Composting and time of application affect corn (Zea mays L.)
grain yield and dry matter response to deep-bedded swine (Sus
scrofa L.) manure

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Composting and time of application affect corn (*Zea mays* L.) grain yield and dry matter response to deep-bedded swine (*Sus scrofa* L.) manure

by

Terrance David Loecke

A thesis submitted to the graduate faculty in partial fulfillment of the requirements for the degree of MASTERS OF SCIENCE

Major: Crop Production and Physiology

Program of Study Committee:
Matt Liebman (Major Professor)
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Iowa State University
Ames, Iowa
2002

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This is to certify that the master's thesis of

Terrance David Loecke

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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CHAPTER 1. GENERAL INTRODUCTION

Literature Review

Livestock manures have been used as soil organic amendments since the dawn of agriculture. The possible benefits of applying swine manure to agricultural fields include increased soil organic matter, aggregate stability, water holding capacity, and plant nutrient availability (Khaleel et al., 1981). Unfortunately, current practices for management and utilization of swine manure have contributed to problems with water and air quality (Sharpley et al., 1998; Zebarth et al., 1999). This thesis investigates a new swine manure management system that may help achieve the positive benefits of manure with minimal environmental risk.

Most swine manure in the United States is handled and stored as a liquid (NRCS, 2000). Nevertheless, the environmental and social impacts of doing so have some producers and scientists searching for alternatives (Honeyman, 1996; Pote et al., 2001). Swine production in hoop structures is a relatively new husbandry system in which manure is handled as a solid. In Iowa alone hoop house production accounts for nearly one million finished head a year (Leopold Center for Sustainable Agriculture, 2001). Swine hoop structures typically utilize a deep bedding system, in which corn stalk residue or cereal straw is added to soak up urine and feces throughout the production cycle (four to six months). During this time, some in-situ composting occurs, although the extent and conditions of this unmanaged decomposition vary widely.

Hoop house swine manure, like many solid animal manures, can be applied directly to crop fields or piled for conventional composting (Tiquia et al., 2000). Manure or compost
application can occur anytime of the year that does not disturb crop production. At the end of each swine production cycle, when the pigs are removed from the hoop structure, the farmer faces the decision to haul the manure directly to the crop field or pile it for composting. Pigs and crops have different production cycles, so there are many possible permutations of the management questions of when (fall or spring) and in what form (fresh or composted) to apply the hoop manure to best utilize it as a cropping system resource and to safeguard against environmental contamination. This thesis is an effort to try to address these management questions in a systematic way.

Composting livestock manure offers several potential benefits, including reductions in densities of viable weed seeds contained in manure or manure/bedding mixtures (Wiese et al., 1998; Eghball and Lesoing, 2000), reduced application costs by decreasing volume and increasing bulk densities, and increased field application uniformity due to a reduction in particle size (Rynk et al., 1992). Composted manure can also be safely stored until land application (Rynk et al., 1992), which creates substantial flexibility in timing of application. Phytotoxic substances contained in fresh solid swine manure decrease with time of composting (Tiquia and Tam, 1998) and may also decrease with time following soil application.

Disadvantages of composting livestock manure are potentially large losses of C and N, and greater requirements for labor and capital associated with extra handling. Nitrogen losses during composting of animal manures have typically ranged from 20 to 70% (Martins and Dewes, 1992; Rao Bhamidimarri and Pandey, 1996; Eghball et al., 1997; Tiquia et al., 2002). Tiquia et al. (2002) estimated that 57% and 52% of the total C and N, respectively,
contained in fresh hoop swine manure was lost during two months of intensively managed composting.

Nitrogen is the plant nutrient that most commonly limits corn production in Midwestern cropping systems and its management is a major environmental concern. Nitrogen is thus a major focus of this thesis. Synchrony of plant available soil nutrients and crop nutrient demand is key to optimum crop performance and environmental protection (Magdoff, 1995). If plant available soil N (NO$_3^-$ and NH$_4^+$) is supplied in advance of crop demand, then substantial N losses can occur via nitrate leaching, denitrification, or ammonia volatilization. Alternatively, if plant available soil N is supplied in quantities less than the instantaneous crop N demand, then plant performance will be inhibited.

