Liquid swine manure as a nitrogen source for corn and soybean production

by

Sudipta Rakshit

A thesis submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Soil Science (Soil Fertility)

Program of Study Committee:
John E. Sawyer (Major Professor)
Antonio Mallarino
Dan Nettleton

Iowa State University

Ames, Iowa

2002

Graduate College

Iowa State University

This is to certify that the master's thesis of

Sudipta Rakshit

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy

TO:

God

My Parents

Sister

TABLE OF CONTENTS

GENERAL INTRODUCTION

Utilization of liquid swine (*Sus scrofa domesticus)* manure nutrients for corn (*Zea mays* L) and soybean [*Glycine max* (L.) Merr.] production is of large concern in Iowa as well as other areas of the Midwest and USA. The growing number of concentrated swine facilities, and resulting large amount of manure nutrients, provides a good opportunity for use of liquid swine manure as a nutrient resource for raising crops. In Iowa as an example, approximately 11,820,000 market hogs have the potential to generate about 40,247,100 kg crop available-N per year as manure (Killorn and Lorimor, 1999; assumed 50% of manure nutrients recoverable and 50% crop-available in the first year). The numbers for P and K would be 43,198,554 and 64,395,360 kg crop available P_2O_5 and K_2O per year. This large amount of manure nutrients produced statewide, as well as those in local geographic areas, needs good management (Bitzer et al., 1988) for economic and agronomic crop production, and for reducing the risk of potential deterioration of water quality (Powers et al., 1975).

Nitrogen is one of the most important nutrients to manage for corn production because of frequent applications and large crop use. Problems associated with uncertainty in crop availability of N from liquid swine manure have not been completely resolved. Also there is need for improving producer confidence in crop availability of N in manure, and the ability to produce high yields solely with manure application. Therefore, the demand for more research about swine manure-N to determine correct application rates for economic and agronomic crop production is evident.

The variability of manure-N content from different manure sources imposes an extra challenge to the manure management practices. In their study, Randall et al. (1999) found it was necessary to consider each of their sites differently because of the variability in swine manure nutrient analysis, and the resultant nutrient application rates. This highlights the risk of using a book value for manure nutrient content, and the uncertainty in regard to actual application rates. Therefore, there is a need to better understand manure nutrient content prior to application and for calibration of application rates.

As soybean occupies large acreage in Iowa, the potential of soybean to utilize liquid swine manure nutrients is an important issue. Soybean has traditionally been accepted as a crop that satisfies it's N needs from N-fixation when soil inorganic-N is not sufficient to meet crop needs. Liquid swine manure application to soybean can provide needed P and K. However, research is necessary to understand the fate of N added with manure. If not used by the soybean crop, the added manure-N converted to inorganic nitrate could be detrimental to the environment (Schmidt et al., 2000). With demand for nutrient management planning, it is necessary to understand effects on soybean production with liquid swine manure application and at the same time the potential environmental consequences from nitrate (Schmidt et al., 2000). It has been shown that soybean can act as an N sink and actively use inorganic-N available in soil (for example Varvel et al., 1992). They reported grain N removal of 150-200 kg N ha^{-1} at yields of 2.5 to 3.4 Mg ha^{-1}. In recent soybean N fertilization studies, Sawyer and Barker (2001) found soybean aboveground biomass N at the R6 growth stage of 185 to 290 kg N ha^{-1} and an average 45 kg of N per Mg soybean grain. Schmidt et al. (2000) reported that liquid swine manure application to a nodulating soybean variety did not affect maximum yield, irrespective if no N, sufficient N, or excess N was applied.

The main objective of this study was to determine effect of liquid swine manure-N on corn and soybean production in producers' fields. In addition, an objective was to determine second-year residual manure-N effects on corn and soybean crops.

THESIS ORGANIZATION

The thesis is organized with a general introduction, two papers that will be submitted to the *Agronomy Journal,* and an overall conclusion. Each individual paper has an abstract, introduction, materials and methods, results and discussion, and conclusion.

REFERENCES

Bitzer, C. C. and J. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. J. Environ. Qual. 17:47-54.

Killorn, R. and J. Lorimor. 1999. Managing manure nutrients for crop production. Iowa State University Extension pub. Pm-1811. Iowa State University, Ames, IA.

Powers, W.L., G.W. Wallingford, and L. S. Murphy. 1975. Research status on effects of land application of animal wastes. p. 44-46. EPA 660/2-75-010. U. S. Printing Office, Washington, D. C.

Randall, G. W., M. A. Schmitt, and J. P. Schmidt. 1999. Corn production as affected by time and rate of manure application and nitrapyrin. J. Prod. Agric. 12:317-323.

Sawyer, J. E. and D. W. Barker. 2001. In-season nitrogen fertilization of soybean. p. 158-161. *In* Proc, 31st North Central Ext.-Ind. Soil Fert. Conf., Des Moines, IA. 14-15 Nov. 2001. Potash and phosphate Inst., Brookings, SD.

Schmidt, J. P., M. A. Schmitt, G. W. Randall, J. A. Lamb, J. H. Orf, and H. T. Gollany. 2000. Swine manure application to nodulating and nonnodulating soybean. Agron J. 92:987-992.

Varvel, G. E. and T. A. Peterson. 1992. Nitrogen fertilizer recovery by soybean in monoculture and rotation systems. Agron. J. 84:215-218.

LIQUID SWINE MANURE AS A NITROGEN SOURCE FOR CORN PRODUCTION

A paper to be submitted to Agronomy Journal

Sudipta Rakshit and John E. Sawyer

Abstract

Liquid swine (*Sus scrofa domesticus)* manure is a large crop nutrient resource in Iowa, but one that must be appropriately managed to gain maximum effectiveness. A multi-year project was initiated on producers' fields to document corn (*Zea mays* L) productivity based on manure-N, and compare response to additional fertilizer-N. Three calibrated liquid swine manure rates were applied in replicated strips across field length. The rates were zero, low and high based on manure total-N: target of 0, 84, 168 kg total-N ha^{-1} for corn following soybean [*Glycine max* (L.) Merr.], and 0,112, and 224 kg total-N ha^{-1} for corn following corn.). The liquid swine manure was injected except for two sites where manure was broadcast applied with incorporation the next day. Four fertilizer-N rates (0, 45, 90, 135 kg N ha^{-1} for corn following soybean, and 0, 67, 135, and 202 kg N ha^{-1} for corn following corn) were applied in small split-plots to each manure strip to measure response to additional N application. The experimental design was a randomized complete block with a split-plot treatment arrangement. In both years corn yield showed large increase to low manure-N rates, and frequent but smaller additional yield increases with high manure-N rates, except at non-responsive sites or sites where the low manure-N rate was adequate to meet corn N needs. The non-responsiveness of two sites was attributed to a high manure application history and a dry growing season. Corn typically produced highest yield response to

additional fertilizer-N with the no-manure rate, frequent increase with the low manure-N rates, and no response with the high manure-N rates (except for one site in 2001 where manure-N was suspected to be lost through volatilization during broadcast application and before incorporation). Liquid swine manure provided adequate to above adequate-N to corn with the high manure-N rate and occasionally with the low manure-N rate. The sites showed similar variability in their responsiveness to both manure and fertilizer-N. Post-harvest soil profile nitrate was not increased by swine manure application, except when sites were non-responsive or more than adequate manure plus fertilizer-N was applied. Liquid swine manure was shown to readily supply crop-available N and that the manure total-N is highly crop-available. Because of this, best management should consider practices that optimize application rates, minimize potential for loss, and estimate optimal rates of needed N.

Introduction

Liquid swine manure is an important resource to fulfill corn nutrient needs. However, problems associated with uncertainty in crop availability of nutrients like N from liquid swine manure have not been completely resolved. Likewise, there is need for improving producer confidence in crop availability of N in manure, and the ability to produce high yields solely with manure application. Sometimes producers, being uncertain about correct manure application rates, tend to over-apply manure; or they apply additional fertilizers to be certain about desired soil nutrient supply. This triggers problems related to reduction of producers' profit and potential deterioration of water quality (Powers et al., 1975).

In Iowa as an example, approximately 11,820,000 market hogs have the potential to generate about 40,247,100 kg crop available N per year as manure (Killorn and Lorimor, 1999; assumed 50% of manure nutrients recoverable and 50% crop available for the first year). This large amount of available N necessitates good management practices (Bitzer and Sims, 1988) to achieve adequate corn production for high profit, and to avoid degradation of water quality.

Nitrogen is one of the most important nutrients to manage for corn production because of frequent application and large crop use. Producer interest has increased in using animal manures as a N source, and best management for improving corn yields (Sutton et al., 1982). Jokela (1992), for example, found that corn yield increased significantly compared to check plots with application of dairy manure at a rate of 9 Mg dry matter ha^{-1}, and additional N fertilization on top of the manure application did not significantly enhance corn yield. In that study, manure-N availability to corn was reported at 27 to 44%, which was similar to 73 to 122 kg fertilizer-N ha^{-1} in terms of yield response.

There is need to compare the N availability from manure to commercial fertilizer to help achieve most efficient nutrient management for corn production. More research is needed regarding the potential of manure-N to supply crop N needs, and to help farmers understand the economic rate of manure application. Adeli and Varco (2001) found similar dry matter yield for forage grasses with application of swine lagoon effluent compared to commercial fertilizer, indicating both sources were equal in availability of N and P at the specific rate used. Eghball and Power (1999) reported that beef manure and compost application resulted in similar grain yield compared to inorganic fertilizers except for one year in a four-year field study. Killorn (1998) reported evidence of higher corn yield with liquid swine manure compared to N only fertilizer when no response to other nutrients would be expected. In addition, results of the study suggested that for liquid swine manure stored in anaerobic pits, the total-N content could be considered plant-available.

Nitrogen use efficiency of manure-N has been an important issue. Nitrogen loss from manure through denitrification and leaching is critical for understanding manure nitrogen availability. McCormick et al. (1984) reported that use of a nitrification inhibitor generally had no significant effect in increasing corn yield with spring applied swine manure, but did have a significant effect in increasing corn yield with fall applied swine manure indicating potential for less chance of manure-N loss with spring application. Sawyer et al. (1991) reported that use of nitrification inhibitors did not consistently increase yield significantly with spring applied liquid beef manure application. With good manure-N management (injection, spring application), they found the estimate of 75% of total-N worked well for estimating crop availability of liquid beef manure-N. Randall et al. (1999) in Minnesota found liquid swine manure applied in spring resulted in greater grain yields than when applied in fall. However, results varied among sites depending on the rainfall amount and temperature.

The variability of manure-N content from different manure source imposes an extra challenge to manure nutrient management. In their study, Randall et al. (1999) found it necessary to consider each of their sites separately because of the variability in swine manure nutrient analysis, and resultant nutrient application rates. This highlights the risk of using a book value for manure nutrient content, and the uncertainty in regard to actual application rates. Therefore, there is a need to better understand manure nutrient content prior to application and for calibration of application rate.

The main objective of this project was to determine the effect of liquid swine manure-N on corn production in producers' fields and to determine corn response to fertilizer-N in addition to applied manure-N.

Materials and Methods

This study was conducted at five producer field sites in 2000 and six sites in 2001 across Iowa. The previous crop for all the sites in 2000 was soybean. In 2001, four sites were corn following soybean, with two sites corn following corn. Site characteristics are given in Table 1. The soil types listed in Table 1 correspond to the strips and split plot area.

The experimental design was a randomized complete block with a split-plot treatment arrangement (Fig. 1). The main plots were three liquid swine manure rates applied in strips across the field length with producer equipment or custom application equipment. The planned manure application rates were a check or 0 kg N ha^{-1}, low or 84 kg total-N ha^{-1}, and high or 168 kg total-N ha^{-1} at most of the corn following soybean sites. At some sites manure was applied based on other planned rates. At the Washington-1 site in 2000, the intended high rate was 224 kg total-N ha^{-1}. At the Washington-1 site no low manure rate was applied. The low rate at the Hardin-1 site in 2000 and low and high rates at Cerro Gordo-1 site in 2001 were P based. At the corn following corn sites, the intended low and high application rates were P and N based, respectively. The intended high N rate for these sites (Hardin-3 and Cerro Gordo-2) was 224 kg total-N ha^{-1}. The actual applied manure rates varied among sites due to differences in manure-N concentration and applicator constraints (at the Plymouth-1 site, the actual application rates were considerably higher than intended because of manure applicator flow and tractor speed constraints, which limited the lowest rate possible to the one reported for the low rate, Table 2). The strip width and length ranged between 150-760 m x 9-18 m with size depending on the manure applicator width, combine header width, and field length (Table 2).

The split plots were four fertilizer-N rates (0, 45, 90 and 135 kg N ha^{-1} for corn following soybean, and 0, 67, 135 and 202 kg N ha^{-1} for corn following corn) arranged in a set of four small plots (approximately 12 m x 3 m) within each manure main-plot strip. The small fertilizer-N split plots were set at a distance of approximately 24 m from the beginning of the strip. Ammonium nitrate was surface broadcast shortly after corn emergence. The split N application allowed measurement of corn response to the applied manure and to additional fertilizer-N. Blanket P and K fertilizers (67 kg P_2O_5 ha^{-1} and 67 kg K_2O ha^{-1}) were broadcast applied to the split-plot area before final spring tillage to mask the effect of P and K applied with manure.

No N, P or K fertilizer was applied to the field strip area, except at Cerro Gordo-1 and Cerro Gordo-2. At Cerro Gordo-1, fertilizer was applied across all strips at a rate of 13 kg N, 45 kg P_2O_5, and 134 kg K_2O ha^{-1} in the fall. At Cerro Gordo-2, P and K were applied (at unknown rate) in the fall and starter fertilizer was applied at a rate of 11 kg N ha^{-1} and 38 kg P_2O_5 ha^{-1}. Producers used common cultural practices for the geographic area.

The manure sources were from confined swine production facilities. The manure storage structure was under building pits at all sites except Plymouth-1 where the storage was an outdoor cement tank. Manure was injected below the soil surface using knife-injection or disk-soil covering at application, except the Clay-1 site and Clay-3 sites (Table 1) where manure was surface broadcast applied and incorporated within 24 hr. Application timing was spring pre-plant, except at the Washington-1 and Washington-2 sites, where application was in the fall (Table 2).

Manure application rates were determined by pre-application manure sampling and laboratory chemical analysis (Table 2), and manure applicator calibration. The calibration procedure was accomplished by first weighing the applicator when it was full, and then weighing again after application through a known area at a set speed. The rate was calculated from the difference of these two weights. Some of the applicators had flow control rate monitors to set the rate of application, although the same calibration procedure was followed for these applicators. Speed or flow was adjusted if needed, and calibration determined again.

Pre-application manure samples were collected approximately 2-3 weeks before planned application from the producers' storage structures. Samples were either dipped off the manure surface, or collected from a probe of the storage profile. Manure was then transferred to plastic bottles with a soup ladle during continuous stirring. The manure samples were analyzed for total-N, P, and K (APHA, 1995) by the Iowa State University Analytical Service Laboratory. These pre-application samples were used, in conjunction with the applicator calibration, to set manure application rates. Manure samples were collected from multiple loads (every load at most of the sites) during application and analyzed for total-N, P, and K (Table 2). These samples were used to confirm as-applied nutrient content, and in conjunction with applicator calibration to determine total manure nutrient application rates.

Before manure application, 0-15 cm composite soil samples (8 cores per sample) were taken from the split-plot area and control strips. Each strip was flagged at approximately 46 m intervals to create strip points. This distance varied among sites, but was constant within sites. The soil cores were collected from within the control strip, and within 6 m of the point along the strip length. These soil samples were analyzed for soil test P, K, pH, and organic matter in Iowa State University Soil Testing Laboratory. Soil extractable P was determined colorimetrically with the Mehlich-3 P availability index (Frank et al., 1998). Soil extractable K was determined with the 1 M ammonium acetate extractant (Warncke and Brown, 1998). Soil pH was determined on a 1:1 water soil paste using an electronic pH meter (Watson and Brown, 1998). Organic carbon was determined using dry combustion (Matejovic, 1997) with a LECO CHN-2000 and converted to organic matter by multiplying with a standard numerical factor.

When corn was about 15-30 cm tall (late May to mid June), soil samples (Blackmer et al., 1997) from the strip points and selected small plots (0 and 90 kg N ha^{-1} rate for corn following soybean and 0 and 135 kg N ha^{-1} rate for continuous corn) were collected at depth of 0-30 cm for nitrate-N analysis. The soil samples were collected following the procedure described by Blackmer et al. (1997). Nitrate-N was analyzed with a colorimetric procedure using Lachat flow injection (Lachat Instruments, Milwaukee, WI) (Gelderman and Beegle, 1998). Soil nitrate-N from the strip sample points were arranged to obtain a single value for each manure treatment strip.

When corn plants were at the R1 growth stage (Ritchie et al., 1986), chlorophyll meter readings were taken from both the strips and in the fertilizer-N split-plots with a

Minolta 502 SPAD meter (Peterson et al., 1993). The chlorophyll meter readings were taken from the leaf opposite and below the primary ear leaf, and at a point one-half the distance from the leaf tip to the collar, and halfway between the leaf margin and the leaf midrib using the procedure of Peterson et al. (1993). In the fertilizer-N split-plots, fifteen random readings were averaged from plants in the middle two rows. In the strips, fifteen readings were taken randomly from the middle four rows within a distance of 12 m centered along the length of each strip point and the individual plant readings averaged. Values from each strip sample points were averaged to obtain a single value for each manure treatment strips. No chlorophyll meter readings were collected at the Washington-1 site.

Stalk samples were collected from the split fertilizer-N plots after corn physiological maturity using the procedure discussed by Blackmer and Mallarino (1996). Collected samples were dried at 60^0 C and ground to pass a 1.0 mm screen. Samples were then analyzed for nitrate-N concentration (Binford at al., 1992).

After corn physiological maturity, ears were hand harvested from the middle two rows (6 m length) of the fertilizer-N split-plots to determine grain yield. Split plot yields were not reported for the Plymouth-1 site because dry weather conditions caused extreme yield variability across the location of the split plots. Grain yields were adjusted to 155 g kg^{-1} moisture content. The corn was machine harvested from the center of each field-length strip by the cooperating producers and the yield data collected using a yield monitor at the Hardin-1, Webster-1, Clay-1, and Washington-1 sites in 2000; and the Wright-1, Hardin-3, Clay-3, and Washington-2 sites in 2001. At Cerro Gordo-1 and Clay-2R sites in 2001, the strip yield data was collected using weigh wagon because the yield monitor was not available at these sites. The yield from the split-plot portion of each strip was discarded at sites using yield-monitor data, except at Washington-1 in 2000, to calculate the strip yields. Weigh wagon yields include the split-plot portion of the strips. The width harvested from the strips varied depending on the combine header width available at each site, but harvest widths were narrower than the overall strip width.

After harvest, profile soil samples from the 0 and 90 kg fertilizer-N ha^{-1} split-plots (for corn following soybean sites) and 0 and 135 kg fertilizer-N ha^{-1} split-plots (for corn following corn sites) were collected at depths of 0-30, 30-60, 60-90, 90-120 cm to determine residual soil nitrate. In 2000, samples were collected only from 0 kg fertilizer-N ha^{-1} split-plots. The samples were analyzed for nitrate-N using a colorimetric Lachat flow injector method (Gelderman and Beegle, 1998). The nitrate-N concentration was converted from mg nitrate-N kg^{-1} to kg nitrate-N ha^{-1} soil by adjusting for bulk density at each depth using assumed bulk densities (Dr. Tom Fenton, personal communication).

