THE PENNSYLVANIA STATE UNIVERSITY
SCHREYER HONORS COLLEGE

ENVIRONMENTAL RESOURCE MANAGEMENT PROGRAM

EXPLORING POTENTIAL SOIL PHOSPHORUS MOVEMENT IN FOUR ORGANIC AGRICULTURE FORAGE SYSTEMS

LAUREN KATHERINE SEILER

Fall 2009

A thesis
submitted in partial fulfillment
of the requirements
for baccalaureate degrees
in Environmental Resource Management and Agricultural and Extension Education
with honors in Environmental Resource Management

Reviewed and approved* by the following:

Jason P. Kaye
Assistant Professor of Soil Biogeochemistry
Thesis Supervisor

Robert D. Shannon
Associate Professor of Agricultural Engineering
Honors Advisor

* Signatures are on file in the Schreyer Honors College

Abstract:
Phosphorus (P) runoff from agricultural lands is a significant environmental problem for freshwater aquatic systems because the input of P into these waters aggravates the process of eutrophication. Many studies are now being conducted in an attempt to pinpoint agricultural practices that prevent P from agricultural areas from entering the environment via runoff. Organic agriculture systems are a special concern for researchers because the use of manure as a fertilizer leads to the buildup of P in soils, which may become subject to runoff. In this study, four organic forage systems that differed in manure application rates, tillage practices, and other variables were assessed for P vulnerable to subsurface drainage and plant available P. It was found that none of the treatments differed in P vulnerable to subsurface drainage, and P concentrations ranged from 0.019 mg/kg to 0.110 mg/kg. However, after manure was applied to one of the treatments, the treatment with the manure addition had a mean P concentration of 0.053 mg/kg, while other treatment means were significantly lower. Additionally, none of the treatments differed in plant available P, and P concentrations ranged from 21.00 mg/kg to 64.00 mg/kg. Therefore, despite a variety of treatments and manure applications, none of the treatments exhibited a high degree of potential for P loss. These results indicate that sustainable P management can be achieved in a diverse set of organic systems and that organic agriculture does not necessarily create soil P levels that generate pollution concerns.

Table of Contents

Acknowledgements

My sincere gratitude to

Dr. Jason Kaye
for graciously helping me with this project

Dr. Robert Shannon
for invaluable support and advice throughout my undergraduate career

Mary Katherine Seiler
without whom none of this would be possible

Introduction:

A common environmental concern of agricultural systems is runoff from agricultural practices (Carpenter et al., 1998; Sharpley et al., 2003). Agricultural runoff refers to the total loss of water from a watershed by all surface and subsurface pathways (Sharpley et al., 2003). Many farms use fertilizers on crops or keep livestock, and the fertilizers and manure associated with these practices may be washed away with rain and eventually pollute nearby ecosystems.

Nutrients such as nitrogen (N) and phosphorus (P) are commonly present in fertilizers and animal manure and, when washed away from agricultural areas or other sources, have several impacts on our natural environment. Most importantly, N and P can be washed into our country's waterways, where the excess nutrients aggravate a process known as eutrophication. Eutrophication is the natural degradation of lakes or streams caused by nutrient enrichment, and this process can be greatly accelerated by human activities that increase the input of nutrients into waterways (Sharpley et al., 2003). The excess nutrients present in these waterways spur rapid growth of algae and aquatic weeds, and the oxygen shortages caused by the death and decomposition of these organisms can lead to hypoxia, or severe oxygen depletion in the water (Sharpley et al., 2003). These symptoms greatly hinder affected lakes and streams from supporting a wide range of natural organisms and habitats (Conley et al., 2009). Furthermore, eutrophic conditions deter lakes and streams from being used for fisheries, recreation, industry, and consumption (Sharpley et al., 2003). According to research, the most common impairment of surface waters in the United States is eutrophication caused by excessive inputs of P and N (Carpenter et al., 1998). It is for these reasons that agricultural practices must be strictly monitored to prevent excess nutrients and pollutants from entering the surrounding ecosystems via runoff.

The goal of this experiment was to assess P runoff or leaching potential from a variety of cropping systems. This experiment is part of a larger project established to create sustainable cropping systems that produce high value organic livestock, feed, and forages. The parent project, entitled "Weed Management, Environmental Quality and Profitability in Organic Feed and Forage Production Systems," or WMEQP, centers around four organic agricultural crop rotations. Organic farming is a form of agricultural production that strives to sustain the health of soils, ecosystems, and people, and in order to be considered organic, farmers must follow a strict set of guidelines set out by the United States Department of Agriculture (USDA). Organic farming relies on crop rotation, green manure, compost, biological pest control, and mechanical cultivation to maintain soil productivity and control pests, and excludes the use of synthetic fertilizers, synthetic pesticides, plant growth regulators, livestock feed additives, and genetically modified organisms. The four organic agricultural crop rotations in the WMEQP project involve different forage crops, tillage methods, and manure application rates. In the experiment discussed herein, the four organic farming systems used in the WMEQP project were tested for their potential for P runoff, thus determining which crop rotation may be the best at preventing the problems associated with nutrient runoff from agricultural systems.

Phosphorus was chosen as the focal point of this project because P management is special concern for organic farming systems. In organic farming, farmers are prohibited from utilizing synthetic fertilizers, which places additional constraints on alternatives for nutrient management. Consequently, some scientists are concerned about the suitability of nutrient management practices in organic systems. Many organic farmers choose to fertilize their crops with animal manure, and in this experiment, bedded pack beef cattle manure was used as the sole fertilizer source. In general, the application of animal manures to provide nutrients for crop growth is based on crop N needs (Toth et al., 2006). However, manures have a lower N to P ratio (N:P) than most harvested crops, so N-based manure management often oversupplies the cropping system with P, which can build up in the soil or be lost from the system via runoff (Toth et al., 2006). According to Carpenter et al. (1998), P-laden runoff from manure-amended soils is an important source of P for many eutrophic water bodies in North America. Furthermore, research has found that P, not N, is the limiting nutrient for freshwater eutrophication (Sharpley et al., 2003).

The aim of this thesis was to understand how P loss potential varies among the four organic systems in the WMEQP project and to assess whether manure fertility leads to increases in P loss potential from organic agriculture. The following questions were addressed in this experiment: What is the potential for P movement (via subsurface drainage or leaching) in each of the soil systems? Out of the four treatments, which organic agricultural system had the smallest quantity of P in forms that are susceptible to runoff and leaching? Answering questions like these may help make organic farming the new standard in mass agricultural production.

To assess potential P cycling, we collected soils from the field and used Mehlich 3 soil tests as an indicator of plant-available P and calcium chloride ($CaCl_2$) extraction procedures as an indicator of the potential for P loss via runoff.

Hypothesis and Predictions:

In this experiment, there are four specific organic agriculture forage systems being implemented at the Rock Springs research facility. Based on the field event plans associated with each of these treatments, I predict that treatment 2 will have the most potential P runoff and plant-available P out of all of the treatments. The reason for my prediction is that treatment 2 is the only treatment that will experience a manure application during the time period of this experiment, and surface application of manure can result in high dissolved reactive P losses in runoff (Romkens et al., 1973; Mueller et al., 1984).

My alternative hypothesis is that none of the treatments are significantly different from the others in terms of P loss, which could imply that recent manure additions are not the main drivers of P loss potential. In this scenario, a history of manure application could be the main driver of P loss potential. All of the treatments in question have been fertilized with manure for at least four years prior to this experiment, and a history of manure applications has been shown in pervious experiments to result in P accumulation in the soil, which could be vulnerable to runoff and leaching (Whalen & Chang, 2001; Toth et al., 2006).

Methods:

Study Site Description:

The "Weed Management, Environmental Quality and Profitability in Organic Feed and Forage Production Systems," or WMEQP, project is being conducted at the Russell E. Larson Agricultural Research Center near Rock Springs, PA. Before the WMEQP study was implemented, a different experiment, known as the Transition project, was being conducted on the site. The dominant soil type at this location is Hagerstown silt loam. The soil texture in the experimental fields is predominantly clay loam with differences in silt (range of 39.9-48.1%), clay (range of 29.6-34.3%), and sand (21.4-27.0%) content across the site. The total combined area of the field experiment is approximately four hectares and is surrounded by a minimum of seven meters of grassy border on all sides. The field experiment has been established twice, once in the summer of 2008 and again in the summer of 2009, in a randomized complete block design with four replications. There are sixteen main plots (4 treatments x 4 blocks) in each start year, which are each 0.067 hectares in size. The experiment discussed herein mostly deals with data collected from start 1 of the WMEQP project.

