

Literature Review

Utilization of Manure Nutrients for Soybean Crop Production

Matt J. Helmers, Lara B. Moody, and Robert Burns

Iowa State University
Agricultural and Biosystems Engineering

(Review completed January 20, 2008)



This literature review was prepared under contract to the National Pork Board and funded by the Pork Checkoff. National Pork Board has responsibility for Checkoff-funded research, promotion and consumer information projects and for communicating with pork producers and the public. The Pork Checkoff funds national and state programs in advertising, consumer information, retail and foodservice marketing, export market promotion, production improvement, technology, swine health, pork safety and the environment.

Utilization of Manure Nutrients for Soybean Crop Production

Matthew Helmers¹, Lara Moody², and Robert Burns³

Introduction

This review of the available scientific information concerning the impacts of manure application to soybean crops was completed with Pork Checkoff funds. This review is not intended to provide a comprehensive discussion and analysis of the issue but rather to provide summary information concerning the current state of available scientific information on this topic.

Literature Review Methodology

A review of available literature on utilization of manure nutrients for soybean crop production was performed during 2007. The literature search mechanisms used included electronic library databases, AGRICOLA and Web of Science, and searches on the World Wide Web using Google. AGRICOLA is a database maintained by the National Agricultural Library, and Web of Science provides access to the expanded Science Citation Index. While a wide topic range was initially used to identify literature related to utilization of manure nutrients for soybean crop production, only a limited amount of literature was obtained. The majority of literature used for the review was obtained by identifying relevant material listed within the reference sections of literature from the initial search. Of the papers reviewed, most dealt with the yield response of soybeans to manure application and a lesser number presented data on the potential groundwater quality impact from manure application to soybeans. It is the opinion of the authors that only materials providing scientific and unbiased information are represented here. Refereed and non-refereed literature referenced for this review included journal articles, conference proceedings, books, graduate student thesis and dissertations, extension publications and university reports.

Industry Summary

In summary, the literature reviewed supports the following statements: 1) manure, when applied to soybeans, may improve soybean crop performance and yield compared to soybeans fertilized with commercial fertilizer or unfertilized soybeans, 2) the application of manure nitrogen to soybeans has the potential to be a sound practice provided the nitrogen application rates are reasonable because soybeans rely on soil nitrogen sources for half or more of the nitrogen required by the crop, and 3) long-term studies found that nitrate levels in tile drainage

¹ Assistant Professor of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA, 50011.

² Extension Program Specialist, Agricultural and Biosystems Engineering, Iowa State University, Ames, IA, 50011.

³ Associate Professor of Agricultural and Biosystems Engineering, Iowa State University, Ames, IA, 50011.

water increased when manure nitrogen was applied to soybeans at rates equivalent to 85 percent of the crop nitrogen need in a corn-soybean rotation.

In general, existing literature indicates that soybeans fertilized with manures have the potential to produce higher yields than soybeans fertilized with commercial fertilizer alone or unfertilized soybeans, but it is sometimes difficult to predict when and if yield increases will result from the manure application. The data reviewed suggests that the improved bean performance and yields associated with manures is not due solely to the provision of nitrogen, but can be related to other residual effects from manure application such as added phosphorus, potassium, and organic matter as well. However, no publications were found to document research conducted to better evaluate this theory, and a clear conclusion could not be drawn as to the reason for the increased yield response to manure.

Soybeans have the ability to symbiotically fix nitrogen; however, not all of the soybean's nitrogen needs are met through fixation (Sawyer et al., 2006). Therefore, Sawyer recommends that it is appropriate to provide approximately 50 percent of a soybean crop's total nitrogen need through manure nitrogen and the plant will fix the remaining nitrogen required. Using this approach, a manure application nitrogen rate of 112 – 140 kg-N/ha (100 – 125 lbs-N/acre) is suggested for a soybean crop with a 3,358 kg/ha (50 bu/acre) yield and a total nitrogen requirement of 269 – 280 kg-N/ha (240 – 250 lbs-N/acre). Unfortunately, no studies measured the effect on groundwater nitrate levels from applying manure to soybeans at this suggested rate.

While a yield response can be shown using manure as fertilizer, there is information indicating that when manure is applied to soybeans at a rate of 224 kg-N/ha (200 lb-N/acre) (Kanwar et al. 2006) or 168 kg-N/ha (150 lb-N/acre) (Lawlor et al. 2007) there is a statistically significant increase in tile drainage water nitrate levels. And, in limited instances manure inhibition of soybean performance was reported. Potential concerns included increased lodging, poor performance in fields with a history of white mold problems and increased occurrences of some fungal soybean diseases (Schmidt et al. 2001, Oelke, 1998).

Technical Summary

This paper provides a review of literature available at the time of this writing (2007) concerning the application of animal manures to soybeans. Papers found during a literature search on the topic were divided into two groups, those that address potential advantages from the application of manure to soybeans and those that address potential disadvantages of manure application to soybeans. This document is divided into three sections: 1) the paper summary which provides a summary of the potential advantages and disadvantages of manure application to soybeans as reported in the reviewed literature, 2) a section that provides a summary of each paper reviewed that addressed potential advantages of manure application to soybeans and 3) a section that provides a summary of each paper reviewed that addressed potential disadvantages of manure application to soybeans. It should be noted that a limited number of papers regarding the utilization of manure nutrients by soybeans were identified by our literature review.

Additionally, the majority of the papers we reviewed dealt with the yield response of soybeans to manure application and a lesser number collected data on the potential groundwater quality impact from manure application to soybeans. Of the papers that did try to reach conclusions concerning the potential impact on groundwater, only two reported actual groundwater nitrate data while the remainder used soil nitrate data in an effort to predict groundwater impact.