Corn grain samples were digested using the procedure of Hach et al. (1987). Finely ground grain samples were heated at 440^0 C for 4 min in a Hach digester in 100 ml volumetric flasks with concentrated (18 M) H_2SO_4, and then 10 ml H_2O_2 was added and heated until a clear solution was obtained. More H_2O_2 was added if needed to clear the solution. After cooling, the solution was made up to volume in the volumetric flask, and an aliquot analyzed for nitrate-N in using a colorimetric Lachat flow injection (Gelderman and Beegle, 1998).

Analysis of variance was carried out with the Statistical Analysis System (SAS Institute, 1992) using the GLM and Mixed procedures. Single degree of freedom contrasts were used to compare response to fertilizer-N. When appropriate, means were separated by Fisher's protected LSD.

Results and Discussion

Field Strip Application

Grain yields, chlorophyll meter readings, and late spring soil nitrate-N concentrations were measured in the strips to monitor corn response to liquid swine manure application (Table 3). Data were analyzed separately from each site and then discussed based on crop rotation (corn following soybean and corn following corn).

Corn Following Soybean Sites

Corn grain yields were increased significantly ($P \leq 0.10$) with liquid swine manure application at seven of nine sites in 2000 and 2001. Yield increase could be due to any of the nutrients (N, P, or K) applied with manure. However, from the soil test phosphorus (STP) and soil test potassium (STK) levels across the field sites, it is evident that at the responsive sites, except Clay-3 (STP 7 mg kg^{-1}), the P and K added with manure would not be expected to cause yield increase. At the Clay-3 site, yield increase with the low manure rate could be from a combination of N and P. Yield increases from low to high manure application rates were significant ($P \leq 0.10$) only at Clay-1 in 2000 and at Wright-1 and Clay-3 sites in 2001. The reasons for non-responsiveness of the Hardin-1 and Plymouth-1 sites are explained later. Yield did not increase from the low to high manure rates at the other sites. This could be attributed to the fact that the low rate provided adequate N. These low manure rates at Webster-1 in 2000, Cerro Gordo-1, and Washington-2 in 2001 were 78, 103, and 118 kg total-N ha^{-1}, respectively. Conversely, at Clay-1 in 2000 and Wright-1 and Clay-3 in 2001, the yield increased from the low to high manure rates (low manure-N rates of 86, 102 and 80 kg-N ha^{-1}, respectively). This indicates inadequate manure-N supply at the low rates. Although the yield increase at Clay-3 could be from additional P added with the high manure rate, more likely it is due to N because as discussed later with fertilizer-N response in the split-plots (where effect of other nutrients was masked by addition of P_2O_5 and K_2O) both additional fertilizer-N and manure increased yields.

At the Hardin-1 site, corn yield did not increase with manure application. This might be attributed to a high manure application history in that field, which was suspect because of producer information regarding past applications, high soil test values for P and K (STP, and STK were 123 and 269 mg kg^{-1}, respectively). Likewise, at the Plymouth-1 site yield did not increase with manure application. This could be explained by a dry growing season at that location, uneven yield across the split plot locations, and possible high manure rate application history indicated by a high late spring soil nitrate concentration in the no-manure check strips (24 mg kg^{-1}).

Chlorophyll meter readings from the leaf opposite and below the ear leaf were taken as a measure of N sufficiency in the plant (Table 3). In most cases, the lowest reading within a site was related to lowest yield (other than the Hardin-1 and Plymouth-1 sites in 2000) documenting N deficiency in check strips. The values ranged between sites from approximately 43-52, 51-58 and 53-60 for the no-manure check, low, and high manure application strips, respectively. Differences between sites indicate different soil N supply (variation between no-manure strips and differences in response between low and high rates) and corn hybrids. Chlorophyll meter readings increased significantly ($P \leq 0.10$) from check to low and high manure rates at all N responsive sites, indicating N uptake and response to manure-N. This was consistent with yield increase. However, at the Hardin-1 and Plymouth-1 sites, there was an increase in the leaf chlorophyll meter reading from the check to low manure rate. This was not consistent with yield responses at these sites, however, the chlorophyll meter readings were high (Piekielek et al., 1992) in the no-manure check strips, indicating high available soil-N status.

At N responsive sites, chlorophyll meter readings significantly increased from the low to high manure rate (although sometimes by small amounts) indicating additional N uptake. However, the yield increase did not always follow the same trend. This may occur because leaf greenness at the R1 stage (Ritchie et al., 1986) may not fully reflect season-long crop N need (Piekielek et al., 1992) or late season impacts of soil-N supply. Or, some other factor besides N influenced leaf greenness.

In 2000, late spring soil nitrate-N concentrations in 0-30 cm soil samples collected in late May to early June were low (< 10 mg kg^{-1}) in check strips for all sites except Plymouth-1 (Table 3), indicating potential N-responsiveness of the sites. The soil nitrate-N level was low at the Hardin-1 site, but corn yield did not respond to manure application. Other than Hardin-1 and Plymouth-1, where soil nitrate levels were high, soil nitrate-N values ranged among sites from 14-15 mg kg^{-1} in the low manure application strips and from 20-30 mg kg^{-1} in the high manure application strips. Moreover, the soil nitrate concentrations followed the optimal range of 20-25 mg kg^{-1} (Blackmer et al., 1989) with the high manure rate, indicating adequate N present for corn. However, at the Webster-1 site, the yield did not increase significantly ($P \leq 0.10$) from the low to high manure application rate even though the soil nitrate-N concentration increased from below optimum level in the low manure rate to marginally adequate with the high manure rate. This indicates that soil nitrate-N concentrations below the optimal range with manure application did not always relate to low N supply. At the Hardin-1 and Plymouth-1 sites, the manure application history and high manure total-N application rates were reflected in high soil nitrate values.

Late spring soil nitrate-N concentrations were low in the no-manure check strips (ranged 3-8 mg kg^{-1} among sites) and increased with low and high manure application rates at all sites in 2001 showing potential N-responsiveness of the sites. The soil nitrate-N concentrations ranged among sites from about 8-16 mg kg^{-1} and 11-20 mg kg^{-1} in the low and high manure-N rates, respectively. However, the soil nitrate-N concentrations with manure application were not consistent with application rates and were below the critical range. For example, the low manure application rates were 103, 102, 80, and 118 kg total-N ha^{-1} and the strip average soil nitrate concentrations were 16,10, 15, and 8 mg kg^{-1}. In addition, below critical level soil nitrate-N concentrations with the high manure-N rates did not consistently correspond to N deficiency, as reflected by yield or chlorophyll meter readings. For example, at Washington-2 in 2001, the soil nitrate value was the lowest of any site with the high manure rate (11.9 mg kg^{-1}), but there was no significant yield difference between the low and high rates. Also, the yield was highest (11.13 Mg ha^{-1}) of any sites. This was similar at the Cerro Gordo-1 site. The trend of low late spring soil nitrate-N concentrations with high swine manure rates was not necessarily unexpected as this potential problem is mentioned for swine manure application rates greater than 168 kg N ha^{-1} by Blackmer et al. (1997). Late spring soil nitrate-N concentrations tended to be lower in 2001 than 2000, perhaps a reflection of a cooler and more moist spring. Other reasons might be that the applied manure-N was still in ammonium form at the time of sampling, nitrate-N leached below the sampling depth, or the sampling protocol was not adequate to correctly represent the soil nitrate-N status because manure was injection applied.

Corn Following Corn Sites

Strip yield was not collected by the producer at the Cerro Gordo-2 corn following corn site in 2001. At the Hardin-3 corn following corn site, yield increased significantly ($P \leq 0.10$) with the low manure rate, but there was no further significant yield increase with the high rate. From STP and STK values, yield increases would be due mostly to addition of manure-N, with some potential increase due to manure-K addition.

At the Hardin-3 site in 2001, corn ear leaf chlorophyll meter readings increased from the check to low, and from the low to high manure rates indicating manure-N uptake by corn. The N deficiency in the check strip is indicated by the low chlorophyll meter reading and confirmed by the yield increases with manure application. However, from low to high rates of manure-N, despite the chlorophyll meter readings increasing, the yield increase was not significant ($P \leq 0.10$).

At the Cerro Gordo-2 site, the no-manure check strips showed high leaf chlorophyll meter readings indicating presence of a large soil N-supply. Part of the N-supply was from the starter fertilizer, but the rate was low (11 kg N ha^{-1}). The chlorophyll meter readings increased only slightly in the low and high rates of manure indicating leaf greenness was near maximum with the no-manure check.

The late spring soil nitrate-N concentrations followed a similar trend as measured at the corn following soybean sites in 2001. Low soil nitrate-N levels were measured in the control strips at both sites, but levels did not consistently match yield response, leaf chlorophyll readings, or changes in leaf greenness with manure application. Soil nitrate-N levels with high manure rates were not substantially increased, despite large manure-N being applied. At the Hardin-3 site, for example, the soil nitrate-N concentration was below 20 mg kg^{-1} with 212 kg total manure-N ha^{-1}.

Fertilizer-N Responses

The fertilizer-N rates applied to small split-plots within each manure application strip were designed to measure responses to N in addition that applied with the manure. To mask potential response from P and K applied with manure, P and K were added at a uniform rate to all split-plot fertilizer-N rates (including zero fertilizer-N rates). The data were analyzed individually from each site and then discussed based on crop rotation.

Corn Following Soybean Sites

The corn yields and associated statistical analysis for the corn following soybean sites in 2000 and 2001 are shown in Tables 4 and 5. Among the corn following soybean sites, the Hardin-1 site in 2000 did not show N responsiveness, i.e. yield did not increase with manure-N, fertilizer-N, or manure plus fertilizer-N. The same trend was obtained in the strip manure applications (Table 3). These results confirm the non-responsiveness of the Hardin-1 site. As was explained earlier, the non-responsiveness of the Hardin-1 site could be due to past manure application history and large soil-N supply. At the Plymouth-1 site in 2000, yield data was not collected from fertilizer-N split-plots because of severe drought that caused extreme yield variability, and some zero yields. All other sites in 2000 and 2001 showed N-responsiveness, that is fertilizer-N increased yield significantly (N rate significant at $P \leq 0.10$) in no manure check plots. Although the N rate was not significant at the Cerro Gordo-1 site (Table 5), the contrast (C_0 vs. C_N), N rate quadratic, and manure by N rate interactions (linear and residual) were significant ($P \leq 0.10$) indicating N responsiveness of that site.

Grain yield was increased with both low and high rates of manure at all N-responsive sites in 2000 and 2001 (Tables 4 and 5). Additional fertilizer-N increased yields with the low manure rates (contrasts L_0 vs. L_N, or manure by N rate interactions were significant at $P \leq 0.10$) at all the responsive sites (low manure rate was not applied at Washington-1 site in 2000) indicating manure-N did not supply adequate N with the low manure rates. The effect of manure-N applied at the low rate on corn can be compared with that of fertilizer-N by using the yield data in the no-manure fertilizer-N check plots and the yield with the low manure rate when no additional fertilizer-N was applied. At the Webster-1 and Clay-1 sites in 2000, the low manure rate (78 and 86 kg total-N ha^{-1}, respectively) compared to approximately between 45 to 90 and 90 kg fertilizer-N ha^{-1}, respectively. In 2001 at Cerro Gordo-1, Wright-1, Clay-3, and Washington-2 sites, the low manure rates (103, 102, 80 and 118 kg total-N ha^{-1}) compared to approximately 90 to 135, 45, 45, and 90 to 135 kg fertilizer-N ha^{-1}, respectively. At the Webster-1, Clay-1, and Cerro Gordo-1 sites, an additional 45 kg fertilizer-N ha^{-1} resulted in approximate maximum yields (compared to highest yield response to fertilizer-N without manure application). At the Wright-1 and Clay-3 sites (these being more responsive), an additional 90 kg fertilizer-N ha^{-1} was required.

Additional fertilizer-N application did not increase yield in either year at any site with the high manure except at Clay-3 in 2001. This indicates adequate or more than adequate-N supply from manure-N and that no additional-N was required. At the Clay-3 site, fertilizer-N application increased yield significantly ($P \leq 0.10$) in the high manure application strips indicating additional N need. This could be partially a result of the manure being surface broadcast applied on a hot and windy day, and no incorporation until the next day (that is volatile N loss reducing the manure-N remaining in the soil). This could be a factor in the large fertilizer-N response measured for both manure rates, and low apparent manure-N supply. This was not seen at Clay-1 site in 2000. That site had the same broadcast application, but conditions were cool and not conducive to volatile loss before manure incorporation. Another contributing factor to the low manure-N response could be yield variability in the split-plots as a result of barren stalks and soil wetness variability within the location of the split-plots.

Both absolute and relative corn ear leaf chlorophyll meter readings from the corn following soybean sites are shown in Tables 6, 7, 8, and 9 (chlorophyll meter readings were not collected at the Washington-1 2000 site). Chlorophyll meter readings, other than at Hardin-1 in 2000, reflected N deficiencies in the no-manure check plots when no fertilizer-N was applied. Lower readings were always related to lower soil (Tables 10 and 11) and stalk nitrate concentrations (Tables 12 and 13), and lower corn grain yield (Tables 4 and 5). For example, at the Wright-1 2001 site, the lowest reading (42.9) related to lowest yield (8.27 Mg ha^{-1}) and lower soil and stalk nitrate concentrations (4 and 33 mg N kg^{-1}, respectively). At all the N responsive sites, additional fertilizer-N increased chlorophyll meter readings significantly (N rate significant at $P \leq 0.10$) in the no manure check strips, with the increase being consistent with yield increase. Likewise, the low and high rates of manure-N with no additional fertilizer-N, resulted in increased chlorophyll meter readings, indicating corn N-uptake of the applied manure-N.

Relative chlorophyll meter readings (Tables 8 and 9) were calculated using the chlorophyll meter reading at the highest applied N rate (high manure-N rate plus 135 kg fertilizer-N ha^{-1}) at each site as 100%. At all sites the relative chlorophyll meter readings in the no-manure, no-fertilizer split-plots were at or below the critical level value of 93% reported by Piekielek et al. (1995) and the 95% critical level reported by Peterson et al. (1993), indicating N deficiency in those plots. At the Hardin-1 site in 2000, the no-manure plots (at any rate) had relative chlorophyll meter readings at or below reported critical levels. These low relative chlorophyll meter readings at Hardin-1 were mainly a result of the very high chlorophyll meter readings used as a reference. Overall at that site, chlorophyll meter readings were high and indicated N deficiency at the R1 stage with the no N check plots was slight to none. Also, there was no yield response to applied fertilizer-N or manure-N. Perhaps the corn greenness responded to other constituents in the manure, or late-season N supply compensated for crop N needs. The same response was noted in the strips at the Hardin-1 site.

Relative chlorophyll meter readings increased with manure application and were greater than critical levels in five of seven sites with both the low and high manure rates. Relative chlorophyll meter readings increased from the low to high manure rates at several sites indicating additional manure-N supply and plant uptake. Additional fertilizer-N applications in the no-manure check plots and low manure rate plots increased chlorophyll meter readings (eventually going above critical levels), with the increases generally corresponding to yield increases. On the other hand, at the high manure-N rate, additional fertilizer-N sometimes increased the chlorophyll meter readings, but this was not consistent with yield increase. The readings were typically high with the high manure-N rate (with no fertilizer-N), and increases in readings were not large with additional N. The exception was the Clay-3 site, where fertilizer-N response was measured with all manure-N rates.

Late spring soil nitrate-N concentrations in 0-30 cm soil samples collected in late May to mid June were low (and below the critical level of 20-25 mg kg^{-1}, Blackmer et al., 1989) in no-manure, no fertilizer-N check plots at all sites in 2000 and 2001. This indicates potential N responsiveness of the sites (Tables 10 and 11). Despite the Hardin-1 site having soil nitrate-N concentration below 20 mg kg^{-1}, yield was not increased with N application.

Liquid swine manure application increased the late spring soil nitrate-N concentrations in both the low and high rates, with greater increases with high rates. In 2000, the soil nitrate-N concentrations with the low manure-N rate (except at Hardin-1 site) would indicate expectation of yield response to applied N, and this occurred. Additional fertilizer-N in the check and low manure-N plots increased the soil nitrate-N concentration with corresponding yield increase. With the high rates of manure-N, soil nitrate-N concentration was above the critical range and additional fertilizer-N did not increase yield.

In 2001, the soil nitrate-N concentrations were generally low (without fertilizer-N), and especially so considering the amount of manure-N applied. Values were lower than measured in 2000, and even with high manure-N application, nitrate-N concentrations were low and below the critical range of 20-25 mg nitrate-N kg^{-1}. Also, the soil nitrate-N concentrations were not very differentiating between non-responsive, responsive, and highly responsive situations (that is, approximately the same soil nitrate-N concentrations were found at non-responsive to responsive sites with manure application). Fertilizer-N application increased soil nitrate-N concentrations much more than swine manure-N. Additional fertilizer-N (90 kg N ha^{-1} rate) increased soil nitrate-N concentrations in low manure-N rates to or above the critical range at all locations, indicating additional N-needs at low manure-N rates. Moreover, at high manure rates additional fertilizer-N did not increase yields other than Clay-3, even though the soil nitrate concentrations were well below the critical range at these rates. Unlike 2000, data obtained in 2001 suggest that soil nitrate-N concentrations were not accurately related to yield. According to Blackmer et al. (1997), caution is urged in using the soil nitrate-N in cases when manure is applied above a rate of 168 kg total-N ha^{-1}. However, the problem of obtaining low concentrations was observed even in cases when manure was applied at or below a rate of 168 kg total-N ha^{-1}. For example, at the Washington-2 site in 2001, the high manure-N rate (212 kg total-N ha^{-1}) resulted in soil nitrate-N concentration of 12 mg kg^{-1}, which was increased to 22 mg kg^{-1} with 90 kg ha^{-1} fertilizer-N, yet yield was not increased significantly (Tables 2, 5, and 11). A similar lack of yield response to additional fertilizer-N, but low soil nitrate-N concentration with high manure-N rates, was found for the Cerro Gordo-1 and Wright-1 sites in 2001. The specific reasons for the low soil nitrate-N concentrations with manure application in 2001 is unknown, but could be related to the manure being injected in concentrated bands (difficult to uniformly sample), a cool spring limiting manure organic-N mineralization, or nitrate movement below the 30 cm soil depth (not measured by the test) but remaining in the root zone.

Interestingly, despite low late spring soil nitrate-N levels with manure application at some sites, corn stalk nitrate-N levels were not correspondingly low (below the optimal range). This indicates that stalk nitrate may be a better reflection of plant available-N from swine manure than soil nitrate-N concentrations. Or the soil nitrate-N levels considered deficient with swine manure application are not so. Randall et al. (1999) also noted that soil nitrate critical levels were lower with swine manure compared to published values derived from fertilizer application. This is also reflected in corn N fertilizer recommendations based on soil nitrate testing (Blackmer et al., 1997).

At all sites in 2000 and 2001, corn stalk nitrate-N concentrations (Tables 12 and 13) were below the optimal range (< 700-2000 mg kg^{-1}, Binford et al., 1992) in the no-manure check plots indicating crop-N deficiency. Addition of fertilizer-N increased stalk nitrate-N concentrations, with concentration increases generally related to the yield response to N. However, specific fertilizer-N rates where yield no longer was increased did not always relate to concentrations at or above the optimal range.