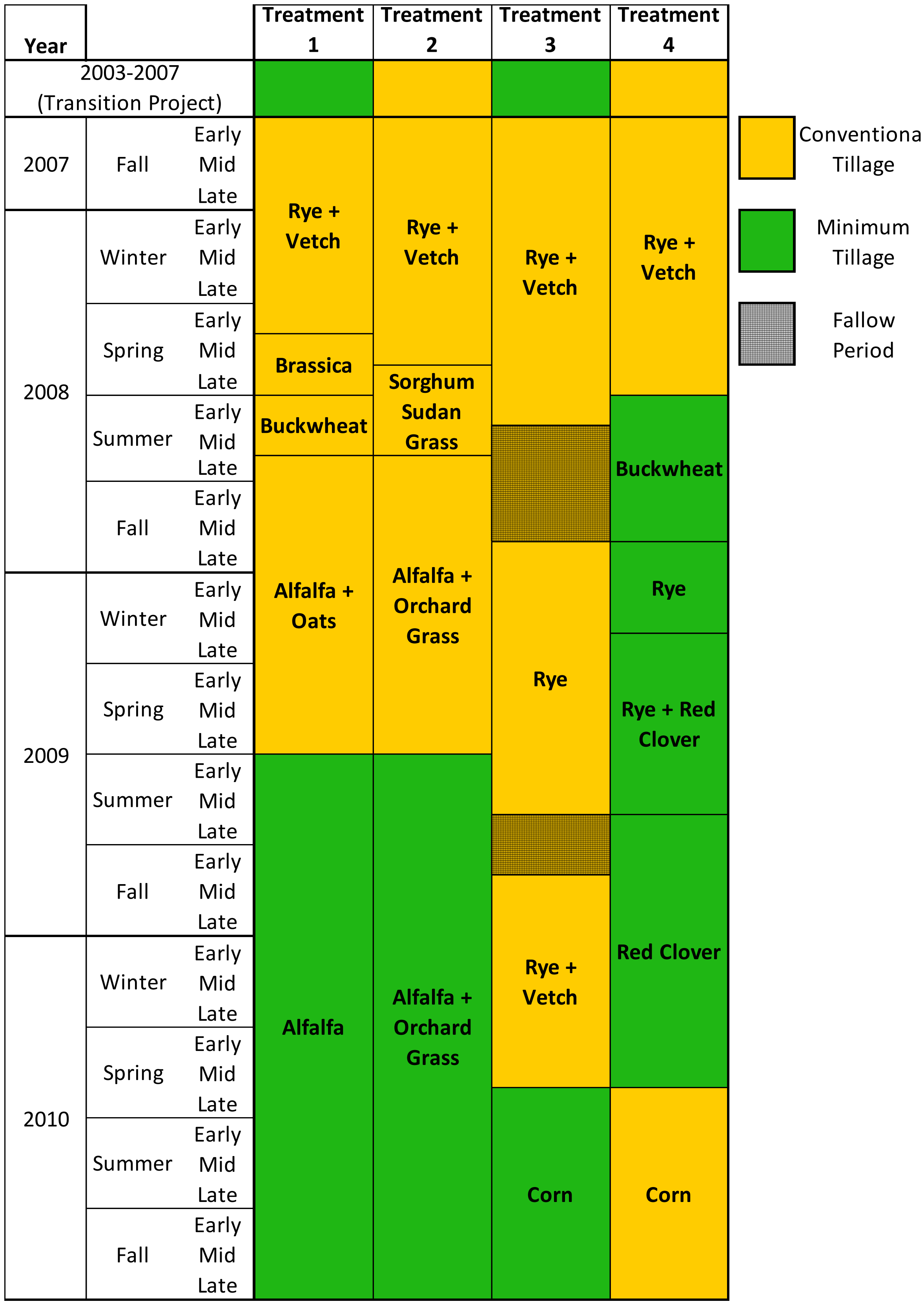

Figure 1. Planting and tillage plan for each treatment. Includes forage species, planting time, and tillage method (conventional, minimum, or fallow period) for fall 2007 to fall 2010.

The planting plans for each treatment, displayed in Figure 1, imply a considerable amount of preparation of the field, other than just tilling events. Each of the experimental plots has undergone a series of different field events, based on the plot's corresponding system or treatment number. Plots were moldboard plowed, disked, s-tined, roller harrowed, cultimulched, flail chopped, rolled, and mowed according to the experimental design of the treatment assigned.

Treatment 1

DATE	OPERATION
10/7/2003	Manure
10/10/2003	Lime application
10/13/2003	Cultimulched
10/13/2003	S-tined
10/14/2003	Planted Rye
7/29/2004	Rye combined
8/2/2004	Mowed straw
8/3/2004	Baled straw
8/25/2004	Compost application
8/26/2004	Chisel plowed
10/3/2004	Hairy Vetch planted
6/1/2005	Rolled Hairy Vetch
6/8/2005	Flail mowed
6/8/2005	Haybined vetch
6/9/2005	Planted Soybeans
6/10/2005	Yetter tool bar no-till coulter set
6/10/2005	Planted Soybeans
7/20/2005	Cultivated (half the plots)
7/27/2005	Cultivated
10/27/2005	Harvested soybeans
Feb/Mar 2006	Manure
4/19/2006	Miller disked
4/28/2006	Disked
5/3/2006	S-tined
5/3/2006	Planted corn
5/22/2006	Rotary hoed
5/31/2006	Rotary hoed
5/16/2006	Cultivated
12/5/2006	Harvested corn
4/3/2007	mulch tilled
4/23/2007	S-tined
4/23/2007	Cultimulched
4/23/2007	Pea/Tricale planting
5/30/2007	Mowed thistle tops
6/26/2007	Mowed pea/tricale
8/3/2007	Mowed pea/tricale (2nd cut)
8/14/2007	Mowed pea/tricale (3rd cut)
8/28/2007	Moldboard plowed
8/29/2007	Disked
9/4/2007	S-tined
9/5/2007	Cultimulched
9/6/2007	Rye/Hairy Vetch planting

Treatment 2

DATE	OPERATION
10/7/2003	Manure
10/10/2003	Lime application
10/13/2003	Cultimulched
10/13/2003	S-tined
10/14/2003	Planted Rye
7/29/2004	Rye combined
8/2/2004	Mowed straw
8/3/2004	Baled straw
8/25/2004	Compost application
8/26/2004	Moldboard plowed
10/3/2004	Hairy Vetch planted
5/26/2005	Mowed Hairy Vetch
5/26/2005	Moldboard plowed
5/27/2005	Disked
6/1/2009	Disked
6/1/2009	Cultimulched
6/6/2005	Planted soybean seeds
6/15/2005	Roatary hoed
7/20/2005	Cultivated (half of plots)
7/27/2005	Cultivated
10/27/2005	Harvested soybeans
Feb/Mar 2006	Manure
4/19/2006	Miller disked
4/20/2006	Moldboard plowed
4/28/2006	Disked
5/3/2006	S-tined
5/3/2006	Planted corn
5/22/2006	Rotary hoed
5/31/2006	Rotary hoed
5/16/2006	Cultivated
12/5/2006	Harvested corn
4/3/2007	mulch tilled
4/23/2007	S-tined
4/23/2007	Cultimulched
4/23/2007	Pea/Tricale planting
5/30/2007	Mowed thistle tops
6/26/2007	Mowed pea/tricale
8/3/2007	Mowed pea/tricale (2nd cut)
8/14/2007	Mowed pea/tricale (3rd cut)
8/28/2007	Moldboard plowed
8/29/2007	Disked
9/4/2007	S-tined
9/5/2007	Cultimulched
9/6/2007	Rye/Hairy Vetch planting

Treatment 3

DATE	OPERATION
10/7/2003	Manure
10/10/2003	Lime application
10/13/2003	Cultimulched
10/13/2003	S-tined
10/14/2003	Planted Timothy/Jay Oats
4/19/2004	Re-seeded Jay Oats
4/19/2004	Planted Red Clover
5/14/2007	Mowed volunteer Rye
5/25/2004	Mowed volunteer Rye
5/28/2004	Weeded volunteer Rye and Wheat
8/2/2004	Baled Timothy as high moisture hay
8/25/2004	Compost application
10/14/2004	Timothy/Clover harvest
5/26/2005	Chisel plowed
5/27/2005	Disked
6/1/2005	Disked
6/1/2005	Cultimulched
6/6/2005	Planted soybean seeds
6/15/2005	Rotary hoed
7/11/2005	S-tined
7/13/2005	Replanted Soybeans
7/20/2005	Cultivated (half the plots)
7/28/2005	Cultivated
10/27/2005	Harvested soybeans
Feb/Mar 2006	Manure
4/19/2006	Miller disked
4/20/2006	Disked
4/28/2006	Disked
5/3/2006	S-tined
5/3/2006	Planted corn
5/22/2006	Rotary hoed
5/31/2006	Rotary hoed
6/16/2006	Cultivated
12/5/2006	Harvested corn
4/3/2007	mulch tilled
4/23/2007	S-tined
4/23/2007	Cultimulched
4/23/2007	Pea/Tricale planting
5/30/2007	Mowed thistle tops
6/26/2007	Mowed pea/tricale
8/3/2007	Mowed pea/tricale (2nd cut)
8/14/2007	Mowed pea/tricale (3rd cut)
8/28/2007	Moldboard plowed
8/29/2007	Disked
9/4/2007	S-tined
9/5/2007	Cultimulched
9/6/2007	Rye/Hairy Vetch planting

Treatment 4

DATE	OPERATION
10/7/2003	Manure
10/10/2003	Lime application
10/13/2003	Cultimulched
10/13/2003	S-tined
10/14/2003	Planted Timothy/Jay Oats
4/19/2004	Re-seeded Jay Oats
4/19/2004	Planted Red Clover
5/14/2004	Mowed volunteer Rye
5/25/2004	Mowed volunteer Rye
5/28/2004	Weeded volunteer Rye and Wheat
8/2/2004	Baled Timothy as high moisture hay
8/25/2004	Compost application
10/14/2004	Timothy/Clover harvest
5/26/2005	Moldboard plowed
5/27/2005	Disked
6/1/2005	Disked
6/1/2005	Cultimulched
6/6/2005	Planted soybean seeds
6/15/2005	Rotary hoed
7/11/2005	S-tined
7/13/2005	Replanted Soybeans
7/20/2005	Cultivated (half the plots)
7/28/2005	Cultivated
10/27/2005	Harvested soybeans
Feb/Mar 2006	Manure
4/19/2006	Miller disked
4/20/2006	Moldboard plowed
4/28/2006	Disked
5/3/2006	S-tined
5/3/2006	Planted corn
5/22/2006	Rotary hoed
5/31/2006	Rotary hoed
6/16/2006	Cultivated
12/5/2006	Harvested corn
4/3/2007	mulch tilled
4/23/2007	S-tined
4/23/2007	Cultimulched
4/23/2007	Pea/Tricale planting
5/30/2007	Mowed thistle tops
6/26/2007	Mowed pea/tricale
8/3/2007	Mowed pea/tricale (2nd cut)
8/14/2007	Mowed pea/tricale (3rd cut)
8/28/2007	Moldboard plowed
8/29/2007	Disked
9/4/2007	S-tined
9/5/2007	Cultimulched
9/6/2007	Rye/Hairy Vetch planting

Figure 2. Transition project; history of field events for each treatment, includes date and operation performed. Timeline covers 10/7/2003 to start of WMEQP project.

TREATMENT 1

DATE	OPERATION
4/25/2008	Moldboard plowed
5/2/2008	Disked
5/15/2008	Roller harrowed
5/15/2008	Planted brassica
7/11/2008	Mowed
7/16/2008	Moldboard plowed
7/18/2008	Disked
7/18/2008	Roller harrowed
7/18/2008	S-tined
7/18/2008	Planted buckwheat
8/14/2008	Moldboard plowed
8/26/2008	S-tined
8/26/2008	Roller harrowed
8/26/2008	Planted alfalfa/oats

TREATMENT 2

DATE	OPERATION
4/11/2008	Manure
5/7/2008	Flail chopped
5/30/2008	Moldboard plowed
6/6/2008	Disked
6/9/2008	S-tined
6/11/2008	Roller harrowed
6/12/2008	Planted sorghum sudan grass
8/12/2008	Mowed
8/14/2008	Raked sorghum sudan grass
8/15/2008	Baled soghum sudan grass
8/18/2008	Moldboard plowed
8/26/2008	S-tined
8/26/2008	Roller harrowed
8/27/2008	Planted alfalfa/orchardgrass

TREATMENT 3

DATE	OPERATION
5/7/2008	Flail chopped
7/3/2008	Mowed
7/16/2008	Moldboard plowed
7/18/2008	Disked
7/18/2008	Roller harrowed
7/18/2008	S-tined
8/26/2008	S-tined
8/26/2008	Roller harrowed
9/17/2008	S-tined
9/19/2008	Planted rye

TREATMENT 4

DATE	OPERATION
6/18/2008	Rolled
7/3/2008	Rolled
7/17/2008	Planted buckwheat
8/14/2008	Mowed
9/12/2008	Mowed
9/19/2008	Planted rye

Figure 3. Field event timeline for each treatment in start 1 of the WMEQP project, includes date and operation performed.