The quantity of plant available soil N is the result of gross N mineralization (conversion of organic N into inorganic N) and gross N immobilization (assimilation of inorganic N into organic N) processes, as well as the removal of inorganic or organic N from the rooting zone of the plant. The balance of gross N mineralization and gross N immobilization is termed net N mineralization. For a given soil amendment, soil physical conditions, including temperature, water status, and aeration, as well as the initial soil inorganic N content are the most important factors affecting N mineralization rates (Jenny, 1980). Among soil amendments, C to N ratios and C constituents (especially lignin quantities) are the key factors affecting mineralization rates (Swift et al., 1979; Tian et al., 1997). The C:N ratio of an amendment usually determines whether immobilization or mineralization will dominate in the early stages of decomposition (Jenny, 1980). Organic amendments with C:N ratios of <20 are commonly thought not to immobilize soil N when soil incorporated (Mathur et al., 1993). However, short-term immobilization with partially
composted hoop manure has been observed at C:N ratios of 12 to 15 (Cambardella et al., in press).

In general, net N mineralization occurs in two phases: a rapid immobilization or mineralization phase, followed by a slow mineralization phase (Bernal and Kirchmann, 1992; Hadas and Portnoy, 1994; DeLuca and DeLuca, 1997). The relative length of time and direction (either net N mineralization or net N immobilization) associated with the initial phase determines the basic N mineralization pattern for the entire season. This suggests that the abiotic soil conditions from the time of application until crop N demand and the composition of an applied soil amendment will affect the net N mineralization pattern relative to crop demand. However, little information is available about these interactions for livestock manure and composted manure used as soil organic amendments.

Anaerobic and aerobic decomposition can result in similar C:N ratios, but involve different metabolic byproducts. For example, anaerobic metabolism results in the production of phenols, alcohols and volatile fatty acids, which are easily decomposed by aerobic soil microorganisms. Application of anaerobically decomposed organic amendments to soil typically results in the immobilization of N due to the presence of these C-rich compounds (Bernal and Kirchmann 1992). Aerobic decomposition provides an opportunity for microbial assimilation of manure N (Hadas and Portnoy 1994) and enhances the hydrolysis of easily decomposable C-rich compounds. The resulting product is more resistant to microbial degradation (DeLuca and DeLuca 1997), thus less likely to immobilize N when soil applied. The bedded manure pack in hoop structures includes both anaerobic (dunging) and aerobic (resting/sleeping) areas, and the resulting implications for net N mineralization are unknown.
Plant N demand is driven by plant growth and development. Several factors influence crop growth and development in response to soil organic amendments, including (1) the spatial distribution of the amendments (which may influence crop-stand evenness); (2) soil nutrient supplying capacity; (3) soil quality characteristics such as water holding capacity (Hornick, 1988); (4) the presence of microbially-derived plant growth promoting and plant pathogen inhibiting substances (Hoitink and Kuter, 1986); and (5) phytotoxic substances affected by the degree of humification (Zucconi et al., 1985). Chen and Aviad (1990) have suggested that humic acids derived from composts promote root growth more than shoot growth.

Field trials comparing composted to fresh animal manures have demonstrated similar corn yields (Brinton, 1985; Ma et al., 1999; Eghball and Power, 1999), with equivalent (Ma et al., 1999) or lower N use efficiencies (Brinton, 1985; Eghball and Power, 1999) from the composts. The lower N use efficiency of compost is typically attributed to increased humification of the compost relative to its feedstock, fresh manure. A more humified organic material is more resistant to microbial degradation, thus the release of the nutrients contained in that material will be slower than those from less humified materials when soil applied (Stevenson and He, 1990). Comparing sunflower (Helianthus annuus L.) seedling growth response to composts at increasing stages of humification, Baca et al. (1995) found phytotoxic inhibition from immature composts and nutrient deficiencies with more mature composts. “Fresh hoop manure” is likely to be partially composted, due to in-situ composting prior to hoop clean out, and thus should be in an intermediate stage of humification between newly excreted swine manure and mature compost. Phytotoxicity and nutrient limitation effects are clearly important, but a substantial number of studies have also
demonstrated that animal manure, composts, and compost extracts can increase plant growth beyond levels explainable by increases in nutrient supply (Cooke, 1979; Chen and Aviad, 1990). These stimulatory effects also warrant consideration.

