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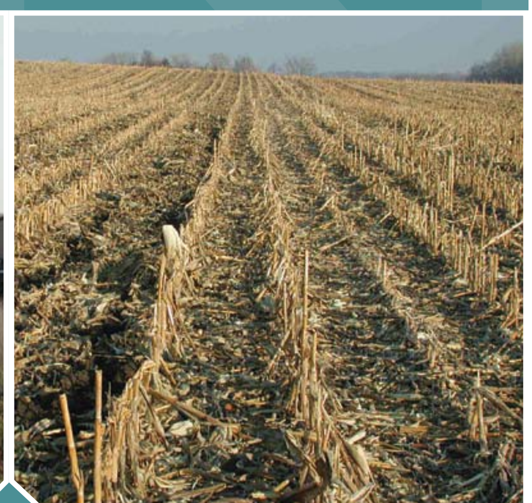
Metrics for Nitrate Contamination of Ground Water at CAFO Land Application Sites - Iowa Swine Study



Office of Research and Development
National Risk Management Research Laboratory, Ada, Oklahoma 74820

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Iowa Swine Study

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Notice

This work was supported through Interagency Agreement DW-12-921711-4 between EPA's Ground Water & Ecosystems Restoration Division, National Risk Management Research Laboratory (Elise Striz, Stephen Hutchins, Project Officers) and USDA-ARS's Conservation and Production Research Laboratory (David Brauer, USDA-ARS Contact). Although this work was funded substantially by the U.S. Environmental Protection Agency, it has not been subjected to Agency review and therefore does not necessarily reflect the views of the Agency, and no official endorsement should be inferred.

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Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This work was supported by EPA's Office of Research and Development through the Regional Applied Research Effort (RARE) Program. This program is designed to 1) provide the Regions with near-term research on high priority, Region-specific technical needs, 2) improve collaboration between Regions and ORD laboratories, 3) build the foundation for future scientific interaction, and 4) develop useful tools for state, local and tribal governments to address near-term environmental issues. EPA Region 6 and ORD's Ground Water & Ecosystems Restoration Division (GWERD) recognized the need to evaluate whether properly-designed Comprehensive Nutrient Management Plans (CNMPs) developed for land application of waste from Concentrated Animal Feeding Operations (CAFOs) are truly protective of ground water quality. Funding ($130K total) was awarded to EPA Region 6 (Nancy Dorsey, EPA Region 6 Contact) and administered through GWERD (Elise Striz, Stephen Hutchins, Project Officers), and was used by USDA's Agricultural Research Service (David Brauer, USDA-ARS Contact) to conduct two separate site investigations at CAFO facilities where CNMPs were being followed. The objective was to conduct comprehensive sampling of soil, soil water, and crops for nutrients throughout the growing season to determine which simple soil/crop metrics are the best indicators of the potential for nutrients to escape the root zone and become a threat to ground water. This report describes the site investigation conducted by Dr. Jerry L. Hatfield for a swine operation in Iowa. The other site investigation was conducted by Dr. Philip A. Moore, Jr., and Dr. David Brauer for a dairy farm in Arkansas and is described in the companion report.

Robert W. Puls, Acting Director
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Figures and Tables

Abbreviations

CAFOs	Concentrated Animal Feeding Operations
CNMP	Comprehensive Nutrient Management Plan
DOY	Day of Year
MCL	Maximum Contaminant Level
N	Nitrogen
NMP	Nutrient Management Plan
P	Phosphorus

Acknowledgements

Dale Bumpers Small Farms Research Center (Booneville, AR) and Southern Plains Area Office (College Station, TX) of ARS/USDA provided administrative support for the interagency agreement.

Executive Summary

Nitrate (NO_3^-) is the most common chemical contaminant found in ground water and there are increasing indications that agriculture contributes to this contamination. In the United States, concentrated animal feeding operations (CAFOs) are a common agricultural practice. CAFOs lead to concentrated production of animal waste and manure. In most instances, this manure is then utilized as an input for crop production because the manure is relatively rich in plant nutrients, including nitrogen (N) and phosphorus (P). Manure disposal on agricultural land by CAFOs is usually dictated by a Comprehensive Nutrient Management Plan (CNMP or NMP). The stated intention of the CNMP is to utilize the manure as beneficially as possible without a high risk of contaminating surface and ground water. The objectives of this research were to monitor changes in soil nutrient composition at various depths in response to various scenarios of swine manure applications according to an approved CNMP and determine if site characteristics or management protocols that pose a risk to ground water can be identified.

A study was conducted for one year (2006) on a swine-row crop farm in central Iowa. The row crop operation consisted primarily of corn (*Zea mays* L.) -soybean (*Glycine max* (L.) Merr.) rotation. Swine production consisted of growing-finishing operation of 4,200 head. Swine waste was stored in pits for up to a year before being applied. Land application consisted of injecting the effluent into a slit approximately 20 cm below the soil's surface. Eight plots (10 x 10 m) were established. Two plots were in a field in which swine manure effluent was applied in the fall to supply a corn crop's N requirement (approximately 150 kg N ha^{-1}). Four plots were in a field in which swine manure effluent was applied in the spring to supply approximately 100 kg N ha^{-1} with the additional crop N (50 kg ha^{-1}) being supplied post-planting as sidedressed fertilizer. The last two plots were in a soybean field; one received swine effluent application in 2005 and the other did not. Soil core samples (0-15, 15-30, 30-45, 45-60, and 60-120 cm depths) were taken in May (planting time) and October (after harvesting). Soil samples from the top 22.5 cm were also collected biweekly throughout the growing season. These samples were analyzed for soluble components (nitrate, ammonium, SRP, pH, and EC), as well as exchangeable ammonium and Mehlich III extractable P. Plant samples were also collected and analyzed for biomass and N content.