Stalk nitrate-N concentrations increased with manure application, indicating increased N supply from the manure-N. However, concentrations often did not reflect the large differences in manure-N rates (for example Cerro Gordo-1 and Clay-3 in 2001 and Hardin-1 and Washington-1 in 2000). The most consistent trend was for very high stalk nitrate-N concentrations (> 2000 mg kg^{-1}) when manure and fertilizer was supplying N at rates greater than crop need; which occurred when manure was applied and there was no N response (Hardin-1 in 2000), or fertilizer-N was above the maximal yield response (occurred at all sites except at Washington-2 in 2001). It is clear that corn stalk nitrate-N reflects overall N supply from fertilizer or manure because the trend in stalk nitrate was for lowest values with no-manure and fertilizer, to highest values with the high manure-N plus 135 kg fertilizer-N ha^{-1} rates. If producers are applying high rates of swine manure, and supplementing with additional fertilizer-N, the corn stalk nitrate-N test should provide positive feed back that too much available-N is being placed into the soil system.

At all sites both years (except the non-responsive sites), the total amount of post-harvest 0-120 cm soil profile nitrate-N showed little to no increase with low or high manure application rates (Tables 14 and 15). Low amounts in the check treatments reflect uptake of soil nitrate-N by the corn crop, and would be expected if no manure-N or fertilizer-N was applied. The largest amount of residual nitrate-N was usually in the top 30-cm soil depth. Application of fertilizer-N in conjunction with manure-N tended to result in more uniform nitrate-N throughout the 120-cm depth.

In 2000, the large amount of profile nitrate-N in the no-manure check plots at the Hardin-1 and Plymouth-1 site reflected the high manure application history, apparent large soil N supply, and the non-responsiveness to applied manure or fertilizer-N. At the Plymouth-1 site, high profile nitrate was also present because of dry growing-season conditions and large manure-N applications. Both low and high manure rates accumulated significant amounts of nitrate-N, indicating N not used by corn. This was corroborated by lack of yield response to applied-N. At Webster-1, Clay-1, and Washington-1 sites in 2000, the amount of profile nitrate-N at high manure rates was significantly higher than the no-manure check, but the values were sufficiently low as to not raise an environmental concern

(Schmidt et al., 2000). These higher amounts would not be expected because of N deficiencies that developed in the check plots.

In 2001, the post-harvest profile soil samples were collected from both the zero N and 90 kg N ha^{-1} fertilizer applications for all three manure rates. The samples were collected only from the Wright-1 and Washington-2 sites. At these sites, the amount of profile nitrate-N was quite low in both the low and high manure rates (without N-fertilizer applied) indicating N-uptake by corn. This was supported by high yields at these sites and response to applied N. Nitrate-N was higher in the soil profiles with the 90 kg N ha^{-1} fertilizer application, and with fertilizer-N plus manure-N application. This documents N-supply from the manure-N application, and more than adequate N supply in some instances.

Grain N concentrations (Tables 16 and 17) increased significantly ($P \leq 0.10$) with both the low and high rates of manure at all corn-soybean rotation sites in 2000 and 2001. However, in 2000 the grain-N increase did not always correspond to yield increase, whereas it tended to in 2001. Additional fertilizer-N increased grain-N concentration with low manure rates at all sites, with the high rate at several sites indicating increased N-uptake and N movement to corn grain, even with N supplied in excess. Increases in grain N concentration with fertilizer-N application on top of manure-N applications were not as large as when no manure was applied, and were low or not significant with the high manure rates at many sites. The grain N concentration response to applied N followed a similar trend as with plant N status measurements, like stalk nitrate and leaf chlorophyll meter readings. Larger increases from fertilizer-N on the no-manure plots indicated the N responsiveness of the sites.

Corn Following Corn Sites

Corn grain yields and associated statistical analyses for the corn following corn sites are shown in Table 18. Corn grain yields were increased significantly ($P \leq 0.10$) with liquid swine manure application at both sites in 2001. Additional fertilizer-N increased yield significantly in the no-manure check strips at both sites, indicating the N responsiveness of these sites. At Hardin-3, additional fertilizer-N increased yield significantly (L_0 vs. L_N significant at $P \leq 0.10$) with the low manure-N rate (77 kg total-N ha^{-1}) indicating more crop N need than supplied by the low manure-N rate. Conversely, at Cerro Gordo-2, additional fertilizer-N did not increase yield significantly with the low manure-N rate (105 kg total-N ha^{-1}) indicating adequate crop N supply with that manure rate. At both sites, addition of fertilizer-N did not increase yield with the high manure-N rates (212 and 236 kg total-N ha^{-1} at the Hardin-3 and Cerro Gordo-2 sites, respectively) indicating adequate or above N supply with these rates.

The comparison between fertilizer-N and manure-N can be done is the same way as was done with the corn following soybean sites. At Hardin-3, the low manure-N rate compared approximately to the 67 kg fertilizer-N ha^{-1} rate. The Cerro Gordo-2 site was not very N responsive, so the manure-N to fertilizer-N comparison was not clear, but appears that the low manure-N rate supplied adequate N (105 kg total manure-N ha^{-1}). Since fertilizer-N did not increase yield in conjunction with the high manure-N rates, it is not possible to compare fertilizer-equivalence of the high manure-N rates.

Chlorophyll meter readings of the corn ear leaf at the R1 growth stage (Ritchie et al., 1986) and calculated relative values are shown in Tables 19 and 20. At both sites, the no-manure, no fertilizer check plots had the lowest chlorophyll meter readings, thus indicating N deficiency at these sites. The relative chlorophyll meter readings (89 and 90 at Hardin-3 and Cerro Gordo-2, respectively) being below the reported critical levels of 93% (Piekielek et al., 1995) and 95% (Peterson et al., 1993) confirmed this. Additional fertilizer-N increased the relative chlorophyll meter readings in the no-manure check plots at both sites, indicating N-responsiveness of the sites.

Similar chlorophyll meter reading response occurred with manure applications. The fertilizer-N rate where yield response became plateau was essentially the same rate where relative chlorophyll meter values increased to the 95%. The low manure-N rate (with no fertilizer-N) at Hardin-3 had relative chlorophyll meter readings below the critical level, and values increased with fertilizer-N application. At Cerro Gordo-2, the readings and relative values with the low manure-N rate were high and above the critical level. This indicates the low manure rate supplied adequate N at the Cerro Gordo-2 site, but not at Hardin-3. Yield data showed the same trend. At both sites the chlorophyll meter readings and relative values with the high manure-N rate were high and above the critical level, indicating adequate manure-N supply. This is similar to the yield response. Although leaf greenness usually does not continue to increase with above-adequate N supply, the combination of manure-N and fertilizer-N resulted in increased chlorophyll meter readings. A similar trend was observed at the corn-soybean sites. It is unknown what caused this situation to occur, but it could be related to other factors influenced by manure application.

The late spring soil nitrate-N concentrations are shown in Table 21. At the Hardin-3 site, the soil nitrate-N concentration was low in the no manure check plots indicating N deficiency at that site. Addition of fertilizer-N at a rate of 135 kg N ha^{-1} increased the soil nitrate concentration above the optimal range (Blackmer et al., 1989). The low and high manure rates increased soil nitrate-N concentration, but they were below and stayed below 20 mg kg^{-1}, especially for the low manure-N rate. Grain yield and plant greenness responded to fertilizer-N with the low manure-N rate, but did not respond to the high manure-N rate; despite fairly low soil nitrate-N with the high manure-N rate and soil nitrate-N increased with fertilizer-N application. At the Cerro Gordo-2 site, the no-manure check plots had higher soil nitrate-N concentration than the Hardin-3 site, and yield response to fertilizer and manure was smaller. The low manure-N rate (without fertilizer-N) had below optimal soil nitrate-N concentration, yet the addition of fertilizer-N did not significantly increase grain yield. This same trend was found in 2001 at several corn-soybean sites.

Corn stalk nitrate-N concentrations showed similar trends as measured at the corn-soybean sites (Table 22), and indicated when N supply was deficient, and when it was greater than crop need. As at the corn-soybean rotation sites, the trend was for low values in the no-manure, no fertilizer-N, to very high levels at high manure-N plus high fertilizer-N application. The concentrations increased linearly (NR_L significant at $P \leq 0.10$) with fertilizer-N application at both sites. At the Hardin-3 site, the low manure rate (with no fertilizer-N) had low concentrations, and the high manure rate had above optimal concentrations, indicating inadequate N supply from the low manure-N rate, but above adequate N from the high rate. At the Hardin-3 site, when the fertilizer-N rate, or low manure-N rate plus fertilizer-N rate, was at a level to achieve plateau yield, the stalk nitrate-N concentrations fell within the optimal range. At Cerro Gordo-2, as expected in relation to results measured with yield, chlorophyll meter and soil nitrate concentrations, the stalk nitrate-N levels were within the optimal range with low manure-N application. Since stalk nitrate-N concentration trends for the corn-corn rotation sites were similar to those found with the corn-soybean rotation sites, similar interpretations could be used for fertilizer-N, manure-N, and crop rotation systems.

At both the Hardin-3 and Cerro Gordo-2 sites in 2001, the low and high manure rates (with no fertilizer-N applied) did not result in a significant ($P \leq 0.10$) increase in post-harvest profile nitrate-N compared to the no-manure check rate (Table 23). This indicates the manure-N supply was not excessive (although leaching or other losses were not measured). Comparatively, the amount of post-harvest profile nitrate-N increased markedly (though not statistically significant) with 135 kg N ha^{-1} fertilizer-N applications, especially in conjunction with the manure applications. This was evident especially at Cerro Gordo-2, where the soil N supply was more adequate and needed N achieved at a lower N application rate.

Grain N concentrations were increased with fertilizer-N (no manure applied) and with manure-N application (Table 24). Additional fertilizer-N application increased grain N concentrations in the no-manure plots and the low manure-N rate (linear increase). Additional fertilizer-N did not increase grain-N concentration significantly with the high manure rates.

Conclusion

In general, liquid swine manure application provided N that was highly crop available. Adequate N to meet corn N needs was supplied in the field-length strips with the high manure rate, and occasionally with the low manure rate. Similar impacts of manure-N on corn production were noted across fields in corn-soybean and corn-corn rotations. Leaf chlorophyll meter readings, stalk nitrate-N concentrations, amount of profile nitrate-N, and grain N concentrations supported the availability of manure-N to corn, and the corn N status following manure application. However, late spring soil nitrate-N concentrations did not adequately reflect the manure-N application rates, or manure-N supply. Late spring soil nitrate values tended to be low with manure application, and increased less than for equivalent fertilizer-N application rates. Addition of fertilizer-N did not increase corn grain yield with the high manure-N rate, but did when the low manure-N rates were not adequate to meet corn requirements. The low manure-N rate in conjunction with 45 to 90 kg fertilizer-N ha^{-1} resulted in optimal yield. However, it can be hard to predict a specific liquid swine manure-N rate needed at a site due to differences in site N requirements. This difficulty is the same for determining fertilizer-N requirements. While it was not possible in this study to determine the specific first-year availability of liquid swine manure-N, we found no reason to suspect it is much different from fully crop available. The amount of residual soil profile nitrate-N resulting from the manure application rates used in this study did not increase significantly. Additional fertilizer-N applied on top of the high manure rates significantly increased the amount of post-harvest profile nitrate-N. Because of the high crop availability of liquid swine manure-N, it is an excellent source for corn production and one that should be managed carefully to obtain full agronomic benefit.

References

Adeli, A. and J. Varco. 2001. Swine lagoon effluent as a source of nitrogen and phosphorus for summer forage grasses. Agron J. 93:1174-1181.

American Public Health Association. 1995. Standard methods for the examination of water and waste water. 18th edition. American Public Health Association, Washington, D. C.

Binford, G. D., A. M. Blackmer, and B. G. Meese. 1992. Optimal concentrations of nitrate in cornstalks at maturity. Agron. J. 84:881-887.

Bitzer, C. C. and J. Sims. 1988. Estimating the availability of nitrogen in poultry manure through laboratory and field studies. J. Environ. Qual. 17:47-54.

Blackmer, A. M., D. Pottker, M. E. Cerrato, and J. Webb. 1989. Correlations between soil nitrate concentrations in late spring and corn yields in Iowa. J. Prod. Agric. 2:103-109.

Blackmer, A. M., R. D. Voss, A. P. Mallarino.1997. Nitrogen fertilizer recommendations for corn in Iowa. Iowa State University Extension pub. Pm-1714. Iowa State University, Ames, Iowa.

Blackmer, A. M. and A. P. Mallarino. 1996. Cornstalk testing to evaluate nitrogen management. Iowa State University Extentsion pub. Pm-1584, Iowa State University, Ames, Iowa.

Cerrato, M. E. and A. M. Blackmer. 1991. Relationships between leaf nitrogen concentrations and the nitrogen status of corn. J. Prod. Agric. 4:525-531.

Eghball, B. and J. Power. 1999. Composted and noncomposted manure application to conventional and no-till systems: corn yield and nitrogen uptake. Agron. J. 91:819-825.

Frank, K., D. Beegle, and J. R. Denning. 1998. Phosphorus. p-21-26. *In* Brown et al. (ed.) Recommended Chemical Soil test Procedures for North Central Region. North central Regional research Publication No. 221 (Revised) Missouri Agricultural Experiment Station SB 1001.

Gelderman, R. H. and D. Beegle. 1998. Nitrate-nitrogen. p. 17-20. *In* Brown et al. (ed.) Recommended Chemical Soil test Procedures for North Central Region. North central Regional research Publication No. 221 (Revised) Missouri Agricultural Experiment Station SB 1001.

Hach, C. C., B. K. Bowden, A. B. Kopelove, and S. V. Brayton. 1987. More powerful peroxide Kjeldahl digestion. J. Assoc. Off. Anal. Chem. 70:783-787.

Jokela, E. W. 1992. Nitrogen fertilizer and dairy manure effects on corn yield and soil nitrate. Soil Sci. Soc. Am. J. 56:148-154.

Killorn, R. Frequency of liquid swine manure application. 1998. p 34-36 Northern Research and Demonstration Farm Annul. Prog. Rep. ISRF98-22 Iowa State Univ. Ames, Iowa.

Killorn, R. J. and J. Lorimor. 1999. Managing manure nutrients for crop production. Iowa State University Extentsion pub. Pm-1811, Iowa State University, Ames, Iowa.

Matejovic, I. 1997. Determination of carbon and nitrogen in samples of various soils by the dry combustion. Commun. Soil Sci. Plant Anal. 28:1499-1511.

McCormick, R. A., D. W. Nelson, A. L. Sutton, and D. M. Huber. 1984. Increased N efficiency from nitrapyrin added to liquid swine manure used as a fertilizer for corn. Agron. J. 76:1010-1014.

Peterson, T, A., T. M. Blackmer, D. D. Francis, and J. S. Schepers. 1993. Using a chlorophyll meter to improve N management. Neb Guide G93-1171-1, Coop. Ext., Inst. Ag. N of. Res., Univ. Nebraska, Lincoln, NE.

Piekielek, P. W., R. H. Fox, J. D. Toth, and K. E. Macneal. 1995. Use of a chlorophyll meter at the early dent stage of corn to evaluate nitrogen sufficiency. Agron J. 87:403-408

Powers, W.L., G.W. Wallingford, and L. S. Murphy. 1975. Research status on effects of land application of animal wastes. p. 44-46. EPA 660/2-75-010. U. S. Printing Office, Washington, D. C.

Randall, G. W., M. A. Schmitt, and J. P. Schmidt. 1999. Corn production as affected by time and rate of manure application and nitrapyrin. J. Prod. Agric. 12:317-323.

Ritchie, S. W., J. J. Hanway, and G. O. Benson. 1986. How a corn plant develops. Spec. Rep. 48. Rev. ed. Iowa State Coop Ext. Serv., Ames, IA.

Sawyer, J. E., M. A. Schimitt, R. G. Hoeft, J. C. Siemens, and D. H. Vanderholm. 1991. Corn production associated with liquid beef manure application methods. J. Prod. Agric. 4:335-344.

Schmidt, J. P., M. A. Schmitt, G. W. Randall, J. A. Lamb, J. H. Orf, and H. T. Gollany. 2000. Swine manure application to nodulating and nonnodulating soybean. Agron J. 92:987-992.

Statistical Analysis Systems Institute. 1992. SAS user's guide: Statistics. SAS Institute, Inc., Cary, NC.

Sutton, A. L., D. W. Nelson, J. D. Hoff, and V. B. Mayrose. 1982. Effects of injection and surface application of swine manure on corn yield and soil composition. J. Environ. Qual. 11:468-473.

Warncke, D. and J. R. Brown. 1998. Potassium and other basic cations. p-31-33 *In* Brown et al. (ed.) Recommended Chemical Soil test Procedures for North Central Region. North central Regional research Publication No. 221 (Revised) Missouri Agricultural Experiment Station SB 1001.

Watson, M. E. and J. R. Brown. 1998. p-13-16. *In* Brown et al. (ed.) Recommended Chemical Soil test Procedures for North Central Region. North central Regional research Publication No. 221 (Revised) Missouri Agricultural Experiment Station SB 1001.

Table 1. Site Characteristics.

Site Name	Crop	Previous Crop	Predominant Soil	Soil Taxonomic Name	pH	STP[†]	STK[†]	Organic Matter
					Soil Chemical Characteristics			
2000						- - mg kg^{-1} - -		g kg^{-1}
Hardin-1	Corn	Soybean	Clarion	Fine-loamy, mixed, mesic Typic Hapludoll	6.4	123	269	54
Webster-1	Corn	Soybean	Webster	Fine-loamy, mixed, noncalcarious, mesic, Typic Haplaquoll	7.0	21	133	60
			Nicollet	Fine-loamy, mixed, mesic Aquic Hapludoll				
Clay-1	Corn	Soybean	Marcus	Fine-silty, mixed, mesic Typic Haplaquoll	5.8	44	220	68
Washington-1	Corn	Soybean	Mahaska	Fine, montmorillonitic, mesic Aquic Argiudoll	- -[‡]	- -	- -	- -
Plymouth-1	Corn	Soybean	Galva	Fine-silty, mixed, mesic Typic Hapludoll	6.0	45	228	37
2001								
Cerro Gordo-1	Corn	Soybean	Clarion	Fine-loamy, mixed, mesic Typic Hapludoll	6.0	19	218	40
			Nicollet	Fine-loamy, mixed, mesic Aquic Hapludoll				
			Webster	Fine-loamy, mixed, noncalcarious, mesic, Typic Haplaquoll				
Wright-1	Corn	Soybean	Talcot	Fine-loamy over sandy or sandy-skeletal, mixed, calcereous,mesic, Typic Haplaquoll	6.5	39	211	41
			Wadena	Fine-loamy over sandy or sandy-skeletal, mixed,mesic, Typic Hapludoll				
			Cylinder	Fine-loamy over sandy or sandy-skeletal, mixed, calcereous,mesic, Aquic Haplaquoll				
Clay-3	Corn	Soybean	Marcus	Fine-silty, mixed, mesic Typic Haplaquoll	5.8	7	170	59
Washington-2	Corn	Soybean	Kalona	Fine, montmorillonitic, mesic Typic Haplaquoll	7.0	48	216	61
			Taintor	Fine, montmorillonitic, mesic Typic Argiaquoll				
Hardin-3	Corn	Corn	Webster	Fine-loamy, mixed, noncalcarious, mesic, Typic Haplaquoll	7.3	44	115	53
			Nicollet	Fine-loamy, mixed, mesic Aquic Hapludoll				
Cerro Gordo-2	Corn	Corn	Webster	Fine-loamy, mixed, noncalcarious, mesic, Typic Haplaquoll	6.7	31	186	60
			Harps	Fine-carbonic, mesic Typic Calciaquoll				
			Clarion	Fine-loamy, mixed, mesic Typic Hapludoll				

[†]STP and STK represent strip average soil test phosphorus (Mehlich-3) and potassium (1 M amonium acetate), samples taken before manure application.