Figure 3 covers only the field events that took place during the 2008 growing season (start 1 of the WMEQP project), which correspond to the timeline of the $CaCl_2$ P extractions performed in the experiment herein.

Soil Phosphorus Sampling and Analysis:

The purpose of the $CaCl_2$ extraction was to measure the amount of P in the plots that would be vulnerable to subsurface drainage. If P was present in subsurface drainage, it could potentially percolate into the ground water and enter into freshwater lakes and streams via baseflow. Mcdowell and Sharpley (2001) established the correlation between $CaCl_2$ extracted soil test P and dissolved reactive P in drainage waters.

For the $CaCl_2$ extractions in this experiment, the soils analyzed were sampled approximately once every two weeks, with additional sampling before and after manure application and other alteration events. The blocks were sampled down to 20cm with a 1.9cm diameter sampler. Soil samples were then air dried for a week and placed in a 60ºC oven for two days until dry. Within each block, there were four soil samples taken per plot, which were combined to form a composite sample for each plot. Therefore, there were 16 samples available per testing date in start 1, and soil samples from 18 different testing dates were extracted with $CaCl_2$ for this experiment.

The soil samples extracted using $CaCl_2$ were soils sampled on 8/16/07, 11/6/07, and all of the soils sampled between 4/4/08 and 10/6/08. The 8/16/07, 11/6/07, and early spring sampling dates were tested to establish an accurate baseline for P concentrations in the soil before the start of the WMEQP project, which started in the summer of 2008. The soil sampling dates tested stopped at 10/6/08 because the extraction procedures were initiated in the lab in October 2008. Generally, the purpose of analyzing the soils taken at these particular sampling dates was to obtain an accurate idea of how the new WMEQP treatments were affecting the amount of P vulnerable to subsurface drainage in the treatment plots.

The $CaCl_2$ extraction procedures used in this experiment are described by Self-Davis et al. (2000). All of the soils tested with the $CaCl_2$ extraction were from the first start, plots 1-8 and 11-18, of the WMEQP experiment. Approximately 2 grams of soil were added to 50 milliliters of a 0.01 molar $CaCl_2$ solution and vigorously shaken for 60 minutes using an electronic reciprocating shaker. Three "blank" samples (samples without soil to check the concentration of P in the extraction solution) were created per each 16 extraction samples. After shaking, these samples were refrigerated for approximately 48 hours. Samples were then inverted several times to homogenize the sample and filtered through Whatman 42 125mm filter paper until 20 to 30 milliliters of the sample were extracted. These samples were kept frozen until analysis. The remainder of the unfiltered sample was sieved (2 mm mesh) to extract any rocks present in the sample. Any rocks present were dried and weighed to provide a more accurate soil weight for data analysis.

The $CaCl_2$ extraction analysis was performed using seven 8 x 12 cell microplates, or 96 well plates, and a SpectraMax 190 microplate reader. For the analysis, a 0.05 ppm, 0.1 ppm, 0.2 ppm, 0.5 ppm, 1 ppm, 2 ppm, 4 ppm, 6 ppm, and 10 ppm P standard solution was created using anhydrous potassium phosphate monobasic (KH_2PO_4) and DI water. These standards were stored by refrigeration for use in each of the seven microplates. A Murphy-Riley stock solution and Murphy-Riley working solution were prepared fresh each day during the analysis, based on methods described by Murphy and Riley (1962).

In each of the seven microplates, the standards were plated out in triplicate and the samples were plated out singly by sample date. The samples were pipetted in a larger volume than the standards to amplify the low values into the detectable range of the spectrophotometer, and this alteration was accounted for when converting microplate data to final concentrations. The cells between each sample date were filled with the sample "blanks" and check standards of 0.2 ppm. Lastly, the Murphy-Riley working solution was pipetted into each of the occupied cells to make a total of 300 µL of liquid in each microplate cell.

After filling each cell, the microplates were mixed thoroughly by swirling the plate horizontally. The plates were then left for one hour to allow the color to develop. Then, each of the microplates were inserted into the SpectraMax 190 microplate reader and analyzed at a wavelength of 712 nm.

Other than the $CaCl_2$ extractable data, which is indicative of P vulnerable to subsurface drainage, this experiment analyzed P data extracted by Mehlich 3 extraction procedures. The purpose of testing the soil with Mehlich 3 extraction procedures was to discover what the plant available P was in each of the test plots sampled. The plant available P concentration is an excellent indicator of soils that represent an increased risk for P leaching losses and, as discussed above, P that leaches into the subsurface drainage may flow into freshwater lakes and streams. The correlation between Mehlich 3 extractions and an increased risk for P leaching losses was discussed by Maguire and Sims (2002).

The Agricultural Analytical Services Laboratory (AAS) conducted the Mehlich 3 extractions for this experiment. Soils samples that were tested with the Mehlich 3 extraction procedure were taken from a variety of plots at approximately one year intervals. The soil samples collected for this soil test method spanned sampling dates from 10/27/04 to 6/1/09, which included soil samples from the Transition project and both starts of the WMEQP project. These soil samples usually consisted of one to three subsamples per experimental plot. These soil samples were sent to the Agricultural Analytical Services Laboratory located at Penn State University, University Park, PA 16802. At AAS, the soil samples were analyzed for P using Mehlich 3 soil P testing procedures outlined by Wolf and Beegle (1995).

In this experiment, the $CaCl_2$ and Mehlich 3 soil testing procedures were the sole determinants of the difference in P leaching and drainage potential between experimental treatments. The Pennsylvania 'P Index' was consulted to rule out the necessity of testing the soil for surface runoff potential. The P Index is a field evaluation tool that was developed to identify areas of land that have a high risk of P loss via surface runoff to bodies of water. Part A of the index is a screening tool that asks four questions to determine whether more data is needed, which would require that Part B be completed. Completing Part B leads to a P Index value, which indicates (under 'Management Guidance") what actions the land manager should take to manage the area to control P runoff into surface water. For the WMEQP site, the screening tool indicated that continuing to Part B was not necessary. However, when Part B was completed, a P Index value of 26 was obtained. Both of these results indicated that the WMEQP site had a low potential for P loss via surface runoff. Thus, additional soil testing methods that were more indicative of P loss via surface runoff potential were not utilized

In order to calculate a P Index value for the WMEQP site, it was necessary to collect a great deal of data about the site and make several assumptions. In these calculations, the entire WMEQP site was evaluated as a whole, not on an individual plot basis, and in order to obtain the greatest estimate of runoff potential, the calculations were performed as if all of the plots were experiencing conventional tillage. In Table 1 a list of the data that was input into the P Index calculator and any corresponding assumptions made are shown. Figure 4 displays the P Index results for the WMEQP project.

Table 1. P Index value, justification, and corresponding assumptions for each section of the P Index.

Section of the Pennsylvania P Index	P Index Inputs & Justification	Assumptions
Source Factors: Soil Test	37.57 ppm; average of the most recent (6/1/09) Mehlich 3 soil test results for each of the plots.	The Mehlich 3 soil test P concentrations have not changed significantly since 6/1/09.
Fertilizer P Rate	0; no fertilizer was applied.	
Fertilizer Application Method	0; no fertilizer was applied.	
Manure P Rate	140.57 lbs P_2O_5/acre; 16.46 tons of manure per acre was applied, and manure tests indicated 8.54 pounds of P_2O_5 per ton of manure.	
Manure Application Method	0.6; the manure application methods utilized on this site have varied widely since 2003, so an average was used.	
P Source Coefficient	0.8; the manure used was bedded pack beef cattle manure.	
Transport Factors: Erosion	0.096 tons/acre/yr; the Revised Universal Soil Loss Equation (RUSLE) was used (directions and information found in Jarrett, 2008): A = RKLSCP R = 112 (based on location: Centre County, PA) K = 0.33 (based on soil: Hagerstown; corrected for region 111) LS = .13 (based on slope and length of slope) C = 0.02 (based on cropping factor) P = 1.0 (based on conservation practices; and there were no contour farming, strip cropping, terraces, or subsurface drainage practices implemented) A = RKLSCP = (112)(0.33)(.13)(.02)(1.0) = 0.096	For the LS value, it was assumed that each block was a perfect square (067 ha = 7,211.8 ft^2, so assumed block was 85 ft x 85 ft), and that the slope length is 4 blocks long, or 340 ft (the P Index was calculated as if the study site was one area of land, so the grassy borders between blocks were not included). Also assumed slope = 0.5% (based on estimate by Sara Eckert, Lab Technician). For the C value, it was assumed that cropping factor is just slightly above the cropping factor for planting a continuous meadow.
Runoff Potential	4; Hagerstown soil is well drained	
Subsurface Drainage	0; none.	
Contributing Distance	0; the nearest body of water is greater than 500 ft from the site.	
Modified Connectivity	1.0; none.	