Detailed soil sampling revealed that soil N and P concentrations were greatest in the upper 20 and 10 cm, respectively. In addition, the variations in soil P and N were greater at the soil surface than at lower depths. Concentrations of soil P and N at all depths decreased during the growing season. The largest decrease in soil P and N concentrations was found in the upper 10 cm, and at 20-40 cm, respectively. Nutrient removal from the soil was also calculated from changes in soil concentrations. Changes in soil N concentration indicated that the soybean and corn crop removed approximately 140 and 200 N ha^{-1}. Analyses of the plant biomass indicated that approximately 140 and 200 kg N ha^{-1} had been accumulated in the soybean and corn crop, respectively. Similarly, P removals based on soil removal versus grain and biomass removal were not significantly different and averaged 62 kg ha^{-1}. Thus, crop removal by the two methods was in excellent agreement for both P and N. There were no differences in the P or N removal rates between the two management practices, one in which all of the N requirement was supplied by manure and another where sidedressed N supplemented the amount of N added by manure application. These results suggest that P additions to the soil from manure application can be reduced without affecting crop production if sufficient N is added from sidedressed fertilizer.

The results from this study indicate that application of swine manure effluent at this farm according to the existing CNMP should supply N and P in sufficient amounts for crop production without leading to a further accumulation of N or P in the soil. There were no significant differences in the corn yields between the two manure management practices. Sparse rainfall during the early part of the 2006 growing season resulted in weather that was not typical of central Iowa. Therefore, far-reaching conclusions from this research may not be possible. The use of soil characteristics in the topsoil as indicators of the potential of downward movement of soil N and P will be made more difficult by the large variations in soil N and P concentrations in this zone.

1.0 Introduction

Modern American farms often have large numbers of animals and a relatively limited land base to apply the manure. This can lead to the problem of over application of nutrients, particularly nitrogen (N) and phosphorus (P) to agricultural lands. Nitrate (NO_3^-) is soluble in water, hence, it can be easily leached from soils into ground water. As a result, nitrate is the most ubiquitous chemical contaminant in the world's ground-water supplies (Spalding and Exner, 1993). The U.S. EPA established a maximum contaminant level (MCL) of 10 mg NO_3-N L^{-1} for nitrate in drinking water (U.S. EPA, 1995). Nolan et al. (1998) estimated that 24 percent of the ground water in the United States exceeded the U.S. EPA MCL between 1993 and 1995. Likewise, the European Community (EC) has established an upper threshold on drinking water nitrate levels of 11.3 mg NO_3-N L^{-1}. Approximately 10 million people in France depend on ground water with nitrate levels above the EC's upper threshold (Spalding and Exner, 1993). Nitrate contamination of ground water near intensive vegetable production has been reported in Japan (Babiker et al., 2004).

Surveys of ground water in areas with concentrated animal feeding operations (CAFOs) have reported higher than normal nitrate levels. In Sussex County, Delaware, the number one broiler producing county, 37 percent of the wells had nitrate levels above the MCL (Ritter and Chirnside, 1984). However, only 3.2 percent of the 1232 wells sampled in a ten county area of Arkansas, another state with numerous poultry CAFOs, had nitrate levels above the MCL (Arkansas CES, 1990). Steele and McCalister (1991) reported the average nitrate-N concentration was only 3 mg NO_3-N L^{-1} in areas receiving heavy applications of poultry litter in the Ozark region of Arkansas. Waste from poultry CAFOs is not the only potential source of nitrate contamination in ground water. Nitrate levels were high in ground water taken from wells under or near fields on which swine waste has been applied (Becker et al., 2003; Gillam et al., 1996; Mikkleson, 1995; Sloan et al., 1999). Nitrate derived from the N in swine manure that has been applied to agricultural fields has been found in shallow ground-water wells and this nitrate can be transferred to adjacent streams and waterways, thus decreasing surface water quality (Israel et al., 2005).

Rate of N application is an important determinate of the leaching potential of nitrates. Results from Adams et al. (1994) indicate that manure additions that supply N more than twice the crop's needs are likely to lead to nitrate contamination in ground water. However, other factors influence the concentration of nitrates in soil ground water below the plants' rooting depth. Both the amount and timing of precipitation events and irrigation applications relative to time of N applications affect the amount of nitrate found deep in the soil profile (Gärdenäs et al., 2005; van Es et al., 2006). Leaching potential of nitrate through coarse texture soils is greater than for finer texture soils (van Es et al., 2006). Source of the N, including the type of manure, also influences the rate at which nitrate moves through the soil profile (Giullard and Kopp, 2004; Wu and Powell, 2007).

Spalding and Exner (1993) stated that high temperatures, abundant rainfall and relatively high organic contents in Coastal Plain soils of the southeastern United States promote denitrification below the root zone and naturally remediate nitrate leaching into ground water. In North Carolina, Gilliam (1991) found that high levels of nitrates (15-20 mg N L^{-1}) occurred in soil solutions in Coastal Plain soils cropped to corn. However, these high concentrations were not measured below 4 m. Gilliam (1991) attributed these low nitrate levels at greater depths to denitrification (soluble organic carbon compounds provide an energy source for microbial reduction of nitrate).

Total N excreted in livestock and poultry manure represents nearly 35 percent of the U.S. commercial fertilizer N use; 30-85 percent of this may be lost to atmosphere during manure storage and application depending upon the manure management system (Hess et al., 2008). Additional losses of the N content may occur because of application timing, method, and weather conditions (Hess et al., 2008). Given the magnitude of these losses, methods and decision support tools are needed to identify areas and practices that increase the risk of nitrate contamination in ground water. Several methods for monitoring nitrate leaching have been used in the past. Results from Zotarelli et al. (2007) indicate that analyses of soil cores for nitrate provided as reliable estimates of nitrate leaching as soil lysimeters. Zhu et al. (2002) and Toth et al. (2006) demonstrated that passive capillary lysimeters also provided reliable estimates of nitrate leaching, while being easier to install and maintain than other types of lysimeters. The problem with all of these methods for use by producers is that they are labor intensive during installation and/or sample collection.

