acre in cranberry production requires 21,320 to 30,460 m$^3$ ha$^{-1}$ yr$^{-1}$ of water for these floods and irrigation (Cape Cod Cranberry Growers Association 2001). The water comes in from an upstream source such as a reservoir, flows through bog ditches, and gets released into a settling pond or downstream river (Cape Cod Cranberry Growers Association 2013). Cranberries thrive on the sandy mineral soils in bogs, but these soils do not hold water and nutrients well (Prouse 1999). The effects of frequent flooding...
and fertilizer application combined with the porous bog soils create opportunities for fertilizers (as well as pesticides and herbicides also used) to wash into and impact downstream waters.

Conventional cranberry farming, like most commercial agriculture, uses ammonium sulfate as nitrogen fertilizer, while organic producers use fish meal or crushed bones and feathers which release nitrogen more slowly (Davenport et al 2000, Zeldin 2008). Howes and Teal (1995) found that although plants and sediments on the bog they studied were a net sink for nitrogen, the addition of fertilizers made the bog as a whole a nutrient source. On 94% of the days sampled, the bog lost ammonium, nitrate, and phosphate to the stream. Flooding proved to be the biggest factor causing nutrient loss from the bog and most of the nitrogen leaving the system was in the form of ammonium, the form applied through fertilizers. Nitrogen flux was twice as high as a natural freshwater wetland system, indicating that this agricultural activity impacted downstream ecosystems more so than a natural wetland would.

This study examined how conventional and organic management influence the presence and cycling of nutrients in cranberry bogs in comparison with an abandoned system. Commercial bogs have been shown to leach nutrients but the effects of organic production on downstream ecosystems are unknown. I determined the differences in nutrient cycling among organic, commercial, and abandoned cranberry bogs to compare nutrient cycling inside and outside of these systems. I hypothesized that the organic system would leach fewer nutrients from the site than the conventional bog.

**Methods**

**Sampling sites and experimental design**

Three sites were compared in this study: the Cape Farm Cranberry Bog in Harwich, MA (organically managed), Pearceville Beaton’s bog in Wareham, MA (conventionally managed), and Zeke’s Way along the Coonamessett River in Falmouth, MA (80 year abandoned bog control site) (Figures 1-3).

At each bog site, pH, temperature, and conductivity were measured with an Oakton meter, and dissolved oxygen was measured with a WTW Oxi 340i meter. A 60 mL stream water sample was collected for nutrient analyses at each site and the number of stream sites sampled at each bog depended on the length of their outflow streams (Table 1 & Figures 1-3). Physical parameter measurements and water samples were taken from downstream to upstream to avoid contamination which would influence analysis results.

Sediment samples were collected from two sites in each bog’s outflow stream: at the termination of the bog where the water flowed into the stream and approximately 100 to 150 m downstream from the first location. At both sites, three samples were collected from sandy/rocky substrate and three samples from areas with leafy organic material. I collected soil cores from five randomized locations on each bog using a metal soil corer (Figures 1-3). Groundwater samples were collected using a wellpoint sampler along a transect perpendicular to the stream flow at three depths (Figures 5-7).
Sample processing and analyses in lab

All water samples were filtered using unashed 25 mm glass fiber filters (GFF). Samples for ammonium and nitrate analysis were acidified with 20 uL of 1N HCl acid and samples for nitrate analysis were frozen. I homogenized soil samples by removing debris and roots and homogenized sediment samples through a 2.5 mm sieve. I took a wet weight sample (10-20 g wet soil) and dried soil and sediment samples in an oven for at least 24 hours to calculate a wet/dry weight ratio.

Phosphate:

Phosphate concentration in all samples was determined using a method adapted from Murphy and Riley (1962). A reagent solution comprised of ammonium molybdate solution, sulphuric acid, ascorbic acid, and potassium antimonyl-tartrate was created in a 2-5-2-1 ratio and 0.3 mL was vortexed with 3.00 mL of sample water in a test tube. Samples were incubated for 30 minutes before absorbance was measured at 885 nm on a colorimetric spectrophotometer and converted to concentrations (uM) using a standard curve. Duplicate analyses were run because field replicates were not collected from each bog site.