A review of published research indicates that soybeans fertilized with manures have the potential to out-yield soybeans fertilized with commercial fertilizer alone (McAndrews et al., 2006; Schmidt et al., 2001; Killorn, 1998; Barbazan, 2004; Rakshit, 2002; DeJong, 1995; and Hati et al., 1995). Multiple papers reported that improved bean performance and yields associated with animal manure fertilization is not due solely to the provision of nitrogen to the soybeans, but to other residual effects from manure application as well. A review of this literature indicates that animal manure application can increase soybean performance through a variety of ways including: provision of additional nitrogen, provision of phosphorus, provision of potassium, increased soil organic matter, improved soil water holding capacity and by other unidentified residual factors. While the literature reviewed clearly shows that the use of manure fertilizer is beneficial to soybean production, some instances where manure could inhibit soybean performance are also reported. These potential concerns included increased lodging, poor performance in fields with a history of white mold problems and increased occurrences of some fungal soybean diseases (Schmidt et al. 2001, Oelke, 1998).

While soybeans have the ability to symbiotically fix nitrogen, not all of the soybean's nitrogen needs are met through fixation (Sawyer et al., 2006). Sawyer indicates that at least 50 percent of a soybean plant's nitrogen requirement over a growing season is provided by the soil system. As such, Sawyer recommends that it is appropriate to provide approximately 50 percent of a soybean crop's total nitrogen need through manure nitrogen and the plant will fix the remaining nitrogen required. Using this approach, a manure application nitrogen (N) rate of 112 – 140 kg-N/ha (100 – 125 lbs-N/acre) is suggested for a soybean crop with a 3,358 kg/ha (50 bu/acre) yield and a total nitrogen requirement of 269 – 280 kg-N/ha (240 – 250 lbs-N/acre) (Sawyer et al., 2006).

Rakshit and DeJong interpreted their work measuring soil nitrate levels in soybean production to indicate that manure can be applied to soybeans up to rates of 200 kg-N/ha (179 lbs-N/acre) and 240 kg-N/ha (214 lbs-N/acre) respectively with little or no effect on groundwater quality (Rakshit, 2002, DeJong, 1995). Both Rakshit and DeJong measured soil nitrate levels and found that the soil nitrate levels in un-manured soybeans were similar to the soil nitrate levels in soybeans receiving manure up to the rates listed above. It should be noted however that the conclusions these researchers reached based on soil nitrate levels do not match the conclusions reached by Kanwar and Lawlor in two long-term studies in Iowa that monitored tile drainage flow from manured soybeans (Kanwar et al. 2006, Lawlor et al. 2007). These studies found that when manure was applied to soybeans at a rate of 224 kg-N/ha (200 lb-N/acre) (Kanwar et al. 2006) or 168 kg-N/ha (150 lb-N/acre) (Lawlor et al. 2007) there was a statistically significant increase in tile drainage water nitrate levels. The number of studies on this topic that measured

groundwater nitrate levels are limited. Note that of the two we identified one is a manuscript that is still in the publication process. Unfortunately, we found no studies that measured the effect on groundwater nitrate levels from applying manure to soybeans at the 112 – 140 kg-N/ha (100 – 125 lbs-N/acre) rate suggested by Sawyer.

In summary the papers reviewed in regards to this topic support the following three statements; 1) manure, when applied to soybeans, may improve soybean performance and yield compared to soybeans fertilized with commercial fertilizer or unfertilized soybeans, but it is difficult to predict when and if yield increases will result from the manure application, 2) the application of manure nitrogen to soybeans has the potential to be a sound practice provided the nitrogen applications are reasonable because soybeans rely on soil nitrogen sources for half or more of the nitrogen required by the crop, and 3) long-term studies found that nitrate levels in tile drainage water increased when manure nitrogen was applied to soybeans at rates equivalent to ~ 85 percent of the crop nitrogen need in a corn-soybean rotation.

Overall, these summarized points support the recommendation by Sawyer that manure application rates matching 50 percent ~~percent~~ of the total soybean nitrogen requirement may be appropriate, but no research publications were found that include groundwater nitrate data associated with soybeans manured at this rate. This suggests there is a clear need for direct water quality measurements of nitrate concentrations when manure application rates matching 50 percent of the total soybean nitrogen requirement are utilized.

Advantages of Manure Application to Soybean Crops

The ability of soybeans to utilize manure nutrients has economic and environmental impacts. Soybeans have the potential to utilize manure nitrogen (N), phosphorus (P), and potassium (K), thus increasing the potential manure application rate when comparing a corn-soybean rotation to application based only on corn and reducing the costs of commercial fertilizer for soybean production. Soybeans have the potential to act as a sink for nitrogen by using inorganic nitrogen available in the soil. Varel et al. (1992) showed that soybeans can remove up to 200 kg N/ha (178 lb N/ac). Additionally, liquid manure will provide phosphorus and potassium to crops in deficient soils.

In 1987, Harper prepared a review of literature concerning nitrogen metabolism in soybeans. The review evaluated the two pathways for nitrogen assimilation by the plant and the interaction between them: 1) nitrate uptake and reduction and, 2) nodulation and di-nitrogen fixation. Harper (1987) states that in most cropping systems soybeans assimilate nitrogen using both pathways during the growing season depending on the environmental conditions. For nodulation and di-nitrogen fixation, the symbiotic relationship between the soybean and the rhizobium exposes the system to limitations that may affect either the plant or the bacteria. Reduction in di-nitrogen fixation can result from any effect that reduces plant vigor, mineral deficiency, disease, or adverse environmental conditions. There is evidence that nitrate uptake is necessary for the initial growth stages of the plant; yet, evidence shows that residual soil nitrogen

is usually sufficient to meet this need. However, nitrate uptake and reduction may be necessary during the growing season if the plant is undergoing environmental stressors. For example, during research on inorganic nitrogen application to soybeans by Katoch et al. (1983), the authors found the number of nodules was reduced by 27 – 40 percent when the soil was compacted, and they reported this result to be similar to that seen by others where a slight compaction restricting root growth reduced the number of nodules by 22-30 percent. A reduction in the number of nodules results in a reduction in the plants ability to fix nitrogen.