Recent work by U.S. EPA personnel in Oklahoma have demonstrated that land application of swine manure can cause nitrate contamination of ground water above the MCL at depths greater than 10 m (Elise Striz, unpublished data). These findings, along with similar findings around the country, are raising concerns for ground-water degradation on or adjacent to CAFOs. Currently, land application of manures from CAFOs must follow a comprehensive nutrient management plan (CNMP) in most states. One of the main underlying assumptions of using a well designed and executed CNMP is that ground water will be protected from excessive amounts of nitrate or other nutrients. One question that occurs is what are the nutrient dynamics when these plans are followed for land application? There is little information to help understand the seasonal changes in nutrient dynamics in soil when manure is applied according to a plan, although it is assumed that following CNMPs will alleviate potential environmental impacts. This study was designed to evaluate CNMPs for an integrated row crop-swine production system in the Midwestern United States. The Midwest environment is unique from other parts of the United States in which integrated row crop-swine production systems are practiced, like the coastal plains of North Carolina. Many Midwestern soils are derived from fine-textured glacial deposits, which results in these soils being poorly drained (Eidem et al., 1999; Rodvang and Simkins, 2001). To facilitate agriculture, many of these soils have been artificially drained (McCorvie and Lant, 1993). Thus, the hydrology of these Midwestern soils is probably very unique. In addition, the existing soil conditions impair the ability of shallow lysimeters to provide reliable estimates of nutrient composition in ground water at and just below the plant rooting depth (Hatfield, personal communications).

This study evaluated N and P dynamics in a corn-soybean production system using swine manure as the primary nutrient source. Specific objectives were: 1) evaluate the seasonal dynamics of N and P in the soil profile under CNMP-based applications of swine manure; and 2) evaluate the potential for ground-water contamination from the nutrient balance in the root zone. This study complemented one conducted in Arkansas using a different source of manure (dairy) and soils.

2.0 Study Design

Study sites were established at a cooperator's farm in central Iowa (Hardin County). This farm was chosen because CNMPs are an integral part of the swine operation. The cropping component of this farm's operation is primarily a two-year rotation of corn and soybeans. The farm operator at this site has provided detailed records on nutrient content of applied manure, rates and timing of manure application, soil tests records, crop production, and meteorological data. Manure for this study was supplied from deep-pit manure storage from a 4,200 head grow-finish production unit. Manure is stored for up to a year in the pits underneath the building, and then stirred before pumping into the application equipment. Manure was applied with a knife injection system in the fall or spring when the pits are pumped out. According to the CNMPs, swine manure is applied to fields in the fall or spring of the year to supply the anticipated nutrient requirements of the corn crop the following season, approximately 150 kg N ha^{-1} (135 pounds N $acre^{-1}$). Manure was applied with a knife injector to a depth of 20 cm; this type of system is typical in central Iowa. Manure application rates based on the CNMP for these fields are shown in Table 1 and nutrient application rates were based on manure samples and the application rate made to supply these rates. Three areas of the farm, representing different cropping strategies and sequences in the cropping rotation, were selected to provide details about the metrics of N and P movement through the soil profile (Figure 1). These fields were tilled with a field cultivation operation in the spring before planting with additional soil disturbance caused by the injection of the manure. These three areas were as follows: 1) CNMP based spring application of manure supplying the nitrogen needs for that year's corn (Table 1; Field 2, Sites 5 and 6); 2) CNMP based fall manure application rates and sidedressed N during the corn's early season growth (Table 1, Field 1, Sites 1-4) to reduce P loads from manure; 3) evaluation of the residual N and P levels in the soil profile grown in corn in 2005 and in soybeans in 2006, the year of the study (Table 1, Field 3, Sites 7 and 8). The difference between Sites 7 and 8 is that the N requirement of the corn crop in 2005 was supplied by manure and fertilizer applications, respectively. The rationale behind the management protocol in Field 2 compared to Field 1 was to reduce the P application from the manure while supplying a constant amount of N. The soil type at each site is listed in Table 1. Four soil types were found among the eight sites and detailed descriptions are given in Table 2. The month and amounts of N applied as manure are shown in Table 1. Crops were not irrigated and long term no-till was not being practiced.

Sites were identified as 10 x 10 m sampling areas. All sites were located with GPS equipment to ensure samples were collected from the same area throughout the study. Soil samples were collected at each of the four corners and in the center of the sampling plot at depths of 0-15, 15-30, 30-45, 45-60, and 60-120 cm at planting (May 18, 2006, Day of Year, DOY 139) and after harvest (October 22, 2006, DOY 297) in 5 cm diameter samples. During the growing season (DOY 165 to 235), biweekly soil samples were collected at 0-7.5, 7.5-15.0 and 15.0-22.5 cm depths by aggregating five 2.5 cm diameter soil cores randomly collected from the sampling area. At the same time biweekly, soil water content measurements were collected to a depth of 10 cm using a time domain reflectometry (TDR) probe.

Samples from each soil depth were analyzed for bulk density, N, P, K, C, and pH at the Iowa State University Soil Testing Laboratory (Missouri Agricultural Experiment Station, 1998). Nitrogen content was expressed as total N in both inorganic and organic forms (Missouri Agricultural Experiment Station, 1998). Total plant available P was measured with a Mehlich III test, which is appropriate for the soils of Iowa (Missouri Agricultural Experiment Station, 1998). Duplicate samples were analyzed within the National Soil Tilth Laboratory as a cross reference to evaluate quality of the process and differences in N and P content were less than 5 percent between the two laboratories. Concentrations were expressed as mg kg^{-1} (dry weight) for all nutrients. Bulk density samples were collected at the initial sampling period for each depth by removing a 125 cm^3 volume of soil with an open sided sampler, weighing the sample, drying the soil volume at 105°C for 48 hours, reweighing to determine the dry weight, and then using that weight to determine the dry mass of soil per unit volume of soil.

Plant samples from the corn sites were collected biweekly (DOY 165 to 235) on the first fully expanded leaf from the top and the ear leaf after tasseling by removing 1 cm^2 disk from the center point of the leaf to the side of the midrib. Five different leaves were sampled from each site during the course of the study with different leaves sampled each week. Nutrient contents of P and N were obtained from the Iowa State University Soil Testing Laboratory (Missouri

Table 1. Soil Types and Cropping Management Characteristics for Each Site.

Site	Field	Soil Type	Crop	Manure Application			Sidedress N Applied (kg ha^{-1})	Manure Applied in 2005
				Month Applied	N Added (kg ha^{-1})	P Added (kg ha^{-1})		
1	1	Coland clay loam	Corn	April 2006	112	52	56	
2	1	Webster clay loam	Corn	April 2006	112	52	56	
3	1	Clarion loam	Corn	April 2006	112	52	56	
4	1	Clarion loam	Corn	April 2006	112	52	56	
5	2	Lawler loam	Corn	October 2005	157	76	0	
6	2	Coland clay loam	Corn	October 2005	157	76	0	
7	3	Clarion loam	Soybeans		0	0	0	Yes
8	3	Clarion loam	Soybeans		0	0	0	No

Table 2. Detailed Descriptions of the Soil Types within the Study Site in Central Iowa. Data from Soil Survey of Hardin County.