Ammonium:

Ammonium was measured in water samples and soil and sediment extractions using a modification of the method from Solarzano (1969) (Strickland & Parsons 1972). After adding phenol solution, sodium nitroprusside, and oxidizing solution to 3.00 mL of sample water, samples incubated in the dark for one hour. Absorbance was measured at 640 nm using a colorimetric spectrophotometer and converted to concentrations (uM) using a standard curve. Duplicates were run on six of the groundwater samples from the Organic bog with 10:1 dilutions because initial absorbances were too high to be accurately represented by the standard curve.

Nitrate:

Nitrate concentrations in stream, groundwater, soil, and sediment samples were measured using the Lachat Quik-Chem method (Diamond 2008). I used distilled water standard curves for all samples because the Lachat Flow Injection Analyzer machine was unable to use KCl as a carrier solution.

Soil and sediment experiments

pH:

Approximately 10 g of soil or sediment sample was mixed into a slurry with 50 mL of distilled water to measure pH using an Accumet Model 20 pH/Conductivity Meter (Fisher Scientific).

%C and %N measurements:

Soil and sediment samples were each dried, crushed, and 20-30 mg was packed into a tin vial for the CHN analyzer. Samples expected to contain high levels of carbon and nitrogen were packed with 10-15 g of soil (Control site soils and Conventional bog leafy sediments).
Nitrogen Mineralization (bog soils only):

For all soil samples, 15 g of wet soil were combined with 100 mL of 1 N KCl and put on a shaker table for one hour. KCl extract was filtered using 25 mm GFF filters for ammonium and nitrate analyses. Nitrate samples were stored in the freezer and because KCl was a strong enough preservative, ammonium samples were refrigerated without further acidifying. Two blanks of KCl were included to account for influence of nutrients from the extraction solution. A subsample of each soil was stored in an incubator at 20.0 °C for approximately three weeks (Conventional soils for 20 days, Control and Organic for 22 days). After the incubation period, another KCl extraction was completed to measure final ammonium and nitrate concentrations.

Initial and final nutrient concentrations were compared to determine average rates of nitrogen mineralization and nitrification. Using the wet/dry weight ratio for each sample, I calculated the dry soil equivalent used in the extractions and the total volume of extractant. I converted nutrient concentrations (uM) in the extractant to amount of nitrogen per gram of dry soil (ug N/g dry soil) before calculating nitrogen mineralization and nitrification rates. I extrapolated daily rates to a per year basis.

Equation 1: N mineralization = ((NH$_4$ + NO$_3$)$_{final}$ – (NH$_4$ + NO$_3$)$_{initial}$)/days incubated

Equation 2: Nitrification = (NO$_3$$_{final}$ – NO$_3$$_{initial}$)/ days incubated

Potential Nitrification:

A 48-hour potential nitrification incubation was conducted using methods adapted from Bernhard et al. (2007) to determine how much ammonium soil organisms were capable of converting into NO$_3^-$. The assay was conducted on the twelve sediment samples from each bog site and on three of five soil samples. Approximately 1 g wet sample was measured into each of three 50 mL falcon tubes. To each tube I added 30 mL of a nutrient solution comprised of ammonium chloride (NH$_4$Cl), mono and dibasic phosphate (KH$_2$PO$_4$ and K$_2$HPO$_4$), and bicarbonate (NaHCO$_3$). Tubes were placed in a covered shaker table at 150 rpm and samples were harvested after 12 hours, 24 hours, and 48 hours. After being removed from the shaker table, samples were centrifuged, extracted using unashed 25 mm GFF filters, and frozen for nitrate analysis.

Results

Site background and management

The type and quantity of fertilizer applied to the Conventional and Organic bog systems influenced soil quality, nutrient cycling, and nutrients present in ground and surface water relative to the Control site. On the Conventional bog, 168 kg ha$^{-1}$ yr$^{-1}$ of 18-8-18 fertilizer was applied in June and nitrogen is supplied as urea which quickly breaks down in the soil into ammonium (C. DeMoranville, personal communication, 9 December 2013). On the Organic bog, 68 kg / ha of 6-4-4 organic chicken feather pellet fertilizer was applied three years ago.
(equivalent to approximately 56 kg ha\(^{-1}\) yr\(^{-1}\), or 30\% of the Conventional bog’s rate) (L. Cakounes, personal communication, 25 November 2013). In the soil, microbes break down the pellets into inorganic ammonium which cranberries take up, but also inorganic nitrate which gets slowly released onto the bogs throughout the growing season and beyond (Zeldin 2008). The Organic bog gets flooded three times a year: in October for harvesting, in the winter for icing and plant protection, and in the spring for two weeks for weed and insect control (L. Cakounes, personal communication, 25 November 2013).

