St. Olaf College

Local Ecology Research Papers

Effects of Hog Manure Fertilizer on Nutrients, Soil Properties, and E. coli Presence in Agriculture Fields in Corn Production in Northfield, Minnesota, U.S.A.

Mitchell, David
2009

Effects of Hog Manure Fertilizer on Nutrients, Soil Properties, and *E. coli* Presence in Agricultural Fields in Corn Production in Northfield, Minnesota, U.S.A.

David C. Mitchell
St. Olaf College
Biology 371
Prof. Kathy Shea, advisor
December 16, 2009

ABSTRACT

Use of hog manure as agricultural fertilizer provides a substitute for synthetic fertilizer and disposes of animal waste. However, hog manure may cause pollution by adding excessive nutrients to the soil and introduce *E. coli* bacteria. In this study, soil nutrient content and composition, soil *E. coli* presence, cornstalk nitrate concentration, and yield and return data were compared between three sections of a cornfield on the property of St. Olaf College, Northfield, MN, U.S.A. The three sections of the field had been treated with 7,000 gallons/acre (Field 1), 1500 gallons/acre (Field 2), and 0 gallons/acre (Field 3) of hog manure fertilizer. Soil nitrate concentration was greatest in Field 1 and lowest in the Field 3 ($P = 0.0137$). Soil phosphate concentration was greatest in Field 1 ($P = 0.0000$) and inconsistent in Fields 2 and 3 between months of soil collection. Soil moisture, bulk density, percent organic matter, macroinvertebrate biomass, and macroinvertebrate diversity did not differ significantly between the fields. Cornstalk nitrate concentration was excessive in Field 1 and deficient in Fields 2 and 3. No *E. coli* were found in soil from the three fields. Yield and gross return were greatest from Field 1 but the cost of manure determined a greater net return for Field 2 than for Field 1. The large amount of manure applied to Field 1 appears to have created excess of soil nutrients that may contribute to pollution without returning a greater profit.

INTRODUCTION

Use of hog (*Sus domestica*) manure as an agricultural fertilizer offers a potential substitute for synthetic fertilizer and a way to recycle animal waste (Malley *et al.* 2002). Studies have proposed that use of hog manure as fertilizer improves soil quality in addition to providing nutrients (Elmi *et al.* 2004). Hog manure has been shown to effectively restore productivity to intentionally eroded soil in Alberta (Larney and Janzen 1996). The organic matter and nutrients added to soil by liquid hog manure has been found to allow development of greater soil microbial diversity and biomass than inorganic fertilizer (Lalande *et al.* 2004, Lupwayi *et al.* 2005).

Despite its advantages, use of hog manure as fertilizer may introduce excess nutrients to the soil and cause greater pollution from nutrient runoff compared to inorganic fertilizer. Agricultural fertilizers have been implicated as significant contributors to non-point source nitrate and phosphate pollution in ground and surface waters in the U.S. (Carpenter *et al.* 1998). The degree of nutrient pollution caused by different fertilizer types varies with cropping system and location, but some studies have shown hog manure to contribute more pollution in comparison with synthetic fertilizer. Studies have found that hog manure application increases the concentrations of ammonia (Gangbazo *et al.* 1995) and dissolved organic carbon (Royer *et al.* 2007) compared to synthetic fertilizer. Elmi *et al.* 2005 found that liquid hog manure application increased both soil and runoff nitrates compared to inorganic fertilizer without significantly boosting crop yields in Nova Scotia. Mullen (2007) found greater nitrate and concentrations in tile runoff from fields treated with hog manure than from a field treated with synthetic fertilizer in Minnesota; later testing of these fields by the Cannon River Watershed Partnership also found this trend (Cannon River Watershed Partnership, 8997 Eaves Ave, Northfield, MN 55057; personal communication, 2009). In contrast, Thoma *et al.* (2005) found no significant differences in runoff nitrate, ammonia, and phosphorous concentrations between fields treated with liquid hog manure and urea in Minnesota. Gangbazo *et al.* (1997) also found no significant difference in N and P pollution in runoff from fields treated with liquid hog manure and inorganic fertilizer in Quebec.

Use of manure as fertilizer may also introduce pathogens, such as *Escherichia coli* bacteria, to soil, runoff water, and crops, posing a threat to human health. Although the dangerous *E. coli* strain O157:H7 is infrequently found in live hogs, the presence of this strain in improperly treated manure fertilizer and subsequent transmission to croplands is a potential environmental problem (Holley *et al.* 2008). Application of hog manure fertilizer to forage and vegetable crops has been found to introduce *E. coli* populations into the soil (Cote and Quessy 2005, Holley *et al.* 2008). However, tile runoff from fields treated with hog manure fertilizer in Minnesota was found to be contaminated with comparable populations of *E. coli* bacteria as an adjacent field treated with inorganic fertilizer (Cannon River Watershed Partnership, personal communication, 2009).