PART A: SCREENING TOOL					**CMU/Field ID**	**WMEQP**
Is the CMU in a Special Protection watershed?					If the answer is Yes to <u>any</u> of these questions, Part B must be used.	**No**
Is there a significant farm management change as defined by Act 38?						**No**
Is the Soil Test Mehlich 3 P greater than 200 ppm P?						**37.57**
Is the Contributing Distance from this CMU to receiving water less than 150 ft.?						**No**
						N-based
PART B: SOURCE FACTORS					**CMU/Field ID**	**WMEQP**
SOIL TEST	Mehlich 3 Soil Test P (ppm P)					37.57
					Soil Test Rating = 0.20* Mehlich 3 Soil Test P (ppm P)	8
FERTILIZER P RATE	Fertilizer P (lb P_2O_5/acre)					0
	P Applied from multiple fertilizer applications, if any (From Multiple Applications Calculator)					0
FERTILIZER APPLICATION METHOD	0.2 Placed or injected 2" or more deep	0.4 Incorporated <1 week following application	0.6 Incorporated > 1 week or not incorporated following application in April - October	0.8 Incorporated >1 week or not incorporated following application in Nov. - March	1.0 Surface applied to frozen or snow covered soil	0
					Fertilizer Rating = Fertilizer Rate x Fertilizer Application Method	0
MANURE P RATE	Manure P (lb P_2O_5/acre)					140.57
	P Applied from multiple manure applications, if any (From Multiple Applications Calculator)					0
MANURE APPLICATION METHOD	0.2 Placed or injected 2" or more deep	0.4 Incorporated <1 week following application	0.6 Incorporated > 1 week or not incorporated following application in April - October	0.8 Incorporated >1 week or not incorporated following application in Nov. - March	1.0 Surface applied to frozen or snow covered soil	0.6
P SOURCE COEFFICIENT	Refer to: Test results for P Source Coefficient OR Book values from P Index Fact Sheet Table 1					0.8
					Manure Rating = Manure Rate x Manure Application Method x P Source Coefficient	67
					Source Factor Sum	75
PART B: TRANSPORT FACTORS					**CMU/Field ID**	**WMEQP**
EROSION	Soil Loss (ton/acre/yr)					0.096
RUNOFF POTENTIAL	0 *Drainage Class is* Excessively	2 *Drainage Class is* Somewhat Excessively	4 *Drainage Class is* Well/Moderately Well	6 *Drainage Class is* Somewhat Poorly	8 *Drainage Class is* Poorly/Very Poorly	4
SUBSURFACE DRAINAGE	0 None		1 Random		2 * Patterened	0
CONTRIBUTING DISTANCE	0 > 500 ft.	2 350 to 500 ft.	4 200 to 349 ft.	6 100 to 199 ft. OR < 100 ft. with 35 ft. buffer	9 ‡ < 100 ft.	0
					Transport Sum = Erosion + Runoff Potential + Subsurface Drainage + Contributing Distance	4
MODIFIED CONNECTIVITY	0.85 50 ft. Riparian Buffer APPLIES TO DIST < 100 FT		1.0 Grassed Waterway or None		1.1 Direct Connection APPLIES TO DIST > 100 FT	1.0
					Transport Sum x Modified Connectivity / 24	0.17
MANAGEMENT GUIDANCE:					**P Index Value = 2 x Source x Transport**	**26**
P Index Rating: Values	Nutrient Application Guidance					
Low: 59 or less	Nitrogen based management					
Medium: 60 to 79	Nitrogen based management					
High: 80 to 99	Phosphorus limited to crop removal					
Very High: 100 or greater	No Phosphorus applied					

Figure 4. Calculated P Index spreadsheet for the WMEQP project.

Data Analysis:

In the $CaCl_2$ extraction procedures, the microplate reader produced a value for each of the sample dates, blanks, and check standards that indicated the amount of P present in each well in ppm, or mg/L. This result was converted into mg P / kg soil by multiplying each value by a conversion factor of .30 (to account for the total volume of liquid in each microplate well and for several unit changes) and dividing by the grams of soil in each sample. The data was then sorted and an average P concentration per sampling date and treatment number was acquired. Those data were utilized in creating Figures 5 and 6.

In the Mehlich 3 data analysis, the AAS laboratory reported the initial data in ppm P, which is equivalent to mg P / kg soil. This data was manipulated like the $CaCl_2$ extractable data to yield Figure 7.

To determine whether or not any of treatments were significantly different from the others, a statistical analysis was performed. Before the analysis, both data sets were divided into relevant time periods. The $CaCl_2$ data were divided into those taken before and after the manure application to treatment 2, which occurred on 4/11/09. The Mehlich 3 data were divided into the Transition project and WMEQP project data. An average P concentration per plot number was found for each of the sets of data. To perform the statistical analysis, it was necessary to determine whether the data sets were parametric or nonparametric. To do this, a test for equal variance and a test of normal distribution were performed on each of the data sets, and all of the data sets were found to be parametric. Thus, a One-Way ANOVA test was run for each of the sets of data, and a Tukey's test for significance was performed on the data set that yielded a statistically significant result from the One-Way ANOVA test. Minitab Statistical Software was utilized to perform all of the statistical analyses for this experiment.

Results:

The mean $CaCl_2$ and Mehlich 3 P extraction concentrations and standard errors for each period of time are given in Table 2. In general, the average Mehlich 3 soil test P concentrations and standard errors were greater than the $CaCl_2$ soil test P concentrations.

Table 2. $CaCl_2$ and Mehlich 3 mean P concentration (±1 standard error) for each time period. The treatments are described in Figure 1.

Phosphorus Extraction Method		$CaCl_2$						Mehlich 3					
Data Set		Before Manure Application		After Manure Application		Grand Mean		Transition Data		WMEQP Data		Grand Mean	
Treatment Number & Average P Concentration in mg P / kg soil (standard error)	1	0.061	(0.022)	0.042	(0.008)	0.046	(0.013)	40.988	(5.075)	37.533	(3.359)	39.549	(4.483)
	2	0.034	(0.008)	0.053	(0.018)	0.049	(0.017)	41.583	(3.155)	42.000	(3.962)	41.757	(3.475)
	3	0.041	(0.006)	0.040	(0.009)	0.040	(0.009)	42.179	(4.130)	34.383	(2.484)	38.931	(4.008)
	4	0.050	(0.015)	0.037	(0.009)	0.040	(0.011)	42.976	(4.633)	38.010	(3.995)	40.907	(4.507)

A graph of the average $CaCl_2$ extractable P concentration for each treatment and soil sampling date with a ±1 standard error shown is given in Figure 5. Figure 6 is also a graph of the average $CaCl_2$ extractable P concentration for each treatment and sampling date with standard error, excluding data from the 8/16/07 and 11/6/07 soil sampling dates. This figure was intended to present a clearer view of the data from soil sampling dates 4/4/08 to 10/4/08. Figure 5 and 6 do not show any obvious outliers between the treatments; however, the figures do display a large peak in $CaCl_2$ extractable P concentration for treatments 1 and 2 at soil sampling dates 11/16/07 and 7/3/2008, respectively.

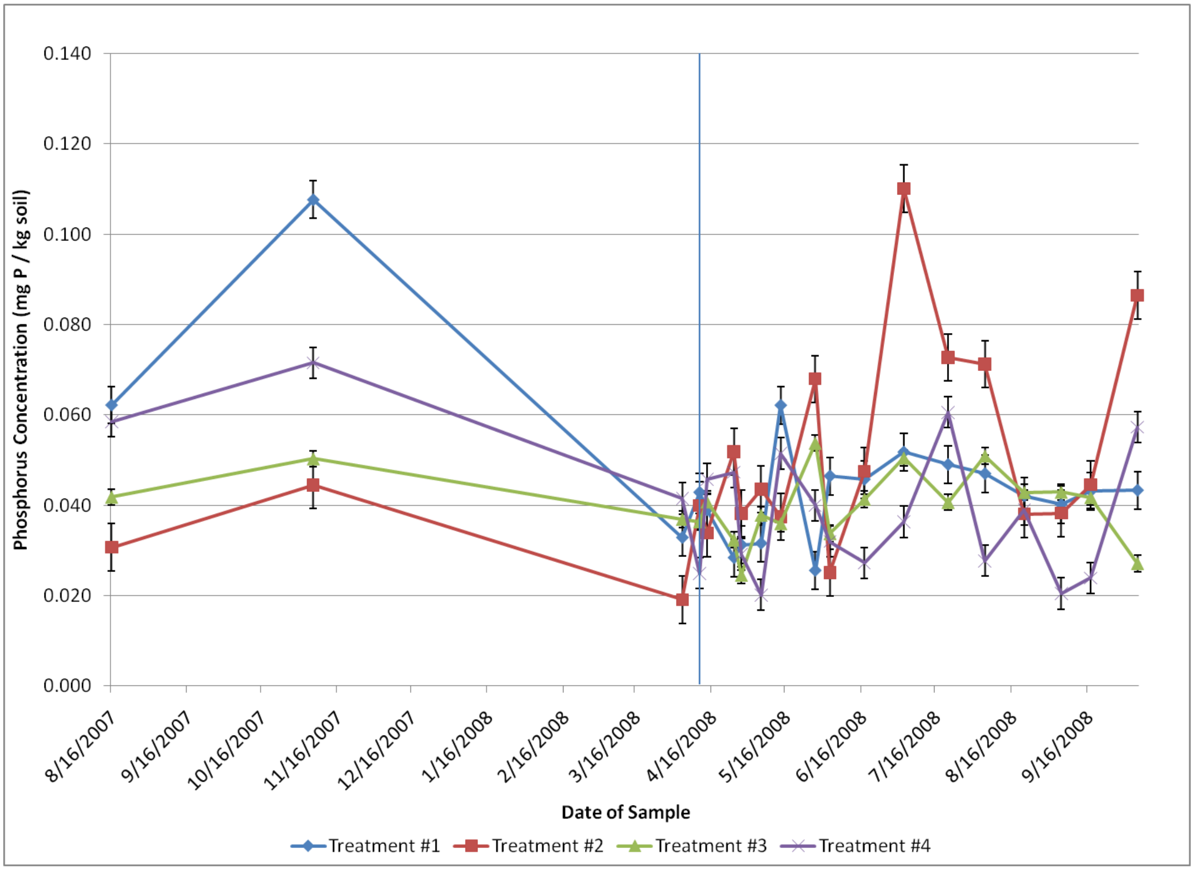

Figure 5. $CaCl_2$ extractable average P concentration (mg P / kg soil) for each treatment and sampling date with ±1 standard error and line delineating the manure application (4/11/08) shown. The treatments are described in Figure 1.