Streamwater, soil, and sediment physical characteristics

The pH, temperature, dissolved oxygen, and conductivity was measured at each location on a single sampling day. Although there were slight variations among the three study locations and also within a single location along the length of its stream, the study sites had comparable physical parameters. pH at the Control site had a mean of 6.88±0.0211, which was higher than the Conventional (6.47±0.144) and Organic (6.02±0.0857) sites (Figure 7). Mean temperature at the Control site (9.2±0.10 °C) was the warmest of the three locations (Conventional site was 4.0±0.30 °C and Organic site was 7.7±0.60 °C). Dissolved oxygen levels at the three sites varied more than pH. The Control site had the highest mean of the three locations, at 7.51±0.240 mg/L (Conventional site was 6.17±0.18 mg/L and Organic site 7.04±0.170 mg/L). Conductivity was the most variable physical parameter measured. The Control stream had a mean level of 125.5±0.30 uS/cm, the Conventional site 145.4±7.40 uS/cm, and the Organic site with the lowest mean at 99.3±1.90 uS/cm.

Mean soil pH at the Conventional and Organic sites was almost equivalent (4.31±0.109 and 4.34±0.025 respectively) and these soils had greater pH than ones at the Control site (3.61±0.050) (Figure 8). The pH in bog soils was less variable than in the sediment samples (as seen in standards of error) and were more acidic than the sediments (Figures 8 & 9). There was no clear trend in the pH between sandy and leafy sediment samples, but the Organic site sediments had a slightly lower pH than the Control and Conventional sites (by 0.2).

%C and %N in soils and sediments

All soils had higher carbon than nitrogen composition (Figure 10). The Control site had both the highest %C and %N of all sites. Carbon (mean of 25.33\%) was 16.7 times higher than in the Conventional site (1.51\%) and 10 times higher than in the Organic site (2.54\%). Soil nitrogen in the Control site was 20.4 times higher than in the Conventional and 9.3 times higher than in the Organic sites. The ratio of %C:%N was 25.8 in the Control site soils, 30.5 in the Conventional bog, and 23.2 in the Organic bog. The Organic bog soils had 1.7 times higher %C and 2.2 times higher %N than the Conventional bog soils. The %C:%N ratio in the Conventional soils was 1.3 times higher than in the Organic site, indicating that the Organic soils had more nitrogen relative to carbon content.

Similar to the bog soils, stream sediments at all sites had higher %C than %N (Figures 11 & 12). Sediments in the Conventional bog had the highest %C and %N compositions. The %C
in Conventional sandy sediments was 10.5 times greater than in the Control site and 13.1 times greater than the Organic leafy sediments. Conventional leafy sediments had %C 8.5 times higher than the Control and 7 times higher than the Organic. The %N of both Conventional sandy and leafy sediments was 5 to 10 times greater than %N in Control and Organic sandy and leafy sediments.

*Sediment initial nutrient pools*
All sediments except the Control sandy ones had greater ammonium than nitrate content (Figure 13). Across sites, [NH₄] in the Conventional sandy sediments was 75.6 times higher than in the Control and 14.4 times higher than in the Organic sandy sediments. The highest NH₄ concentration overall was in the Conventional leafy sediments which were 21 times higher than in the Control and 54 times higher than in the Organic leafy sediments. Nitrate in all sediments was under 1 ug N g⁻¹ dry soil and did not vary as much as NH₄ between sandy and leafy sediments or across bog sites.

*Nitrogen mineralization and nitrification in bog soils*
Nitrogen mineralization is a measure of activity and nutrient turnover in soils, or how quickly inorganic nitrogen (NH₄ + NO₃) is created and made available for plant and organism uptake. Highest mineralization over the three-week incubation period was seen in the Control site (322.6±171.6 ug N g⁻¹ dry soil yr⁻¹) (Figure 14). In comparison, the Conventional and Organic bogs had low mineralization rates (12.4±5.4 ug N g⁻¹ dry soil yr⁻¹ and 22.9±2.4 ug N g⁻¹ dry soil yr⁻¹ respectively), although the Organic bog was almost twice as high as the Conventional. Mean flux of ammonium over the incubation was negative for all three sites, indicating that nitrification was occurring as soil microbes converted ammonium into nitrate. The total nitrification rate (difference in NO₃ over the incubation) was highest in the Control site soils (6.7 ug N g⁻¹ dry soil yr⁻¹) (Figure 15). Both active bogs had soils with 19 times lower nitrification than those at the Control site: 0.352 ug N g⁻¹ dry soil yr⁻¹ at the Conventional site and 0.354 ug N g⁻¹ dry soil yr⁻¹ at the Organic site.