[‡]No soil samples collected.

Table 2. Manure application method, manure analysis, and nutrient application rates at each site.

Site	Date of Application	Application Method[†]	Strip Area (Ln x W)[‡]	Manure Application Rate L[§]	Manure Application Rate H[§]	Manure Total Nutrient Analysis N	Manure Total Nutrient Analysis P_2O_5	Manure Total Nutrient Analysis K_2O	Manure Total Nutrient Applied N L	N H	P_2O_5 L	P_2O_5 H	K_2O L	K_2O H
2000			- - m - -	- - - - L ha^{-1} - - - -		- - - - - mg L^{-1} - - - - - -			- - - - - - - - - - - - kg ha^{-1} - - - - - - - - - - - -					
Hardin-1	04-Apr-00	S. dribb.	353 x 12	17980	41747	5104	6245	5095	93	215	112	264	91	214
Webster-1	24-Apr-00	Injected	354 x 12	11220	22440	6917	4770	4264	78	156	54	108	48	96
Clay-1	26-April-00	S. broad.	243 x 9	11220	22440	7720	4546	3828	86	172	52	102	43	86
Washington-1	01-Nov-99	Injected	354 x 12	- -[¶]	37400	6470	5610	5388	- -	242	- -	211	- -	202
Plymouth-1	29-Mar-00	Injected	164 x 15	36465	62271	9507	6075	5000	345	589	223	381	184	318
2001														
Cerro Gordo-1	29-Apr-01	Injected	365 x 12	15895	26647	6485	4111	4686	103	172	65	109	74	124
Wright-1	29-Apr-01	Injected	757 x 8	17297	34595	5818	4168	3934	102	203	73	146	68	137
Clay-3	16-May-01	S. broad.	492 x 9	11220	22440	7023	3460	3802	80	159	39	78	43	86
Washington-2	15-Nov-00	Injected	168 x 9	28985[#]	28985	7303	5336	4324	118	212	83	157	69	125
Hardin-3	26-Apr-01	Injected	274 x 12	13464	37400	5693	4594	3750	77	212	62	168	50	137
Cerro Gordo-2	29-Apr-01	Injected	304 x 18	15895	35904	6568	4136	4714	105	236	67	150	74	168

[†]S. broad. and S. dribb. indicate manure was surface broadcast applied with incorporation next day, and manure was surface dribbled with disk soil covering, respectively.

[‡](Ln x W) represents length x width of each manure treatment srtip at each site.

[§]L and H represents low and high rates of manure.

[¶]No low manure rate was applied at Washington-1 site in 2000.

[#]At Washington-2 site the low manure rate was obtained by 1:1 dilution with water.

Table 3. Effect of liquid swine manure application in field-length strips on corn grain yield, chlorophyll meter reading and late spring soil nitrate concentration.

Site	Grain Yield			Chlorophyll Meter Reading[‡]			Late Spring Soil Nitrate[‡]		
	C[†]	L[†]	H[†]	C	L	H	C	L	H
2000	- - - - - Mg ha^{-1} - - - - - -						- - - mg NO_3-N kg^{-1} - - -		
Hardin-1	9.03a[§]	9.02a	9.10a	57.4a	61.4b	61.7b	14.7a	31.0b	34.6b
Webster-1	7.66a	8.73b	8.93b	49.2a	54.3b	54.7b	9.0a	14.5b	20.1c
Clay-1	7.82a	9.76b	11.18c	43.1a	51.7b	56.0c	5.8a	15.0b	26.6c
Washington-1	8.55a	- -[¶]	10.32b	- -	- -	- -	9.9a	- -	30.3b
Plymouth-1	6.16a	6.19a	6.90a	58.6a	61.3b	61.7b	23.6a	41.9b	59.7c
2001									
Cerro Gordo-1	7.60a	9.74b	10.11b	52.6a	58.5b	60.5c	7.8a	15.9b	19.4c
Wright-1	7.46a	9.09b	9.87c	47.5a	54.4b	57.7c	6.3a	10.1b	16.5c
Clay-3	6.64a	8.24b	9.07c	46.7a	51.3b	53.7c	8.5a	15.0b	20.9c
Washington-2	5.93a	9.83b	11.13b	44.5a	56.2b	58.7c	3.1a	7.9b	11.9c
Hardin-3	8.20a	9.03b	9.25b	50.7a	53.8b	57.8c	7.3a	11.9b	19.9c
Cerro Gordo-2	- -[#]	- -	- -	57.0a	58.5b	58.8b	13.1a	22.5b	23.6b

[†] C, L, and H represent check, low and high rates of manure.

[‡]Mean of all strip sample points.

[§]Means followed by same letter within a site are not significantly different ($P \leq 0.10$).

[¶]No low manure rate was applied at Washington-1 site in 2000.

[#]At Cerro Gordo-2 site yield data was not available due to yield monitor malfunction.

Table 4. Corn grain yield response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2000, corn following soybean sites.

Fertilizer		Hardin-1				Webster-1				Clay-1				Washington-1			
N Rate		C[†]	L[†]	H[†]	Mean	C	L	H	Mean	C	L	H	Mean	C	L	H	Mean
kg N ha^{-1}		Mg ha^{-1}															
0		11.55	12.39	11.60	11.85	8.79	9.86	10.09	9.58	8.88	11.72	12.84	11.15	10.44	--[‡]	11.77	11.11
45		12.26	11.89	12.16	12.10	9.84	10.87	10.38	10.36	9.69	12.32	12.47	11.49	11.73	--	12.91	12.32
90		12.28	11.56	12.63	12.16	10.67	10.83	10.47	10.66	12.48	12.21	12.60	12.43	12.68	--	12.43	12.56
135		13.29	12.38	12.04	12.57	10.52	11.50	10.05	10.69	11.82	12.88	12.75	12.48	10.84	--	10.95	10.90
Mean		12.35	12.06	12.11		9.96	10.77	10.25		10.72	12.28	12.67		11.42	--	12.02	
Source	df[§]	*P* > F															
Manure (M)	2	0.9413				0.1245				0.0031				0.4817			
Rep	2	0.4859				0.7020				0.2974				0.2541			
N Rate (NR)	3	0.4859				0.0009				0.0002				0.0403			
$NR_{Linear(L)}$	1	0.1531				0.0002				<0.0001				0.8373			
$NR_{Quadratic(Q)}$	1	0.8110				0.0468				0.4589				0.0048			
$NR_{Residual(R)}$	1	0.7055				0.7684				0.1090				0.6391			
M x NR	6	0.4969				0.0755				0.0003				0.3605			
M x NR_L	2	0.3131				0.0132				0.0001				0.1146			
M x NR_Q	2	0.3271				0.6142				0.1251				0.9354			
M x NR_R	2	0.7413				0.4004				0.0142				0.4521			
Contrasts[¶]																	
C_0 vs. C_N	1	0.1297				0.0003				<0.0001				0.0491			
L_0 vs. L_N	1	0.4990				0.0030				0.0725				--			
H_0 vs. H_N	1	0.3175				0.5554				0.5648				0.6133			

[†]C, L, and H represents check, low, and high rates of manure.

[‡]No low manure rate was applied at Washington-1 site.

[§]Degrees of freedom for Hardin-1 Rep was 1, and degrees of freedom for Washington-1 M, M x NR, M x NR_L, M x NR_Q, and M x NR_R were 1, 3, 1, 1, and 1, respectively.

[¶]Subscript 0 and N represent without and with fertilizer-N applied.

Table 5. Corn grain yield response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2001, corn following soybean sites.

Fertilizer	Cerro Gordo-1				Wright-1				Clay-3				Washington-2			
N Rate	C†	L†	H†	Mean	C	L	H	Mean	C	L	H	Mean	C	L	H	Mean
$kg\ N\ ha^{-1}$	Mg ha^{-1}															
0	9.54	10.90	11.93	10.79	8.27	10.36	11.44	10.02	8.10	9.20	9.27	8.86	9.18	12.96	14.85	12.33
45	10.59	11.94	11.44	11.32	10.75	11.13	11.86	11.25	9.88	9.82	10.89	10.20	9.74	12.81	14.21	12.25
90	10.80	11.60	12.82	11.74	11.42	12.03	11.89	11.78	11.07	11.11	10.75	10.98	11.74	14.47	15.04	13.75
135	11.33	11.43	11.04	11.27	12.39	11.96	11.33	11.89	10.79	11.21	11.21	11.07	13.38	14.25	14.62	14.08
Mean	10.57	11.47	11.81		10.71	11.37	11.63		9.96	10.34	10.53		11.01	13.62	14.68	

Source	df‡	Cerro Gordo-1	Wright-1	Clay-3	Washington-2
		$P > F$			
Manure (M)	2	0.0592	0.0516	0.3491	0.2651
Rep	2	0.5831	0.5355	0.1042	0.2834
N Rate (NR)	3	0.1385	<0.0001	<0.0001	0.0026
$NR_{Linear(L)}$	1	0.1445	<0.0001	<0.0001	0.0006
$NR_{Quadratic(Q)}$	1	0.0778	0.0070	0.0145	0.4953
$NR_{Residual(R)}$	1	0.5254	0.7534	0.8996	0.0644
M x NR	6	0.1139	0.0003	0.3794	0.0399
M x NR_L	2	0.0890	<0.0001	0.3865	0.0045
M x NR_Q	2	0.8135	0.7327	0.4168	0.7131
M x NR_R	2	0.0691	0.2768	0.2499	0.8380
Contrasts§					
C_0 vs. C_N	1	0.0210	<0.0001	<0.0001	0.0024
L_0 vs. L_N	1	0.1755	0.0018	0.0041	0.1660
H_0 vs. H_N	1	0.7596	0.5015	0.0019	0.7037

†C, L, and H represent check, low and high rates of manure.

‡Degrees of freedom for Washington-2 Rep was 1.

§Subscript 0 and N represent without and with fertilizer-N applied.

Table 6. Corn ear leaf chlorophyll meter reading response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2000, corn following soybean sites.

Fertilizer		Hardin-1				Webster-1				Clay-1			
N Rate		C†	L†	H†	Mean	C	L	H	Mean	C	L	H	Mean
kg N ha^{-1}													
0		53.9	59.9	61.0	58.3	49.0	53.4	55.8	52.7	42.3	50.1	54.2	48.9
45		57.6	61.2	63.1	60.6	52.8	54.2	55.3	54.1	48.2	54.7	56.3	53.1
90		58.5	60.4	62.4	60.4	55.7	53.3	56.6	55.2	54.5	54.3	56.5	55.1
135		60.5	60.7	64.1	61.7	55.3	54.3	55.8	55.1	54.2	55.9	57.7	55.9
Mean		57.6	60.5	62.6		53.2	53.8	55.9		49.8	53.8	56.2	
Source	df‡	---------------------- P > F ----------------------											
Manure (M)	2	0.0335				0.0989				0.0188			
Rep	2	0.1912				0.1070				0.4189			
N Rate (NR)	3	0.0163				0.0925				<0.0001			
$NR_{Linear(L)}$	1	0.0040				0.0203				<0.0001			
$NR_{Quadratic(Q)}$	1	0.4096				0.3477				0.0018			
$NR_{Residual(R)}$	1	0.1655				0.7822				0.6582			
M x NR	6	0.2921				0.1438				0.0001			
M x NR_L	2	0.0510				0.0324				<0.0001			
M x NR_Q	2	0.8930				0.4087				0.0900			
M x NR_R	2	0.9513				0.6397				0.0480			
Contrasts§													
C_0 vs. C_N	1	0.0025				0.0012				<0.0001			
L_0 vs. L_N	1	0.1055				0.7289				<0.0001			
H_0 vs. H_N	1	0.4706				0.9398				0.0126			

†C, L, and H represent check, low and high rates of manure.
‡Degrees of freedom for Hardin-1 Rep was 1.
§Subscript 0 and N represent without and with N-fertilizer applied.

Table 7. Corn ear leaf chlorophyll meter reading response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2001, corn following soybean sites.

Fertilizer		Cerro Gordo-1				Wright-1				Clay-3				Washington-2			
Nrate		C†	L†	H†	Mean	C	L	H	Mean	C	L	H	Mean	C	L	H	Mean
kg N ha^{-1}																	
0		57.7	59.7	60.2	59.2	42.9	53.9	56.5	51.1	51.5	53.9	51.6	52.4	41.5	54.6	53.2	49.7
45		59.1	60.8	62.7	60.9	53.2	55.3	56.6	55.0	51.6	54.2	56.4	54.1	44.8	55.3	56.0	52.0
90		61.3	62.9	59.2	61.1	54.7	54.3	56.9	55.3	53.8	51.7	56.0	53.9	51.6	58.1	59.5	56.4
135		62.2	62.5	61.9	62.2	57.5	55.0	56.4	56.3	55.4	56.6	57.0	56.3	52.5	60.3	61.5	58.1
Mean		60.1	61.5	61.0		52.1	54.6	56.6		53.1	54.1	55.3		47.6	57.0	57.5	
Source	df‡	---------- $P > F$ ----------															
Manure (M)	2	0.2258				0.1044				0.1432				0.0607			
Rep	2	0.6469				0.5840				0.3775				0.1516			
N Rate (NR)	3	0.0345				0.0002				0.0046				0.0021			
$NR_{Linear(L)}$	1	0.0075				<0.0001				0.0009				0.0003			
$NR_{Quadratic(Q)}$	1	0.3273				0.0400				0.5602				0.8166			
$NR_{Residual(R)}$	1	0.4287				0.1499				0.1400				0.3773			
M x NR	6	0.2300				<0.0001				0.1065				0.7522			
M x NR_L	2	0.0765				<0.0001				0.3437				0.3364			
M x NR_Q	2	0.6325				0.0750				0.0540				0.7855			
M x NR_R	2	0.3560				0.3210				0.2170				0.8213			
Contrasts§																	
C_0 vs. C_N	1	0.0019				<0.0001				0.1374				0.0064			
L_0 vs. L_N	1	0.2417				0.4767				0.8561				0.1837			
H_0 vs. H_N	1	0.5748				0.9468				0.0018				0.0321			

†C, L, and H represent check, low and high rates of manure.

‡Degrees of freedom for Washington-2 Rep was 1.

§Subscript 0 and N represent without and with fertilizer-N applied.

Table 8. Relative corn ear leaf chlorophyll meter reading response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2000, corn following soybean sites.

Fertilizer	Hardin-1			Webster-1			Clay-1		
N Rate	C†	L†	H†	C	L	H	C	L	H
kg N ha^{-1}	%								
0	84.1	93.4	95.2	87.8	95.7	100.0	73.3	86.8	93.9
45	89.9	95.5	98.4	94.6	97.1	99.1	83.5	94.8	97.6
90	91.3	94.2	97.3	99.8	95.5	101.4	94.5	94.1	97.9
135	94.4	94.7	100.0	99.1	97.3	100.0	93.9	96.9	100.0

†C, L, and H represent check, low and high rates of manure.

Table 9. Relative corn ear leaf chlorophyll meter reading response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2001, corn following soybean sites.

Fertilizer	Cerro Gordo-1			Wright-1			Clay-3			Washington-2		
Nrate	C†	L†	H†	C	L	H	C	L	H	C	L	H
kg N ha^{-1}	%											
0	93.2	96.4	97.3	76.1	95.6	100.2	90.4	94.6	90.5	67.5	88.8	86.5
45	95.5	98.2	101.3	94.3	98.0	100.4	90.5	95.1	98.9	72.8	89.9	91.1
90	99.0	101.6	95.6	97.0	96.3	100.9	94.4	90.7	98.2	83.9	94.5	96.7
135	100.5	101.0	100.0	102.0	97.5	100.0	97.2	99.3	100.0	85.4	98.0	100.0

†C, L, and H represent check, low and high rates of manure.

Table 10. Effect of manure-N, fertilizer-N, and manure plus fertilizer-N on late spring soil nitrate concentration in 2000, corn following soybean sites.

Fertilizer		Hardin-1				Webster-1				Clay-1				Washington-1			
N Rate		C[†]	L[†]	H[†]	Mean	C	L	H	Mean	C	L	H	Mean	C	L	H	Mean
kg N ha^{-1}		mg NO_3-N kg^{-1}															
0		18	50	35	34	9	14	29	17	11	18	34	21	9	--[‡]	26	18
90		26	47	44	39	18	23	36	26	29	35	47	37	21	--	45	33
Mean		22	49	40		14	19	33		20	27	41		15	--	36	
Source	df[§]	$P > F$															
Manure (M)	2	0.0112				0.0037				0.0027				0.0624			
Rep	2	0.6621				0.0954				0.3475				0.7841			
N Rate (NR)	1	0.2816				0.0034				0.0002				0.0023			
M x NR	2	0.3794				0.9328				0.5934				0.1745			

[†] C, L, and H represent check, low and high rates of manure.

[‡] No Low manure rate was applied at Washinton-1 site.

[§] Degrees of freedom for Hardin-1 Rep was 1, and degrees of freedom for Washington-1 M and M x NR were 1 and 3, respectively.

Table 11. Effect of manure-N, fertilizer-N, and manure plus fertilizer-N on the late spring soil nitrate concentration in 2001, corn following soybean sites.

Fertilizer	Cerro Gordo-1				Wright-1				Clay-3				Washington-2			
Nrate	C†	L†	H†	Mean	C	L	H	Mean	C	L	H	Mean	C	L	H	Mean
kg N ha^{-1}	$mg\ NO_3$-$N\ kg^{-1}$															
0	9	15	18	14	4	12	19	12	12	12	14	13	3	6	12	7
90	22	26	32	27	13	23	23	20	23	34	39	32	9	22	17	16
Mean	16	21	25		9	18	21		18	23	27		6	14	15	

Source	df‡	Cerro Gordo-1	Wright-1	Clay-3	Washington-2
		$P > F$			
Manure (M)	2	0.0415	0.0158	0.3301	0.1897
Rep	2	0.6202	0.0669	0.2755	0.2629
N Rate (NR)	1	0.0022	0.0081	0.0006	0.0395
M x NR	2	0.8482	0.4228	0.1962	0.3592

†C, L, and H represent check, low and high rates of manure.

‡Degrees of freedom for Washington-2 Rep was 1.

Table 12. Effect of manure-N, fertilizer-N, and manure-N plus fertilizer-N on stalk nitrate concentration in 2000, corn following soybean sites.