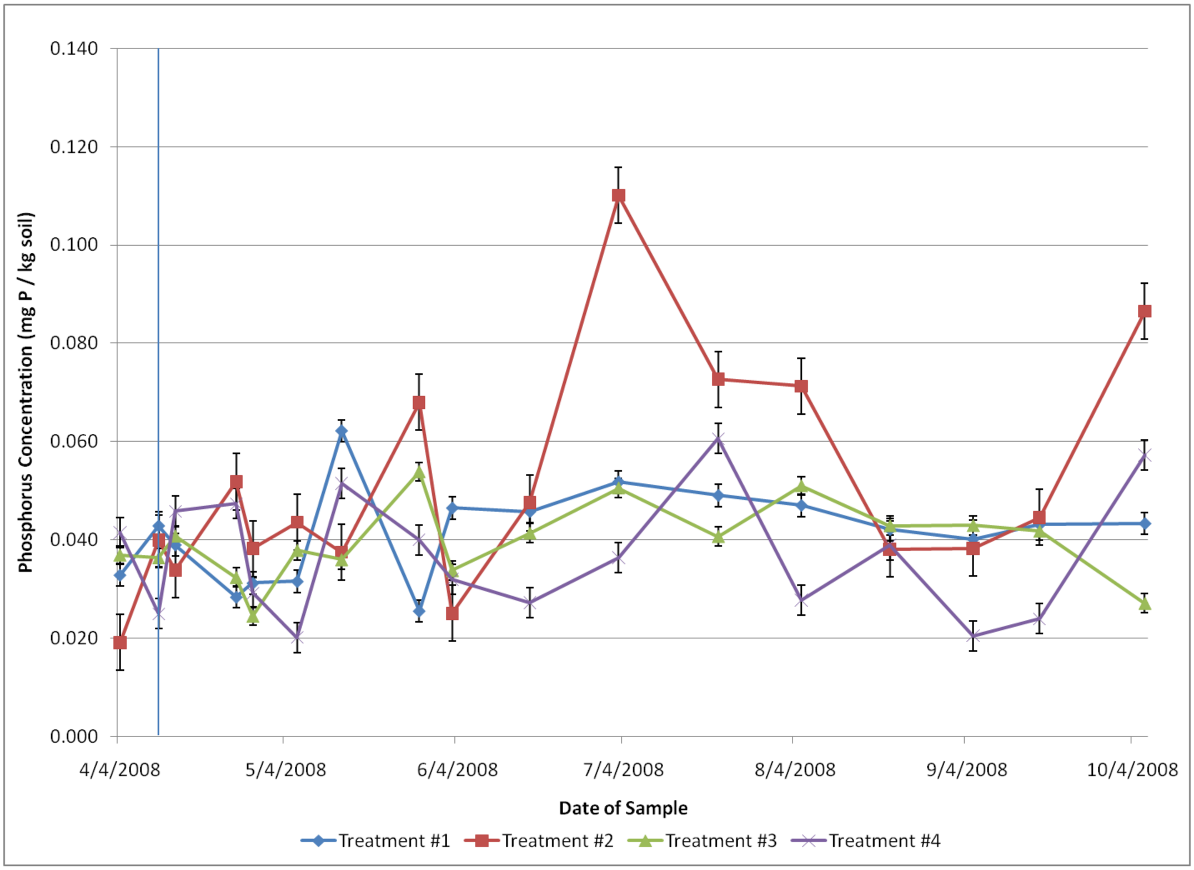

Figure 6. $CaCl_2$ extractable average P concentration (mg P / kg soil) for each treatment and the sampling dates from 4/4/08 to 10/4/08 with ±1 standard error and line delineating the manure application (4/11/08) shown. The treatments are described in Figure 1.

The results of the statistical analysis performed on the $CaCl_2$ extractable data for each time period of interest are given in Table 3. The time periods of interest include data collected before the manure application (4/11/08), after the manure application, and the complete duration of the data. Each of the data sets was found to be parametric in nature. The data set of soil samples collected after the manure application was the only data set to produce statistically significant results, and after a Tukey's Test was performed, it was determined that the data collected from treatment 2 was significantly different from the data collected from treatment 4 during that time interval. The significance of each treatment after manure application is indicated below, where different superscripts denote significantly different means:

Treatment 1^{ab}
Treatment 2^{a}
Treatment 3^{ab}
Treatment 4^{b}

Table 3. Synopsis of statistical tests performed on $CaCl_2$ extractable data for three time periods (before manure application, after manure application, and complete duration). The treatments are described in Figure 1.

Time Period	Parametric or Nonparametric	Statistical Test Performed (p-value)	Statistically Significant Results?	Further Tests and Results
Before Manure Application	Parametric	One-way ANOVA (0.142)	No	
After Manure Application	Parametric	One-way ANOVA (0.020)	Yes	Tukey's Test: Treatment 2 is significantly different from Treatment 4
Complete Duration	Parametric	One-way ANOVA (0.266)	No	

Figure 7 displays the results of the Mehlich 3 extraction procedures in P concentration over time. There is a clear delineation between the sampling dates that are considered to be associated with the Transition project and those considered to be associated with the WMEQP project. The data associated with each treatment seems to fluctuate in unison, and there are no apparent outliers among treatments.

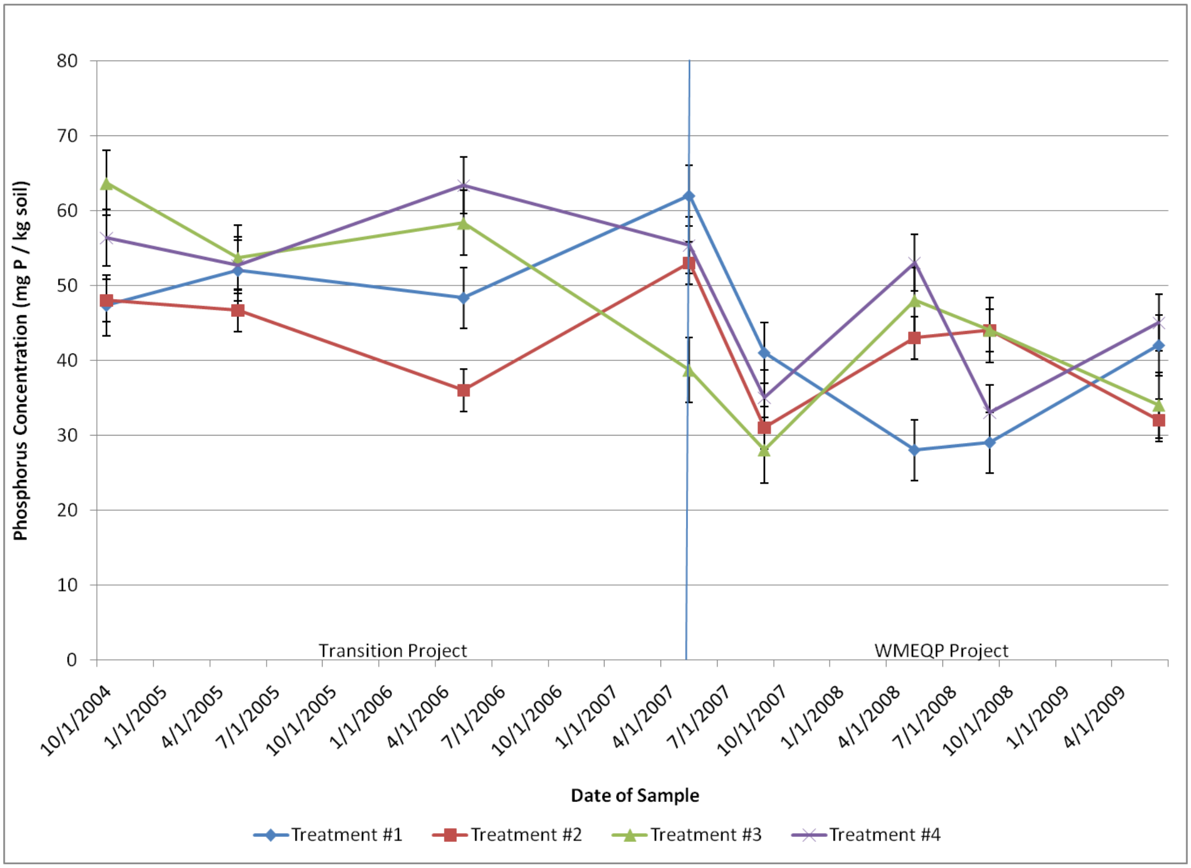

Figure 7. Mehlich 3 extractable average P concentration (mg P / kg soil) for each treatment and sampling date with ±1 standard error shown. The treatments are described in Figure 1.

The results of the statistical analysis performed on the Mehlich 3 extractable data for each time period of interest are given in Table 4. The time period of interests include data collected from the Transition project, the WMEQP project, and the complete duration of the data. Each of the data sets was found to be parametric in nature, and none of the data sets produced statistically significant results.

Table 4: Synopsis of statistical tests performed on Mehlich 3 extractable data for three time periods (Transition project, WMEQP project, and complete duration). The treatments are described in Figure 1.

Time Period	Parametric or Nonparametric	Statistical Test Performed (p-value)	Statistically Significant Results?
Transition Data	Parametric	One-way ANOVA (0.962)	No
WMEQP Data	Parametric	One-way ANOVA (0.077)	No
Complete Duration	Parametric	One-way ANOVA (0.849)	No

Discussion:

One of the goals of organic agriculture is to increase the sustainability of food production, and in order to accomplish this, organic farmers follow strict farming guidelines set by the USDA. One such guideline is that organic farmers may not apply synthetic fertilizers, which means that organic farmers must turn to other nutrient sources to fertilize their crops. Many organic farmers use animal manure as a fertilizer, yet studies have shown that surface application of manure can result in high P losses in runoff (Romkens et al., 1973; Mueller et al., 1984). Other studies conclude that a history of manure applications results in P accumulation in the soil, which could be vulnerable to runoff and leaching (Whalen & Chang, 2001; Toth et al., 2006). Therefore, nutrient management is an important concern in organic agriculture.

One of the goals of this thesis was to assess whether manure fertility leads to an increase in P loss potential from organic agriculture. Organic farmers utilize a variety of farming practices, so it was advantageous to utilize an experimental design that included plots with a variety of management histories. Despite a wide variation in management practices, none of the treatments in question were shown to be susceptible to a significantly different concentration of P vulnerable to subsurface drainage or leaching. After the manure application on treatment 2, the $CaCl_2$ extraction data showed that treatment 2 had a statistically significant difference in P that was vulnerable to subsurface drainage than treatment 4. However, these conclusions are not enough to make a claim that any of these treatments have more or less potential P runoff than the other treatments.

Since the manure application in treatment 2 did not significantly raise the concentration of P vulnerable to runoff compared to the other treatments, these results could imply that recent manure additions are not the main drivers of P loss potential, as some previous studies suggest (Romkens et al., 1973; Mueller et al., 1984). However, to make this conclusion, the P concentration in leachate from lysimeters and water extractable P concentration (WEP) would need to be measured in this experiment to identify more significant trends and the experiment would need to continue for several additional manure applications. The one-time application of manure in treatment 2 was not of sufficient magnitude or duration to support the theory that surface applications of manure can result in high P losses in runoff.