In this study, soil nitrate and phosphate concentrations, moisture, bulk density, organic matter, and macroinvertebrate biomass and diversity, cornstalk nitrate concentration, soil *E. coli* populations, crop yields and economic returns were compared between three fields in corn production treated with different quantities of hog manure and synthetic fertilizer in Northfield, MN, U.S.A. The objective of this study was to evaluate the advantages and disadvantages of hog manure application compared with synthetic fertilizer in terms of environmental impacts and productivity of cropland.

METHODS

Study Site

This study was performed on three adjacent agricultural fields on the property of St. Olaf College in Northfield, MN, rented and cultivated by David Legvold (5103 315th St W, Northfield, MN). The study site is located at 44° 28’ N and 93° 10’ W. The soil type of the study site was sandy loam (Dakota County Interactive Soil Map 2009). All three fields contain buried tile drainages, shown in Figure 1. The fields are planted in a two-year rotation of corn (*Zea mays*) and soybean (*Glycine max*) and contained corn during the year of this study (David Legvold, 2009, personal communication).

Two of the study fields were treated with liquid hog manure from a nearby hog-finishing confinement operation in May of 2009, prior to planting. The 2009 season was the fourth consecutive season of manure application using consistent methods. Field 1, with an area of 4 acres (approximately 1.62 ha), was treated with 7000 gallons/acre manure using a manure application tanker and subsequently full-width conventionally tilled to prepare for planting. Field

2, with an area of 4 acres (approximately 1.62 ha), was treated with 1500 gallons/acre manure using a Honey Warrior machine and subsequently strip-tilled. Both manure application methods incorporated manure into the soil. Field 3, with an area of 97 acres (approximately 39.25 ha), was treated with 0 gallons/acre hog manure. In place of manure, Field 3 was treated with 150 kg dry fertilizer NPK 9-23-30 during the fall of 2008, 60 lbs urea in the spring of 2009, and 30 lbs liquid N fertilizer in June of 2009. Field 3 was strip-tilled prior to planting (David Legvold, 2009, personal communication).

Soil Collection and Analyses

Soil was collected from the three study fields on October 17-18 and November 6-7, 2009. In each field during each sampling period, two random points were chosen for soil collection. At each random point, one soil core was taken and stored in a pre-weighed tin for soil moisture and bulk density analysis. Twelve additional soil cores within a 5-meter radius of each random point were taken; six were placed in a composite bag for soil nutrient and organic matter analysis and six were placed in a composite bag for soil *E. coli* analysis.

Soil moisture was determined by weighing wet soil samples collected in tins, placing the tins with soil in a 105 °C oven for 24 hrs, weighing the tins with dry soil, and finding the difference in weight between wet and dried soil. Soil bulk density was determined by dividing the weights of the dried soil by the volume of the soil core (47.123 cm^3). Soil from the composite bags for nutrient and organic matter analysis was air-dried and sifted through a 1.19 mm sieve. Soil organic content was determined by weighing soil samples from the composite bags in crucibles, placing the crucibles in a muffle furnace at 500 °C for 4 hrs, weighing the crucibles with soil ash, and finding the difference in weights between dried soil and soil ash.

To find soil nitrate concentrations, three 5-g samples of soil from each composite soil bag were each extracted with 15 mL of 10% $CaSO_4$ solution. Two mL of the filtrate from each sample was added to 23 mL of Millipore water. One Hach Nitraver 6 powder pillow (Hach Company, Loveland, CO) was added to each solution and the solutions were vortexed for 3 min. After allowing cadmium particles to settle, one Hach Nitraver 3 powder pillow was added to each solution and the solutions were stirred. The absorbances of the resulting solutions were measured after 4-10 min using a spectrophotometer.

To find soil phosphate concentrations, three 2-g soil samples from each composite soil bag were extracted with 17 mL of 10% Mehlich 2 solution. One mL of each filtrate was added to 22 mL Millipore water. One mL of Phosphate 1 Reagent and 1 mL of Phosphate 2 Reagent was added to each solution and the solutions were inverted to mix. The absorbances of the resulting solutions were measured after 4-10 min using a spectrophotometer.

Macroinvertebrate Collection and Analysis

At each random point, a .25-m x .25-m quadrat frame was placed on the ground and the soil within the frame removed with a spade to a depth of ~12 cm and placed in a small tub. The soil was carefully examined for macroinvertebrates. All macroinvertebrates found were placed in a small jar for each study section. Macroinvertebrates were killed in ethanol and placed in an oven at 105 °C for 24 hrs. The total dry biomass of macroinvertebrates for each study section from each collection period was found and recorded. All macroinvertebrates were classified by Class for diversity index analysis.

***E. coli* Tests**

Soil collected in composite bags was used for *E. coli* analysis. For each study field, a 5-g soil sample was removed from the composite bag from each day of collection, placed in sterile water, and mixed for 1 min in a sterilized blender. For each soil sample, 5 g soil/45 mL water dilutions were prepared first, followed by 5 g soil/90 mL water dilutions. From each dilution, a 1-mL sample of the solution was pipetted onto a 3M Petrifilm E. coli/Coliform Count Plate (3M Microbiology, St. Paul, MN). The plates were placed in an incubator at 35°C for 48 hrs. After incubation, the plates were examined for blue spots with bubbles, which indicate *E. coli* colonies on this medium (3M Microbiology, 2004).