Timing of application can also influence crop responses, but often interacts with weather conditions (Talarczyk et al., 1996; Sanchez et al., 1997). Talarczyk et al (1996) reported inconsistent corn yield responses to fresh solid dairy manure applied immediately before planting in years of wet-cool springs in Wisconsin, but consistent yields with fall applied manure. In contrast, Warman (1995) reported no differences in corn yield response to dairy manure applied immediately before or six weeks prior to planting. The optimal time of application and form of hoop house swine manure (fresh or composted) need to be determined to establish best manure management practices for crop production and environmental protection.

Hypotheses

From the foregoing literature review, it is clear that alternative hoop manure management strategies will influence crop performance through numerous complex and dynamic processes. The following are our principal hypotheses concerning the effects of manure application on crop performance, and their implications for optimal management of hoop manure:

1. Both compost and fresh manure will increase crop yield, but their relative efficacy will depend on the balance between nutrient availability and phytotoxicity, which in turn will be influenced by (1) composting (2) the timing (fall versus spring application) of application, and (3) environmental conditions.
More specifically:

2. Spring applied amendments will have larger phytotoxic effects on corn response (corn seedling emergence in particular) than fall applied amendments. This would be expected due to degradation and/or dispersion of phytotoxic substances with the increase in time between application and corn planting.

3. Fresh hoop manure will have stronger phytotoxic effects on corn growth and development, especially seedling emergence than will composted hoop manure. This would result from degradation of phytotoxic substances during the composting process.

4. Composted hoop manure will supply N more synchronously relative to plant N demand than will fresh manure, because of the predicted slower and more constant net N mineralization from the more humified composted manure.

5. Hoop amendments applied in the spring will result in greater N use efficiencies than will fall applied hoop amendments, because of the greater potential for N losses from the plant rooting zone prior to crop N demand.

**Thesis Organization**

The general objectives of this thesis are to test each of the aforementioned hypotheses in field plot experiments conducted on the Iowa State University's Agronomy and Agricultural Engineering Research Farm, near Boone, IA. The specific objectives of the experiment presented in Chapter 2 are two fold: (1), to determine corn response to the form of hoop manure amendment and the timing of application, and (2) to use these results to develop hoop manure management guidelines. This experiment was designed to test
Hypotheses 2 and 3 directly by examining corn seedling emergence, and to test Hypotheses 4 and 5 indirectly, through monitoring plant and soil N status throughout two growing seasons. The results of the more general Hypothesis 1, will be used to generate guidelines useful to producers making hoop manure management decisions.

The specific objectives of the experiment presented in Chapter 3 were to intensively examine corn growth responses to spring applied fresh and composted manure. This study tested Hypotheses 3 and 4, by using growth analysis techniques to detect phytotoxic effects, and directly measurements the synchrony of plant N uptake to soil N mineralization patterns in response to the hoop amendment treatments.

Chapter four presents a summary of the relevant research findings of chapters two and three, provides guidelines of hoop manure management, and discusses future research needs for hoop manure utilization.

References


CHAPTER 2. TIMING OF APPLICATION AND COMPOSTING

AFFECT CORN (ZEA MAYS L.) YIELD RESPONSE TO SOLID SWINE
(SUS SCROFA L.) MANURE

A paper to be submitted to Agronomy Journal

Terrance D. Loecke, Matt Liebman, Cynthia A. Cambardella, and Tom L. Richard

Abstract

Swine production in hoop structures is a relatively new swine husbandry system in which a mixture of manure and bedding accumulates. This manure/bedding pack can be applied to crop fields directly from the hoop structure or can be piled for composting. During 2000 and 2001, field experiments were conducted near Boone, IA, to determine the effects of time of application (fall or spring) and form of manure (fresh or composted) on corn (Zea mays L.) and soil N parameters and corn grain yield. Fresh and composted manure were applied at a total N rate of 336 kg N ha\(^{-1}\). These treatments were augmented with four side-dressed urea-N fertilizer treatments (0, 60, 120, and 180 kg N ha\(^{-1}\)) to determine N fertilizer equivalency values for the organic amendments. In 2000, but not in 2001, applications of fresh hoop manure resulted in decreased plant emergence. In 2000, no corn yield differences were detected due to the form or the time of manure application, but all amended plots yielded higher than the unamended control. In 2001, fall application of amendments increased corn grain yield more than spring application (p<0.01) and composted manure application increased corn grain yields more than fresh manure (p<0.001), with spring-applied fresh manure providing no yield response beyond the unamended control.
Mean N supply efficiency, defined as N fertilizer equivalency as a percentage of the total N applied, was greatest for fall-applied composted manure (34.7%), intermediate for fall-applied fresh manure (24.3%) and spring-applied composted manure (25.4%), and least for spring-applied fresh manure (10.9%). Based on these results, the optimum management strategies would be to apply fresh manure in the fall rather than composting it for spring application, and to compost fresh manure removed from hoops in the spring for fall application. Possible losses of N and economic impacts associated with the time and form of application need to be evaluated and could affect these recommendations.