Fertilizer	Hardin-1				Webster-1				Clay-1				Washington-1			
N Rate	C[†]	L[†]	H[†]	Mean	C	L	H	Mean	C	L	H	Mean	C	L	H	Mean
kg N ha^{-1}	mg NO_3-N kg^{-1}															
0	200	5847	5531	3859	50	1328	3688	1689	25	23	1119	389	20	- -[‡]	3915	1968
45	215	6505	4998	3906	89	2264	4637	2330	25	179	2747	984	31	- -	6368	3200
90	270	7343	5320	4311	836	3208	4457	2834	133	1265	5075	2158	210	- -	5343	2777
135	1248	6303	6198	4583	1036	3868	5428	3444	702	3048	4967	2906	1127	- -	7074	4101
Mean	483	6500	5512		503	2667	4553		221	1129	3477		347	- -	5675	

Source	df[§]	Hardin-1	Webster-1	Clay-1	Washington-1
		$P > F$			
Manure (M)	2	0.1668	0.0035	0.0001	0.0325
Rep	2	0.1941	0.0321	0.2283	0.5386
N Rate (NR)	3	0.2853	0.0009	<0.0001	0.1365
$NR_{Linear(L)}$	1	0.0729	<0.0001	<0.0001	0.0440
$NR_{Quadratic(Q)}$	1	0.7088	0.9519	0.5130	0.9388
$NR_{Residual(R)}$	1	0.6987	0.8326	0.0660	0.2245
M x NR	6	0.4038	0.5476	<0.0001	0.5049
M x NR_L	2	0.9495	0.2241	<0.0001	0.3696
M x NR_Q	2	0.1021	0.9374	<0.0001	0.5064
M x NR_R	2	0.6478	0.4386	0.0275	0.3072

[†]C, L, and H represent check, low and high rates of manure.

[§]Degrees of freedom for Hardin-1 Rep was 1, and degrees of freedom for Washington-1 M, M x NR, M x NR_L, M x NR_Q, and M x NR_R were 1, 3,1, 1, and 1, respectively.

[‡]No low manure rate was applied at Washington-1 site.

Table 13. Effect of manure-N, fertilizer-N, and manure-N plus fertilizer-N on stalk nitrate concentration in 2001, corn following soybean sites.

Fertilizer		Cerro Gordo-1				Wright-1				Clay-3				Washington-2			
N Rate		C†	L†	H†	Mean	C	L	H	Mean	C	L	H	Mean	C	L	H	Mean
kg N ha^{-1}		mg NO_3-N kg^{-1}															
0		10	1611	1613	1078	33	1046	3720	1600	15	13	29	19	45	70	34	50
45		117	3513	5537	3056	14	2989	5830	2944	22	132	667	274	10	28	897	312
90		2487	5390	9840	5906	1304	6453	6833	4863	103	1420	2598	1374	19	1156	1135	770
135		5903	8843	11667	8804	4547	6497	7007	6017	2463	2560	3563	2862	56	1415	1455	975
Mean		2129	4839	7164		1475	4246	5848		651	1031	1714		33	667	880	
Source	df‡	$P > F$															
Manure (M)	2	0.0007				0.0371				0.1674				0.2559			
Rep	2	0.2914				0.4220				0.1831				0.1774			
N Rate (NR)	3	<0.0001				<0.0001				<0.0001				0.0625			
$NR_{Linear(L)}$	1	<0.0001				<0.0001				<0.0001				0.0106			
$NR_{Quadratic(Q)}$	1	0.3920				0.8390				0.0456				0.9021			
$NR_{Residual(R)}$	1	0.7301				0.5264				0.7267				0.6662			
M x NR	6	0.1179				0.1318				0.3538				0.3972			
M x NR_L	2	0.0553				0.2379				0.2741				0.1329			
M x NR_Q	2	0.1291				0.0536				0.3640				0.7392			
M x NR_R	2	0.7393				0.4843				0.3485				0.5377			

†C, L, and H represent check, low and high rates of manure.

‡Degrees of freedom for Washington-2 Rep was 1.

Table 14. Effect of manure-N application on post-harvest soil profile nitrate in 2000, corn following soybean sites.

Sample	Hardin-1			Webster-1			Clay-1			Washington-1			Plymouth-1		
Depth	C[†]	L[†]	H[†]	C	L	H	C	L	H	C	L	H	C	L	H
cm	kg NO_3-N ha^{-1}														
0-30	40.4	47.9	61.7	7.9	10.5	40.8	20.1	29.2	49.8	8.6	--[‡]	19.1	17.0	42.5	119.1
30-60	5.7	13.7	43.3	4.3	4.3	23.4	4.0	4.0	4.0	4.0	--	9.9	4.0	15.1	25.7
60-90	4.9	9.7	28.0	4.9	4.9	9.7	4.0	4.0	4.0	4.3	--	7.1	4.0	43.5	23.0
90-120	12.9	19.4	34.9	6.9	9.5	11.2	4.3	4.3	9.2	4.3	--	4.3	36.9	55.3	22.7
Profile Total	63.9a[§]	90.6a	167.8b	23.9a	29.1ab	85.1b	32.3a	41.3a	67.0b	21.0a	--	40.3a	61.8a	156.5b	190.5b

[†]C, L, and H represent check, low and high rates of manure.

[‡]No low manure rate was applied at Washington-1.

[§]Means followed by same letter within a site are not significantly different ($P \leq 0.10$) within a site.

Table 15. Effect of manure-N, fertilizer-N, and manure plus fertilizer-N on post-harvest soil profile nitrate in 2001, corn following soybean sites.

	Wright-1						Washington-2					
	Fertilizer-N Rate											
Sample	0 kg N ha^{-1}			90 kg N ha^{-1}			0 kg N ha^{-1}			90 kg N ha^{-1}		
Depth	C[†]	L[†]	H[†]	C	L	H	C	L	H	C	L	H
cm	kg NO_3-N ha^{-1}											
0-30	11.4	14.2	18.4	24.1	21.3	25.5	25.7	23.7	33.6	31.6	27.7	23.7
30-60	2.1	7.1	8.5	7.1	24.1	22.7	5.9	9.9	7.9	5.9	7.9	11.9
60-90	2.3	2.3	8.4	13.7	33.4	22.8	2.4	2.4	2.4	2.4	3.7	9.7
90-120	2.6	6.5	13.8	11.2	10.3	15.5	2.6	2.6	2.6	2.6	3.9	20.7
Profile Total	18.3a[‡]	30.0a	49.1b	56.1a	89.1a	86.5a	36.6a	38.6a	46.5a	42.5a	43.1a	65.9b

[†] C, L, and H represent check, low and high rates of manure.

[‡] Means followed by same letter within a site and within a fertilizer-N rate are not significantly different ($P \leq 0.10$).

Table 16. Effect of manure-N, fertilizer-N, and manure plus fertilizer-N on corn grain N in 2000, corn following soybean sites.

Fertilizer N Rate	Hardin-1 C[†]	Hardin-1 L[†]	Hardin-1 H[†]	Hardin-1 Mean	Webster-1 C	Webster-1 L	Webster-1 H	Webster-1 Mean	Clay-1 C	Clay-1 L	Clay-1 H	Clay-1 Mean	Washington-1 C	Washington-1 L	Washington-1 H	Washington-1 Mean
kg N ha^{-1}	- - - - -								g N kg^{-1}							- - - - -
0	11.0	13.7	14.4	13.0	11.2	12.5	13.2	12.3	10.0	11.3	12.4	11.3	11.7	- -[‡]	13.0	12.4
45	12.5	14.8	13.9	13.7	12.2	13.4	13.4	13.0	10.5	12.2	13.0	11.9	12.1	- -	14.0	13.0
90	12.7	14.3	13.9	13.6	12.7	13.4	14.3	13.4	12.9	13.0	13.2	13.1	12.8	- -	14.3	13.5
135	13.6	14.4	14.6	14.2	12.2	13.8	13.8	13.3	12.4	13.0	13.3	12.9	13.2	- -	14.7	13.9
Mean	12.4	14.3	14.2		12.1	13.3	13.7		11.5	12.4	13.0		12.4	- -	14.0	

Source	df[§]	Hardin-1	Webster-1	Clay-1	Washington-1
		- - - - -	$P > F$		- - - - -
Manure (M)	2	0.0557	0.0124	0.0134	<0.0009
Rep	2	0.1375	0.0800	0.3328	0.1725
N Rate (NR)	3	0.0132	0.0005	<0.0001	0.1738
$NR_{Linear(L)}$	1	0.0031	0.0002	<0.0001	0.0175
$NR_{Quadratic(Q)}$	1	0.7150	0.0175	0.0161	0.7499
$NR_{Residual(R)}$	1	0.1190	0.5984	0.0174	0.9822
M x NR	6	0.0407	0.4141	0.0044	0.9135
M x NR_L	2	0.0126	0.7747	0.0019	0.9272
M x NR_Q	2	0.1031	0.3189	0.5312	0.6086
M x NR_R	2	0.5874	0.2033	0.0212	0.6490
Contrasts[¶]					
C_0 vs. C_N	1	0.0006	0.0015	<0.0001	<0.0001
L_0 vs. L_N	1	0.0766	0.0065	0.0002	--[‡]
H_0 vs. H_N	1	0.5643	0.0755	0.0289	0.0429

[†] C, L, and H represents check, low, and high rates of manure.

[‡] No low manure rate was applied at Washington-1 site.

[§] Degrees of freedom for Hardin-1 Rep was 1, and degrees of freedom for Washington-1 M, M x NR, M x NR_L, M x NR_Q, M x NR_R were 1, 3, 1, 1, and 1, respectively.

[¶] Subscript 0 and N represent without and with fertilizer-N applied.

Table 17. Effect of manure-N, fertilizer-N, and manure plus fertilizer-N on corn grain N in 2001, corn following soybean rotation.

Fertilizer	Cerro Gordo-1				Wright-1				Clay-3				Washington-2			
N Rate	C[†]	L[†]	H[†]	Mean	C	L	H	Mean	C	L	H	Mean	C	L	H	Mean
kg N ha^{-1}	----------	----------	----------	----------	----------	----------	----------	g N kg^{-1}	----------	----------	----------	----------	----------	----------	----------	----------
0	11.2	12.0	12.6	11.9	9.1	11.6	13.1	11.3	10.3	11.7	11.4	11.1	10.3	11.5	12.3	11.4
45	12.2	12.6	12.7	12.5	10.8	12.1	12.9	11.9	11.0	11.9	12.2	11.7	10.3	12.1	12.8	11.8
90	12.5	12.8	13.2	12.9	11.8	12.4	12.7	12.3	11.9	13.0	12.9	12.6	11.2	14.1	13.3	12.8
135	13.1	12.9	13.6	13.2	12.9	13.1	13.3	13.1	12.4	12.6	13.7	12.9	11.8	14.3	13.8	13.3
Mean	12.2	12.6	13.0		11.1	12.3	13.0		11.4	12.3	12.5		10.9	13.0	13.1	

Source	df[‡]	Cerro Gordo-1	Wright-1	Clay-3	Washington-2
		----------	---------- P > F	----------	----------
Manure (M)	2	0.0426	0.0012	0.0025	0.0279
Rep	2	0.0227	0.0129	0.0141	0.0886
N Rate (NR)	3	0.0017	0.0001	0.0002	0.0120
$NR_{Linear(L)}$	1	0.0002	<0.0001	<0.0001	0.0018
$NR_{Quadratic(Q)}$	1	0.6167	0.7481	0.6183	0.8926
$NR_{Residual(R)}$	1	0.8493	0.4631	0.4000	0.4242
M x NR	6	0.7503	0.0071	0.7675	0.7602
M x NR_L	2	0.3811	0.0004	0.3197	0.3498
M x NR_Q	2	0.6467	0.4788	0.9370	0.8406
M x NR_R	2	0.7892	0.9995	0.7069	0.7569
Contrasts[§]					
C_0 vs. C_N	1	0.0024	<0.0001	0.0060	0.3040
L_0 vs. L_N	1	0.0634	0.0341	0.1317	0.0197
H_0 vs. H_N	1	0.1597	0.8159	0.0063	0.1888

[†]C, L, and H represent check, low and high rates of manure.

[‡] Degrees of freedom for Washington-2 Rep was 1.

[§]Subscript 0 and N represent without and with fertilizer-N applied.

Table 18. Corn grain yield response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2001, corn following corn sites.

Fertilizer	Hardin-3				Cerro Gordo-2			
N Rate	C[†]	L[†]	H[†]	Mean	C	L	H	Mean
kg N ha^{-1}	Mg ha^{-1}							
0	9.95	10.74	11.83	10.84	10.64	11.08	11.20	10.97
67	11.55	11.50	11.45	11.50	11.41	10.82	11.00	11.08
135	11.83	11.77	11.72	11.77	12.04	11.58	11.88	11.83
202	11.39	12.28	12.27	11.98	12.02	11.24	11.62	
Mean	11.18	11.57	11.82		11.53	11.18	11.43	

Source	df[‡]	Hardin-3	Cerro Gordo-2
		$P > F$	
Manure (M)	2	0.0786	0.1149
Rep	2	0.4457	0.0074
N Rate (NR)	3	0.0007	0.0006
$NR_{Linear(L)}$	1	<0.0001	0.0003
$NR_{Quadratic(Q)}$	1	0.2163	0.2614
$NR_{Residual(R)}$	1	0.6997	0.0160
M x NR	6	0.0401	0.2170
M x NR_L	2	0.1957	0.0728
M x NR_Q	2	0.0075	0.4651
M x NR_R	2	0.8259	0.4532
Contrasts[§]			
C_0 vs. C_N	1	<0.0001	0.0004
L_0 vs. L_N	1	0.0045	0.6257
H_0 vs. H_N	1	0.9547	0.2770

[†]C, L, and H represent check, low and high rates of manure.

[‡]Degrees of freedom for Hardin-3 Rep was 3.

[§]Subscript 0 and N represent without and with fertilizer-N applied.

Table 19. Corn ear leaf chlorophyll meter reading response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2001, corn following corn sites.

Fertilizer N Rate	Hardin-3 C[†]	Hardin-3 L[†]	Hardin-3 H[†]	Hardin-3 Mean	Cerro Gordo-2 C	Cerro Gordo-2 L	Cerro Gordo-2 H	Cerro Gordo-2 Mean
kg N ha^{-1}								
0	51.9	52.1	57.1	53.7	54.5	58.3	57.9	56.9
67	52.4	52.5	56.7	53.9	58.4	60.3	59.9	59.5
135	55.1	54.7	58.5	56.1	58.7	60.6	59.6	59.6
202	54.8	54.3	58.2	55.7	59.4	60.9	60.9	60.4
Mean	53.5	53.4	57.6		57.8	60.0	59.6	

Source	df[‡]	Hardin-3 P > F	Cerro Gordo-2 P > F
Manure (M)	2	0.0236	0.3078
Rep	2	0.2987	0.3445
N Rate (NR)	3	0.0008	<0.0001
$NR_{Linear(L)}$	1	0.0003	<0.0001
$NR_{Quadratic(Q)}$	1	0.5532	0.0343
$NR_{Residual(R)}$	1	0.0297	0.0802
M x NR	6	0.9275	0.7522
M x NR_L	2	0.4576	0.2342
M x NR_Q	2	0.9121	0.4320
M x NR_R	2	0.9747	0.8178
Contrasts[§]			
C_0 vs. C_N	1	0.0244	<0.0001
L_0 vs. L_N	1	0.0692	0.0106
H_0 vs. H_N	1	0.4303	0.0102

[†]C, L, and H represent check, low and high rates of manure.

[‡]Degrees of freedom for Hardin-3 Rep was 3.

Table 20. Relative corn ear leaf chlorophyll meter reading response to manure-N, fertilizer-N, and manure plus fertilizer-N in 2001, corn following corn sites.

Fertilizer	Hardin-3			Cerro Gordo-2		
Nrate	C†	L†	H†	C	L	H
kg N ha^{-1}	-------------	-------------	------------- % -------------	-------------	-------------	-------------
0	89.2	89.5	98.1	89.5	95.7	95.1
67	90.0	90.2	97.4	95.9	99.0	98.4
135	94.7	94.0	100.5	96.4	99.5	97.9
202	94.2	93.3	100.0	97.5	100.0	100.0

†C, L, and H represent check, low and high rates of manure.

Table 21. Effect of manure-N, fertilizer-N, and manure plus fertilizer-N on the late spring soil nitrate concentration in 2001, corn following corn sites.

Fertilizer		Hardin-3				Cerro Gordo-2			
Nrate		C†	L†	H†	Mean	C	L	H	Mean
kg N ha^{-1}		mg NO_3-N kg^{-1}							
0		8	10	19	12	16	17	23	19
135		29	31	38	33	29	40	37	35
Mean		19	21	29		23	29	30	
Source	df‡	P > F							
Manure (M)	2	0.0775				0.2681			
Rep	2	0.3344				0.4745			
M x Rep	4	0.5042				0.4956			
N Rate (NR)	1	<0.0001				0.0029			
M x NR	2	0.9616				0.4548			

† C, L, and H represent check, low and high rates of manure.
‡Degrees of freedom for Hardin-3 Rep was 3.

Table 22. Effect of manure-N, fertilizer-N, and manure-N plus fertilizer-N on stalk nitrate concentration in 2001, corn following corn sites.

Fertilizer	Hardin-3				Cerro Gordo-2			
N Rate	C†	L†	H†	Mean	C	L	H	Mean
kg N ha^{-1}	------------- mg NO_3-N kg^{-1} ------------							
0	71	309	3760	1380	146	1927	1510	1194
67	778	2560	4290	2543	3303	5667	7953	5641
135	2565	3445	4833	3614	5970	10663	10020	8884
202	3458	5685	6840	5328	9273	10853	11400	10509
Mean	1718	3000	4931		4673	7278	7721	

Source	df‡	Hardin-3	Cerro Gordo-2
		---------- $P > F$ ------------	
Manure (M)	2	0.0417	0.0562
Rep	2	0.1314	0.2018
N Rate (NR)	3	<0.0001	<0.0001
$NR_{Linear(L)}$	1	<0.0001	<0.0001
$NR_{Quadratic(Q)}$	1	0.2395	0.0389
$NR_{Residual(R)}$	1	0.4802	0.8851
M x NR	6	0.0521	0.5394
M x NR_L	2	0.0225	0.9605
M x NR_Q	2	0.3672	0.2518
M x NR_R	2	0.1725	0.3667

†C, L, and H represent check, low and high rates of manure.

‡Degrees of freedom for Hardin-3 Rep was 3.

Table 23. Effect of manure-N, fertilizer-N, and manure plus fertilizer-N on post-harvest soil profile nitrate in 2001, corn following corn sites.

Sample	Hardin-3						Cerro Gordo-2					
	Fertilizer-N Rate											
	0 kg N ha^{-1}			135 kg N ha^{-1}			0 kg N ha^{-1}			135 kg N ha^{-1}		
Depth	C[†]	L[†]	H[†]	C	L	H	C	L	H	C	L	H
cm	kg NO_3-N ha^{-1}											
0-30	9.9	15.8	18.8	42.5	23.7	36.5	12.3	15.0	13.7	16.4	28.7	34.2
30-60	2.7	6.4	5.3	17.0	9.0	18.1	2.3	2.3	2.3	5.3	25.8	25.8
60-90	2.3	5.1	4.0	10.8	5.7	19.4	2.4	2.4	2.4	17.8	29.2	25.9
90-120	2.4	10.9	12.8	20.7	13.4	26.7	2.6	6.9	13.8	18.1	31.0	25.8
Profile Total	17.2a[‡]	38.2a	40.8a	91.0ab	51.8b	100.7a	19.6a	26.6a	32.2a	57.6a	114.7a	111.8a

[†]C, L, and H represent check, low and high rates of manure.