Soil Type	Depth (cm)	Texture	Clay (%)	Bulk Density (g cm^{-3})	pH	Available Water (cm cm^{-1})
Clarion Loam	0-33	Loam	22	1.42	6.2	0.21
	33-84	Clay loam	27	1.60	6.8	0.18
	84-152	Sandy loam	17	1.75	7.8	0.18
Coland Loam	0-100	Clay loam	31	1.45	6.7	0.21
	100-152	Sandy loam	19	1.57	7.0	0.15
Lawler Loam	0-53	Loam	23	1.42	6.2	0.21
	53-76	Sandy clay loam	24	1.52	5.8	0.17
	76-152	Sandy loam	7	1.62	5.8	0.03
Webster Clay Loam	0-55	Silty clay loam	31	1.37	7.0	0.20
	55-96	Clay loam	30	1.45	7.1	0.17
	96-152	Sandy loam	23	1.60	7.9	0.18

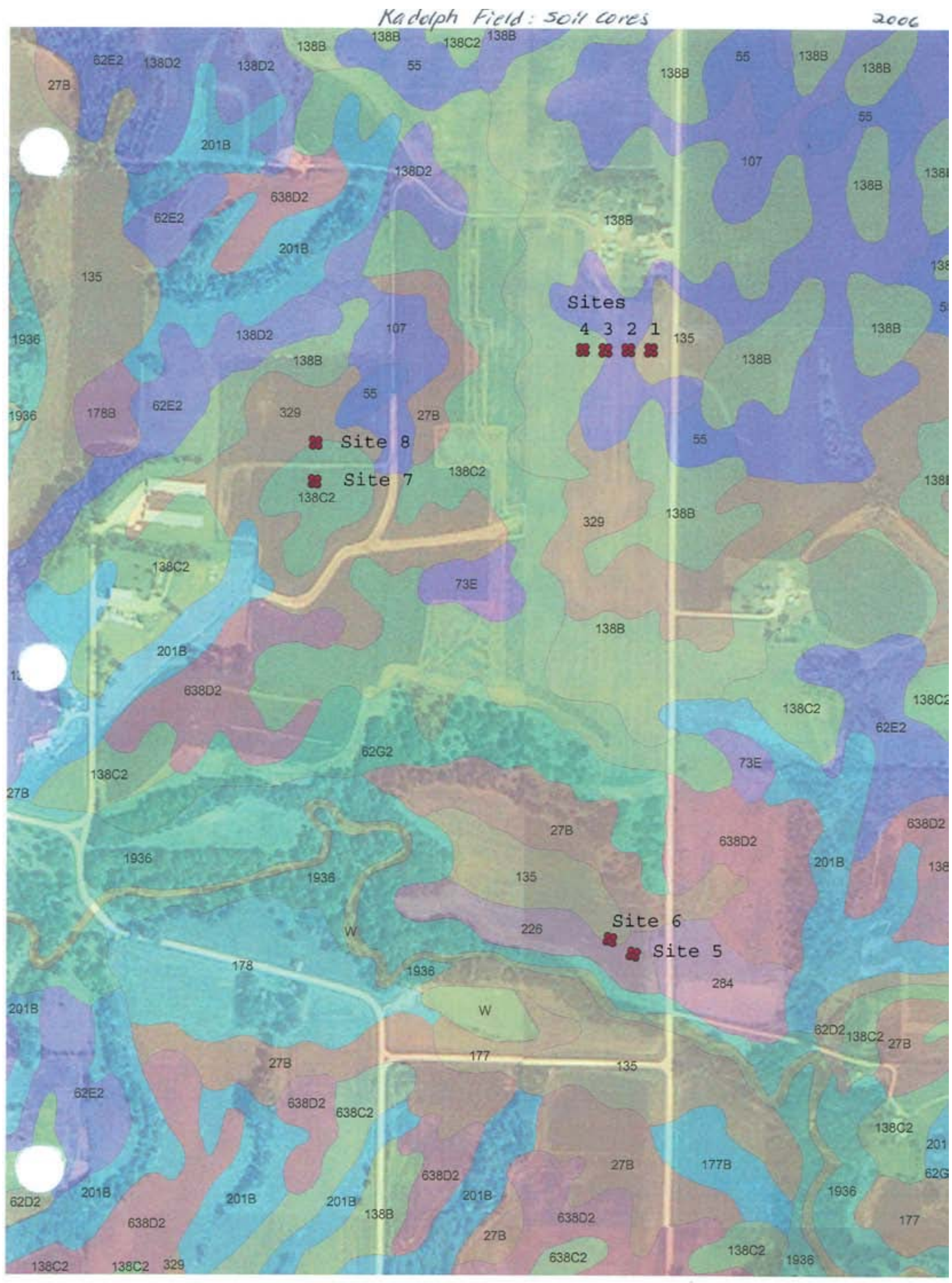

Figure 1. Locations of the eight sites at the Hardin County swine production farm for the 2006 CAFO nutrient sampling study. Scale: 0.25 km per cm.

Agricultural Experiment Station, 1998). Corn biomass samples were collected from two plants from the edge of the sampling area at the biweekly interval. After tasseling, biomass samples were separated into leaves, stalks, and ears. Plant biomass samples were dried. These data were used to estimate N and P removal from the soil into the plant biomass during the season. Biomass plant samples were collected at the end of the growing season from the soybean sites. Soybean biomass samples were divided into vegetative and seed fractions, dried, and analyzed for N content at the Iowa State Soil Testing Laboratory (Missouri Agricultural Experiment Station, 1998).

Meteorological data (maximum and minimum daily temperature, and daily precipitation) were collected from an automated weather station located on the cooperator's farm within 0.5 km of the field sites.