The amount of nitrogen capable of being fixed by a soybean crop over a growing season is reported to range 70 to 120 kg-N/ha (63 to 107 lbs-N/acre) (Tisdale and Nelson, 1975). Likewise, in a 1973 publication edited by Caldwell et al. (1973) two studies were reported indicating 94 kg/ha and 81 kg/ha of nitrogen fixation. The average soybean yield in Iowa for 2006 was reported to be 3,089 kg / ha (46 bu / acre) and is estimated to have ~~ana~~ nitrogen removal of 194 kg / ha. A comparison of these values suggests that soybeans may be unable to fix the total quantity of nitrogen required by yields that can be achieved under optimal growing conditions. Comparison of such values should be made with care however, because the soybean yield with a reported nitrogen fixation of 70 to 120 kg-N/ha (63 to 107 lbs-N/acre) by Tisdale and Nelson is unknown. This value was published in 1975 when the average U.S. soybean yield was 1,746 / ha (26 bu / acre) (Padgitt, 1982). The nitrogen removal from 1747 kg/ha (26 bu/acre) soybeans is estimated at 110 kg-N/ ha (98 lbs-N/acre) and is within the range reported by Tisdale and Nelson in 1975.

When nitrogen is available to the crop, a decrease in enzymatic activity by the nitrogen fixing bacteria occurs to reduce nitrogen fixation by the plant; however, studies have shown that enzymatic activity resumes following the depletion of the nitrate solution (Harper, 1987).

Several studies have been performed in the Midwest region of the United States resulting in positive yield increases related to liquid swine manure application on soybeans. However, there is no single conclusion as to why an increase in yield occurs. The studies identify yield increases from manure as the potential result of pre-application soil nitrate deficiency, pre-application phosphorus or potassium deficiency, and the provision of nutrients or other unknown factors via liquid manure. One study, from India, identifies the effect manure has on clayey soil (Vertisols) as reasons for improved seed yield, including increased organic carbon content and improved water-use efficiency.

Schmidt et al. (2001) published yield increases in soybeans with varying rates of manure application, and stated that the increased yields coincided with sites having low available soil nitrogen during mid-June. Killorn (1998) reported yield increases of 6-9 bu/acre on crops in corn/soybean rotation that received manure every year. Barbazan (2004) found sites receiving manure had slightly higher and more frequent early plant growth as compared to sites only receiving phosphorus fertilizer. However, the early plant growth did not translate to higher yields. Rakshit (2002) compared soil nitrate levels and soybean yield from various manure application rates and a control. This study showed statistically significant yield increases at three of the five manured sites compared to the control. DeJong (1995) compared manure application

to soybeans with inorganic nitrogen application to soybeans. This study noted yield increases with increasing manure nitrogen application rates while application of increasing urea-ammonium nitrate (UAN) fertilizer did not result in increasing yields with increasing rates. These studies theorize increases in yield may be related to increased availability of phosphorus, potassium, or other unknown factors in manure. The Indian publication (Hati et al., 2006) describes yield increases from 16 – 103 percent above the control in plots receiving nitrogen, phosphorus, and potassium as inorganic fertilizer. In this study, not only were the organic content and water use efficiency of the soil increased with manure application to the plots, but the root proliferation of the soybeans was also increased which is attributed to lower mechanical resistance, better aeration, and lower bulk density of the surface soil.

Two of the studies reporting yield responses also looked at the potential for nitrate (NO_3) contamination from manure and inorganic nitrogen application on soybeans. Rakshit (2002) reported that maintaining manure nitrogen applications below grain nitrogen removal numbers was sufficient to keep soil nitrate levels below the concentrations obtained from the non-manured sites. DeJong (1995) found the highest soil nitrate concentrations (twice that of manured soils) when the highest rate of UAN was applied. Though not as high, soil nitrate was also elevated at the highest rate of manure application. This was the expected result given the slower release of inorganic nitrogen in manure. However, by the third soil sample collection in the growing season, soil test nitrate levels were less than 10 mg $\text{NO}_3\text{-N/kg}$ at 120 cm of the soil sample profile. The results of the studies showing yield responses imply that manure application to soybeans can overcome deficiencies in the soil that might otherwise require amendment with inorganic fertilizers. Additionally, these studies suggest that when manure nutrient application rates are matched to crop removal there is no negative impact on water quality.

Unfortunately, while some authors indicate that manure may have other unknown factors besides nitrogen, phosphorus and potassium contributing to increased soybean yield, no publications were found to document research conducted to better evaluate this theory. For instance, only one of the studies had both inorganic nitrogen and phosphorus applied to a crop for comparison to manure applications. And, in that case, the manure plots received the manure nutrients as well as the same amount of inorganic nitrogen, phosphorus and potassium as the fertilized control. So, in all the studies here, a clear conclusion can not be drawn as to the reason for the increased yield response to manure.

Summary of Studies Related to Soybean Yields

In a study conducted by Schmidt et al. (2001), soybean yield response was shown to increase with increasing manure nitrogen application rates for three of seven field locations. Manure was applied at seven field locations in Minnesota, to multiple soybean cultivars at zero, low, and high rates of nitrogen. Low rates ranged from 43 – 230 kg N/ha (38 – 205 lb N/acre), and high rates ranged from 72 – 460 kg N/ha (64 – 409 lb N/acre). Soil tests for each of the sites showed that sufficient amounts of phosphorus and potassium were available for each plot. Increases in yield coincided with sites having lower available soil nitrogen in mid-June. In cases

where the site had a history of white mold, the application of manure was generally unfavorable. The authors summarize that improving the ability to identify fields requiring additional nitrogen would improve soybean yield responses to manure.