Introduction

Over one billion Mg of N are excreted in swine (*Sus scrofa* L.) manure in the United States annually (NRCS, 2000). Swine manure applied to crop fields can be an important source of plant nutrients and organic matter, which can improve soil quality (Khaleel et al., 1981). Nevertheless, current practices for management and utilization of swine manure can contribute to problems with water and air quality (Sharpley et al., 1998; Zebarth et al., 1999). Better management options are needed.

Most swine manure in the US is handled and stored as a liquid (NRCS, 2000), but the environmental and social impacts of doing so have some producers and scientists searching for alternatives (Honeyman, 1996; Pote et al., 2001). Swine production in hoop structures is a relatively new husbandry system, in which manure is handled as a solid. In Iowa alone hoop house production accounts for nearly one million finished head a year (Leopold Center for Sustainable Agriculture, 2001). Swine hoop structures typically utilize a deep bedding system, in which corn stalk residue or cereal straw is added to soak up urine and feces throughout the production cycle (four to six months). During this time, some in-situ
Composting occurs, although the extent and conditions of this unmanaged decomposition vary widely. Hoop house swine manure, like many solid animal manures, can be applied directly to crop fields or piled for additional composting (Tiquia et al., 2000). Manure or compost application can occur anytime of the year that does not disturb crop production. Currently, no guidelines are available for when and in what form (composted or fresh) swine hoop manure should be field-applied to best utilize it as a cropping system nutrient resource and to minimize negative environmental impacts.

Composting manure has a number of potential advantages, including reductions in densities of viable weed seeds (Wiese et al., 1998; Eghball and Lesoing, 2000), improvements in handling characteristics (by reducing manure volume and associated transportation costs of field application), and increased uniformity of field application due to a reduction in particle size (Rynk et al., 1992). Composted manure can be safely stored until land application (Rynk et al., 1992), which creates substantial flexibility in timing of application. Compost-amended soils can increase crop growth beyond levels explainable by nutrient effects (Valdrighi et al., 1996), provide protection from plant pathogens (Hoitink and Kuter, 1986), and suppress seedling emergence of some weed species (Menalled et al., 2002). Phytotoxic substances contained in fresh solid swine manure decrease with time of composting (Tiquia and Tam, 1998) and may also decrease with time following soil application.

Disadvantages of composting are potentially large losses of C and N, and labor and capital costs associated with extra handling of the manure and space requirements for the compost piles. Nitrogen losses during composting of animal manure range from 20% to 70% (Martins and Dewes, 1992; Rao Bhamidimarri and Pandey, 1996; Eghball et al., 1997; Tiquia
et al., 2002). Garrison et al. (2001) estimated that 41% of the total N contained in fresh hoop swine manure was lost during two months of intensively managed composting.

Synchrony of plant available soil nutrients and crop nutrient demand is key to optimum crop performance and environmental protection (Magdoff, 1995). If plant available N (NO₃⁻ and NH₄⁺) is not supplied in synchrony with crop demand, then substantial N losses can occur before or after periods of crop demand. The quantity of plant available soil N is the result of gross N mineralization (conversion of organic N into inorganic N) and gross N immobilization (assimilation of inorganic N into organic N) processes, as well as the removal of inorganic or organic N from the soil rooting zone of the plant. The balance of gross N mineralization and gross N immobilization is termed net mineralization.

For a given soil amendment, soil physical conditions, including temperature, water status, and aeration are the most important factors affecting mineralization rates (Jenny, 1980). Among soil amendments, C to N ratios and C constituents (especially lignin quantities) are the key factors affecting mineralization rates (Swift et al., 1979; Tian et al., 1997). In general, net N mineralization occurs in two phases: a rapid immobilization or mineralization phase, followed by a slow mineralization phase (Bernal and Kirchmann, 1992; Hadas and Portnoy, 1994; DeLuca and DeLuca, 1997). The relative length of time and direction (either net N mineralization or net N immobilization) associated with the initial phase determines the basic N mineralization pattern for the entire season. This suggests that the abiotic soil conditions from the time of application until crop N demand and the composition of an applied soil amendment will affect the synchrony of net N mineralization with crop demand. However, little information is available on the interactive effects of time
of application and the form of livestock manure derived soil amendments on net N mineralization pattern.