According to several studies, a history of manure application at a rate to meet plant N requirements will result in P accumulation in the soil, which could be subject to runoff (Whalen & Chang, 2001; Toth et al., 2006). In this study, all of the treatments had been subjected to identical manure application events over at least four years prior to the start of the WMEQP project (Figure 2), and the manure was applied to all of the treatments at application rates intended to meet the N needs of the crops. Since each of the treatments had an identical manure application history and thus, potential P buildup, this may explain why none of the treatments were significantly different from the others in terms of P vulnerable to subsurface drainage or plant available P during the time period explored. In one study that showed P accumulation in the soils, the average Mehlich 3 extractable P pre-treatment concentrations ranged from 64 to 76 mg/kg. After manure accumulation, the average Mehlich 3 extractable P concentration increased by as much as 40 mg/kg in some of the data (Toth et al., 2006). The Mehlich 3 extractable soil P concentrations found in this study, which was conducted under similar conditions, were much lower, ranging from about 35 to 45 mg/kg, which could indicate a lack of P accumulation in the soils. Furthermore, the average Mehlich 3 extractable P concentrations for this experiment decreased for the strong majority of plots as the experiment progressed. These results disagree with the findings by Whalen & Chang (2001) and Toth et al. (2006); however, the short-term nature of this study and limited manure applications preclude further speculation about the long-term potential for repeated manure applications leading to a build-up of soil P.

There have been several studies conducted on the affects of organic agriculture on soil P. Gosling and Shepherd (2004) conducted a study comparing soils managed organically for at least 15 years with soils under conventional management on four farms in England. They found that concentrations of extractable P were significantly lower in soils managed organically and surmised that P builds up in the soil during conventional management (Gosling & Shepherd, 2004). Therefore, organic practices deplete the amount of P in soil and changes to organic management practices that add P are required to maintain yields (Gosling & Shepherd, 2004). This conclusion, that the concentration of P in soil is decreased from organic practices, implies that the amount of P in runoff from these areas would also decrease. However, in a similar study where researchers assessed the accumulation or depletion of available P in an organic farming system compared to conventional practices, the researchers concluded that all of the study treatments still had an adequate level of available P after 21 years of trial. Furthermore, since the crops were grown on a low to moderately P sorbing soil, a soil P equilibrium was reached that allowed P concentrations to stay at a relatively constant level (Oehl et al., 2002). In this study, it was implied that the concentration of P in runoff remained constant when subject to organic practices. The difference between the conclusions for these studies may be due to the different methods, soils, crops produced, and rainfall between the studies. In the WMEQP experiment, the majority of the soil test P concentrations, from both the $CaCl_2$ extraction and the Mehlich 3 extraction, decreased with time. Therefore, the preliminary findings of this study support the findings of Gosling and Shepherd (2004); however, more time would be needed to see if the same results were found after 15 or 21 years.

Several comparisons can be made between the data collected in this study and data collected in other studies. Within this study, the average Mehlich 3 soil test P concentrations were greater than the $CaCl_2$ soil test P concentrations (Table 2). The $CaCl_2$ extraction procedure measures P vulnerable to subsurface drainage, which is the concentration of P dissolved in the soil solution called dissolved reactive P (Mcdowell & Sharpley, 2001). The Mehlich 3 P test, however, measures plant available P, which is the P in solution and the P in inorganic phosphate form bonded to soil particles (Maguire and Sims, 2002). Therefore, it makes sense that the Mehlich 3 P extraction procedures yielded higher P concentrations than the $CaCl_2$ extraction procedures.

When making comparisons between these Mehlich 3 soil test P concentration data and concentrations found in similar studies, it is clear that the soils in this experiment have much lower amounts of P subject to leaching than other studies. For example, Volf et al. (2007) conducted a study to explore the effects of manure rate and incorporation on P losses. They found that pre-treatment Mehlich 3 P concentrations ranged from 92 to 108 ppm and pos-treatment concentrations ranged from 107 to 395 ppm when manure was surface applied on Lacombe soil (Volf et al. 2007). In another example, mentioned above, the average Mehlich 3 extractable P concentrations ranged from 64 to 76 mg/kg pre-treatment, and after manure applications, some of the extractable P concentrations had risen by as much as 40 mg/kg (Toth et al., 2006). The Mehlich 3 extractable soil P concentrations found in this study, which was conducted under similar conditions, range from about 35 to 45 mg/kg. The $CaCl_2$ extractable soil P concentration was also lower in this experiment compared to other research. In an experiment by McDowell and Sharpley (2001), researchers used CaCl2 to measure the potential P concentration in subsurface drainage on soils in southeastern Pennsylvania, which had received different fertilizer and swine manure inputs over the last 10 to 15 years (McDowell & Sharpley, 2001). The average $CaCl_2$ extractable P concentrations for this experiment were between 0.37 and 1.23 mg/L (McDowell & Sharpley, 2001). In the WMEQP project, the average $CaCl_2$ extractable P concentrations were at least 7-8 times lower, between 0.040 and 0.049 mg/kg. Therefore, both the Mehlich 3 and $CaCl_2$ extractable P concentration was lower in this experiment than similar experiments in the literature.

Despite the variability in the treatment plans and manure application rates for the WMEQP project, the experiment did not indicate an increase of P runoff after manure application, did not indicate that a history of manure application to meet crop N needs resulted in a build-up of soil test P, and the concentrations of Mehlich 3 and $CaCl_2$ extractable P were lower in this experiment than in several others with similar parameters. These results indicate that, while organic farmers have more complex nutrient management options than conventional farms, sustainable P management can be achieved in a diverse set of organic systems, and organic agriculture does not necessarily increase soil P to levels that generate pollution concern. Although more research is needed to confirm these findings, this is an important first step in abating the nutrient management concerns of organic farmers.

Bibliography:

Carpenter, S., Caraco, N. F., Correll, D. L., Howarth, R. W., Sharpley, A. N., & Smith, V. H. (1998). Nonpoint pollution of surface waters with phosphorus and nitrogen. *Issues In Ecology*, *3*, 1-14.

Conley, D., Björck, S., Bonsdorff, E., Carstensen, J., Destouni, G., Gustafsson, B., et al (2009). Hypoxia-related processes in the Baltic Sea. *Environmental Science & Technology*, *43*(10), 3412-20.

Gosling, P., & Shepherd, M. (2005). Long-term changes in soil fertility in organic arable farming systems in England, with particular reference to phosphorus and potassium. *Agriculture, Ecosystems & Environment*, *105*(1-2), 425-432.

Jarrett, A. (2008). *Effectively Managing Water*. University Park: The Pennsylvania State University.

Maguire, R. O., & Sims, J. T. (2002). Measuring agronomic and environmental soil phosphorus saturation and predicting phosphorus leaching with Mehlich 3. *Soil Science Society of America*, *66*, 2033-2039.

McDowell, R., & Sharpley, A. (2001). Approximating phosphorus release from soils to surface runoff and subsurface drainage. *Journal of Environmental Quality*, *30*, 508-520.

Mueller, D. H., Wendt, R. C., & Daniel, T. C. (1984). Phosphorus losses as affected by tillage and manure application. *Soil Science Society of America*, *48*, 901-905.

Murphy, J., & Riley, J. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, *27*, 31-36.

Self-Davis M.L., Moore P.A., Jr., Joern B.C.. 2000. Determination of water- and/or dilute salt extractable phosphorus. *In Methods of Phosphorus Analysis for Soils, Sediments, Residuals, and Waters, ed. Pierzynski G.M.*. Southern Cooperative Series Bulletin No. # 396. http://www.sera17.ext.vt.edu/Documents/Methods_of_P_Analysis_2000.pdf.

Sharpley, A., Daniel, T., Sims, T., Lemunyon, J., Stevens, R., & Parry, R. (2003). *Agricultural Phosphorus and Eutrophication*. United States Department of Agriculture, Agricultural Research Service, ARS-149.

Toth, J. D., Dou, Z., Ferguson, J. D., Galligan, D. T., & Ramberg, C. F. (2006). Nitrogen- vs. phosphorus-based dairy manure applications to field crops: nitrate and phosphorus leaching and soil phosphorus accumulation . *Journal of Environmental Quality*, *35*, 2302-2312.

Volf, C., Ontkean, G., Bennett, D., Chanasyk, D., & Miller, J. (2007). Phosphorus losses in simulated rainfall runoff from manured soils of Alberta. *Journal of Environmental Quality*, *36*(3), 730-41.

Whalen, J., & Chang, C. (2001). Phosphorus accumulation in cultivated soils from long-term annual applications of cattle feedlot manure. *Journal of Environmental Quality*, *30*(1), 229-37.

Wolf, A., & Beegle, D. (2009). Chapter 5: Recommended Soil Tests for Macro and Micronutrients and Cation Exchange Capacity by Summations . *Recommended Soil Testing Procedures for the Northeastern United States* (pp. 41-42). Northeastern Regional Publication No. 493.

Appendix A: Phosphorus Concentration by Calcium Chloride Extraction

Sampling Date	Plot Number	Treatment Number	Phosphorus Concentration (mg P / kg soil)	Average Phosphorus Concentration (mg P / kg soil) by Date
8/16/2007	2	1	0.051	
8/16/2007	4	1	0.043	
8/16/2007	8	1	0.071	
8/16/2007	16	1	0.083	0.062
11/6/2007	2	1	0.104	
11/6/2007	4	1	0.079	
11/6/2007	8	1	0.205	
11/6/2007	16	1	0.043	0.108
4/4/2008	2	1	0.046	
4/4/2008	4	1	0.027	
4/4/2008	8	1	0.036	
4/4/2008	16	1	0.023	0.033
4/11/2008	2	1	0.067	
4/11/2008	4	1	0.040	
4/11/2008	8	1	0.035	
4/11/2008	16	1	0.029	0.043
4/14/2008	2	1	0.041	
4/14/2008	4	1	0.043	
4/14/2008	8	1	0.044	
4/14/2008	16	1	0.027	0.039
4/25/2008	2	1	0.026	
4/25/2008	4	1	0.031	
4/25/2008	8	1	0.033	
4/25/2008	16	1	0.023	0.028
4/28/2008	2	1	0.022	
4/28/2008	4	1	0.032	
4/28/2008	8	1	0.037	
4/28/2008	16	1	0.033	0.031
5/6/2008	2	1	0.036	
5/6/2008	4	1	0.025	
5/6/2008	8	1	0.026	
5/6/2008	16	1	0.040	0.032
5/14/2008	2	1	0.081	
5/14/2008	4	1	0.054	
5/14/2008	8	1	0.075	
5/14/2008	16	1	0.039	0.062
5/28/2008	2	1	0.016	
5/28/2008	4	1	0.051	