In 2001 and 2002, McAndrews et al. (2006) investigated the residual effects of manure application on soybean growth and yield. Fresh or composted solid swine manure from hoop structures was applied in the fall or spring prior to corn. The residual impacts of the manure application were evaluated on the following soybean crop. For comparison, three urea treatments and a control treatment with no manure or urea were included. The manure treatment had an application rate of 340 kg-N/ha (304 lb-total N/acre) and the urea treatments had application rates of 60, 120, and 180 kg-N/ha (54, 107, and 161 lb-N/acre). In both 2001 and 2002, at most measurement dates, the soybean plants that had composted or fresh manure applied before the previous corn crop were significantly taller than soybean plants in plots where urea was applied or where no fertilizer was applied. Additionally, they found greater potassium concentrations (27 percent in 2001 and 29 percent of 2002) in the soybeans that were grown in the manure amended plots. In both 2001 and 2002, the soybean yield was greater in manure plots than the control or urea plots, and soybean yield was not affected by time of manure application or form of manure. It is speculated that soil factors not measured as part of the study such as microbial activity and concentrations of substances that mimic the effects of plant growth regulators may have contributed to soybean responses observed. Overall, the residual effects of manure had a positive effect on soybean yield.

In a non-refereed Iowa State University research report, Killorn (1998) provided a review of data suggesting increased yields from soybean plots receiving manure. During a four-year study with a corn/soybean rotation, manure was applied at three frequencies (every year, every other year to corn and every fourth year to corn), plus a control that did not receive any manure. Manure was applied at a rate of 168 kg N/ha (150 lb N/acre). When manure was applied for each year of the study, the soybean yield was 6-9 bu/acre greater in the fourth year crop. However, during the second year of the study (the first soybean crop during the rotation), no yield increase was shown. When manure was applied every other year to corn, soybean yields were 4-7 bu/acre greater in the ~~fourth~~fourth year crop. Killorn concludes that soybeans are a good crop to receive manure applications, and that this topic needs more study because if soybean yields can be increased, then farmers have more acres for profitable manure application.

A study performed in Iowa (Barbazan, 2004), examined the affect of manure application and phosphorus fertilizer application on soybeans. In the study, manure and nitrogen were applied at rates equivalent to half (100 kg N/ha (89 lb N/acre)) and total (200 kg N/ha (178 lb N/acre)) of the expected nitrogen removal. Manure and fertilizer applications were made in the spring, four weeks prior to planting either via injection or broadcast and incorporation. Results indicated that slightly higher and more frequent early plant growth occurred with manure application as compared to phosphorus fertilizer application at comparable phosphorus application rates. Control plots showed that the early plant growth was not due to soil test phosphorus already present. The author suggests higher early plant growth could be the result of

additional nitrogen available in the manure, or it could be the result of other nutrients and unknown growth factors in the manure. However, early growth response did not translate to a grain yield response in this study. Conclusions from this study suggest that liquid swine manure is a valuable resource of phosphorus for crop production, and provide no evidence for a lower availability of phosphorus in manure compared with phosphorus in fertilizer for early crop growth.

During graduate studies at Iowa State University, Rakshit (2002) conducted experiments to study the impact of manure application on soybean production and residual soil nitrogen. Liquid swine manure nitrogen rates at target levels of 0, 112, and 224 kg-N/ha (0, 100, 200 lb-N/acre) were applied to multiple plots. Soybean yield increases occurred at all sites receiving manure (though minimal at some), but at three of the five sites the yield increase was statistically significant. The reasons for increases in yield response following manure application are undetermined. Two of the five sites showed potential for a yield response with addition of phosphorus and potassium, but the increase could also be due to nitrogen or some other unknown factor in the manure.

In 1993 and 1994, DeJong (1995) studied the effect of liquid swine manure and UAN application on soybean yields response and grain nitrogen content. In 1993, the study incurred poor growing conditions resulting from overly wet and cool weather. The result was low soybean yields and reduced treatment effects. However, in 1994 growing conditions were optimal and soybean yields increased with increasing manure application rate, while no increase was shown with increasing UAN rate. DeJong (1995) indicated the highest yields were shown in the plots receiving manure. The author believes the results were due to a soil deficiency in phosphorus and potassium at the plots only receiving UAN. The nitrogen concentrations in the grain were greatest in the soybeans receiving the highest manure application rates. In 1994, manure application rates were 0, 54, 64, and 188 kg-N/ha (48, 57, and 167 lb-N/acre) and UAN rates were 0, 84, 168, and 252 kg-N/ha (75, 150, and 225 lb-N/acre).

For three cropping seasons, 1998 – 2000, Hati et al. (2006) studied the effect of farmyard manure (dairy manure mixed with wheat straw) on soybeans in a soybean-mustard cropping system. They examined the effect manure had on the soil physical properties, water-use efficiency, root growth, and soybean yield in a clayey soil. The plots included controls with no nutrient application, inorganic fertilizer applied at rates of 25:25.8:16.6 kg/ha (N:P:K), and farmyard manure at 10 Mg/ha (11.02 tons/ha) plus inorganic fertilizer again at 25:25.8:16.6 kg/ha (N:P:K). The manure contained approximately 0.48 percent, 0.17 percent, and 0.38 percent N, P, and K, respectively (or 48, 17, and 38 kg/ha N, P, and K, respectively). The results showed that manure in combination with inorganic fertilizer improved soil physical conditions through improved aggregation, increased hydraulic conductivity, reduced mechanical resistance and bulk density, and enhanced root proliferation of soybean. The farmyard manure plus inorganic fertilizer amendment increased average soybean yield by 103 percent over the non-amended control and by 40 percent over the control receiving only inorganic fertilizer.