3.0 Data Analyses

Results were obtained for each soil depth and sampling location within the sampling area. These data were then evaluated to determine the variation within the sampling area. Amounts of soil P and N were expressed as g m^{-3} and kg m^{-3}, respectively. These values were derived by adjusting the P and N concentrations at each depth by the bulk density of the soil obtained at the initial sampling period. Differences in soil N and P concentrations were determined from the intensive samples collected in the spring and fall to evaluate changes over the course of the growing season. Statistical differences were deemed significant at the 0.05 level.

Meteorological Conditions

Maximum and minimum temperatures during the growing season were typical of most years in central Iowa (Figure 2). Maximum temperatures exceeded 30°C for a few days during the season. Precipitation, however, was characterized by sparse rainfall during the early growing season and abundant rainfall during the latter part of the growing season (Figure 3). The lack of precipitation events created a situation in which the upper soil profile was extremely dry through most of the early growing season.

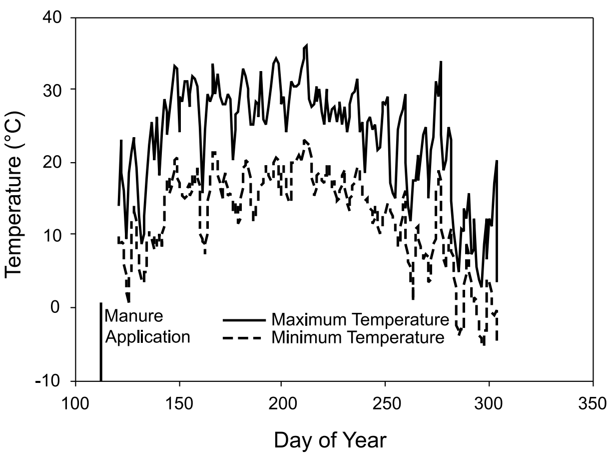

Figure 2. Maximum and minimum daily temperatures during the 2006 growing season in central Iowa. A bar in the figure indicates date of the spring manure application.

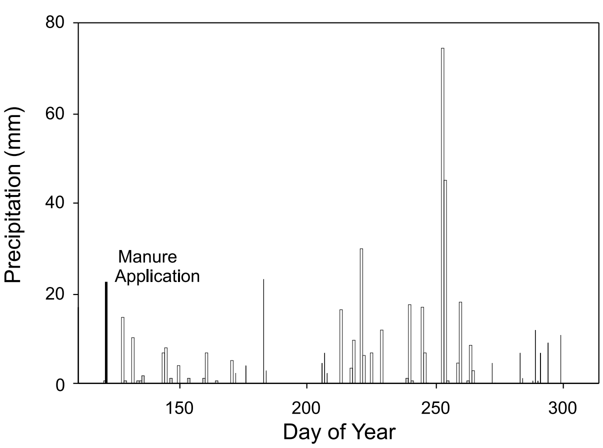

Figure 3. Daily precipitation during the 2006 growing season in central Iowa. A bar in the figure indicates date of the spring manure application.

Variation of Soil Nutrient Concentrations within Sampling Sites

The largest variation in total soil P was in the upper sampling depth for the five subsamples within Site 1 for the May sampling date (Figure 4). The standard deviation of the mean was larger relative to its mean compared to means and standard deviations at lower depths. This pattern was observed across all eight sites.

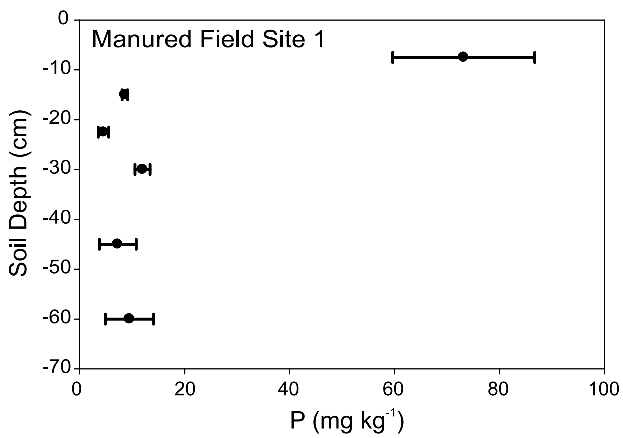

Figure 4. Means and standard deviations of Mehlich III P concentrations over the six sampling depths for the five subsamples from Site 1. Site 1 is in Field 1, which received spring application of swine manure. Soil samples were collected in May 2006. Crop management characteristics are summarized in Table 1.

An example for changes in soil N concentration with depth is shown in Figure 5. Changes in soil N concentrations with depth were slightly different compared to soil P. Similar to changes in soil P concentrations, the highest concentration of N was in the upper layer. However, the decrease in N concentration from the uppermost layer to the next depth was less with soil N compared to soil P. The decline in the total N concentration with soil depth was similar among Sites 1-4 in Field 1 (Figure 6). These four sites represent three different soil types (Table 1). In comparing the profile concentrations for N and P among the three soils within Field 1 there was no significant difference among the soils (data not presented). Variations among soils were insignificant for this field for the spring and fall sampling periods. Similar trends were found for the total P concentrations with depth for Sites 1-4. Total P concentration differed significantly among the four sites only in the upper sampling depth (Figure 7). Concentrations of total P were lower at Site 3. There was a rapid decrease in the concentrations of both P and N with depth in the profile which is expected since the manure is applied in the upper profile and there is a large amount of plant residue from the previous crop present in these layers as well.

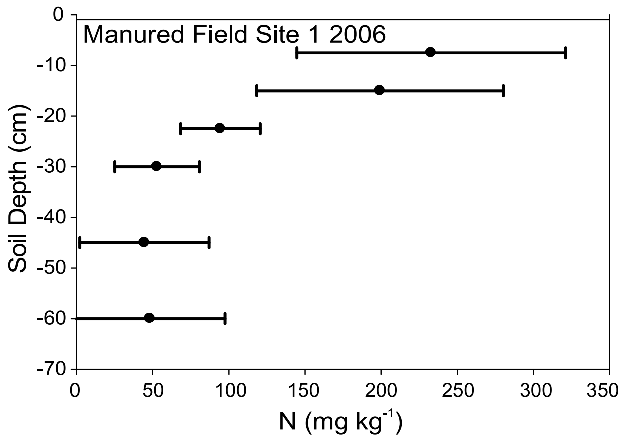

Figure 5. Means and standard deviations of soil total N concentrations over the six sampling depths for the five subsamples from Site 1. Site 1 is in Field 1, which received spring manure application. Data are from samples collected in May 2006. Cropping characteristics are summarized in Table 1.