*Potential nitrification in soils and sediments*
Soils in the Control site had the highest mean nitrification over the 2-day incubation (0.044±0.022 umol NO₃ g⁻¹ dry soil day⁻¹) (Figure 16). Both the Conventional and Organic bog soils typically had negative nitrification rates (-0.0063±0.0072 umol NO₃ g⁻¹ dry soil day⁻¹ and -0.0087±0.018 umol NO₃ g⁻¹ dry soil day⁻¹ respectively), indicating that immobilization occurred.

Sediments in all sites had higher rates of nitrification than the soils. Over the 2-day incubation, the Conventional leafy sediments increased to the highest net amount (0.677 umol NO₃ g⁻¹ dry soil day⁻¹), followed by the Control leafy (increased to 0.488 umol NO₃ g⁻¹ dry soil day⁻¹) and Control sandy sediments (increased to 0.387 umol NO₃ g⁻¹ dry soil day⁻¹) (Figure 17). The Conventional leafy, Organic sandy and Organic leafy sediments did not increase as much in
nitrate over the incubation and their endpoints were approximately half of the other three types. The mean rates of nitrification in the Control and Conventional leafy sediments (0.204±0.065 umol NO$_3$ g$^{-1}$ dry soil day$^{-1}$ and 0.207±0.131 umol NO$_3$ g$^{-1}$ dry soil day$^{-1}$ respectively) were greater than their sandy sediments, but this trend was not observed in the Organic sediments (Figure 18). The Control and Conventional leafy sediments were twice as high as the Control sandy, 5.4 times higher than the Conventional sandy, and 7.6 times higher than the Organic sandy sediments. In the sandy sediments, the Control site had the highest average nitrification rate at 0.105±0.063 umol NO$_3$ g$^{-1}$ dry soil day$^{-1}$ compared to 0.038±0.025 umol NO$_3$ g$^{-1}$ dry soil day$^{-1}$ in the Conventional sandy and 0.027±0.027 umol NO$_3$ g$^{-1}$ dry soil day$^{-1}$ in the Organic sandy sediments. The Organic leafy sediments average nitrification rate was -0.020±0.020 umol NO$_3$ g$^{-1}$ dry soil day$^{-1}$, showing that nitrogen was immobilized and ammonium was not converted into nitrate over the incubation.

Groundwater nutrients

Phosphate concentrations in groundwater at all three sites were below 10.0 uM (Figure 19). The Organic site had the highest [PO$_4$] in water samples, with three samples reaching approximately 8 uM. These concentrations were almost four times greater than the highest [PO$_4$] at the Control site (2.1051 uM) and five times greater than the highest concentration at the Conventional site (1.5682 uM). The Organic site had the highest [NH$_4$] of all groundwater samples in the three sites (Figure 20). Six of nine samples analyzed were between 279 uM and 348 uM and the other three were between 40-50 uM which was comparable to the one highest [NH$_4$] at the Conventional bog (48.9 uM). The mean nitrate concentration in groundwater at the Conventional site (4.9144±1.0730 uM) was 50 times greater than in the Control site (0.0977±0.0342 uM) and 13.5 times greater than the Organic site (0.3636±0.0742 uM) (Figure 21).

Stream water nutrients

The Control site had the most consistent phosphate concentrations across stream sites, with an average of 0.1211±0.0228 uM (Figure 22). Phosphate concentration in stream water at the Conventional site peaked in the two sites directly below the bog (7.42 uM and 8.48 uM respectively) before decreasing in the remainder of the outflow stream. The Organic bog had the highest concentration within the bog (5.1 uM at -110 m) and was twice as high as the Conventional site (2.44 uM at -30 m), although the greatest overall [PO$_4$] was in the sites immediately after the Conventional bog.