Summary of Studies Related to Residual Soil Nitrate and Groundwater Quality

Two of the studies related to soybean yield response that were discussed above also include data pertaining to residual soil nitrate concentrations, and in the case of DeJong (1995) the author also attempted to study groundwater nitrate. The results of those studies are described below.

In the study performed by Rakshit (2002), which looked at soybean yield response to manure application, they found that when the manure application rate was less than 200 kg N/ha (178 lbs / acre), post harvest nitrate profiles of all the sites revealed only one instance where concentrations were above the non-manure soil nitrate levels. Application rates of less than 200 kg N/ha generally represent grain removal nitrogen levels. The author summarized that liquid manure applied at these rates should have minimal environmental impact (low potential for leaching) due to high uptake by the plant.

In the DeJong (1995) publication, in addition to yield response and grain nitrogen concentration, the study also evaluated soil and groundwater nitrate-nitrogen($\text{NO}_3\text{-N}$) and ammonium-nitrogen ($\text{NH}_4\text{-N}$) concentrations throughout the growing season. During the 1994 growing season, ammonium-nitrogen soil concentration increased with increasing UAN application rates for the plots receiving UAN during the first and second soil sampling dates. The highest UAN application rate had ammonium-nitrogen soil concentration twice that of any other UAN or manure application rate. The manure application rates (low, medium and high) had no effect on soil ammonium-nitrogen concentrations. Likewise, the highest UAN application rate had the highest soil nitrate-nitrogen concentration during the first two sampling dates. The highest manure application rate also had elevated soil nitrate-nitrogen levels. However, by the third soil sampling date, all fields receiving manure and UAN applications had less than 10 mg $\text{NO}_3\text{-N/kg}$ at 120 cm in the soil profile.

The groundwater quality data collected from the lysimeters in this study were indicated to be semi-quantitative at best. However, the data indicated that the highest rate of UAN application resulted in the highest lysimeter nitrate concentrations peaking at 49 mg/kg in early July. The injected manure plot receiving comparable nitrogen rates peaked at 32 mg/kg in early July. DeJong (1995) indicated this was the expected result given the availability of the UAN compared to the expected slower release inorganic nitrogen form in manure.

Based on soil nitrate-nitrogen concentrations at the 120 cm soil profile, DeJong (1995) summarized that it is possible to apply liquid swine manure at a rate of 240 kg N/ha (214 lbs / acre) on soybeans in a corn-soybean rotation with little or no effect on groundwater quality.

Disadvantages of Manure Application to Soybeans

While there may be some economic, practical and environmental reasons to apply manure to both corn and soybeans there also are some disadvantages of such practices. One area of concern is related to the environmental consequences of manure application to soybeans,

specifically nitrate losses through subsurface drainage systems. In addition, there are questions on whether there are any negative impacts of manure application on soybean yields.

While few studies have documented the environmental impacts of manure application to soybeans, one study in Minnesota reported impacts of liquid swine manure application prior to soybeans on post harvest soil nitrate levels (Schmidt et al., 2000) and two drainage water quality studies in Iowa included a treatment where liquid swine manure was applied prior to soybeans.

Schmidt et al. (2000) evaluated the impact of liquid swine manure application on nodulating and non-nodulating soybeans. They found that applying manure at greater nitrogen rates than needed for maximum soybean yields did not adversely affect soybean yield. However, they found that application of nitrogen from the liquid swine manure increased post harvest soil nitrate levels. They also found greater increases in soil nitrate levels early in the growing season than post harvest (Randall and Schmitt, 1998 and Schmitt et al. 1996). While direct water quality measurements were not taken as part of the study, the reported increase in residual nitrate could pose a potential risk to the environment.

Two drainage water quality studies in Iowa have evaluated the impact of liquid swine manure application to both corn and soybeans within a corn-soybean rotation. For the four-year study (2001-2004) at the Gilmore City research site in Pocahontas County, applying liquid swine manure at the rate of 168 kg N /ha (150 lb N/acre) before both corn and soybeans did not increase either corn or soybean yields compared to a rate of 224 kg N /ha (200 lb N/acre) of manure applied every other year before corn (Lawlor et al. 2007). In addition, the total of 336 kg-N/ha (300 lbs (two years of 150 lb N/acre)) versus the 224 kg-N/ha (200 lb N/acre) two-year-rate resulted in nitrate-N concentrations in tile drainage increasing on average from 17 to 23 mg/L, a 35 percent increase that was statistically significant. For the six-year study (2001-2006) at the Iowa State University Northeast Iowa Research Farm in Floyd County, applying liquid swine manure at the rate of 168 kg-N/ha (150 lb-N/acre) before corn and 224 kg-N/ha (200 lb-N/acre) before soybeans increased corn and/or soybean yields slightly some years (on average 3 and 2 bu/acre for corn and soybeans, respectively) compared to 168 kg-N/ha (150 lb N/acre) of manure applied every other year before corn. The total of 392 kg-N/ha (350 lb-N/acre(one year of 150 lb N/acre and one year of 200 lb N/acre)) versus the 168 kg-N/ha (150 lb N/acre) two-year-rate resulted in nitrate-N concentrations in tile drainage increasing on average from 21 to 38 mg/L, an 81 percent increase. Both of these studies applied a relatively high nitrogen rate to the soybeans, but at these rates when liquid swine manure was applied every year in a corn-soybean rotation there was an increase in nitrate-nitrogen concentrations in the subsurface drainage water.