Cornstalk Nitrate Analysis

Segments from corn stalks were collected from the three study sections of the field on November 7, 2009. Stalk segments 8 in (~20.4 cm) long were collected 6 in (~15.5 cm) above the ground according to standard procedure (Schlieman 2007). Two stalk segments each were collected from three random points in each study field, for a total of six stalk segments per field. Stalk sections were refrigerated until shipment to Minnesota Valley Testing Laboratories in New Ulm, MN, where stalk-nitrate analysis was performed. Results were emailed to the author. Stalk nitrate concentrations 0-700 ppm were considered "deficient," 700-2000 ppm were considered "optimum," and >2000 ppm were considered "excessive" according to Schlieman (2007).

Yield and Economic Return

The corn from the study fields was harvested in mid-December of 2009. The yield, yield per acre, gross return per acre, and return per acre after cost of hog manure data from the three fields were provided by David Legvold (2009, personal communication).

Statistical Analyses

One-way ANOVA analyses were performed to compare soil nitrate and phosphate concentrations between the three fields. Additional one-way ANOVA analyses were performed to compare phosphate concentrations between the months of soil collection for each field. Two-way ANOVA analyses were performed to compare soil nitrate and phosphate concentrations between the two months of soil collection and to determine the interaction between field and month of soil collection. One-way ANOVA tests were performed to compare soil moisture between fields and between the months of soil collection. One-way ANOVA tests were performed to compare soil bulk density, soil organic matter, and macroinvertebrate biomass between fields. Intercooled STATA software at St. Olaf College, Northfield, MN was used for statistical analyses (Statacorp 2006). The Simpson's Diversity Indexes with test for significance were found for Classes of soil macroinvertebrates for each field using Hypercard software available at St. Olaf College (Farris, unpublished software).

RESULTS

Soil nitrate concentrations varied significantly between the three study fields ($P = 0.0137$, Table 1). Mean nitrate concentration was highest in Field 1 and lowest in Field 3. Soil phosphate concentrations varied significantly between the three fields ($P = 0.0000$, Table 2). Mean phosphate concentration was highest in Field 1 and lowest in Field 2.

Soil nitrate concentration did not vary significantly by month of soil collection ($P = 0.3524$, Table 3) and there was no significant interaction between field and month of soil collection ($P = 0.8218$, Table 3). Soil phosphate concentration did vary significantly by month of soil collection ($P = 0.0000$, Table 4) and there was a significant interaction between field and month of soil collection ($P = 0.0000$, Table 4). Phosphate concentration did not vary significantly between the two months of soil collection in Field 1 ($P = 0.2417$, Table 5) but was significantly higher in October than November in Field 2 ($P = 0.0104$, Table 5) and significantly higher in November than October in Section 3 ($P = 0.0000$, Table 5).

Soil moisture did not vary significantly by field (P = 0.5035, Table 6) nor by month of soil collection (P = 0.2168, Table 7). Soil bulk density did not vary significantly by field (P = 0.6960, Table 8). Soil percent organic matter did not vary significantly by field (P = 0.7343, Table 9). Macroinvertebrate dry biomass did not vary significantly by field (P = 0.3087, Table 10). The numbers of macroinvertebrates found in each field organized by Class and Simpson's Diversity Indexes for each field are shown in Table 11. The Simpson's Diversity Indexes for Classes of macroinvertebrates did not significantly differ between any two fields. No *E. coli* colonies were found growing on any of the test plates.

Stalk nitrate concentrations are shown in Table 12. Nitrate concentration was highest in cornstalks from Field 1 and lowest in stalks from Field 3. The stalk nitrate concentration in Field 1 qualified as "excessive" and the concentrations in Fields 2 and 3 qualified as "deficient." Yield of corn and economic return from each field are shown in Table 13. Yield of corn was greatest in Field 1 and least in Field 3. The economic return per acre after subtracting the cost of hog manure fertilizer was greater in Field 2 than in Field 1.

DISCUSSION

Hog Manure Affected Soil and Cornstalk Nitrates

The significantly high nitrate concentration of the soil of Field 1 was probably due to the large volume of hog manure fertilizer applied to this field. The amount of inorganic nitrogen fertilizer applied to Field 3 was intentionally lesser than conventional practice (David Legvold, 2009, personal communication), which was the likely reason for the significantly low nitrate concentration in the soil of Field 3. The excessive nitrate concentration in cornstalk segments from Field 1 indicate that the amount of nitrogen available to the corn is greater than can be effectively utilized to produce greater yield, and is likely to contribute to water pollution

(Wilhelm *et al.* 2005, Binford *et al.* 1990). The full-width tillage used in Field 1 may further contribute to greater nitrate pollution from this field compared to Fields 2 and 3; Gregory *et al.* (2004) found greater volume of runoff from conventionally-tilled soil compared to no-till soil in Minnesota. Mullen (2007) tested the tile drainage from this study site in November of 2007 and found significantly higher nitrate concentrations in the runoff from Field 1 than from Fields 2 and 3. Monitoring data from the tile drainages in these three fields from August 2009 also show greatest total nitrogen runoff from Field 1 (Table 14) (Cannon River Watershed Partnership, 2009, personal communication). The deficient concentrations of nitrate in cornstalks from Field 2 and especially from Field 3 indicate that yields from these fields could have increased with greater application of nitrogen fertilizer (Binford *et al.* 1990).