5/28/2008	8	1	0.023	
5/28/2008	16	1	0.013	0.026
6/3/2008	2	1	0.029	
6/3/2008	4	1	0.034	
6/3/2008	8	1	0.066	
6/3/2008	16	1	0.056	0.046
6/17/2008	2	1	0.059	
6/17/2008	4	1	0.048	
6/17/2008	8	1	0.040	
6/17/2008	16	1	0.036	0.046
7/3/2008	2	1	0.051	
7/3/2008	4	1	0.036	
7/3/2008	8	1	0.092	
7/3/2008	16	1	0.028	0.052
7/21/2008	2	1	0.047	
7/21/2008	4	1	0.038	
7/21/2008	8	1	0.032	
7/21/2008	16	1	0.080	0.049
8/5/2008	2	1	0.069	
8/5/2008	4	1	0.044	
8/5/2008	8	1	0.042	
8/5/2008	16	1	0.033	0.047
8/21/2008	2	1	0.049	
8/21/2008	4	1	0.045	
8/21/2008	8	1	0.036	
8/21/2008	16	1	0.038	0.042
9/5/2008	2	1	0.051	
9/5/2008	4	1	0.049	
9/5/2008	8	1	0.042	
9/5/2008	16	1	0.020	0.040
9/17/2008	2	1	0.082	
9/17/2008	4	1	0.030	
9/17/2008	8	1	0.034	
9/17/2008	16	1	0.027	0.043
10/6/2008	2	1	0.059	
10/6/2008	4	1	0.042	
10/6/2008	8	1	0.041	
10/6/2008	16	1	0.031	0.043
8/16/2007	1	2	0.030	
8/16/2007	5	2	0.030	
8/16/2007	13	2	0.027	
8/16/2007	17	2	0.036	0.031
11/6/2007	1	2	0.068	

11/6/2007	5	2	0.039	
11/6/2007	13	2	0.035	
11/6/2007	17	2	0.036	0.044
4/4/2008	1	2	0.039	
4/4/2008	5	2	0.015	
4/4/2008	13	2	0.004	
4/4/2008	17	2	0.018	0.019
4/11/2008	1	2	0.051	
4/11/2008	5	2	0.020	
4/11/2008	13	2	0.036	
4/11/2008	17	2	0.053	0.040
4/14/2008	1	2	0.024	
4/14/2008	5	2	0.020	
4/14/2008	13	2	0.060	
4/14/2008	17	2	0.031	0.034
4/25/2008	1	2	0.101	
4/25/2008	5	2	0.020	
4/25/2008	13	2	0.043	
4/25/2008	17	2	0.043	0.052
4/28/2008	1	2	0.058	
4/28/2008	5	2	0.045	
4/28/2008	13	2	0.026	
4/28/2008	17	2	0.025	0.038
5/6/2008	1	2	0.045	
5/6/2008	5	2	0.026	
5/6/2008	13	2	0.077	
5/6/2008	17	2	0.026	0.044
5/14/2008	1	2	0.063	
5/14/2008	5	2	0.048	
5/14/2008	13	2	0.027	
5/14/2008	17	2	0.013	0.037
5/28/2008	1	2	0.033	
5/28/2008	5	2	0.022	
5/28/2008	13	2	0.102	
5/28/2008	17	2	0.115	0.068
6/3/2008	1	2	0.002	
6/3/2008	5	2	0.044	
6/3/2008	13	2	0.032	
6/3/2008	17	2	0.022	0.025
6/17/2008	1	2	0.050	
6/17/2008	5	2	0.029	
6/17/2008	13	2	0.028	
6/17/2008	17	2	0.084	0.048

7/3/2008	1	2	0.073	
7/3/2008	5	2	0.111	
7/3/2008	13	2	0.044	
7/3/2008	17	2	0.212	0.110
7/21/2008	1	2	0.083	
7/21/2008	5	2	0.061	
7/21/2008	13	2	0.075	0.073
8/5/2008	1	2	0.062	
8/5/2008	5	2	0.035	
8/5/2008	13	2	0.061	
8/5/2008	17	2	0.127	0.071
8/21/2008	1	2	0.042	
8/21/2008	5	2	0.022	
8/21/2008	13	2	0.048	
8/21/2008	17	2	0.040	0.038
9/5/2008	1	2	0.048	
9/5/2008	5	2	0.024	
9/5/2008	13	2	0.037	
9/5/2008	17	2	0.043	0.038
9/17/2008	1	2	0.045	
9/17/2008	5	2	0.017	
9/17/2008	13	2	0.069	
9/17/2008	17	2	0.048	0.045
10/6/2008	1	2	0.147	
10/6/2008	5	2	0.052	
10/6/2008	13	2	0.089	
10/6/2008	17	2	0.057	0.086
8/16/2007	6	3	0.028	
8/16/2007	12	3	0.039	
8/16/2007	14	3	0.058	
8/16/2007	18	3	0.042	0.042
11/6/2007	6	3	0.054	
11/6/2007	12	3	0.038	
11/6/2007	14	3	0.041	
11/6/2007	18	3	0.068	0.050
4/4/2008	6	3	0.023	
4/4/2008	12	3	0.059	
4/4/2008	14	3	0.026	
4/4/2008	18	3	0.039	0.037
4/11/2008	6	3	0.038	
4/11/2008	12	3	0.037	
4/11/2008	14	3	0.031	
4/11/2008	18	3	0.040	0.036

4/14/2008	6	3	0.030	
4/14/2008	12	3	0.042	
4/14/2008	14	3	0.063	
4/14/2008	18	3	0.029	0.041
4/25/2008	6	3	0.026	
4/25/2008	12	3	0.044	
4/25/2008	14	3	0.030	
4/25/2008	18	3	0.030	0.032
4/28/2008	6	3	0.024	
4/28/2008	12	3	0.023	
4/28/2008	14	3	0.035	
4/28/2008	18	3	0.016	0.025
5/6/2008	6	3	0.035	
5/6/2008	12	3	0.016	
5/6/2008	14	3	0.026	
5/6/2008	18	3	0.075	0.038
5/14/2008	6	3	0.046	
5/14/2008	12	3	0.029	
5/14/2008	14	3	0.031	
5/14/2008	18	3	0.037	0.036
5/28/2008	6	3	0.092	
5/28/2008	12	3	0.053	
5/28/2008	14	3	0.029	
5/28/2008	18	3	0.040	0.054
6/3/2008	6	3	0.037	
6/3/2008	12	3	0.055	
6/3/2008	14	3	0.024	
6/3/2008	18	3	0.020	0.034
6/17/2008	6	3	0.020	
6/17/2008	12	3	0.072	
6/17/2008	14	3	0.035	
6/17/2008	18	3	0.039	0.041
7/3/2008	6	3	0.071	
7/3/2008	12	3	0.041	
7/3/2008	14	3	0.047	
7/3/2008	18	3	0.043	0.051
7/21/2008	6	3	0.016	
7/21/2008	12	3	0.058	
7/21/2008	18	3	0.048	0.041
8/5/2008	6	3	0.028	
8/5/2008	12	3	0.035	
8/5/2008	14	3	0.040	
8/5/2008	18	3	0.101	0.051

8/21/2008	6	3	0.026	
8/21/2008	12	3	0.058	
8/21/2008	14	3	0.041	
8/21/2008	18	3	0.047	0.043
9/5/2008	6	3	0.026	
9/5/2008	12	3	0.037	
9/5/2008	14	3	0.055	
9/5/2008	18	3	0.054	0.043
9/17/2008	6	3	0.018	
9/17/2008	12	3	0.027	
9/17/2008	14	3	0.052	
9/17/2008	18	3	0.070	0.042
10/6/2008	6	3	0.042	
10/6/2008	12	3	0.024	
10/6/2008	14	3	0.027	
10/6/2008	18	3	0.015	0.027
8/16/2007	3	4	0.031	
8/16/2007	7	4	0.100	
8/16/2007	11	4	0.079	
8/16/2007	15	4	0.024	0.059
11/6/2007	3	4	0.071	
11/6/2007	7	4	0.110	
11/6/2007	11	4	0.073	
11/6/2007	15	4	0.033	0.072
4/4/2008	3	4	0.028	
4/4/2008	7	4	0.058	
4/4/2008	15	4	0.038	0.041
4/11/2008	3	4	0.023	
4/11/2008	7	4	0.047	
4/11/2008	11	4	0.021	
4/11/2008	15	4	0.008	0.025
4/14/2008	3	4	0.023	
4/14/2008	7	4	0.054	
4/14/2008	11	4	0.033	
4/14/2008	15	4	0.074	0.046
4/25/2008	3	4	0.035	
4/25/2008	7	4	0.056	
4/25/2008	11	4	0.064	
4/25/2008	15	4	0.035	0.047
4/28/2008	3	4	0.022	
4/28/2008	7	4	0.026	
4/28/2008	11	4	0.039	
4/28/2008	15	4	0.030	0.029

5/6/2008	3	4	0.022	
5/6/2008	7	4	0.019	
5/6/2008	11	4	0.022	
5/6/2008	15	4	0.018	0.020
5/14/2008	3	4	0.034	
5/14/2008	7	4	0.081	
5/14/2008	11	4	0.074	
5/14/2008	15	4	0.017	0.051
5/28/2008	3	4	0.060	
5/28/2008	7	4	0.045	
5/28/2008	11	4	0.014	
5/28/2008	15	4	0.040	0.040
6/3/2008	3	4	0.027	
6/3/2008	7	4	0.035	
6/3/2008	11	4	0.031	
6/3/2008	15	4	0.035	0.032
6/17/2008	3	4	0.027	
6/17/2008	7	4	0.025	
6/17/2008	11	4	0.032	
6/17/2008	15	4	0.025	0.027
7/3/2008	3	4	0.046	
7/3/2008	7	4	0.048	
7/3/2008	11	4	0.019	
7/3/2008	15	4	0.032	0.036
7/21/2008	3	4	0.063	
7/21/2008	7	4	0.059	
7/21/2008	11	4	0.058	
7/21/2008	15	4	0.062	0.061
8/5/2008	3	4	0.022	
8/5/2008	7	4	0.041	
8/5/2008	11	4	0.035	
8/5/2008	15	4	0.013	0.028
8/21/2008	3	4	0.041	
8/21/2008	7	4	0.028	
8/21/2008	11	4	0.049	
8/21/2008	15	4	0.038	0.039
9/5/2008	3	4	0.025	
9/5/2008	7	4	0.024	
9/5/2008	11	4	0.022	
9/5/2008	15	4	0.011	0.020
9/17/2008	3	4	0.025	
9/17/2008	7	4	0.038	
9/17/2008	11	4	0.017	