Some studies have found a slightly positive effect of manure application prior to soybeans, but one question that might arise is if there would be a residual effect if manure was just applied prior to corn and not to both corn and soybeans. McAndrews et al. (2006) investigated the residual effects of fresh and composted solid swine manure from a hoop building on soybean yields. In this study, manure was applied just prior to the corn crop but the residual effects on the soybeans were evaluated. They found that soybean yields were greater on plots where manure had been applied prior to corn than on plots where urea fertilizer had been applied

prior to corn. This provides some evidence that manure application every year is not necessary to get positive soybean yield responses.

In addition to potential environmental concerns, some studies have noted reductions in soybean yield when manure is applied prior to soybeans. While Schmidt et al. (2001) found yield increases with manure application at three of the seven sites they studied; at one site there was a reduction in soybean yield with the application of liquid swine manure. This site had a high incidence of white mold. As a result they recommended that application of manure be avoided on fields with a history of white mold. Additionally, they found increased lodging with increasing manure application but this did not lead to yield differences. Yang and Martinson (1996) also note that manure application prior to soybeans can increase certain soybean diseases, specifically *Pythium* and *Phytophthora* damping off and *Phytophthora* root rot. Increases in the incidence of soybean fungal diseases when manure was applied to soybeans were found by Oelke (1998).

Sawyer (2001) raised other precautions related to liquid swine manure application to soybeans. One was that soybean seed germination and emergence can be sensitive to salts, so that as manure is applied close to planting time, there is a potential for injury especially if the soybean is planted into the manure or very near the manure. Also, manure application in the spring could cause compaction issues which could adversely impact soybean production, although this would also be a concern if there is compaction due to manure applied prior to corn.

Overall, there is a lack of studies fully evaluating the potential environmental impacts of manure application prior to soybeans. The two Iowa drainage water quality studies applied manure prior to both corn and soybeans and compared the nitrate-nitrogen concentrations in tile drainage water to a system that received manure prior to just the corn crop. These studies indicated an increase in nitrate-nitrogen concentrations in the subsurface drainage but the studies applied relative high rates of nitrogen to the soybean crop and it is unknown what environmental risk there would be with lower application rates especially those proposed by Sawyer et al. (2006) of 112-140 kg / ha (100-125 lb-N/acre) to soybeans. Additionally, these studies did not evaluate a system where manure was applied prior to the soybean crop but not the corn crop, and they did not evaluate a continuous corn system where manure was applied every year. While the Minnesota study did not specifically evaluate water quality impacts they found greater residual soil nitrate levels where liquid swine manure had been applied prior to soybeans. Combining the potential environmental risks and potential production concerns related to certain soybean diseases, there may be both environmental and production disadvantages associated with liquid swine manure application prior to soybeans.

Summary of Studies Related to Soybean Yields

In 1996 and 1997, field studies were conducted at seven sites in Minnesota to evaluate the impacts of liquid swine manure application on seed yield, dry matter accumulation, nitrogen accumulation and lodging for a cross-section of public and private soybean cultivars (Schmidt et al., 2001). Generally, they found the soybean response was positively affected or unaffected by

manure application at six of the seven sites. The soybean yield response at one of the sites contrasted with the other six sites. Soybean yield was adversely affected by the manure application for 6 of the 12 cultivars used as part of the study at one of the seven sites. They could not statistically attribute the divergent results to a single factor, but based on circumstantial evidence and local knowledge attributed the reduced yield to white mold. As a result, they recommended that application of manure be avoided on fields with a history of white mold. The only consistent negative agronomic response they found regardless of location and cultivar was an increase in soybean lodging with an increasing manure rate. However, at six of the seven sites this did not result in soybean yield decreases.

Oelke (1998) studied the impacts of swine manure application to soybeans on common soybean fungal diseases. Overall, it was found that manure applications to fields before planting the soybeans resulted in reduced seedling emergence, increased post emergence damping off, and increase in *Phytophthora* diseases, increased *Sclerotinia* stem rot incidence, less brown stem rot incidence, and the potential for yield loss. The timing of the manure application had some effect since increased damping off was associated with manure applications close to soybean planting. However, this did not result in decreased soybean yield. They also found that planting *Phytophthora sojae* resistant soybean varieties resulted in decreased losses due to pre- and post-emergence damping off and resulted in higher yields. This study recommended that manure application be either broadcast or injected between the soybean row to reduce damping off and *Phytophthora* root rot, use of *Phytophthora* resistant varieties, and fungicide treatment of soybean seed to minimize the increased disease potential of manure application.

Summary of Studies Related to Water Quality and Residual Soil Nitrate

A long-term replicated study was initiated at the Iowa State University Northeast Iowa Research Farm in 2000 to study the impacts of liquid swine manure application on drainage water quality (Kanwar et al., 2006). Two specific treatments are directly applicable to the question of manure application to soybeans. One of these treatments used a 168 kg-N /ha (150 lb-N/acre) application rate of liquid swine manure prior to corn in a corn-soybean rotation and another treatment applied liquid swine manure prior to both corn and soybeans within the corn-soybean rotation. The rates in the every year application were 168 kg N /ha (150 lb-N/acre) prior to corn and 224 kg-N /ha (200 lb-N/acre) prior to soybeans. Both of the treatments used a fall application of manure. Reviewing soybean yields for the years from 2001-2006 (year 2000 was a transition year from previous treatments) indicates there were slight soybean yield increases with manure application prior to soybeans in four of the six years (3-5 bu/acre). On average over the six years, the soybean yield in the treatment with manure application prior to soybeans was 56 bu/acre versus 54 bu/acre where manure was applied just prior to the corn crop. The corn yields for the system where manure was applied each year were increased four of the six years when compared to yields for the system where manure was applied just prior to corn (4-7 bu/acre yield increases). The average corn yield for the system with every year application was 190

bu/acre versus 187 bu/acre for an application prior to just the corn year. The study also evaluated nitrate-nitrogen concentrations in the subsurface drainage. Annual flow-weighted nitrate-nitrogen concentrations were always greater for the treatment where manure was applied prior to both corn and soybeans. The average six-year flow weighted nitrate-nitrogen concentrations were approximately 38 mg/L for the every year application compared to 21 mg/L for the every other year application prior to just corn.