Soil Phosphate Results Inconsistent

Just as with soil nitrates, the significantly high soil phosphate concentration in Field 1 was likely due to the large volume of hog manure fertilizer applied to this field. Royer *et al.* (2003) found that repeated application of large quantities of hog manure significantly increased the total P concentration, the degree of P saturation, and the concentration of forms of P prone to entering runoff water in soil compared to application of mineral fertilizer. The results of this study suggest that Field 1 should be the greatest potential source of phosphate pollution in drainage water. However, Mullen (2007) found the highest mean phosphate concentration in drainage from Field 2 and the lowest mean concentration in drainage from Field 1. Monitoring data from the tile drainage from this field from August 2009 shows the highest total phosphorus concentration in runoff from Field 2 and the lowest in runoff from Field 1, while the highest ortho-phosphate concentration was found in runoff from Field 1 and the lowest in runoff from Field 3 (Table 14) (Cannon River Watershed Partnership 2009, personal communication). The tile results for ortho-phosphates from August 2009 are more consistent with the soil results from this study than the tile results for total phosphorus; however, overall, the phosphate results from this and previous studies of these fields were inconsistent between years and months of study and between the tile runoff and the soil concentrations.

The mechanisms of phosphate loss from fertilized soil to surface and ground water are complex and still poorly understood (Hart *et al.* 2004). While some studies have shown that phosphate runoff from agricultural fields treated with manure fertilizer have increased with increased rates of manure, other studies have found no difference in phosphate runoff from fields with soil-incorporated manure application and unfertilized control fields (Tarkalson and Mikkelsen 2004). Gangbazo *et al.* (1999) found that application of liquid hog manure in addition to inorganic fertilizer compared to application of only inorganic fertilizer did not affect P runoff from fields in any consistent trend, and even that hog manure application sometimes resulted in decreased P in drainage. "Incidental losses" of soil phosphate to runoff shortly after fertilizer application have been shown by many studies to be the greatest releases of phosphate pollution in agricultural land (Hart *et al.* 2004). Because Mullen (2007) sampled phosphate concentrations in runoff several months after fertilizer application, it is possible that her study did not evaluate the full extent of phosphate pollution from fertilizer use in the study site. Overall, despite the significant differences in soil phosphate concentration in the three fields, the implication of these concentrations for agricultural pollution remains unclear. Further research is needed regarding the relationship between phosphate application to soil and phosphate pollution in runoff.

The inconsistency of soil phosphate concentrations in Fields 2 and 3 between the two months of soil collection presents a perplexing result. Local precipitation data from 2009 show greater precipitation in October than in November, including precipitation after the date of the first soil collection (Carleton College Weather Database 2009), which may explain the lower phosphate concentration in Field 2 in November. However, the dramatically higher phosphate concentration in Field 3 in November compared to October has no apparent explanation. Drastic variation of soil phosphate concentration within this field due from unknown physical causes is the only available potential explanation. Additional phosphate sampling is necessary to more accurately determine the soil phosphate concentration of Field 3.

Other Soil Characteristics did not Vary Significantly

The results of this study indicate that fertilization and tillage techniques used in this study had no significant impact on soil percent moisture and bulk density. These results are noteworthy because reduced tillage practices have been shown to significantly increase both moisture and bulk density of the upper soil layer (Romaneckas *et al.* 2009). However, Gregory *et al.* (2004) found soil compaction greater and percent moisture lower in soil treated with full tillage compared to no-tillage in agricultural land in Minnesota.

Though a large quantity of organic matter was added to the soil of Field 1 by fertilizer compared to a lesser amount of organic matter added to Field 2 and only inorganic fertilizer added to Field 3, the soil percents organic matter did not vary significantly between the three fields. The reduced tillage practices used in Fields 2 and 3, which conserve more crop residue than the full-width tillage used in Field 1, may be responsible for the lack of significant difference in soil organic matter (David Legvold, 2009, personal communication). Though conventional tillage has been shown to be detrimental to soil macroinvertebrates compared to reduced tillage (Gregory *et al.* 2004), in this study macroinvertebrate diversity and biomass did not differ significantly between the fields. However, though the difference was not statistically significant, the macroinvertebrate biomass from Field 3 was noticeably lesser than those from

Fields 1 and 2, suggesting that the use of hog manure may be more hospitable to macroinvertebrates. Lupwayi *et al.* (2005) found that hog manure encouraged greater diversity and biomass of microorganisms than inorganic fertilizer, which may indicate better conditions for macroinvertebrates also. However, additional sampling is needed to determine if there is a significant trend in macroinvertebrate biomass or diversity in the study site.