9/17/2008	15	4	0.016	0.024
10/6/2008	3	4	0.070	
10/6/2008	7	4	0.057	
10/6/2008	11	4	0.042	
10/6/2008	15	4	0.059	0.057

Appendix B: Phosphorus Concentration by Mehlich 3 Extraction

Sampling Date	Plot Number	Treatment Number	Phosphorus Concentration (mg P / kg soil)
10/27/2004	21	1	42
10/27/2004	27	1	29
10/27/2004	34	1	28
10/27/2004	36	1	41
5/16/2005	2	1	62
5/16/2005	4	1	48
5/16/2005	8	1	52
5/16/2005	16	1	47
5/16/2005	21	1	36
5/16/2005	27	1	36
5/16/2005	34	1	34
5/16/2005	36	1	33
5/22/2006	2	1	63
5/22/2006	4	1	41
5/22/2006	8	1	50
5/22/2006	16	1	51
5/22/2006	21	1	42
5/22/2006	27	1	38
5/22/2006	34	1	42
5/22/2006	36	1	35
5/23/2007	2	1	52
5/23/2007	4	1	42
5/23/2007	8	1	43
5/23/2007	16	1	44
5/23/2007	21	1	39
5/23/2007	27	1	32
5/23/2007	34	1	23
5/23/2007	36	1	21
9/4/2007	2	1	54
9/4/2007	4	1	46
9/4/2007	8	1	43
9/4/2007	16	1	38
5/27/2008	21	1	44
5/27/2008	27	1	30
5/27/2008	34	1	35
5/27/2008	36	1	33
9/11/2008	21	1	39
9/11/2008	27	1	30
9/11/2008	34	1	31

9/11/2008	36	1	32
6/1/2009	2	1	47
6/1/2009	4	1	36
6/1/2009	8	1	37
6/1/2009	16	1	32
6/1/2009	21	1	37
6/1/2009	27	1	43
6/1/2009	34	1	34
6/1/2009	36	1	29
10/27/2004	24	2	32
10/27/2004	25	2	44
10/27/2004	28	2	43
10/27/2004	32	2	31
5/16/2005	1	2	53
5/16/2005	5	2	36
5/16/2005	13	2	47
5/16/2005	17	2	48
5/16/2005	24	2	37
5/16/2005	25	2	44
5/16/2005	28	2	39
5/16/2005	32	2	35
5/22/2006	1	2	49
5/22/2006	5	2	43
5/22/2006	13	2	49
5/22/2006	17	2	47
5/22/2006	24	2	39
5/22/2006	25	2	54
5/22/2006	28	2	36
5/22/2006	32	2	41
5/23/2007	1	2	45
5/23/2007	5	2	36
5/23/2007	13	2	40
5/23/2007	17	2	35
5/23/2007	24	2	39
5/23/2007	25	2	49
5/23/2007	28	2	40
5/23/2007	32	2	34
9/4/2007	1	2	45
9/4/2007	5	2	35
9/4/2007	13	2	45
9/4/2007	17	2	40
5/27/2008	24	2	37
5/27/2008	25	2	48

5/27/2008	28	2	38
5/27/2008	32	2	39
9/11/2008	24	2	33
9/11/2008	25	2	44
9/11/2008	28	2	34
9/11/2008	32	2	29
6/1/2009	1	2	56
6/1/2009	5	2	39
6/1/2009	13	2	41
6/1/2009	17	2	39
6/1/2009	24	2	38
6/1/2009	25	2	60
6/1/2009	28	2	53
6/1/2009	32	2	47
10/27/2004	26	3	34
10/27/2004	31	3	44
10/27/2004	33	3	48
10/27/2004	37	3	28
5/16/2005	6	3	39
5/16/2005	12	3	58
5/16/2005	14	3	54
5/16/2005	18	3	64
5/16/2005	26	3	44
5/16/2005	31	3	39
5/16/2005	33	3	43
5/16/2005	37	3	41
5/22/2006	6	3	39
5/22/2006	12	3	50
5/22/2006	14	3	55
5/22/2006	18	3	46
5/22/2006	26	3	40
5/22/2006	31	3	33
5/22/2006	33	3	35
5/22/2006	37	3	36
5/23/2007	6	3	38
5/23/2007	12	3	45
5/23/2007	14	3	45
5/23/2007	18	3	40
5/23/2007	26	3	42
5/23/2007	31	3	34
5/23/2007	33	3	34
5/23/2007	37	3	35
9/4/2007	6	3	31

9/4/2007	12	3	36
9/4/2007	14	3	43
9/4/2007	18	3	38
5/27/2008	26	3	35
5/27/2008	31	3	34
5/27/2008	33	3	39
5/27/2008	37	3	29
9/11/2008	26	3	36
9/11/2008	31	3	32
9/11/2008	33	3	37
9/11/2008	37	3	28
6/1/2009	6	3	25
6/1/2009	12	3	31
6/1/2009	14	3	35
6/1/2009	18	3	35
6/1/2009	26	3	42
6/1/2009	31	3	35
6/1/2009	33	3	40
6/1/2009	37	3	26
10/27/2004	22	4	45
10/27/2004	23	4	33
10/27/2004	35	4	53
10/27/2004	38	4	35
5/16/2005	3	4	55
5/16/2005	7	4	63
5/16/2005	11	4	53
5/16/2005	15	4	56
5/16/2005	22	4	48
5/16/2005	23	4	41
5/16/2005	35	4	56
5/16/2005	38	4	39
5/22/2006	3	4	47
5/22/2006	7	4	51
5/22/2006	11	4	47
5/22/2006	15	4	42
5/22/2006	22	4	39
5/22/2006	23	4	30
5/22/2006	35	4	47
5/22/2006	38	4	31
5/23/2007	3	4	40
5/23/2007	7	4	43
5/23/2007	11	4	42
5/23/2007	15	4	36

5/23/2007	22	4	39
5/23/2007	23	4	31
5/23/2007	35	4	33
5/23/2007	38	4	28
9/4/2007	3	4	44
9/4/2007	7	4	55
9/4/2007	11	4	46
9/4/2007	15	4	35
5/27/2008	22	4	43
5/27/2008	23	4	34
5/27/2008	35	4	50
5/27/2008	38	4	43
9/11/2008	22	4	42
9/11/2008	23	4	32
9/11/2008	35	4	41
9/11/2008	38	4	31
6/1/2009	3	4	28
6/1/2009	7	4	46
6/1/2009	11	4	32
6/1/2009	15	4	38
6/1/2009	22	4	32
6/1/2009	23	4	27
6/1/2009	35	4	33
6/1/2009	38	4	27

ACADEMIC VITA
LAUREN KATHERINE SEILER

EDUCATION

The Pennsylvania State University, Schreyer Honors College University Park, PA
Aug 2005 to Dec 2009
B.S. in Environmental Resource Management
B.S. in Agricultural and Extension Education, Environmental Science Option

WORK EXPERIENCE

USDA, Agricultural Research Service State College, PA
Research Assistant - May 2009 to Present

- Work at Pasture Systems and Watershed Management Research Unit.
- Responsible for sampling in the field, processing samples, data collection, and data manipulation for a variety of experiments pertaining to pasture systems.

The Center for ReSource Conservation Boulder, CO
Irrigation Inspector - Jun 2008 to Aug 2008

- Conducted residential and business irrigation inspections to assist residents in improving the efficiency of their irrigation systems, saving water, and saving money.
- Assisted with scheduling appointments, data entry, customer service, and other office duties.
- Received training and certification (*Seal of Knowledge*) in GreenCO's "Best Management Practices for the Conservation and Protection of Water Resources in Colorado."

The Pennsylvania State University, Dept of Crop and Soil Sciences State College, PA
Undergraduate Researcher - Jan 2008 to Dec 2008

- Performed soil extractions, extraction analyses, and analyzed data to explore the effects of organic agriculture techniques on soil phosphorus movement for my honors thesis.
- Responsible for assisting graduate students with various research-related tasks (e.g. soil sample processing) and laboratory maintenance.

The State of New Jersey, Washington Crossing State Park Titusville, NJ
Intern - May 2007 to Aug 2007

- Independently created and instructed environmental education programs and assisted supervisor with instructing programs for school students, summer camp groups, girl and boy scout groups, clubs, and the general public.
- Responsible for assisting visitors (e.g. sharing information about exhibits, answering questions, etc), caring for live exhibits (e.g. feeding and maintaining deer, turtles, fish, etc), and maintaining the trails and facilities.

The Pennsylvania State University, Department of Entomology State College, PA
Research Assistant - Nov 2006 to Dec 2008

- Responsible for assisting graduate students with various experiments involving plants and insects. Duties included maintaining and propagating *Microplitis croceipes* and *Toxoneuron nigriceps* parasitoid wasp populations, planting and maintaining a variety of plants, processing samples, and maintaining laboratory facilities.

Hill Environmental Consultants Pennington, NJ
Intern - May 2006 to Aug 2006

- Performed sampling in the field, helped construct Phase I and Phase II environmental reports (e.g. researching, writing different sections, analyzing data), and performed various administrative responsibilities (e.g. assisting customers).
- Received training and certification in OSHA Hazardous Waste Operations and Emergency Response (HAZWOPER), 29 CFR 1910.120.

HJG Medical Associates Hopewell, NJ
Receptionist - Jun 2005 to Aug 2005

- Responsible for answering the phones, making appointments, producing medical records, and assisting patients with check in and check out.

ACTIVITIES

- Vice President, The Penn State Environmental Society (2 terms; 2007 - 2008)
- Treasurer, The Penn State Environmental Society (2006)
- The Penn State Environmental Society (2005 - 2009)
- Gamma Sigma Delta Honor Society (2007 - Present)
- Golden Key International Honour Society (2007 - Present)
- Phi Kappa Phi Honor Society (2008 - Present)

HONORS

- Hopewell Valley Testamur Scholar (2005)
- The Mae K. Burd Memorial Scholarship (2005)
- The Cory Golis/Anchor House Scholarship (2005)
- Study Abroad Scholarship (2007)
- Harbaugh Scholarship in Agricultural Sciences (2007)
- Rumbaugh Agricultural Leadership Award (2007)
- Horace T. Woodward Scholarship (2007)
- Soil and Water Conservation Society Keystone Chapter Scholarship (2008)
- Oswald Scholarship (2008)
- Angstadt Family Agriculture Scholarship (2009)
- Dean’s List, 8 semesters