A long-term replicated drainage water quality study was initiated in 2000 at the drainage water quality research facility near Gilmore City, IA (Lawlor et al., 2007). Two treatments at this site had direct applicability to the question of manure application prior to soybeans. One treatment applied 200 lb-N/acre of liquid swine manure to corn in a corn-soybean rotation and another treatment applied 150 lb-N/acre of liquid swine manure prior to both corn and soybeans. The study also used fall application of liquid swine manure. Reviewing soybean yields from 2001-2004 (2000 was considered a transition year) indicates the average soybean yield was approximately 41 bu/acre for manure application prior to just the corn crop versus 45 bu/acre for manure application prior to both corn and soybeans (not a statistically significant yield increase). The average corn yields were greater for the treatment with an application prior to just corn when compared to the treatment with manure application every year (169 bu/acre versus 157 bu/acre, a statistically significant increase). Note that the nitrogen application rate was 200 lb-N/acre prior to corn for the treatment when manure was applied to just the corn crop versus 150 lb-N/acre when manure was applied every year to both corn and soybeans. Relative to nitrate-nitrogen concentrations, the four-year flow weighted nitrate-nitrogen concentration was 23 mg/L for the system with every year application to both corn and soybeans versus 17 mg/L when manure was just applied prior to corn (statistically significant increase).

In 1996 and 1997, Schmidt et al. (2000) evaluated the impact of swine manure application on nodulating and non-nodulating soybeans. The objective of the project was to determine soybean seed yield, plant nitrogen accumulation at the R6 growth stage, and soil nitrate-nitrogen response to increasing manure nitrogen and fertilizer nitrogen rates. Manure application rates ranged from 89-446 lb available-N/acre in 89 lb-N/acre increments (nitrogen availability was assumed to be 65 percent of total N). Fertilizer nitrogen application rates ranged from 75-300 lb-N/acre in 75lb-N/acre increments. Maximum soybean seed yields were obtained for nodulating soybeans at all manure and fertilizer rates but the yield for the non-nodulating soybeans increased quadratically from about 60 percent of the maximum yield to maximum yield as nitrogen rates increased from 0 to 200 lb-N/acre. The trends in nitrogen accumulation in the above ground biomass at the R6 growth stage were similar to results for soybean seed yield. However, they found that the N accumulation in the nodulating soybeans was greater for the manure treatments than the fertilizer treatments. Since nitrogen accumulation was similar regardless of nitrogen application rate for the nodulating soybeans a factor other than nitrogen mineral nutrition was attributed. From the post harvest soil nitrate data they found an increase in post harvest soil nitrate as nitrogen application increased. The post harvest soil nitrate followed a quadratic relationship:

Post harvest soil nitrate (kg/ha) =

$$0.0004 (\text{applied N (kg/ha)})^2 + 0.0215 (\text{applied N (kg/ha)}) + 42.271 \quad [r^2 = 0.9294]$$

These results indicate approximate increases of 5 percent, 17 percent, and 35 percent in post-harvest soil nitrate levels when application rates of 56, 112, and 168 kg-N/ha (50, 100, and 150 lb-N/acre) are compared to 0 kg-N/ha (0 lb-N/acre), respectively. While Schmitt et al. (2000) just report post harvest residual soil nitrate levels from 0-120 cm, within season soil nitrate levels (0-30 cm depth) are reported by Schmitt et al. (1996) and Randall and Schmitt (1998) for what appears to be the same study in Minnesota. As described above, Schmitt et al. (2000) documented an increase in residual soil nitrate with increasing nitrogen application rate, however this difference was even more pronounced in earlier season shallow soil samples. June 15, June 30, and July 16 sampling dates in 1996 showed greater than twice the concentration of soil nitrate in the 0-30 cm depth for the case where 185 kg-N/acre (165 lb-N/acre) was applied as manure (less than 10 ppm for control with no manure compared to approximately 20 ppm for 185 kg-N/ha as manure) (Randall and Schmitt, 1998). Schmitt et al. (1996) reports the nitrate levels in the 0-30 cm depth for various nitrogen application rates for sampling dates June 30, July 30, and August 30, 1996. On the June 20, 1996 concentrations of soil nitrate were greater than 20 ppm for all manure application rates reported approximately 56, 112, 168, 224, and 280 kg-N/ha (50, 100, 150, 200, and 250 lbs-N/acre) and the concentration increased as manure application rate increased (maximum concentration was approximately 31 ppm for 280 kg-N/ha (250 lbs-N/acre) application rate). This compares to soil nitrate levels of less than 10 ppm for the control plots where no manure was applied. This difference in soil nitrate was reduced at the July 30, 1996 sampling date and the difference was even smaller on the August 30, 1996 sampling date. Schmitt et al. (1996) noted that the nitrate concentrations decreased significantly through July and August. This indicates that nitrogen was used by the soybean plant and that it is unlikely that all nitrate was lost from the system. They also note that nitrate concentration increases were not detected at deeper depths. Since the majority of nitrate leaching losses to subsurface drainage occur in the months of April through June in the Upper Midwest (Randall, 2004) there may be concern of increased risk of higher nitrate losses if the soil nitrate levels are elevated especially during the predominant drainage period.