Lack of *E. coli* in Soil

The lack of *E. coli* colony-forming units in the soil may have been due to low *E. coli* populations in the hog manure applied. However, an alternative explanation is that *E. coli* added to the soil by manure application had run off into the tile drainage from the fields during the 5-6 months between application of manure and soil collection. Mullen (2007) found no *E. coli* in tile drainage water from these three fields in November of 2007 and attributed this lack of *E. coli* to the time in between manure application and sampling. However, *E. coli* were found in substantial concentrations in the tile drainage from all three fields in August of 2009 (Table 14) (Cannon River Watershed Partnership 2009, personal communication). It is possible that more consecutive years of manure application may be necessary for *E. coli* populations in the soil to reach detectable levels. Cote and Quessy (2005) found that *E. coli* populations in agricultural soil treated with hog manure in Quebec were not detectable until the second year of manure application. Alternatively, *E. coli* populations added to the fields may have died off prior to this study. Cote and Quessy (2005) found *E. coli* added to soil in hog manure to decrease linearly in population after application, with an estimated 56 to 70 days for complete die-off in sandy loam soil. This lifespan of *E. coli* in agricultural soil is considerably shorter than the 5-6 months between manure application and soil collection in this study. Jiang *et al.* (2002) performed laboratory tests of the persistency of *E. coli* in soil treated with manure, and found that low temperature and reduced indigenous soil microbial community encouraged persistence of *E. coli* survival. The high soil temperatures of the summer months between manure application and this study may have inactivated the *E. coli* populations in the fields before soil collection.

Monitoring data from the tile drainages from these fields from August 2009 show that *E. coli* was present in the runoff from Fields 2 and 3 as well as Field 1, and that the most probable number (MPN) of live *E. coli* was actually least in runoff from Field 1, greatest in runoff from Field 2, and greater in runoff from Field 3 than in runoff from Field 1 (Table 14) (Cannon River Watershed Partnership 2009, personal communication). These results cast doubts on the relationship between hog manure application and *E. coli* presence in the soil and runoff from these three fields. Further investigation is needed to determine the role of hog manure application in introducing *E. coli* populations to the soil and runoff water of these fields and the persistence of these populations.

Yield and Economic Return

The results of this study indicate that the large amount of hog manure applied to Field 1 did lead to an increased yield of Field 1 compared to Fields 2 and 3. In addition to increased nitrate concentration, the increased phosphate in the soil of Field 1 may have been an important factor in the greater yield from this field. Phosphate from liquid hog manure has been shown to be more available to crops from 1 to 9 months after application than synthetic phosphate fertilizer (Laboski and Lamb 2003). The full-width tillage used in Field 1 may have also contributed to the greater yield of this field; full tillage has been found to increase corn yield compared to reduced tillage in Minnesota (Thoma *et al.* 2005). However, Gregory *et al.* (2004) found greater corn yields from land under no-tillage practices than from conventionally tilled land.

The excess of stalk nitrate concentration in Field 1 and the potential for increased nitrate and phosphate runoff from this field indicate that a lesser volume of manure should be applied to this field to reduce the threat of pollution from this field. For soils with low organic matter in Saskatchewan, hog manure application rates of 3,000 gallons/acre, in between the rates in Fields 1 and 2, have been found to effectively improve grain yield without exacerbating nutrient leaching (Prairie Agricultural Machinery Institute 2003). The economic return of the fields after the cost of hog manure show that the amount of manure applied to Field 2 increases yield compared to synthetic fertilizer while not incurring an extravagant cost such as that of the manure in Field 1. Overall, the results of this study indicate that the management practices used on Field 2 produced the best economic return without posing an outstanding source of runoff pollution.

Conclusion and Further Study

Large quantities of hog manure and conventional tillage used in Field 1 in this study resulted in significantly greater nitrate and phosphate concentrations than in Fields 2 and 3, potentially posing a greater source of nutrient pollution in runoff. However, other soil qualities examined in this study did not vary significantly due to different practices used on the fields. No *E. coli* were found in the soil from the study site, which was likely due to loss or die-off of the bacteria in the time between application and this study. Though Field 1 produced the greatest yield, the high cost of the volume of hog manure applied to Field 1 resulted in a lower net return than Field 2. Overall, the practices used in Field 1 were economically disadvantageous and poses a greater threat to water quality compared to the practices used in Field 2.

Additional study is needed to determine the presence or absence of *E. coli* in Fields 1 and 2 at closer dates to the application of manure on these fields. Additional studies are also needed to determine the distribution of phosphates in the soils of the fields, especially Field 3, and the effects of these phosphate concentrations on runoff. Further sampling of organic matter and macroinvertebrates form these fields may reveal significant trends not found in this study. Finally, long-term monitoring of these fields is needed to determine the effects of repeated application of large volumes of hog manure to agricultural land and the most beneficial practices for farmers.