[‡]Means followed by same letter within a site and within a fertilizer-N rate are not significantly different ($P \leq 0.10$).

Table 24. Effect of manure-N, fertilizer-N, and manure plus fertilizer-N on corn grain-N in 2001, corn following corn sites.

Fertilizer N Rate		Hardin-3 C[†]	Hardin-3 L[†]	Hardin-3 H[†]	Hardin-3 Mean	Cerro Gordo-2 C	Cerro Gordo-2 L	Cerro Gordo-2 H	Cerro Gordo-2 Mean
kg N ha^{-1}		g N kg^{-1}							
0		11.7	12.6	13.4	12.6	13.1	14.5	14.8	14.1
67		12.9	12.8	13.7	13.1	15.1	16.0	15.3	15.5
135		13.4	13.6	13.1	13.4	14.7	15.3	16.0	15.3
202		13.7	13.7	13.3	13.6	15.2	15.2	15.6	15.3
Mean		13.0	13.2	13.4		14.5	15.2	15.4	
Source	df[‡]	$P > F$							
Manure (M)	2	0.1308				0.1062			
Rep	2	0.2748				0.1033			
N Rate (NR)	3	<0.0001				0.0039			
$NR_{Linear(L)}$	1	<0.0001				0.0067			
$NR_{Quadratic(Q)}$	1	0.1347				0.0137			
$NR_{Residual(R)}$	1	0.6712				0.1485			
M x NR	6	0.0001				0.3611			
M x NR_L	2	<0.0001				0.2373			
M x NR_Q	2	0.3004				0.8586			
M x NR_R	2	0.1225				0.1906			
Contrasts[§]									
C_0 vs. C_N	1	<0.0001				0.0010			
L_0 vs. L_N	1	0.0040				0.0632			
H_0 vs. H_N	1	0.7786				0.1216			

[†] C, L, and H represent check, low and high rates of manure.

[‡]Degrees of freedom for Hardin-3 for Rep was 3.

[§]Subscript 0 and N represent without and with fertilizer-N applied.

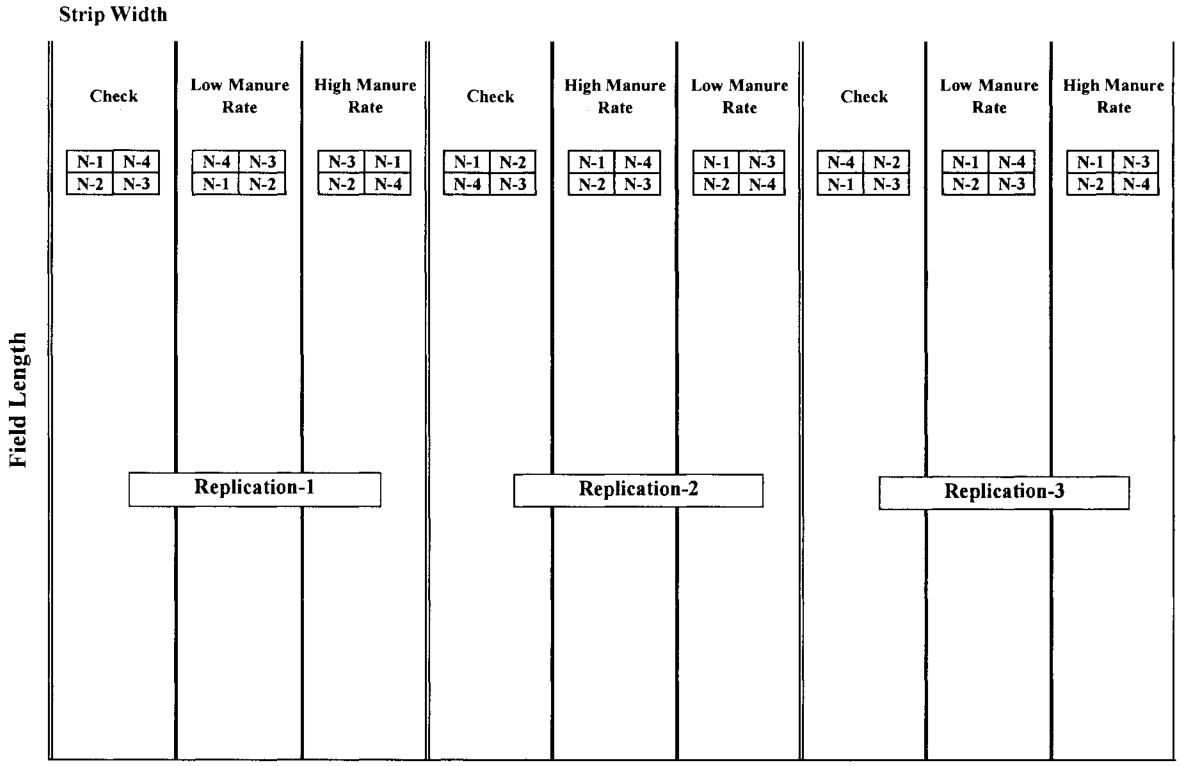

Fig. 1. Example manure field-strip application design and split-plot fertilizer-N rates (N-1, N-2, N-3, and N-4 represent the four fertilizer-N rates).

IMPACT OF LIQUID SWINE MANURE APPLICATION ON SOYBEAN PRODUCTION AND RESIDUAL-YEAR CORN

A paper to be submitted to Agronomy Journal

Sudipta Rakshit and John E. Sawyer

Abstract

The growing number of concentrated swine (*Sus scrofa domesticus*) production facilities necessitates the sound manure management practices to utilize liquid swine manure. Swine manure is typically applied to corn (*Zea mays* L.) to utilize the manure-N component. However, there is interest in utilizing other crops and land for manure application. In Iowa, soybean [*Glycine max* (L.) Merr.] is the second largest crop grown, and therefore is receiving attention for manure application and use of swine manure nutrients. Manure P and K use by soybean has been studied, but the fate of manure-N applied to soybean needs to be resolved. A multi-year project was initiated on producers' fields in 2000 and 2001 to study liquid swine manure effects on soybean production. In addition, the effect of residual-year manure was studied on corn and soybean. Liquid swine manure was applied at zero, low and high rates of total-N (target of 0, 112, and 224 kg total-N ha^{-1}) in replicated strips across field lengths. In the residual manure year, four fertilizer-N rates were applied in small split-plots to each residual manure strip to measure N response. In both years soybean yield was not adversely affected by liquid swine manure application. At three sites, soybean yield increased with manure application. The increase could be due to P or K response (potential indicated at two sites because of optimal to low soil test levels), N response, or some unknown factor.

Post-soybean harvest soil profile nitrate-N did not show elevated accumulation. A residual-year manure-N response was measured at one of two sites in corn where a high manure rate (255 kg total-N ha^{-1}) had been applied to the prior-year soybean crop. Residual profile nitrate-N was highest at that site. At lower swine manure-N rates applied to soybean (less than 225 kg total-N ha^{-1}), no residual-year impact was measured in the corn crop. It appears that if liquid swine manure rates applied to soybean are not excessive (suggested at less than grain-N removal or above ground plant accumulation at maximum yield), then soybean yields should be maintained, or positively increased, with limited potential for N carryover past the soybean crop or for nitrate loss.

Introduction

Soybean is a crop known to satisfy N needs through symbiotic N-fixation when soil inorganic-N is not sufficient to meet crop needs. Therefore, addition of N to soybean is not a common practice. The growing number of concentrated swine facilities necessitates sound manure nutrient management practices for minimizing environmental risks associated with land application, including over application. The search for alternate crops, or a larger base other than land in corn production, could be helpful for the utilization of liquid swine manure nutrients. As soybean occupies large acreage in Iowa, the potential of soybean to utilize manure nutrients is an important issue. Liquid swine manure application to soybean can provide needed P and K. However, research is necessary to understand the fate of N added with manure. If not used by the soybean crop, the applied manure-N remains as inorganic nitrate and could be leached to tile lines or groundwater.

There is need for building producer confidence that economic soybean production can be achieved with liquid swine manure application and at the same time minimize environmental consequences. It has been recognized by researchers that symbiotic-N fixation alone does not produce optimum yield for soybean, and there is need for N from soil or other sources (Harper, 1974). Schmidt et al. (2000) reported that liquid swine manure application to nodulating soybean did not affect maximum yield, irrespective if no N, sufficient N, or excess N was applied. Bhangoo and Albritton (1975) reported that symbiotic-N fixation was inhibited and approached zero with 224 kg fertilizer-N ha^{-1}. They acknowledged that optimum yield of soybean could only be achieved with symbiotically fixed-N together with soil derived or applied-N. However, quantifying the balance between symbiotic-N fixation and applied-N is intricate.

In addition to efficient soybean N use, environmental concern about nitrate-N loss after manure application to soybean is an important issue. It has been shown that soybean can act as a N-sink and actively uses inorganic-N available in the soil (Varvel et al., 1992). Soybean can remove approximately 150-200 kg N ha^{-1} at grain yield levels of 2.5 to 3.4 Mg ha^{-1} (Varvel et al., 1992). Therefore, soybean has the potential to use large quantities of applied manure-N and potentially not cause environmental risks from large profile buildup or nitrate loss to the environment. Schmidt et al. (2000) reported an average 191 kg-N ha^{-1} accumulation in above ground biomass at the R6 growth stage (Ritchie et al., 1988) with swine manure-N or fertilizer-N application to nodulating soybean, thus supporting the ability of soybean to act as a large manure-N sink. However, they found fertilizer-N or manure-N applied in excess of what a soybean crop could use created a build up of profile nitrate remaining after harvest.

No direct adverse effect on soybean yield was observed in the Schmidt et al. (2000) research, even with excessive manure or fertilizer-N. In some instances yield was increased by manure application, even though soil test indicated no response was expected. These increases in yield were not consistent between sites and varieties (Schmidt et al., 2000, 2001). They speculated that yield increase could be associated with manure-N, forms of N in the manure, continuous NH_4^+-N release, N-release characteristics, other manure nutrients, or some other factor or factors. In one instance grain yield was decreased with swine manure application due to disease development, and at some sites lodging was increased (Schmidt et al., 2000, 2001).

Depending upon the manure source, first-year crop availability varies but typically is not the total amount. It is important to know the first-year soybean uptake of applied liquid swine manure-N, and the potential for manure-N to be available in the following crop year. This could be different than when manure is applied before a non-fixing crop, like corn. This would not only give an idea about manure-N availability to the next crop, but would also help understand potential for residual-N build up. Many studies have been carried out with different manure sources. For example, Motavalli et al. (1989) reported a range of 12-63% first-year dairy manure-N availability. They suggested additional need for more information on crop availability and manure-N-availability indexes. Eghball (2000) found estimated residual-year beef manure-N availability at 4%. In another study Eghball and Power (1999) reported second-year beef manure-N availability at 8%. However, more field research with specific manure sources, and specifically corn following soybean, is needed to better understand the second-year manure-N availability.

The objectives of this study are to one, determine the effect of liquid swine manure application on yield and soil profile nitrate when liquid swine manure is applied to the soybean crop; and two, determine second-year residual manure-N availability when corn follows soybean.

Materials and Methods

Soybean

Liquid swine manure application to soybean was studied at six producers' fields in 2000 and 2001 across Iowa. Site characteristics are given in Table 1. The previous crop was corn at all sites. Liquid swine manure was applied in the spring before soybean planting at each site. At the Webster-1R site (the R indicates second-year residual) in 2001, liquid swine manure had been applied in the spring before the previous year corn crop. Therefore, the Webster-1R site in 2001 measures the residual-year manure nutrient supply to soybean.

The treatments were three intended liquid swine manure rates (check or no manure applied, low or 112 kg total-N ha^{-1}, high or 224 kg total-N ha^{-1}) applied in three replicated strips (these were replications of each manure treatment) across the field length with producer equipments or custom applicator. The calculated manure rates varied among sites due to differences in manure-N concentration and application constraints. The strip width and length ranged between 152-790 m x 9-18 m in size (Table 2) depending on the manure applicator width, combine header width, and field length. Except for no N, P, or K fertilizer application, producers used common cultural practices for the geographic area.

The manure sources were confined swine production facilities. The manure storage structure was under-building pits at all sites. Liquid swine manure was used in this study at all locations. Manure was injected below the soil surface using knife-injection or disk-soil covering at application, except the Hardin-2, Clay-2, and Clay-4 sites (Table 2) where manure was surface broadcast and incorporated within 24 hour.

Manure application rates were determined by pre-application manure sampling and laboratory chemical analysis (Table 2), and manure applicator calibration. The calibration procedure was accomplished by first weighing the applicator when it was full, and then weighing again after application through a known area at a set speed. The rate was calculated from the difference of these two weights. Some of the applicators had flow control rate monitors to set the rate of application, although the same calibration procedure was followed for these applicators. Speed or flow was adjusted if needed, and calibration determined again.

Pre-application manure samples were collected approximately 2-3 weeks before planned application from the producers' storage structures. Samples were either dipped off the manure surface, or collected from a probe of the storage profile. Manure was then transferred to plastic bottles with a soup ladle during continuous stirring. The manure samples were analyzed for total-N, P, K (APHA, 1995) by the Iowa State University Analytical Service Laboratory. These pre-application samples were used, in conjunction with the applicator calibration, to set manure application rates. Manure samples were collected from multiple loads (every load at most of the sites) during application and analyzed for total-N, P, and K (Table 2). These samples were used to confirm as-applied nutrient content, and in conjunction with applicator calibration, to determine total manure nutrient application rates.

Before manure application, 0-15 cm composite soil samples (8 cores per sample) were taken from the field-length strips. The number of samples varied from four to ten depending upon strip length. Each strip replicate was flagged at approximately 46 m intervals to create strip sample points. This distance varied among sites but constant within sites. These soil samples were analyzed for soil test P, K, pH, and organic matter at the Iowa State University Soil Testing Laboratory. Soil extractable P was determined with the Mehlich 3-P availability index (Frank et al., 1998). Soil extractable K was determined with the 1 M ammonium acetate extractant (Warncke and Brown, 1998). Soil pH was determined on a 1:1 water soil paste using an electronic pH meter (Watson and Brown, 1998). Organic carbon was determined using dry combustion method (Matejovic, 1997) in LECO CHN-2000, and converted to soil organic matter multiplying by a numerical standard factor.

In the fall, post-harvest profile soil samples were collected from each strip at depths of 0-30, 30-60, 60-90, 90-120 cm to determine residual soil nitrate. The samples were analyzed for nitrate-N at the Iowa State University Soil Testing Lab with a colorimetric procedure using lachat flow injection (Gelderman and Beegle, 1998). The nitrate-N concentration was converted from mg kg^{-1} to kg nitrate-N ha^{-1} soil by adjusting for bulk density at each sample depth using assumed bulk densities for each soil and depth obtained from soil survey characterization (Dr. Tom Fenton, personal communication).

The cooperating producers harvested the soybean treatment strips, with yield determined by yield monitor or weigh wagon (Clay-4 site). Yields were corrected to standard

13% moisture. The width harvested varied depending on the combine header width, with one pass from the center portion being harvested to determine strip yield. Weigh wagon data included the split-plot portion of the yield, whereas, yield monitor data was cleaned to not including the split plot area.

The experimental design was a randomized complete block. Analysis of variance was determined with the GLM procedure (Statistical Analysis System, SAS Institute, 1992). Significant differences between treatment means were determined by Fisher's protected LSD.

Corn

The second-year effect of liquid swine manure-N was studied at two sites (Webster-2R and Clay-2R) cropped to corn in 2001. At these sites manure had been spring-applied the previous year before a soybean crop. The experimental design was a randomized complete block, with a split-plot treatment arrangement (Fig 1). The main plots were three prior-year liquid swine manure rates (planned rates of check or 0 kg N ha^{-1}, low or 112 kg total-N ha^{-1}, and high or 224 kg total-N ha^{-1}) applied in strips across the field length to soybean crops. The actual applied manure rates varied among sites due to differences in manure-N concentration and application constraints (Table 2). The strip width and length in the previous year ranged between 354-365 m x 9-12 m with size depending on the manure applicator width, combine header width, and field length. The split-plots were four fertilizer-N rates (0, 45, 90, and 135 kg total-N ha^{-1}) arranged in a set of four small plots (approximately 12 m x 3 m) within each manure main-plot strip. Ammonium nitrate was surface broadcast applied shortly after corn emergence. The split-plot N application allowed measurement of corn response to the applied residual manure-N and to additional fertilizer-N. Blanket P and K fertilizers (67 kg P_2O_5 and K_2O ha^{-1}) were broadcast applied to the split-plot area before final spring tillage to mask the effect of P and K applied with the prior-year manure application.

When corn was about 15-30 cm tall (late May to mid June), soil samples from all the strip points and selected small plots (0 and 90 kg N ha^{-1}) were collected at depth of 0-30 cm for nitrate-N analysis. The soil samples were collected following the procedure described by Blackmer et al. (1997). Nitrate-N was analyzed in Iowa State University Soil Testing Lab with a colorimetric procedure using a lachat flow injection (Lachat Instruments, Milwakee, WI) (Gelderman and Beegle, 1998). Soil nitrate-N values from the strip sample points were averaged to obtain a single value for each manure treatment strip.

When corn plants were at the R1 growth stage (Ritchie et al., 1986), chlorophyll meter readings were taken from both the strips and in the fertilizer-N treatments with Minolta 502 SPAD meter (Peterson et al., 1993). The chlorophyll meter readings were taken from the leaf opposite and below the primary ear-leaf, and at a point one-half the distance from the leaf-tip to the collar, and halfway between the leaf margin and the leaf midrib using the procedure of Peterson et al. (1993). In the small plots, fifteen random readings were averaged from the middle two rows (which were selected for hand harvest). In the strips, fifteen readings were taken randomly from the middle four rows within a distance of 12 m centered along the length of each strip point and the individual plant readings averaged. Values from each strip points were averaged to obtain a single value for each manure treatment strip.

Stalk samples were collected after corn physiological maturity from the split fertilizer-N using the procedure discussed by Blackmer and Mallarino, (1996). Collected samples were dried at 60^0 C and ground to pass a 1.0 mm screen. Samples were then analyzed for stalk nitrate-N concentration (Binford at al., 1992)

After corn physiological maturity, ears were hand harvested from the middle two rows (length of 6 m) of the split-plots to determine grain yield. Grain yields were adjusted to 155 g kg^{-1} moisture content. Field length-strip treatments were machine harvested by the cooperating producers. Yield was determined using a weigh wagon at Clay-2R. The width harvested varied depended upon the combine header width, with one pass from each strip center being harvested to determine yield. Strip yield data were lost at the Webster-2R site due to yield monitor malfunction and failure to store yield data. Weigh wagon data include the split-plot portion of each strip.

Corn grain samples were digested using the procedure of Hach et al. (1987). Finely ground grain samples were heated at 440^0 C for 4 min in a Hach digester in a 100 ml volumetric flask with concentrated (18 M) H_2SO_4, and then 10 ml H_2O_2 was added and heated until a clear solution was obtained. More H_2O_2 was added if needed to get a clear solution. After cooling, the solution was made up to volume in the volumetric flask, and an aliquot was analyzed colorimetrically for nitrate-N using Lachat flow injection (Gelderman and Beegle, 1998).

Analysis of variance was carried out with the Statistical Analysis System (SAS Institute, 1992), using the GLM and Mixed procedures. Single degree of freedom contrasts were used to compare response to fertilizer-N. When appropriate, means were separated by Fisher's protected LSD.