Ammonium concentrations at the Control site decreased from 0.9098 uM to 0.3238 uM over the course of the stream section and were the lowest of the three locations studied (Figure 23). The Conventional bog had the highest ammonium concentrations. [NH$_4$] within the bog was 6 uM or below but then increased to 18.5 uM in the first site after the bog before declining to 3 uM by 100 m from that site. The highest concentration at the Conventional site was two times higher than the Organic bog and twelve times greater than the Control site. Ammonium at the
Organic site increased within the bog to 10.3 uM but the majority was retained before exiting into the outflow stream (where the [NH₄] was between 1.2254 uM and 2.2541 uM). Within the bogs themselves, this site had higher [NH₄] than the Conventional (10.3320 uM vs. 6.3893 uM) but immediately after the bog, [NH₄] decreased in the Organic site to 2.4467 uM and increased in the Conventional site to 18.5533 uM. By the end of the water pathway, [NH₄] in both active bogs had decreased to levels lower than within the bogs.

The Control site had consistently high nitrate concentrations in stream water samples, ranging from 46.5 uM to 54.5 uM as water moved downstream (Figure 24). The Conventional bog had the lowest [NO₃] of the three bogs, and maintained a small range from 0.2 uM in the first site after the bog (at 50 m) to 2.3 uM at 220 m and 320 m into the outflow stream. The Organic bog increased in [NO₃] to 70.0 uM within the bog but then decreased by 56% to 30.9 uM by the end of the bog. Concentration continued to decline in the outflow stream until 23.2 uM. The [NO₃] in the stream water leaving the Organic site was 23.6 times greater than the outflow at the Conventional site (0.982 uM) but only 42.6% of the [NO₃] leaving in the Control site stream (54.5 uM).

**Discussion**

*Soil properties and activity*

Differences in carbon and nitrogen content among bog soils reflected variations in levels of human disturbance on these sites. The Control site had the highest %C and %N of the three sites (Figure 10) because leaves and organic matter are allowed to accumulate compared to farmed sites where organic matter is removed during harvest. However, the Organic site did have a lower C:N ratio than the Conventional, potentially due to the slow-releasing nitrogen fertilizers still being broken down in the soil. The differences between both active bogs and the forested Control site reflect how human disturbance of these bogs has altered the quality of organic, nutrient-rich material in soils.

The Control site also had the highest nitrogen mineralization and nitrification rates (Figures 14 & 15). Slow mineralization in the Conventional and Organic bog soils were due to their low organic content which may not support strong microbial communities. These soil properties are products of agricultural management, which has been shown to drastically influence mineralization and nitrification rates in soils (Compton & Boone 2000). However, mineralization at the Organic site was still twice as high as the Conventional site even though nitrification rates were the same (Figures 14 and 15). Since nitrification was the same, this shows that the Organic soils were better at converting organic nitrogen into ammonium than the Conventional soils. The potential nitrification incubation conducted on all soil samples showed that even when soils were saturated with nutrients, the Conventional and Organic soils still did not process nitrogen as much as the Control site (Figure 16). The pH of the bog soils was low enough to affect the ability of microbes to nitrify (below 4.5), which may have influenced the observed results (R. Mulvaney 1994, Figure 8).
Sediment properties and nutrient cycling

At all sites, leafy sediments had greater carbon and nitrogen composition than sandy sediments because they contained more organic material than the mineral sands (Figures 11 & 12). Through qualitative observation, the Conventional stream bottom was found to consist mostly of fine organic material whereas the Control site stream bottom was dominated by gravel substrate and the Organic site mostly sandy bottom (T. Zimmermann, personal observations, November 2013). The Organic bog is flooded frequently throughout the year, which washes away fine organic particles on the stream bottom and deposits sand from the bog fields. The differences in stream bottom substrate due to flooding management were reflected in the %C and %N differences, especially between the Conventional and Organic sites.