Acknowledgements

Thank you to Professor Kathy Shea for a tremendous amount of guidance and assistance in the formation and completion of this project in the course Biology 371. Thank you to David Legvold for permission to study in his fields, for much guidance and assistance in the project, and for the data and information about the study site and the techniques used. Thank you to the Biology 371 classmates for providing a good learning community. Thank you to David Burton, Professor Ted Johnson, and Professor Kim Kandl from St. Olaf College for help with the *E. coli* analyses and autoclave use.

Literature Cited:

3M Microbiology. 2004. 3M Petrifilm Coliform Count Plate instructions. St. Paul, MN, U.S.A.

Binford, G.D., A.M. Blackmer, and N.M. El-Hout. 1990. Tissue Test for Excess Nitrogen during Corn Production. *Agronomy J* 82:124-129.

Carleton College Weather Database. 2009. Northfield, MN, U.S.A. http://weather.carleton.edu/

Carpenter, S.R., N. F. Caraco, D. L. Correll, R. W. Howarth, A. N. Sharpley, V. H. Smith. 1998. Nonpoint Pollution of Surface Waters with Phosphorus and Nitrogen. *Ecological Applications* 8 (3): 559-568.

Cote, C. and S. Quessy. 2005. Persistence of *Escherichia coli* Bacteria and Salmonella in Surface Soil Following Application of Liquid Hog Manure for Production of Pickling Cucumbers. *J. Food Prot.* 68 (5): 900-905.

Dakota County Interactive Soil Map. 2009. http://www.co.dakota.mn.us/EnvironmentRoads/EnvirProtect/Agriculture/MappingTool.htm

Elmi, A., A. Madani, R. Gordon, P. MacDonald, G.W. Stratton. 2005. Nitrate Nitrogen in the Soil Profile and Drainage Water as Influenced by Manure and Mineral Fertilizer Application in a Barley-Carrot Production System. *Water, Air, Soil Pollut.* (160) 1-4: 119-132.

Farris, M. Unpublished. Species Diversity and Morisita's Index, Hypercard Stack Software.

Gangbazo, G., A.R. Pesant, G.M. Barnett, J.P. Charuest, and D. Cluis. 1995. Water Contamination by Ammonium Nitrogen Following the Spreading of Hog Manure and Mineral Fertilizers. *J of Environmental Quality* 24 (3): 420-425.

Gangazo, G., A.R. Pesant, D. Coté, G.M. Barnett, and D. Cluis. 1997. Spring Runoff and Drainage N and P Losses from Hog-manured Corn. *J of the Amer. Water Resources Assoc.* 33 (2): 405-411.

Gangbazo, G., G.M. Barnett, A.R. Pesant, and D. Cluis. 1999. Disposing Hog Manure on Inorganically-fertilized Corn and Forage Fields in Southeastern Quebec. *Can. Agric. Eng.* 41:001-012.

Gregory, M.M., K.L. Shea, E.B. Bakko. 2004. Comparing Agroecosystems: Effects of Cropping and Tillage Patterns on Soil, Water, Energy Use and Productivity. *Renewable Agriculture and Food Systems* 20 (2): 81-90.

Hart, M.R., B.F. Quinn, M.L. Nguyen. 2004. Phosphorus Runoff from Agricultural Land and Direct Fertilizer Effects. *J. Environ. Qual.* 33:1954-1972.

Holley, R., J. Walkty, G. Blank, M. Tenuta, K. Ominski, D. Krause, L.-K. Ng. 2008. Examination of *Salmonella* and *Escherichia coli* Translocation from Hog Manure to Forage, Soil, and Cattle Grazed on the Hog-Manure Treated Pasture. *J of Environmental Quality* 37: 2083-2092.

Jiang, X., J. Morgan, M.P. Doyle. 2002. Fate of *Escherichia coli* O157:H7 in Manure-Amended Soil. *Applied and Environmental Microbiology* 68 (5): 2605-2609.

Laboski, C.A.M., and J.A. Lamb. 2003. Changes in Soil Test Phosphorus Concentration After Application of Manure or Fertilizer. *Soil Science Society of America J* 67:544-554.

Lalande, R., B. Gagnon, R.A. Chapman, G.M. Barnett. 2005. Soil Microbial Populations, Activity, and Community Structure in Continuous Corn or Forage Systems under Organic or Inorganic Fertilization in Eastern Canada. *Canadian J. of Soil Science* 85 (1): 27-38.

Larney, F.J., H.H. Janzen. 1996. Restoration of Productivity to a Desurfaced Soil with Livestock Manure, Crop Residue, and Fertilizer Amendments. *Agron J.* 88: 921-927.

Lupwayi, N.Z., T. Lea, J.L. Beaudoin, and G.W. Clayton. 2005. Soil Microbial Biomass, Functional Diversity, and Crop Yields Following Application of Cattle Manure, Hog Manure, and Inorganic Fertilizers. *Canadian J. of Soil Science* 85: 193-201.