Results and Discussion

Soybean Yield

Soybean grain yield was increased significantly ($P \leq 0.10$) by liquid swine manure application at three of five sites (Table 3). Overall, the yield increases were not large even though some of the increments were statistically significant. At the residual-year site, soybean yield was also increased from the previous manure application (Table 3). Soybean yield was not decreased with liquid swine manure application at any site in 2000 or 2001. These results correspond with research in Minnesota and Iowa where swine manure and fertilizer-N application to soybean either enhanced (swine manure) or had no effect on yield (Killorn, 1998; Schmidt et al., 2000; 2001; Sawyer et al., 2001). The finding of no adverse effect on yield was similar to results of Schmidt et al. (2000; 2001) where liquid swine manure was applied at rates of 78 to 255 kg N ha^{-1} (a similar range used in this study).

In 2000, the largest soybean yield increase (0.15 Mg ha^{-1}) occurred at the Webster-2 site in the high manure application rate. In 2001, the largest yield increases were in the high manure rate, but the increase was greatest (0.29 Mg ha^{-1}) at the Washington-3 site. The yield increase was minimal and not significant from low to high manure application rate at the sites.

It is assumed that soybean yield increases associated with swine manure application were due to N or other factors as discussed by Schmidt et al. (2000). Soil test P (STP) and soil test K (STK) levels were high enough that no to only small yield response to added P and K would be expected. Only at Clay-4 and Washington-3 where STP was low to optimal might a response to P application occur (Voss et al., 1999). Across Iowa soils, response to other manure nutrients would not generally be expected.

At the second-year residual Webster-1R site (manure applied before the previous corn crop), yield was increased with both manure rates over the control yield. Soil test K was low enough (Voss et al., 1999) that the residual effect could be due to response to manure-K, especially at the high manure application rate.

Post-Harvest Profile Nitrate

The post-harvest profile nitrate-N amount (samples were not collected at the Webster-1R 2001 site) did not increase significantly ($P \leq 0.10$) with low or high manure application rates (Tables 4 and 5). This indicates potential N uptake and use by the soybean crop. At the Hardin-2 low manure-N rate and Clay-1 high manure-N rate in 2000, the amount of profile nitrate (though not statistically significant) was increased compared to the no-manure check. Liquid swine manure-N rates were 93 and 215 at Hardin-2, and 128 and 255 kg total-N ha^{-1}, respectively for low and high rates. The high profile nitrate-N at Hardin-2 site could be associated with a high manure application history and at Clay-2 with a large N application at the high rate. The range of post-harvest profile nitrate-N at all sites in 2000 and 2001 was from 28 to 132 kg N ha^{-1}, all below the 158 kg N ha^{-1} profile nitrate-N amount reported by Schmidt et al. (2000) as an upper level not expected to represent a large accumulation of nitrate-N and potential loss due to leaching following swine manure application to soybean. However, manure application rates less than approximately 200 kg total-N ha^{-1} more closely matched soybean N use with little increase of post-harvest soil nitrate-N (Schmidt et al., 2000). This represents the approximate range of most manure-N rates applied in this study, with the result being no significant measured-increase in profile nitrate-N. Varvel et al. (1992) reported soybean at a grain yield level of 2.5-3.4 Mg ha^{-1} could remove 150-200 kg-N ha^{-1}. The soybean yields in our study fall in that range, indicating potential removal of significant manure-N. This was corroborated by the low amount of post-harvest profile nitrate-N measured.

Other than one instance, the amount of post-harvest profile remaining after manure-N rates > 200 kg total-N ha^{-1} was quite low and basically equivalent to the non-manured levels. This indicates that liquid swine manure application at the rates used in this study for soybean production should not build up residual nitrate in soil profiles that could cause potential for large nitrate-N loss. For conservative reasons, if swine manure-N application rates were limited to grain removal levels (generally < 200 kg total-N ha^{-1}), then soybean uptake should be high and environmental impact minimized.

Residual-Year Corn Yield

At the Webster-2R and Clay-2R sites, manure had been applied to the prior-year soybean (Tables 1 and 2). These sites were used to determine the second-year effect of manure on corn production. Strip yield was not collected at the Webster-2R site due to yield monitor failure to record data. At the Clay-2R site, corn yield was significantly higher (Table 6) in both the low and high rates of manure compared to the no-manure check. This indicates an impact of the previous-year manure. This might be due to manure-N carryover from the previous year, which is indicated by high post-harvest profile nitrate-N remaining after the soybean crop (Table 4). Soil test P and K suggest that yield increases would not be due to residual supply from applied manure P or K. The site did have root lodging due to extended rootworm diapose, which may have influenced yields and treatment effects.

Chlorophyll meter readings of the corn ear leaf and and late spring soil nitrate-N concentrations (Table 6) indicate enhanced N supply from previous-year manure applications. However, increases were not large, and are at the levels that indicate N deficiency (Piekielek et al., 1995). At the Clay-2R site, increases in leaf chlorophyll and late spring soil nitrate-N concentrations correspond to the strip yield increases, and although not significant, to the higher post-harvest profile nitrate-N (taken in the prior-year after soybean harvest). At the Webster-2R site, post-harvest profile nitrate-N (taken in the prior-year after the soybean harvest) was not greatly influenced by manure application, and this was reflected in the leaf chlorophyll meter and late spring soil nitrate-N concentrations.

Fertilizer-N Responses In Residual-Year Corn

At the Webster-2R site, there was no significant yield response to the prior-year low or high manure-N rates (Table 7). Yield response to fertilizer-N rate was the same for the check, low, and high prior-year manure rates. This indicates no residual-year manure effect from the prior-year manure-N application before soybean.

The Clay-2R site behaved differently than the Webster-2R site. Yield was increased by the prior-year manure application (Table 7) indicating residual manure-N carryover (the same trend in yield increase was observed in the field-length strips). Yield increase to fertilizer-N rate was similar for the no-manure check and low prior-year manure-N rate, but was less with the high prior-year manure-N rate. Also, yield increase from applied fertilizer-N was much larger than the residual manure-N effect. This indicates some residual manure-N availability, but only up to approximately 45 kg N ha^{-1} with the high prior-year manure-N rate (yield with 45 kg fertilizer-N ha^{-1} on the no-manure check was about the same as that with the prior-year high manure rate). This trend of yield response to the prior-year manure application tends to follow the amount of post-harvest profile nitrate-N measured after the soybean crop.

Corn ear leaf chlorophyll meter readings are shown in Table 8. Calculated relative chlorophyll meter readings are shown in Table 9. At the Webster-2R site, chlorophyll meter readings were similar in the no-manure check, low, and high prior-year manure rates with no additional fertilizer-N. This indicates no additional N uptake from the prior-year low and high manure rates. The chlorophyll meter readings and calculated relative readings were quite high. Absolute and relative chlorophyll meter reading response to fertilizer-N rate was the same for the no-manure check, low, and high prior-year manure rates. This indicates no residual-year manure-N effect at that site. This followed the trend in yield response.

At the Clay-2R site, the chlorophyll meter readings and relative values were low for all prior-year manure rates when no fertilizer-N was applied (Tables 8 and 9). These values indicate N deficiency, with values below reported critical levels (Peterson et al., 1993; Piekielek et al., 1995). Low and high rates of prior-year manure increased absolute and relative chlorophyll meter readings, indicating some residual manure-N effect. This was similar to the yield increases. Increases in ear leaf chlorophyll meter readings were larger with fertilizer-N application than for residual manure-N rates. Increases in readings with fertilizer-N application were similar for the no-manure check and prior-year low rate, but smaller with high prior-year rate. This suggests a greater possibility of residual manure-N carryover from the high manure rate than the low rate. As noted with the yield increases, the amount of carryover effect from the high manure rate was not large, perhaps around 45 kg N ha^{-1}.

At both sites, the late spring soil nitrate concentrations (Table 10) were obtained for the check, low and high prior-year manure application rates when no additional fertilizer-N was applied. At the Clay-2R site, the levels measured indicate that the late spring soil nitrate test did not discern the crop available-N carried over from the previous year application. At both sites, addition of 90 kg fertilizer-N ha^{-1} increased soil nitrate-N concentrations the same with all prior-year manure rates. The levels would indicate deficient N supply (with the 90 kg N ha^{-1}), but yield response and leaf chlorophyll meter readings did not indicate this. The late spring soil nitrate test appears not to be sensitive to residual-N availability from liquid swine manure.

Corn stalk nitrate-N concentrations shown in Table 11 were very low for all treatments at both sites, and the corn stalk nitrate concentrations were not sensitive to differences in residual-year manure-N supply as found with leaf chlorophyll meter readings or grain yields. Additional fertilizer-N increased stalk nitrate concentrations in the no-manure check, low, and high prior-year manure-N rates at both sites. However, none of the sites had stalk nitrate-N concentrations in the optimal range or higher, other than with 135 kg fertilizer-N ha^{-1} at the Webster-2R site (that is not in the 700-2000 mg nitrate-N kg^{-1} range or higher). With the higher residual manure-N supply, this would have been expected at the Clay-2R site, but did not occur.

At the Webster-2R site, grain N (Table 12) did not increase considerably from the prior-year manure application, thus indicating little to no residual manure-N supply. Additional fertilizer-N increased grain N concentration, especially in the check and high prior-year manure rate. At the Clay-2R site, grain-N concentration increased in response to the prior-year manure rates. Additional fertilizer-N increased grain N concentration at all prior-year manure rates. This indicates some residual manure-N at that site, but as found for yield and other corn N status indicators, only a small amount.

Conclusion

Liquid swine manure application did not adversely affect soybean yield, even when applied at rates greater than 200 kg total N ha^{-1}. Soybean yield increase was minimal at all the sites, though was statistically significant at three of the five sites with manure applied to the soybean crop and at one site where manure had been applied the year before to a corn crop. Post-soybean harvest soil profile nitrate-N levels did not show large increase from manure-N application, or levels that would pose risk of large nitrate-N accumulation and potential for loss. A small residual-year manure-N response in corn was measured at one site (for corn grown after manured soybean) where a high manure-N rate (255 kg-N ha^{-1}) had been applied to the prior-year soybean crop. At lower manure-N rates, no residual-year effect was measured in the corn crop that followed manured soybean. It appears that if liquid swine manure-N rates applied to soybean are limited to no more than expected grain-N removal, or plant accumulation at maximum yield (generally 150-200 kg N ha^{-1}), then soybean uptake of applied manure-N should be high, soybean yields not adversely affected (may be increased), and residual-N accumulation minimized. However, if soybean yields are not increased, then economic loss of manure-N occurs.

References

American Public Health Association. 1995. Standard methods for the examination of water and wastewater. 18th edition. American Public Health Association, Washington, D. C.

Bhangoo, M. S. and D. J. Albritton. 1976. Nodulating and non-nodulating lee soybean isolines response to applied nitrogen. Agron. J. 68:642-645.

Binford, G. D., A. M. Blackmer, and B. G. Meese. 1992. Optimal concentrations of nitrate in cornstalks at maturity. Agron. J. 84:881-887.

Blackmer, A. M. and A. P. Mallarino. 1996. Cornstalk testing to evaluate nitrogen management. Iowa State University Extentsion pub. Pm-1584, Iowa State University, Ames, Iowa.

Blackmer, A. M., R. D. Voss, and A. P. Mallarino. 1997. Nitrogen fertilizer recommendations for corn in Iowa. Iowa State University Extension pub. Pm-1714. Iowa State University, Ames, Iowa.

Eghball, B. 2000. Nitrogen mineralization from field-applied beef cattle feedlot manure or compost. Soil Sci. Soc. Am. J. 64:2024-2030.

Eghball, B. and J. F. Power. 1999. Phosphorus and nitrogen-based manure and compost application:Corn production and soil phosphorus. Soil Sci. Soc. Am. J. 63:895-901.

Frank, K., D. Beegle, and J. R. Denning. 1998. Phosphorus. p. 21-26. *In* Brown et al. (ed.) Recommended Chemical Soil test Procedures for North Central Region. North central Regional research Publication No. 221 (Revised) Missouri Agricultural Experiment Station SB 1001.

Gelderman, R. H. and D. Beegle. 1998. Nitrate-nitrogen. p. 17-20. *In* Brown et al. (ed.) Recommended Chemical Soil test Procedures for North Central Region. North central Regional research Publication No. 221 (Revised) Missouri Agricultural Experiment Station SB 1001

Harper, J. E. 1974. Soil and symbiotic nitrogen requirements for optimum soybean production. Crop Sci. 14:255-260.

Hach, C. C. , B. K. Bowden, A. B. Kopelove, and S. V. Brayton. 1987. More powerful peroxide Kjeldahl digestion. J. Assoc. Off. Anal. Chem. 70:783-787.

Killorn, R. Frequency of liquid swine manure application. 1998. p 34-36 Northern Research and Demonstration Farm Annul. Prog. Rep. ISRF98-22 Iowa State Univ. Ames, Iowa.

Matejovic, I. 1997. Determination of carbon and nitrogen in samples of various soils by the dry combustion. Commun. Soil Sci. Plant Anal. 28:1499-1511

Motavalli, P. P., K. A. Kelling, and J. C. Converse. 1989. First-year nutrient availability from injected dairy manure. Environ. Qual. 18:180-185.

Peterson, A, T., T. M. Blackmer, D. D. Francis, and J. S. Schepers. 1993. Using a chlorophyll meter to improve N management. Published by Cooperative Extension, istitute of Agriculture and Natural Resources, University of Nebraska Lincoln. G-93-1171-A.

Piekielek, P. W., R. H. Fox, J. D. Toth, and K. E. Macneal. 1995. Use of a chlorophyll meter at the early dent stage of corn to evaluate nitrogen sufficiency. Agron J. 87:403-408.

Ritchie, S. W., J. J. Hanway, H. E. Thompson, and G. O. Benson. 1988. How a soybean plant develops. Rev. ed. Iowa State Coop Ext. Serv., Ames, IA.

Ritchie, S. W., J. J. Hanway, and G. O. Benson. 1986. How a corn plant develops. Spec. Rep. 48. Rev. ed. Iowa State Coop Ext. Serv., Ames, IA.

Schmidt, J. P., M. A. Schmitt, G. W. Randall, J. A. Lamb, J. H. Orf, and H. T. Gollany. 2000. Swine manure application to nodulating and nonnodulating soybean. Agron J. 92:987-992.

Schmidt, J. P., J. A. Lamb, M. A. Schmitt, G. W. Randall. J. H. Orf, and H. T. Gollany. 2001. Soybean varietal response to liquid swine manure application. Agron. J. 93:358-363

Sawyer, J. E. and D. W. Barker. 2001. In-season nitrogen fertilization of soybean. p. 158-161. *In* Proc, 31st North Central Ext.-Ind. Soil Fert. Conf., Des Moines, IA. 14-15 Nov. 2001. Potash and phosphate Inst., Brookings, SD.

Statistical Analysis Systems Institute. 1992. SAS user's guide: Statistics. SAS Institute, Inc., Cary, NC.

Varvel, G. E and T. A. Peterson. 1992. Nitrogen fertilizer recovery by soybean in monoculture and rotation systems. Agron. J. 84:215-218.

Voss, R. D., J. E. Sawyer, A. P. Mallarino, and R. Killorn. 1999. General guide for crop nutrient recommendations in Iowa. . ISU-Pm 1688. Iowa State University Extension, Ames, Iowa.

Warncke, D. and J. R. Brown. 1998. Potassium and other basic cations. p-31-33. *In* Brown et al. (ed.) Recommended Chemical Soil test Procedures for North Central Region. North central Regional research Publication No. 221 (Revised) Missouri Agricultural Experiment Station SB 1001.

Watson, M. E. and J. R. Brown. 1998. p-13-16. *In* Brown et al. (ed.) Recommended Chemical Soil test Procedures for North Central Region. North central Regional research Publication No. 221 (Revised) Missouri Agricultural Experiment Station SB 1001.

Table 1. Site Characteristics.

					Soil Chemical Characteristics			
Site Name	Crop	Previous Crop	Predominant Soil	Soil Taxonomic Name	pH	STP[†]	STK[†]	Organic Matter
2000						--- $mg\ kg^{-1}$ ---		$g\ kg^{-1}$
Hardin-2	Soybean	Corn	Clarion	Fine-loamy, mixed, mesic Typic Hapludoll	6.0	113	232	50
Webster-2	Soybean	Corn	Webster	Fine-loamy, mixed, noncalcarious, mesic, Typic Haplaquoll	6.0	31	168	60
			Nicollet	Fine-loamy, mixed, mesic Aquic Hapludoll				
Clay-2	Soybean	Corn	Marcus	Fine-silty, mixed, mesic Typic Haplaquoll	6.0	30	199	60
2001								
Webster-1R[‡]	Soybean	Corn	Webster	Fine-loamy, mixed, noncalcarious, mesic, Typic Haplaquoll	7.0	21	133	60
			Nicollet	Fine-loamy, mixed, mesic Aquic Hapludoll				
Clay-4	Soybean	Corn	Marcus	Fine-silty, mixed, mesic Typic Haplaquoll	6.3	10	170	59
Washington-3	Soybean	Corn	Kalona	Fine, montmorillonitic, mesic Typic Haplaquoll	6.5	17	194	47
Clay-2R[‡]	Corn	Soybean	Marcus	Fine-silty, mixed, mesic Typic Haplaquoll	6.0	30	199	60
Webster-2R[‡]	Corn	Soybean	Webster	Fine-loamy, mixed, noncalcarious, mesic, Typic Haplaquoll	6.0	31	168	60
			Nicollet	Fine-loamy, mixed, mesic Aquic Hapludoll				

[†]STP and STK represent soil test phosphorus (Mehlich-3) and potassium (1 M ammonium acetate), samples collected before manure application.

[‡]Manure was applied previous year to the crop grown that year.

Table 2. Manure application methods, manure analysis, and nutrient application rates at soybean following corn and residual corn sites.

Site	Date of Application	Application Method[†]	Strip Area (Ln x W)[‡]	Manure Application Rate L[§]	Manure Application Rate H[§]	Manure Total Nutrient Analysis N	Manure Total Nutrient Analysis P_2O_5	Manure Total Nutrient Analysis K_2O	Manure Total Nutrient Applied N L	N H	P_2O_5 L	P_2O_5 H	K_2O L	K_2O H
2000			- - m - -	- - - - L ha^{-1} - - - -		- - - - - - mg L^{-1} - - - - - -			- - - - - - - - - - - kg ha^{-1} - - - - - - - - - - -					
Hardin-2	28-Mar-00	S. dribb.	790 x 18	17980	41748	5104	6245	5095	93	215	112	260	91	211
Webster-2	24-Apr-00	Injected	354 x 12	14960	29920	6777	4298	4452	102	204	65	129	66	132
Clay-2	27-Apr-00	S. broad.	365 x 9	15895	31790	8024	5106	3888	128	255	82	164	60	122
2001														
Webster-1R[¶]	24-Apr-00	Injected	354 x 12	11220	22440	6966	4804	4324	78	156	54	108	48	96
Clay-4	15-May-01	S. broad.	483 x 9	15895	31790	7058	3760	3832	112	225	59	118	60	122
Washington-3	19-Apr-01	Injected	152 x 9	35530[#]	35530	6405	3948	3598	128	225	76	140	68	128
Clay-2R[¶]	27-Apr-00	S. broad.	365 x 9	15895	31790	8024	5106	3888	128	255	82	164	60	122
Webster-2R[¶]	24-Apr-00	Injected	354 x 12	14960	29920	6777	4298	4452	102	204	65	129	66	132

[†] S. broad. and S. dribb. indicate manure was surface broadcast applied with incorporation next day, and manure was surface dribbled with disk soil covering, respectively.