Leafy sediments in the outflow streams of the three sites had higher nitrogen concentrations than their respective sandy sediments because of greater organic content (Figure 13). Greater ammonium concentrations in sediments from the Conventional site may be a result of the accumulation of high organic material with conditions that are not conducive to microbial activity. This outflow stream held stagnant water with little turbulence (T. Zimmermann, personal observation, November 2013), likely creating low oxygen conditions which would restrict nitrification in the sediments and decrease the amount of nitrate found (Figure 13). In the potential nitrification incubation however, Conventional sediments exhibited greater nitrification rates than the Organic sediments and levels comparable to the Control site (Figure 18). A study conducted by Compton & Boone found little correlation between actual nitrification and potential nitrification in their samples, suggesting that the presence of nitrifiers was not the only factor influencing a soil or sediment’s ability to nitrify (2000). The Conventional site sediments were exposed to oxygen when being processed in the lab and the correct conditions must have been met for these samples to nitrify more than it seemed they do naturally in the outflow stream.

Organic sediments had little ammonium and nitrate because of the sandy stream bottom with little organic material (Figures 11 & 12). These sediments did not support a strong microbial community because even when saturated with ammonium during the potential nitrification incubation, they had the lowest nitrogen processing of the three bog sites (Figure 18).

Groundwater nutrient levels

Levels of nitrate and ammonium measured in groundwater at each site served as indicators of what nutrients are retained and which are released from bog soils and fields into systems downstream. This is important because groundwater does not move as quickly as surface water to impact downstream ecosystems. In addition, the water table on cranberry bogs is typically shallow, extending to a depth of approximately 1 m, so nutrients held in groundwater are sometimes accessible to cranberry plants and other vegetation for uptake (Stackpoole et al 2011).

Nitrate concentrations in bog groundwater were all below 10 μM (Figure 21), which is comparable to levels measured on cultivated cranberry beds in a study conducted by Stackpoole
et al. (32.14±35.71 uM) (2011). Ammonium in groundwater at the Control, Conventional, and Organic sites fell within the Stackpoole et al. range (68.57±128.57 uM) except for at the Organic bog (Figure 20). Here, ammonium concentrations were influenced by properties of the fertilizer applied on the bog. Soil microbes are still breaking down the chicken feather pellet fertilizer and slowly releasing nitrogen into the ground even though there is little plant uptake during the fall. The ammonium cations stick to soil particles and this nitrogen appears to be accumulating underneath the bog.

Stream water nutrient levels

Nutrients present in the stream water at each bog site represented what was being leached from the bog fields and how those nutrients were retained or released along the outflow pathway. Ammonium is the form of nitrogen fertilizer applied on the Conventional bog and is also created through the break-down of the slow-release chicken feather pellets on the Organic bog. The high ammonium concentrations directly below the Conventional bog suggest that ammonium is leaching off the bog into the outflow stream, where it is then processed in the following 200-300 m (Figure 23). Ammonium seems to be accumulating directly below the bog and is not being processed in that section. On the other hand, ammonium in the Organic bog stream both increased and decreased within the bog itself and little was released in the outflow, showing that this system is able to retain this nutrient better than the Conventional site.

Because nitrate easily leaches from soils, the concentrations measured show how the bog fields and their management influence the water flowing through them. The Control site had high [NO₃] throughout the sampled stretch even though it is an abandoned forest with no direct human nutrient inputs. This site is surrounded by residential developments which are likely leaching lawn fertilizers into the stream (Figure 1). The Conventional site had the lowest [NO₃] because the urea fertilizer applied does not break down into this form of nitrogen. NO₃ is also not being produced on the bog soils for it to get leached out, as was observed in the low mineralization and nitrification rates (Figures 14 & 15). The highest nitrate concentration measured in the Organic site (70 uM) decreased by 56% within the bog and by the end of the outflow was 23 uM (Figure 24), showing that the bog was able to retain a majority of the NO₃ on site. The slow-release chicken pellet fertilizer which takes longer for soil microbes to break-down than the conventional urea, is likely still being processed on the bog into both NH₄ (which was seen accumulating in the groundwater, Figure 20) and NO₃. Because cranberries do not use NO₃ and other weeds and vegetation are slowing their growth as winter approaches, it is leaching into the bog stream. Even though the [NO₃] exiting the Organic bog system was greater than the Conventional site, it was still only half of the nitrogen loss observed in the Control site which is impacted by residential development.

Implications of nutrient cycling and losses in cranberry agriculture

The original hypothesis of this study focused on nutrient losses from organic and conventional cranberry bogs into downstream waters. During the sampling period, the Organic
bog released more nitrate downstream than the Conventional bog, although leaching from this agricultural system was half of the Control site which was surrounded by a residential area.