Malley, D.F., L. Yesmin, and R.G. Eilers. 2002. Rapid Analysis of Hog Manure and Manure-amended Soils Using Near-Infrared Spectroscopy. *Soil Sci Soc Am J* 66: 1677-1686.

Mullen, S. 2007. Nitrate, Phosphate, and *Escherichia coli* Levels in Tile Drainage Water from Areas Treated with Commercial Fertilizer or Hog Manure. Biology 371, St. Olaf College.

Prairie Agricultural Machinery Institute. 2003. "Hog Manure as a Fertilizer in the Gray Soil Zone." PAMI Research Update, Humboldt, Saskatchewan, Canada.

Romaneckas, K., R. Romaneckiene, E. Sarauskis, V. Pilipavicius, and A. Sakalauskas. 2009. The Effect of Conservation Primary and Zero Tillage on Soil Bulk Density, Water Content, Sugar Beet Growth and Weed Infestation. *Agron. Research* 7 (1): 73-86.

Royer, I., R.R. Simard, G.M. Barnett, D. Cluis, D.A. Angers. 2003. Long-term Effects of Liquid Hog Manure on the Status of a Silt Loam Cropped to Corn. *Canadian J of Soil Science* 83:589-600.

Royer, I., D.A. Angers, M.H. Chantigny, R.R. Simard, D. Cluis. 2007. Dissolved Organic Carbon in Runoff and Tile-Drain Water under Corn and Forage Fertilized with Hog Manure. *J. of Environ. Qual.* 36:855-863.

Schlieman, D. 2007. "Cornstalk Nitrates." Minnesota Valley Testing Laboratories Newsletter, Fall 2007.

StataCorp. 2006. *Stata Statistical Software: Release 9.1.* College Station, TX: Stata Corporation.

Tarkalson, D.D. and R.L. Mikkelsen. 2004. Runoff Phosphorus Losses as Related to Phosphorus Source, Application Method, and Application Rate on a Piedmont Soil. *J. Environ. Qual.* 33:1424-1430.

Thoma, D.P., S.C. Gupta, J.S. Strock, J.N. Moncrief. 2005. Tillage and Nutrient Source Effects on Water Quality and Corn Grain Yield from a Flat Landscape. *J of Environ. Qual.* 34:1102-1111.

Wilhelm, W.W., G.E Varvel and J.S. Schepers. 2005. Corn Stalk Nitrate Concentration Profile. *Agronomy J* 97:1502-1507.

Figure 1 – Map of study site showing tile drainage. The three output pipes drain the three fields (Field 1 at the south, Field 2 in the middle, Field 3 at the north) treated with different fertilizer type and quantity (St. Olaf College Agricultural Lands, October-November 2009).

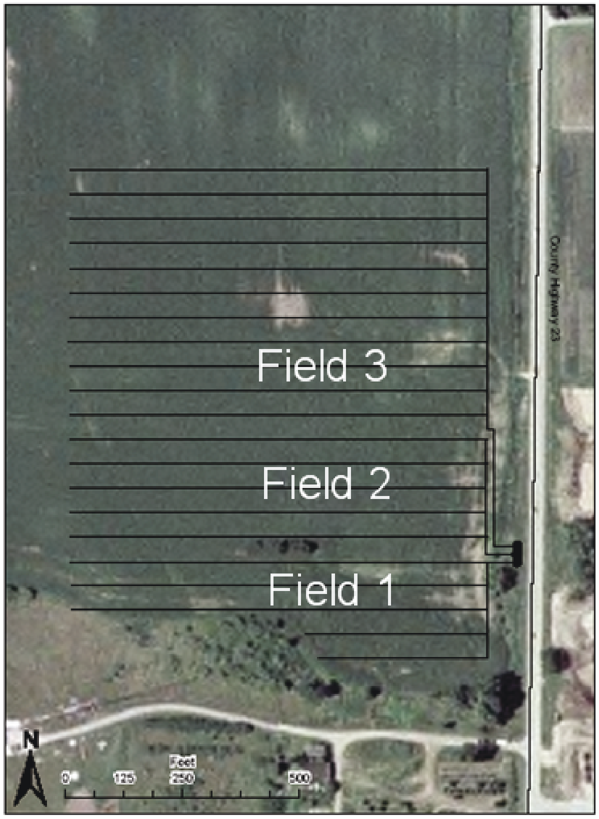

Table 1 – One-way ANOVA of soil nitrate concentration between fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, October-November 2009).

Field	Volume of Hog Manure Applied (gallons/acre)	Frequency	Mean Soil Nitrate Concentration	Standard Deviation
1	7000	6	5.1032	3.851
2	1500	6	2.8469	0.7663
3	0	6	0.6322	0.2233
P = 0.0137				

Table 2 – One-way ANOVA of soil phosphate concentration between agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, October-November 2009).