[‡] (Ln x W) represents length x width for each manure treatment strip at each site.

[§] L and H represent low and high rates of manure.

[¶] Manure was applied previous year to the crop grown that year.

[#] Low rate was achieved by 1:1 dilution of the manure with water.

Table 3. Effect of liquid swine manure application in field-length strips on soybean grain yield and the residual-year manure effect on soybean yield at soybean following corn sites.

	Grain Yield		
Site	C[†]	L[†]	H[†]
2000	-------- Mg ha^{-1} --------		
Hardin-2	3.75a[‡]	3.82a	3.76a
Webster-2	2.85a	2.92b	3.00b
Clay-2	3.21a	3.26a	3.33a
2001			
Webster-1R[§]	2.33a	2.39b	2.52c
Clay-4	3.17a	3.40b	3.44b
Washington-3	3.27a	3.44b	3.56b

[†]C, L, H represent check, low and high rates of manure applied before the soybean crop, or the previous year corn crop.

[‡]Means followed by same letter within a site are not significantly different ($P \leq 0.10$).

[§]Manure was applied to the previous crop corn.

Table 4. Effect of manure-N application on post-harvest soil profile nitrate-N in 2000, soybean following corn sites.

Profile	Hardin-2			Webster-2			Clay-2		
Depth	C†	L†	H†	C	L	H	C	L	H
cm	$kg\ NO_3\text{-}N\ ha^{-1}$								
0-30	40.4	52.1	45.7	34.2	32.9	34.9	28.6	39.5	34.0
30-60	4.6	22.8	6.8	4.3	5.0	20.6	10.5	15.1	20.4
60-90	7.3	10.9	9.7	4.9	4.9	10.5	17.8	30.9	43.5
90-120	20.7	23.2	22.0	8.6	12.1	12.1	21.3	28.4	34.0
Sum	72.9a‡	109.1a	84.3a	52.0a	54.8a	78.0a	78.1a	113.9a	131.9a

†C, L, and H represent check, low and high rates of manure.

‡Means followed by same letter within a site are not significantly different ($P \leq 0.10$).

Table 5. Effect of manure-N application on post-harvest soil profile nitrate-N in 2001, soybean following corn sites.

Profile	Clay-4			Washington-3		
Depth	C†	L†	H†	C	L	H
cm	kg NO_3-N ha^{-1}					
0-30	21.9	23.1	25.5	11.9	11.9	13.2
30-60	9.2	10.5	10.5	6.6	6.6	7.9
60-90	7.9	10.5	11.9	6.4	5.7	7.1
90-120	11.3	12.8	12.8	3.5	5.7	4.3
Sum	50.3a‡	56.9a	60.7a	28.3a	29.8a	32.4a

†C, L, and H represent check, low and high rates of manure.

‡Means followed by same letter within a site are not significantly different ($P \leq 0.10$).

Table 6 . Corn grain yield, corn ear leaf chlorophyll meter reading, and soil nitrate-N response to residual manure-N, fertilizer-N, and residual manure plus fertilizer-N in 2001, corn following soybean sites.

Site	Grain Yield			Leaf Chlorophyll Meter Reading			Late Spring Soil Nitrate		
	C[†]	L[†]	H[†]	C	L	H	C	L	H
	------- Mg ha^{-1} -------						---- mg NO_3-N kg^{-1} ----		
Webster-2R	--[‡]	--	--	57.5a	58.2a	59.7a	8.3a	8.5a	14.8b
Clay-2R	5.29a[§]	6.48b	7.28c	43.1a	47.2b	49.6c	5.7a	7.1b	7.4b

[†]C, L, and H represent check, low and high rates of manure applied before soybean in 2000.

[‡]No yield data available due to failure of yield monitor to record data.

[§]Means followed by same letter within a site are not significantly different ($P \leq 0.10$).

Table 7. Corn grain yield response to residual manure-N, fertilizer-N, and residual manure-N plus fertilizer-N in 2001, corn following soybean sites.

Fertilizer		Webster-2R				Clay-2R			
N Rate		C†	L†	H†	Mean	C	L	H	Mean
kg N ha^{-1}		Mg ha^{-1}							
0		10.83	11.16	10.99	10.99	6.23	6.53	7.87	6.88
45		12.81	12.54	12.41	12.59	7.51	8.18	10.68	8.79
90		13.08	13.50	13.88	13.49	9.36	9.24	10.19	9.60
135		13.75	14.37	14.12	14.08	8.42	9.55	10.80	9.59
Mean		12.24	12.40	12.43		7.70	7.98	9.58	
Source	df	P > F							
Manure (M)	2	0.7770				0.0211			
Rep	2	0.2003				0.6319			
N Rate (N)	3	<0.0001				<0.0001			
$N_{Linear(L)}$	1	<0.0001				<0.0001			
$N_{Quadratic(Q)}$	1	0.0398				0.0006			
$N_{Residual(R)}$	1	0.7017				0.7703			
M x N	6	0.7840				0.1597			
M x N_L	2	0.7328				0.7278			
M x N_Q	2	0.7397				0.6846			
M x N_R	2	0.4075				0.0238			
Contrasts‡									
C_0 vs. C_N	1	<0.0001				<0.0002			
L_0 vs. L_N	1	<0.0001				<0.0001			
H_0 vs. H_N	1	<0.0001				<0.0001			

†C, L, and H represent check, low and high rates of manure applied before soybean in 2001.

‡Subscript 0 and N represent without and with fertilizer-N applied.

Table 8. Corn ear leaf chlorophyll meter reading response to residual manure-N, fertilizer-N, and residual manure-N plus fertilizer-N in 2001, corn following soybean sites.

Fertilizer		Webster-2R				Clay-2R			
N Rate		C†	L†	H†	Mean	C	L	H	Mean
kg N ha^{-1}									
0		57.0	59.6	58.2	58.2	41.2	46.7	49.8	45.9
45		60.1	60.4	58.9	59.8	47.2	49.4	53.4	50.0
90		61.3	60.2	61.7	61.1	51.5	51.7	54.7	52.6
135		61.1	60.9	61.2	61.1	51.3	54.3	56.3	54.0
Mean		59.9	60.3	60.0		47.8	50.5	53.6	

Source	df	---------- $P > F$ ----------	
		Webster-2R	Clay-2R
Manure (M)	2	0.9511	0.0197
Rep	2	0.6992	0.1428
N Rate (N)	3	0.0072	<0.0001
$N_{Linear(L)}$	1	0.0013	<0.0001
$N_{Quadratic(Q)}$	1	0.1918	0.0051
$N_{Residual(R)}$	1	0.7138	0.9410
M x N	6	0.5009	0.0263
M x N_L	2	0.2772	0.0232
M x N_Q	2	0.5227	0.0313
M x N_R	2	0.4999	0.5413
Contrasts‡			
C_0 vs. C_N	1	0.0033	<0.0001
L_0 vs. L_N	1	0.4264	<0.0001
H_0 vs. H_N	1	0.0489	<0.0001

† C, L, and H represent check, low and high rates of manure applied before soybean in 2000.

‡Subscript 0 and N represent without and with N-fertilizer applied.

Table 9. Relative chlorophyll meter reading response to residual manure-N, fertilizer-N, and residual manure-N plus fertilizer-N in 2001, corn following soybean sites.

Fertilizer	Webster-2R			Clay-2R		
Nrate	C[†]	L[†]	H[†]	C	L	H
kg N ha^{-1}			%			
0	93.1	97.4	95.1	73.2	82.9	88.5
45	98.2	98.7	96.2	83.8	87.7	94.8
90	100.2	98.4	100.8	91.5	91.8	97.2
135	99.8	99.5	100.0	91.1	96.4	100.0

[†]C, L, and H represent check, low and high rates of manure applied before soybean in 2000.

Table 10. Effect of residual manure-N, fertilizer-N, and residual manure-N plus fertilizer-N on the late spring soil nitrate concentration in 2001, corn following soybean sites.

Fertilizer		Webster-2R				Clay-2R			
N rate		C[†]	L[†]	H[†]	Mean	C	L	H	Mean
kg N ha^{-1}		mg NO_3-N kg^{-1}							
0		9	9	9	9	8	7	8	8
90		21	15	17	18	18	17	17	17
Mean		15	12	13		13	12	13	
Source	df	P > F							
Manure (M)	2	0.1639				0.9536			
Rep	2	0.5431				0.4498			
N Rate (N)	1	0.0031				0.0025			
M x N	2	0.4139				0.9898			

[†]C, L, and H represent check, low and high rates of manure applied before soybean in 2000.

Table 11. Effect of residual manure-N, fertilizer-N, and manure-N plus fertilizer-N on stalk nitrate concentration in 2001, corn following soybean sites.

Fertilizer	Webster-2R				Clay-2R			
N Rate	C[†]	L[†]	H[†]	Mean	C	L	H	Mean
kg N ha^{-1}	mg NO_3-N kg^{-1}							
0	29	16	10	18	10	10	10	10
45	46	30	58	45	10	10	236	85
90	260	149	616	342	17	72	131	73
135	956	1023	2917	1632	135	239	495	290
Mean	323	305	900		43	83	218	

Source	df	Webster-2R	Clay-2R
		P > F	
Manure (M)	2	0.2285	0.0603
Rep	2	0.3922	0.3856
N Rate (N)	3	<0.0001	0.0311
$N_{Linear(L)}$	1	<0.0001	0.0089
$N_{Quadratic(Q)}$	1	0.0051	0.2794
$N_{Residual(R)}$	1	0.4249	0.2779
M x N	6	0.0725	0.7359
M x N_L	2	0.0141	0.3858
M x N_Q	2	0.2350	0.9876
M x N_R	2	0.9081	0.4884

[†]C, L, and H represent check, low and high rates of manure applied before soybean in 2000.

Table 12. Effect of residual manure-N, fertilizer-N, and residual manure-N plus fertilizer-N on corn grain-N in 2001, corn following soybean sites.

Fertilizer N Rate	Webster-2R C[†]	Webster-2R L[†]	Webster-2R H[†]	Webster-2R Mean	Clay-2R C	Clay-2R L	Clay-2R H	Clay-2R Mean
kg N ha^{-1}	g N kg^{-1}							
0	10.01	11.25	10.77	10.68	9.28	9.89	10.72	9.96
45	10.97	12.08	11.63	11.56	10.34	10.78	11.97	11.03
90	12.04	11.96	12.03	12.01	11.33	11.76	12.12	11.74
135	11.71	11.68	12.16	11.85	11.91	12.07	12.87	12.28
Mean	11.18	11.74	11.65		10.72	11.13	11.92	

Source	df	Webster-2R $P > F$	Clay-2R $P > F$
Manure (M)	2	0.0454	0.0788
Rep	2	0.0115	0.9731
N Rate (N)	3	0.0086	0.0004
$N_{Linear(L)}$	1	0.0030	<0.0001
$N_{Quadratic(Q)}$	1	0.0583	0.4220
$N_{Residual(R)}$	1	0.8874	0.8867
M x N	6	0.6631	0.9829
M x N_L	2	0.2274	0.8086
M x N_Q	2	0.9074	0.9983
M x N_R	2	0.7103	0.7596
Contrasts[‡]			
C_0 vs. C_N	1	0.0073	0.0073
L_0 vs. L_N	1	0.3126	0.0076
H_0 vs. H_N	1	0.0360	0.0209

[†]C, L, H represent check, low and high rates of manure applied before soybean in 2000.

[‡]Subscripts 0 and N represent without and with fertilizer-N applied.

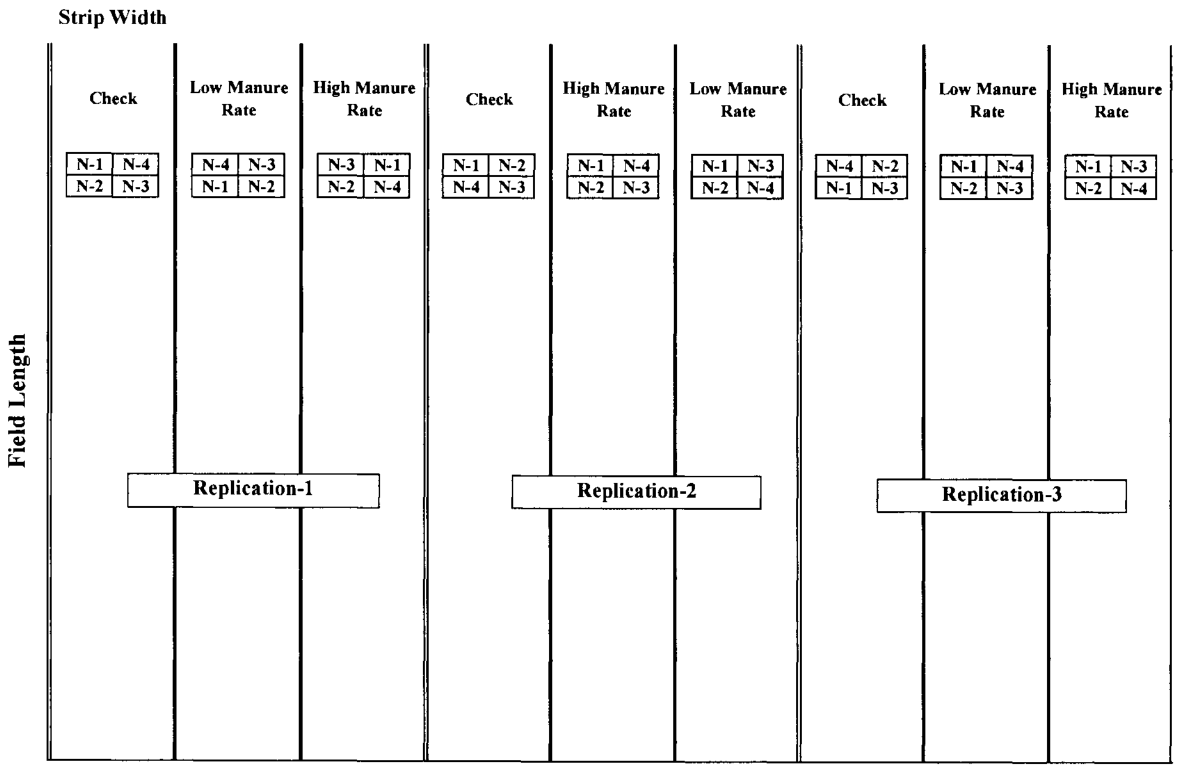

Fig. 1. Example manure field-strip application design and split-plot fertilizer-N rates in residual year corn sites (N-1, N-2, N-3, and N-4 represent the four fertilizer-N rates).

GENERAL CONCLUSIONS

The objectives of these studies were to: one, determine the effect of liquid swine manure-N on corn and soybean production in producers' fields; and two, determine second year effect of residual manure-N when corn follows soybean.

Liquid swine manure application was able to provide adequate-N to corn in field-length strips across production fields. The high manure total-N rate consistently provided all of the corn N needs, and perhaps more than adequate-N in some instances. The low manure total-N rates frequently did not supply enough N because the low rate applied was not sufficient to meet corn N needs at those specific sites. Addition of fertilizer-N did not increase corn grain yield in combination with the high manure rate but often did with the low manure rate. As with prediction of needed fertilizer-N rates, it is difficult to predict liquid swine manure-N application rates because of differences in specific site N requirements. This was noted in our study where different fertilizer-N requirements and differential response to manure-N rates occurred between different sites. The amount of post-harvest soil profile nitrate-N (total in 120 cm) did not increase significantly with manure application when rates were not excessive. Addition of fertilizer-N on top of the highest manure rates increased the amount of residual profile nitrate-N significantly. Results clearly showed that liquid swine manure-N is highly crop available, and that only when manure-N rates are not adequate to meet corn-N needs is supplemental fertilizer-N application is needed.

Liquid swine manure application did not decrease soybean yield, even when applied at rates greater than 200 kg total-N ha^{-1}. Soybean grain yield was significantly increased at several sites, but the yield increase was minimal. Because soil test P (STP) and soil test K (STK) was optimal to low at some sites, yield increase could be due to manure P and K application, or residual P or K, at these sites. However, when STP and STK were high to very high, reasons for yield increase are not known. Post-soybean harvest soil profile nitrate-N levels did not show large increase from manure-N application, except when total manure-N application was well over soybean N uptake and grain removal. When rates of manure-N were at or below expected grain N removal, there was no build up of residual profile nitrate and therefore should not pose an enhanced risk of nitrate-N loss.

A residual-year manure-N response was measured at one site (for corn grown after manured soybean) where a high manure-N rate (255 kg total-N ha^{-1}) had been applied to the previous soybean crop. However, the estimated amount of residual N was low (approximately 45 kg N ha^{-1}). At lower manure total-N rates, no residual-year effect was measured in the corn crop that followed manured soybean. Generally, if liquid swine manure total-N application rates to soybean are limited to no more than expected grain N removal amounts, or plant accumulation at maximum yield (generally 150-200 kg N ha^{-1}), then soybean uptake of applied manure-N should be high, soybean yields not adversely affected (may be increased), and residual nitrate-N accumulation minimized. However, if not monitored by soil testing, soil test P could increase to environmentally problematic levels with high manure rates or frequent application in the corn-soybean rotation.

This on-farm study has shown that liquid swine manure is an excellent source of N for corn production. Management should consider that the manure total-N is highly crop available, and because of this best management should consider practices that minimize potential for loss (late spring application, injection, etc.) and that consider estimates of needed N.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my major professor Dr. John Sawyer, who guided me through an intricate path of learning research and soil science. I appreciate the help of Dr. Dan Nettleton in solving my problems regarding statistics. I am thankful to Dr. Antonio Mallarino for his help. I would like to thank Dr. Thomas Fenton who helped me calculate bulk densities of soil profiles. I would like to thank Angela Rieck-Hinz for her help in our project. I want to thank Daniel Barker and John Lundvall for their efforts in getting our project accomplished. I would like to thank all the farmers, extension field crop specialists, and cooperators for their help and support. I would like to thank Kristen for her GIS work with the yield data. I would like to thank Don and Jeff in soil testing lab for their help. Also I want to thank Esteban Loria, my research co-worker, who helped me as a friend every time. I would like to thank Monica Barbazan for her help in our project. I want to thank all the people who helped me with the fieldwork – Zeb, Christine, Bryan, Brice, Shelly, Mary, and Herman.

I would like to thank my parents and sister who encouraged me to pursue higher education. I would like to thank Dr. N. C. Chottopadhaya, my major professor at the Universtiy of Calcutta, who convinced me to pursue graduate education. I would like to thank my friends for their support.

VITAE

Sudipta Rakshit was born in Calcutta, India. He grew up in a suburb of Calcutta named Howrah. He graduated from the Vivekananda Institution high school in 1994. He received a Bachelor in science with Chemistry as a major from the Scottish Church College, University of Calcutta in 1997. He received his Master of Science in Agricultural Chemistry and Soil Science from Ballygange Science College, University of Calcutta in 1999. After finishing post graduation, he came to USA in 2000 to pursue a Master of Science program in soil science and soil fertility in the department of Agronomy at Iowa State University. He has been working since then towards completion of his Master of Science at Iowa State University.