References

- Barbazan, M. 2004. Liquid swine manure as a phosphorous source for corn-soybean rotation. Thesis. Iowa State University, Ames, Iowa.
- Caldwell, B.E., R.W. Howell, R.W. Judd, H. W. Johnson. 1973. Soybeans: Improvement, Production, and Uses. American Society of Agronomy. Madison, Wisc.
- DeJong, J.M. 1995. Liquid swine manure and nitrogen fertilizer effects on soybean yield, soil profile nitrogen, and mineralization rates. Thesis. Iowa State University, Ames, Iowa.
- Harper, J.E. 1987. Nitrogen Metabolism. Soybeans: Improvement, Production, and Uses. 2nd Edition; Wilcox, J.R., Ed.; Agronomy. No. 16, p. 497-533. Madison, Wisc.

- Hati, K.M., K.G. Mandal, A.K. Misra, P.K. Ghosh, K.K. Bandyopadhyay. 2006. Effect of inorganic fertilizer and farmyard manure on soil physical properties, root distribution, and water use efficiency of soybean in Vertisols of central India. *Bioresource Technology*. 97:2182-2188.
- Iowa State University Extension. 2003. PM 1811, Managing manure nutrients for crop production. <http://www.extension.iastate.edu/Publications/PM1811.pdf>, viewed August, 22, 2007.
- Kanwar, R., C. Pederson, M. Helmers, A. Mallarino, and J. Sawyer. 2006. Impact of Swine Manure Application on Water Quality. Annual progress reports-2006. Northeast Research and Demonstration farm. ISRF06-13. Iowa State Univ., Ames, Iowa.
- Katoch, K., G. Aggarwal, F. Garg. 1983. Effect of nitrogen, soil compaction, and moisture stress on nodulation and yield of soy bean. *J. Indian Soc. Soil Sci.* 31:215-219.
- Killorn, R. 1998. Effect of Frequency of Swine Manure Application on the Yield of Corn and Soybean. Management/Economics Annual Progress Reports. ASL-R1593. Iowa State University, Ames, Iowa.
- Lawlor, P.A., M. J. Helmers, J.L. Baker, S.W. Melvin, and D.W. Lemke. 2007 Comparison of liquid swine manure application and ammonia nitrogen application timing on subsurface drainage water quality. Unpublished Manuscript In Preparation.
- McAndrews, G.M., M. Liebman, C.A. Cambardella, and T.L. Richard. 2006. Residual effects of composted and fresh solid swine (*Sus scrofa* L.) manure on soybean [*Glycine max* (L.) Merr.] growth and yield. *Agron. J.* 98: 873-882.
- Oelke, L.H. 1998. Phytophthora root rot, damping off, Sclerotinia stem rot and Brown stem rot of soybeans in response to swine manure application. Thesis. Iowa State University, Ames, Iowa.
- Padgitt, M. 1982. Technical and Economic Causes of U.S. Corn and Soybean Yield Changes. USDA Statistical Reporting Service.
- Rakshit, S. 2002. Liquid swine manure as a nitrogen source for corn and soybean production. Thesis. Iowa State University, Ames, IA.
- Randall, G. 2004. Subsurface drain flow characteristics during a 15 year period in Minnesota. Proceedings of the Eighth International Symposium. ASAE Publication Number 701P0304, St. Joseph, MI: ASAE.
- Randall, G.W. and M.A. Schmitt. 1998. Fertilizer or manure for soybeans. p. 110-119. In Proc.1998 Wisconsin Fertilizer, Aglime, and Pest Management Conf., Madison, WI. 19-21 Jan. 1998. Univ. of Wisc., Madison, WI.
- Sawyer, J.E. 2001. Nitrogen fertilizer and swine manure application to soybean. Integrated Crop Management Conference, Dec. 5-6, 2001. Iowa State University, Ames, IA.
- Sawyer, J., M. Helmers, A. Mallarino, K. Lamkey, and J. Baker. 2006. Environmental Protection Commission – Alternative Considerations Regarding Liquid Swine Manure Application Rates to Soybean. September 14, 2006. Iowa State University, Ames, IA.

- 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.
- Schmidt, J.P., M.A. Schmitt, G.W. Randall, J.A. Lamb, J.H. Orf, and H.T. Gollany. 2000. Waste management: swine manure application to nodulating and nonnodulating soybean. *Agron. J.* 92: 987-992.
- Schmidt, J.P., M.A. Schmitt, J.A. Lamb, R.A. Levins, G.W. Randall, and J.H. Orf. 1996. Manure management for soybean. *In: Proceedings from 1st Annual Midwest Soybean Conference.* August 9-12, 1996. Des Moines, IA.
- Schmitt, M.A., D.R. Schmidt, L.D. Jacobson. 1996. A manure management survey of Minnesota swine producers: effect of farm size on manure application. *App. Eng. Agric.* 12:595-599.
- Schmitt, Michael A., J. P. Schmidt, G. W. Randall, J. A. Lamb, J. H. Orf, H. T. Gollany. 2001. Effect of Manure on Accumulation of Dry Matter, Nitrogen, and Phosphorous by Soybean. *Communications in Soil Science and Plant Analysis*, vol. 32, no. 11&12, p. 1931-1941.
- Tiltsdale, S.L and W.L Nelson. 1975. *Soil Fertility and Fertilizers*, 3rd Edition. New York. Macmillian.
- Yang, X. B. and Charlie Martinson. 1996. Manure application and soybean disease. *Integrated Crop Management*, 476(7). Iowa State University, Ames, IA.
- Varel, G.E. and T.A. Peterson. 1992. Nitrogen fertilizer recovery by soybean in monoculture and rotation systems. *Agron. J.* 84:215-218.