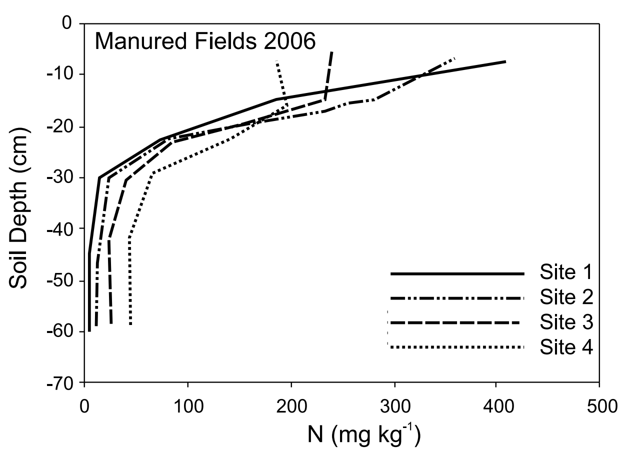

Figure 6. Soil total N concentrations with depth for Sites 1-4 in Field 1. Field 1 received spring application of swine manure in 2006 (Table 1). Samples were collected in May 2006.

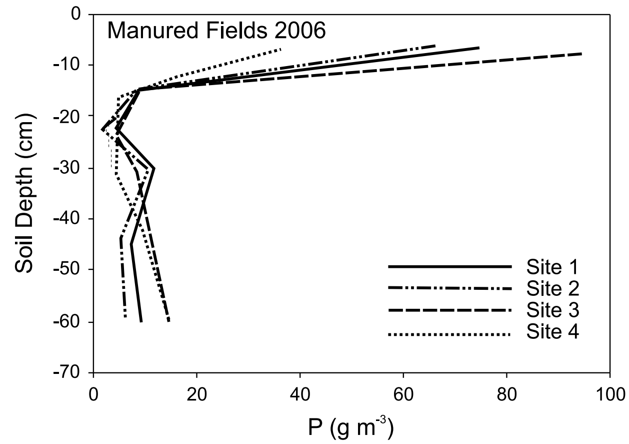

Figure 7. Mehlich III P concentrations with depth for Sites 1-4 in Field 1. Field 1 received a spring swine manure application (Table 1). Samples were collected in May 2006.

Nutrient Concentrations in the Soil during the Growing Season

Total soil N concentrations at the 7.5 cm sampling depth showed large variations among the four sites (1-4) in Field 1 and smaller variations across the season (Figure 8). This variability was attributed to differences in the initial soil N concentrations among the four sites because the patterns remained consistent across the season. This depth of the soil profile is most dynamic in terms of mineralization processes and during the 2006 growing season this part of the soil profile was quite dry with water contents in the upper 10 cm often near 0.1 percent of available water. The variation across the season and among soils was typical of what we have observed in other studies in sampling this soil depth (Hatfield and Prueger, 1994).

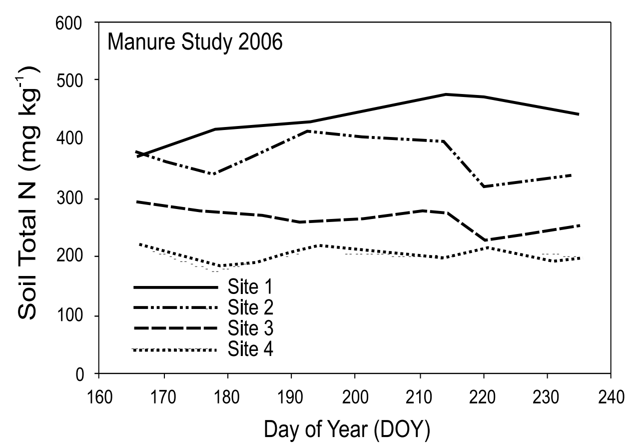

Figure 8. Changes in the total soil N concentrations at the 7.5 cm sampling depth for the four sites (1-4) in Field 1 during the 2006 growing season. Crop and soil management characteristics are presented in Table 1.

Changes in N and P concentrations in the soil profile were evaluated for the three different fields and cropping strategies present in 2006. For these comparisons, data from soil samples collected at the beginning and end of the growing season were averaged across sites within Fields 1 (Sites 1-4) and 2 (Sites 5-6). There was a decrease in P concentrations at all depths for Sites 1-4 in Field 1 (Figure 9), which had a reduced application rate of spring applied manure supplemented with N sidedress application. The change in P within the soil profile was greatest with the soil collected closest to the surface. At all depths there was a decrease in total soil P, consistent with P removal to meet the crop nutrient requirements.

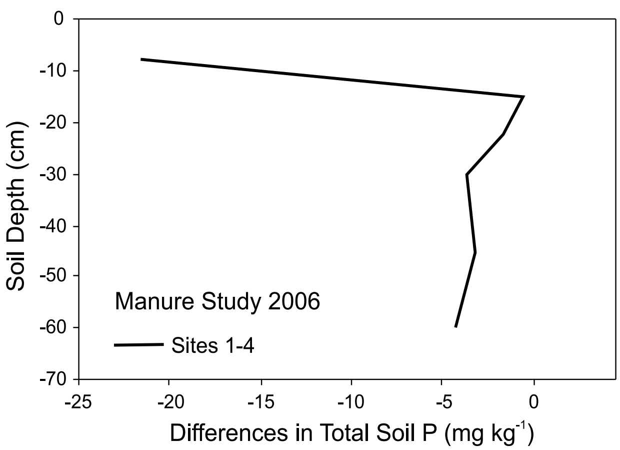

Figure 9. Differences in Mehlich III P concentrations with soil depth in Field 1 between the spring and fall sampling periods in 2006. Field 1 received a spring application of swine manure (Table 1). Concentration values of samples collected in the spring were subtracted from those collected in the fall and data from Sites 1-4 in Field 1 were averaged graphed values.