Corn yield responses to composted and fresh manure have been similar when these amendments were applied at the same time (Reider et al., 2000; Eghball and Power, 1999; Brinton, 1985; Ma et al., 1999; Xie and MacKenzie, 1986). Nitrogen use efficiencies observed in these studies indicate that plant available N from manure-derived compost is typically equal to or less than plant available N from fresh manure. Timing of application can influence crop responses, but often interacts with weather conditions (Warman, 1995; Talarczyk et al., 1996; Sanchez et al., 1997). The optimal time of application and form of hoop house swine manure (fresh or composted) needs to be determined to establish best manure management practices for crop production and environmental protection. The objective of this study was to determine first-year corn yield responses to season of application (fall versus spring) and form of hoop house manure (composted or fresh) by measuring grain yield and plant and soil nutrient status parameters throughout the season.

Materials and Methods

Field Site and Experimental Design

Field plot research was conducted at the Iowa State University Agronomy and Agricultural Engineering Research Farm near Boone, Iowa (42°01' N, 93°45' W) during 2000 and 2001 on Clarion loam (fine-loamy, mixed, superactive, mesic Typic Hapludolls) and Nicollet loam (fine-loamy, mixed, superactive, mesic Aquic Hapludolls) soils. Soil samples taken from the surface 20 cm prior to fall application of amendments indicated adequate P and K fertility levels in both years (Table 1). The field used for the 2000 experiment was cropped with oat (*Avena sativa* L.) in 1999; the field used for the 2001
experiment was cropped with soybean (*Glycine max* L. Merr.) in 2000. Neither field had received animal manure for at least the previous eight years. Annual and long-term weather data were collected from an automated weather station located <1 km from the field sites (Fig. 1).

A factorial treatment design consisting of season of application (fall or spring) and form of manure (fresh or composted hoop manure) was augmented with synthetic N fertilizer treatments used to estimate N fertilizer equivalency of the amendments. Treatments were arranged in a randomized complete block design with four replications. Plot size was 3.8 m (5 rows with a 0.76-m row spacing) by 10.7 m in 2000 and 12.2 m in 2001. Manure treatments were hand applied in the fall (22 Oct 1999, 24 Oct 2000) and spring (25 April 2000, 25 April 2001) at a rate of 336 kg N ha\(^{-1}\) based on moisture and total N content of samples taken two weeks prior to application (Table 2). Amendments were incorporated (disked) into the surface 15 cm within 6 h of application. Application rates were set to provide 112 kg N ha\(^{-1}\) based on the assumption that one-third of the total applied N would be available during the first year after application, as observed by Eghball and Power (1999). This application rate of N is approximately equal to the N removed in 9.0 Mg ha\(^{-1}\) of grain, the expected average yield from the experiment site.

All of the fresh and composted hoop manure was produced on the Iowa State University Rhodes Research Farm in Marshall County, IA, except for the fresh manure applied in the spring of 2001, which came from a commercial farm in Story County, IA. Urea-N was side-dressed in fertilizer N plots at plant stage V6 (Hanway, 1963) (9 June 2000 and 18 June 2001) at 0, 60, 120, and 180 kg N ha\(^{-1}\) and incorporated within 24 h using a interrow cultivator. A corn hybrid (Pioneer 35P12) was planted at 68 000 and 74 000 seeds
ha$^{-1}$ on 4 May 2000 and 9 May 2001, respectively. Weed control was achieved with a preplant incorporated application of metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide] at 1.5 kg a.i. ha$^{-1}$, interrow cultivation at plant growth stage V6, and hand weeding.