Field	Volume of Hog Manure Applied (gallons/acre)	Frequency	Mean Soil Phosphate Concentration	Standard Deviation
1	7000	6	209.5395	7.9267
2	1500	6	26.5808	6.1237
3	0	6	30.8951	24.1423
P = 0.0000				

Table 3 – Two-way ANOVA of soil nitrate concentration between agricultural fields treated with different quantities of hog manure and synthetic fertilizer, between months of soil collection, and interaction between field and month of collection (St. Olaf College Agricultural Lands, October-November 2009).

ANOVA Comparison	P-value
By Field	P = 0.0243
By Month of Soil Collection	P = 0.3524
Field x Month Interaction	P = 0.8218

Table 4 – Two-way ANOVA of soil phosphate concentration between agricultural fields treated with different quantities of hog manure and synthetic fertilizer, between days of soil collection, and interaction (St. Olaf College Agricultural Lands, October-November 2009).

ANOVA comparison	P-value
Field	P = 0.0000
Collection Day	P = 0.0000
Field x Collection Day Interaction	P = 0.0000

Table 5 – One-way ANOVAs of soil phosphate concentration between months of soil collection in three agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, October-November 2009).

	Month of Soil Collection	Frequency	Mean Soil Phosphate Concentration (ppm)	Standard Deviation
Field 1				
(P = 0.2417)	October	3	205.4445	10.0944
	November	3	213.6345	2.2083
Field 2				
(P = 0.0104)	October	3	31.6995	2.6808
	November	3	21.462	2.8208
Field 3				
(P = 0.0000)	October	3	8.8845	1.5408
	November	3	52.9058	1.1608

Table 6 – One-way ANOVA of soil percent moisture between three agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, October-November 2009).

Field	Frequency	Mean Soil % Moisture	Standard Deviation
1	4	25.5708	2.7359
2	4	25.8686	0.5603
3	4	22.733	6.3789
P = 0.5035			

Table 7 – One-way ANOVA of soil percent moisture by month of soil collection in three agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, October-November 2009).

Month of Soil Collection	Frequency	Mean Soil % Moisture	Standard Deviation
October	6	23.2784	3.88
November	6	26.17	3.7169
P = 0.2168			

Table 8 – One-way ANOVA of soil bulk density between three agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, October-November 2009).

Field	Frequency	Mean Soil Bulk Density (g/cm^3)	Standard Deviation
1	4	1.1859	0.051
2	4	1.2311	0.1021
3	4	1.2952	0.289
P = 0.6960			

Table 9 - One-way ANOVA of soil percent organic matter between three agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, October-November 2009).

Field	Frequency	Mean Soil % Organic Matter	Standard Deviation
1	4	5.4967	1.9276
2	4	5.0489	1.7636
3	4	4.4486	1.881
P = 0.7343			

Table 10 - One-way ANOVA of soil macroinvertebrate biomass between three agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, October-November 2009).

Field	Frequency	Mean Soil Macroinvertebrate Biomass (g)	Standard Deviation
1	2	1.245	1.1101
2	2	1.825	0.0778
3	2	0.6	0.1555
P = 0.3087			

Table 11 – Total numbers of soil macroinvertebrates organized by Class and Simpson's Diversity Indexes for three agricultural fields treated with different quantities of hog manure and synthetic fertilizer. The diversity indexes did not vary significantly between fields (St. Olaf College Agricultural Lands, October-November 2009).

Field	Oligochaeta	Gastropoda	Insecta	Diplopoda	Simpson's Diversity Index
Field 1	31	1	1	4	0.292
Field 2	36	1	0	3	0.188
Field 3	18	0	0	1	0.105

Table 12 – Nitrate concentration in cornstalk segments from three agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, November 2009).

Field	Cornstalk Nitrate Concentration (ppm)	Classification of Stalk Nitrate Concentration
1	5822	Excessive
2	535	Deficient
3	162	Deficient

Table 13 – Yield and economic return results from three agricultural fields treated with different quantities of hog manure and synthetic fertilizer (St. Olaf College Agricultural Lands, December 2009).

Field	Yield/acre (bu/acre)	Gross return ($/acre)	Return Minus Cost of Manure ($/acre)
Field 1	222.99	836.19	584.2
Field 2	207.43	777.86	723.86
Field 3	191.87	719.52	719.52

Table 14 – Tile runoff nitrogen, total phosphorus, ortho-phosphorus, and *E. coli* concentrations from three agricultural fields treated with different quantities of hog manure and synthetic fertilizer, collected by staff of the Cannon River Watershed Partnership (8997 Eaves Ave, Northfield, MN 55057) (St. Olaf College Agricultural Lands, August 2009).

Field	Volume of Hog Manure Applied (gallons/acre)	Nitrate and Nitrite (ppm)	Total Phosphorus (ppm)	Ortho-phosphate (ppm)	E. coli colony-forming units (MPN / 100 mL)
1	7500	13.9	0.039	0.076	7.5
2	1500	10.1	0.063	0.024	22.8
3	0	9.45	0.052	0.015	18.5