Soil N concentrations from the beginning to the end of the growing season decreased in Field 1, which received the spring manure application (Figure 10). There was a decrease in the N concentration in the upper soil profile because of uptake from the soil by the crop. However, the largest decrease in total soil N concentration was found in the 20 - 50 cm depth. This depth typically has the highest concentrations of roots to extract N (Kramer and Boyer, 1995). This pattern of N extraction was exaggerated in 2006 because of the dry year and points out the problems in a single year of observations. Sampling N concentration using this method is inclusive of all sources of N within the soil layer which may not be related to the amount of manure applied to the soil.

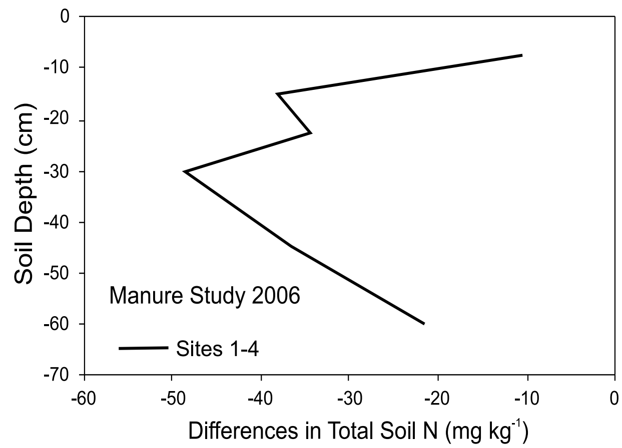

Figure 10. Differences in soil total N concentrations with soil depth in Field 1 between the spring and fall sampling periods in 2006. Field 1 received a spring application of swine manure (Table 1). Concentration values of samples collected in the spring were subtracted from those collected in the fall and data from Sites 1-4 in Field 1 were averaged to obtain graphed values.

Sites 5 and 6 in Field 2 (Table 1) received fall applied manure to supply 157 and 76 kg ha^{-1} of N and P, respectively. Total soil P and N concentrations decreased at all depths in the soil profile over the growing season (Figures 11 and 12). Removal of N from the soil profile was greatest at the 20 - 40 cm depth similar to the other sites. The most noticeable change in the P levels was in the upper layer of the soil profile in which there was a decrease exceeding 15 g m^{-3} in this layer. These changes in P and N concentrations from spring to fall in Field 2 showed similar patterns to that found for Sites 1-4 in Field 1. Thus, there was no difference in the patterns of nutrient changes between the fall and spring applied manure reflected in the patterns of change within the soil profile (Figures 9-12). Although there was less P applied to this field as a result of the lower amount of manure applied and then supplemented with sidedress N, there was no significant difference in the P removal rates between the two fields. There was adequate P within the soil profile to supply the P requirements for the corn crop during this year. In years with a greater amount of rainfall there may be a greater difference between these two systems.

Differences in total soil N and P concentrations throughout soil profiles were not significant for samples collected from Sites 7 and 8. Both fields showed similar patterns in the concentration profiles. There was no difference in the rooting depth between these two fields based on the observations of the soil samples collected after harvest. The soybean field with the manure history (Site 7) showed an insignificant increase in Mehlich III P concentrations in the upper soil depth over the growing season. There was no additional P added to the soil during this period and these differences can be attributed to sampling variation within small areas. Changes over the growing season for Sites 7 and 8 showed similar patterns to Sites 1-4.

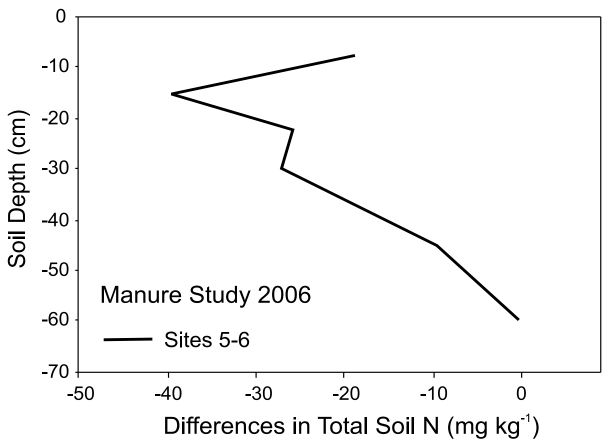

Figure 11. Differences in total soil N concentrations with soil depth in Field 2 between the spring and fall sampling periods in 2006. Field 2 received a fall application of swine manure (Table 1). Concentration values of samples collected in the spring were subtracted from those collected in the fall and data from Sites 5 and 6 in Field 2 were averaged.

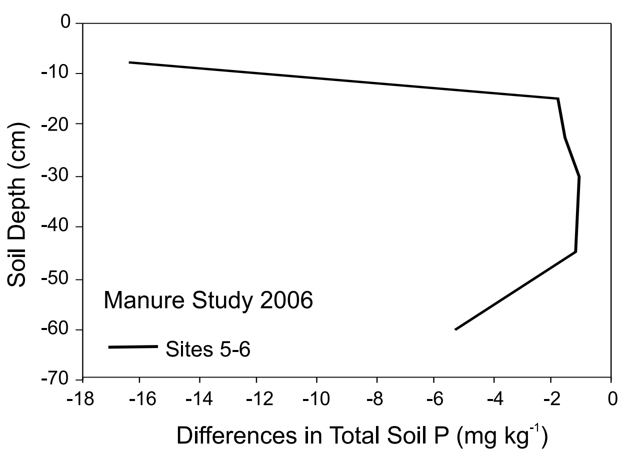

Figure 12. Differences in Mehlich III P concentrations with soil depth in Field 2 between the spring and fall sampling periods in 2006. Field 2 received a fall application of swine manure (Table 1). Concentration values of samples collected in the spring were subtracted from those collected in the fall and data from Sites 5 and 6 in Field 2 were averaged.

Soil samples collected from the soybean fields (Field 3) did not show any difference within the profile throughout the year. This was expected because no manure was applied during this season, and any N or P added from manure in previous years had been removed by the previous year's crop.

Plant Nutrient Concentrations

Changes in the total N concentration in plant leaves showed a decrease during the growing season (Figure 13). There was no significant difference in the N concentrations among Sites 1-4 in Field 1 during this study.