The biggest difference between the two actively-farmed bogs was their ability to retain nutrients within the sites. The Organic bog was more effective at retaining ammonium and nitrate within the bog than the Conventional site which released ammonium into its outflow stream. The level of nutrients deposited in the outflow stream indicates that cranberries are not utilizing all the fertilizer inputs they receive. The Conventional system currently applies three times more fertilizer than the Organic one. By reducing this amount and using the slow-release form which distributes nutrients to plants more evenly, the Conventional bog could have greater nutrient efficiency both ecologically and economically.

Sampling for this study was conducted after both bogs were flooded and harvested, six months after fertilizer application. If sampling were to be done in June when fertilizers were applied, or in October during a bog flood, nutrient releases from the Conventional and Organic system would most likely differ from these findings. The Conventional bog stops fertilizing after the growing season, whereas the Organic bog’s slow-release chicken pellet fertilizer continues to release into the bogs. During application, the large quantities of urea fertilizer could leach out of the bog sites, especially if applied in solution form. In this case, one would expect to see greater nitrogen losses from the Conventional than Organic site. In order to make broader conclusions about the effects on nutrient cycling and losses from Conventional and Organic cranberry bogs, more bogs of each type of management must be sampled in order to rule out individual management styles and specific bog conditions that may influence the processes in question.

If the organic management effectively uses one-third of the fertilizer inputs as the Conventional site and can do so with an approximately 20% reduction in yields (Mader et al 2002), then this could be a viable option for more efficient modern agriculture. Each year in the United States, 4.99 billion kg of chicken waste are produced (Alternative Energy 2010). If all the cropland in the country were converted to organic management and accounting for the decreased yield, there would be enough chicken waste to fertilize all the farmland using the organic fertilizer application rates. Doing so would cost approximately $9 billion less than the conventional agriculture fertilizer rates.

**Conclusion**

While both actively-farmed bogs exhibited characteristics that were different from the undisturbed Control site (soil pH, soil %C and %N, soil mineralization and nitrification), the Organic site was more efficient at retaining the human inputs that were applied onto the bog. The type of fertilizer applied and management with accompanying lower herbicide and pesticide use created a system that could utilize more of the nutrients and release fewer of them downstream than the Conventional site. Although this study showed that Organic cranberry farming changes natural landscapes, it maintained more of the nutrient cycling exhibited in an undisturbed ecosystem in comparison with the Conventional growing practices. In the broader scope of agriculture, if we are to continue producing enough food to feed people while addressing the
ecological impacts that this human activity has on the environment, then at least in terms of fertilizer use and nutrient retention, organic farming is a less environmentally-stressful and more economically-viable alternative to conventional practices.

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Table 1. Breakdown of sampling at each bog. The two stream sediment parameters are stream bottoms with sand vs. leafy material. Reps refer to how many samples were collected in the field from each site.

<table>
<thead>
<tr>
<th>Field sampling at each bog</th>
<th>Sample type</th>
<th># Sites</th>
<th>Parameter</th>
<th>Reps</th>
<th>Total (1 bog)</th>
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<tr>
<td>Bog soil</td>
<td>5</td>
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<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Stream sediment</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Groundwater</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>9</td>
<td></td>
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<tr>
<td>Stream water Zeke's Way</td>
<td>8</td>
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<td>1</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Wareham</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Harwich</td>
<td>12</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Total soils</td>
<td></td>
<td></td>
<td></td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Total water</td>
<td></td>
<td></td>
<td></td>
<td>17-21</td>
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Table 2. Lab analyses run for soil (bog soil and stream sediment) and water samples (groundwater and stream), including totals from all three bogs.

<table>
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<th>Analysis in lab</th>
<th>Test</th>
<th># Samples/bog</th>
<th># Bogs</th>
<th>Reps</th>
<th># Blanks</th>
<th>Total samples</th>
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<td>Soil</td>
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<td>3</td>
<td>1</td>
<td>4</td>
<td>55</td>
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<tr>
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<td>3</td>
<td>1</td>
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<td>17</td>
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<tr>
<td></td>
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<td>3</td>
<td>1</td>
<td>2</td>
<td>17</td>
</tr>
<tr>
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<td>%C&amp;N</td>
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<td>3</td>
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<td>3</td>
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<td>Water</td>
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<tr>
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<td>3</td>
<td>2</td>
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<td>116</td>
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</table>
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