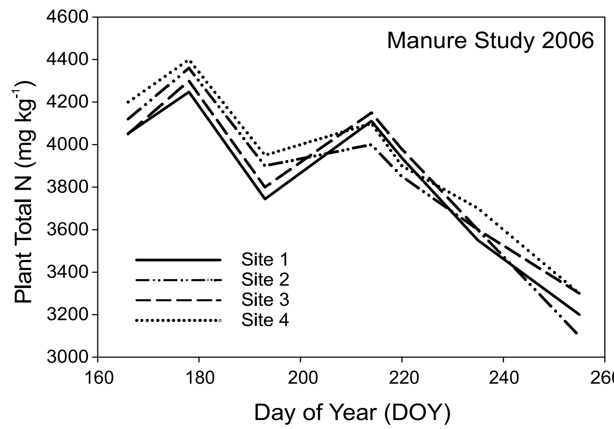

Figure 13. Changes in plant total N concentration in plant leaves throughout the growing season for Sites 1-4 in 2006. Field 1 received spring application of swine manure (Table1).

Nutrient Balance

Analyses of plant biomass production and its N content indicated that N removal in the aboveground biomass for Field 1 (Sites 1-4) was 208 kg ha^{-1}, for Field 2 (Sites 5 and 6) was 197 kg ha^{-1}, and for Field 3 (Sites 7 and 8) was 147 kg ha^{-1}. The calculated nutrient removal based on the changes in the total N from the soil profile for Field 1 (Sites 1-4) was 197 kg ha^{-1}, for Field 2 (Sites 5 and 6) was 200 kg ha^{-1}, and for Field 3 (Sites 7 and 8) was 137 kg ha^{-1}. There is very good agreement between the N changes and crop removal rates in this study (Figure 14). There was no significant difference between Field 1 and Field 2 in the N removal. This is expected because there was no significant difference in the yield between these two manure management systems with a yield of 10,160 kg ha^{-1} for the two fields. For Field 3 with the soybean crop the yield for both sites was 2,500 kg ha^{-1} with no significant difference between the fields.

The P balance showed a similar good agreement between changes in the soil concentration and P content of the biomass and grain. In Field 1, the soil-based P removal was calculated to be 62 kg ha^{-1}. P removal based on biomass and grain content was 65 kg ha^{-1} for Field 1. In Field 2, the soil-based P removal was calculated to be 56 kg ha^{-1} compared to 64 kg ha^{-1} for calculations based on biomass and grain. There was no significant difference between the two methods of estimating P removal rates. This CNMP is based on reapplying nutrients to meet the crop removal, and for the year in the study these results demonstrate the effectiveness of the method. Even though the crop residue was not removed, these nutrients are now present on the surface and would be returned to the soil profile as a result of residue decay, microbial activity and tillage. However, at crop harvest (the endpoint for this study) these nutrients can be considered as being removed from the profile. These values for removal exceed the amount applied with the difference being the extraction from the soil profile during the cropping season.

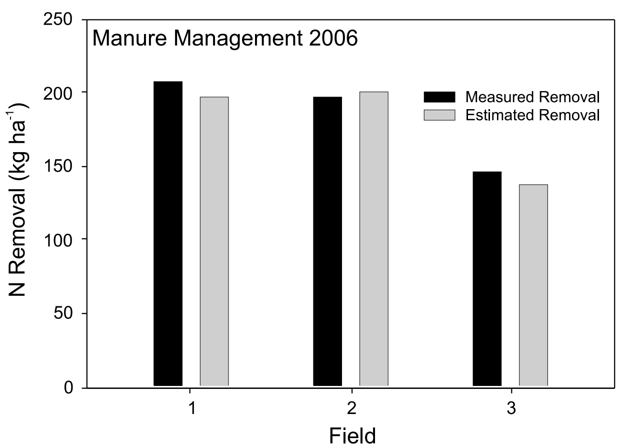

Figure 14. Comparison of measured versus estimated N removal from corn-soybean rotations with manure nutrient additions for the 2006 study. Sites 1 are (1-4), Site 2 (5-6) and Site 3 (7-8).

5.0 Conclusions and Impact

Application of swine manure using CNMPs onto a corn-soybean cropping system creates a condition in which there is extraction of nutrients from the soil profile to meet the crop demand. The 2006 growing season was not typical with the small precipitation events during the portion of the growing season in which there is the most rapid vegetative growth and grain production. This created a condition in which there was a water deficit in the soil profile with the plants extracting water from within the soil profile to depths exceeding 1.5 m. Water contents in the soil samples collected at harvest indicated the soil was near the lower limit of soil water availability (data not shown), thus there was no water for transport of nutrients within the soil profile. This scenario is not atypical of central Iowa where the soil profile is dry at the time of harvest. These meteorological conditions would create a situation that limits any downward movement of nutrients, especially NO_3-N. However, the extraction of nutrients from the soil profile was necessary to offset the amount applied to the soil via manure and sidedress N to the corn crop and this practice did not affect yield between the two practices. Following CNMPs does meet the agronomic demand for the crop and the P and N removal rates from the soil profile were not significant between the two different manure management systems. In the soybean field that had portions with and without a history of manure there was removal of N and P from the profile to meet the crop growth demands for nutrients. The lack of differences in the nutrient contents for these fields showed that there was no residual N or P from the previous manure application. For both the corn and soybean crop a portion of the nutrients removed would be returned to the soil through the crop residue (leaves and stalks) that would be left on the soil profile. The amount returned to the soil from the residue would replenish the profile of the amounts removed during the season.

The metrics for ground-water contamination in this study were not directly assessed because this year with limited rainfall proved to limit water movement. Techniques for sampling shallow ground water in these poorly drained soils require a minimum of one year of adjustment time before sample collection and are not possible to use when the soils are dry. We would conclude from this one-growing season study that following CNMPs provides nutrients in adequate supply for the crop with the addition of that extracted from the soil profile. One of the limitations for this study was the lack of precipitation during the growing season which allowed only for a partial assessment of Objective 2. Variation in precipitation among years requires multiple years of study and other studies being conducted in central Iowa suggest that a minimum of five years may be needed to account for the variation in precipitation timing and amounts during cropping season. These types of studies need to be conducted over a range of meteorological scenarios to address the variable conditions of soil water content induced by different precipitation amounts. We would expect a similar result with the crop demand using the nutrients applied from the manure source. Producers should be aware of the value of developing CNMP for fields and the potential variation among soils in their response in supplying nutrients to the crop.

6.0
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