**Plant, Soil, and Amendment Sampling and Analysis**

A 4-L composite sample of each amendment (fresh or composted manure) was collected immediately before materials were applied to plots. Samples were stored at $-20^\circ$C in plastic freezer bags, then thawed, homogenized, separated for various analyses (total P, K, NH$_4^+$-N, and NO$_3^-$-N, moisture, and ash content, pH and EC), and then refrozen until individual parameter analysis. Amendment total C and N were determined on samples taken two weeks prior to application according to methods described by Cambardella et al. (in press). Total P and K were determined on dried ground samples by US-EPA method 3051 at a commercial laboratory (Midwest Laboratory, Inc., Omaha, NE) following a protocol given by Dancer et al. (1998). Total ammonium-N and nitrate-N were determined using 2M KCl extracts and Lachat flow-analysis (Lachat Instruments, Milwaukee, WI) (Keeney and Nelson, 1982). Amendment moisture content was determined by drying at 70°C for 48 h, ash content was determined by ignition at 550°C, and pH and Electrical conductivity by 1:5 amendment:water slurry.

To monitor plant and soil N status throughout the growing season, late spring soil nitrate concentration, ear leaf N and chlorophyll contents, and fall stalk nitrate concentration were measured. All plant and soil parameters were measured from the center three rows of each plot. Soil nitrate samples, consisting of a composite of ten soil cores from the surface 30 cm, were collected from each plot on 3 June 2000 and 4 June 2001 (Blackmer et al.,
All soil nitrate samples were processed by the USDA-ARS National Soil Tilth Laboratory (Ames, IA) according to procedures described by Blackmer et al. (1989).

Thirty leaf chlorophyll meter readings per plot were taken 1.5 cm from the leaf edge of the center (lengthwise) of the top-most fully expanded leaf or the same location on the ear leaf, when developed, using a Minolta SPAD-502 chlorophyll meter (Minolta, Ramsey, NJ) as others have done (Piekielek and Fox, 1992; Sims et al., 1995).

Ten ear leaf tissue samples were collected per plot at growth stage R1 for nutrient analysis. Ear leaf samples were dried at 60°C for 4 d, ground to pass a 0.85 mm screen, and analyzed for total Kjeldahl N. Ear leaf P concentrations were determined by nitric acid plus peroxide digestion followed by inductively coupled plasma mass spectrometry (Harris Laboratory, Lincoln, NE). Grain was harvested with a combine from 9.8 m and 10.7 m of the center three rows of each plot in 2000 and 2001, respectively. Reported grain yields are adjusted to a moisture content of 155 g kg⁻¹. Fifteen stalk samples (20 cm in length) were collected 15 cm above the soil surface from each plot at grain harvest, dried at 60°C for 4 d, ground to pass a 0.85 mm screen, and analyzed for NO₃⁻-N (Binford et al., 1992).

**Statistical Analysis**

Analysis of variance (ANOVA) was conducted using the PROC GLM routine of SAS (SAS Institute, 1999) to test for main and interaction effects, with blocks, years, and treatments in the model. Single degree of freedom contrasts were used to test specific hypotheses and main and interactive effects. Stalk nitrate concentrations were square root transformed prior to statistical analysis to meet the ANOVA assumption of homogeneity of the variance. Correlations between soil and plant parameters were made on an experimental
unit basis using PROC CORR in SAS. PROC REG of SAS was used to fit quadratic equations to the relationship between grain yields and urea-N fertilizer rates.

Results and Discussion

Weather Conditions

The period following fall amendment application in 1999 until corn planting in 2000 was warmer and drier than the 50-year average (Fig. 1a and 1b). The 2000-2001 winter was wetter and colder than the 50-year average (Fig. 1a and 1b). Mean monthly temperatures were typical compared to the 50-year average from April through September in 2000 and 2001 (Fig. 1a). Both growing season had lower than normal total precipitation (Fig. 1b), but the precipitation patterns differed between years. The 2000 growing season began with dry soil conditions followed by timely but limited precipitation. In contrast, the 2001 growing season was drier than normal from mid-June until September, but began with moist soil conditions in May following the wet winter season (Fig. 1b).

Amendment Composition and Application

Carbon to N ratios of the various amendments ranged from 10.7 to 14.2 with means of 12.5 and 11.6 for fresh and composted manures, respectively (Table 2). Materials with C:N ratios of less than 20 are generally thought not to immobilize soil N (Mathur et al., 1993), although short-term immobilization with partially composted hoop manure has been observed with C:N ratios of 12 to 15 (Cambardella et al., in press). The amendments applied in the spring of 2001 had the highest C:N ratios, perhaps due to the cool and wet conditions of the fall-winter-spring period of 2000-2001, which may have slowed decomposition in the compost windrows. These weather conditions also likely increased the bedding requirement
and/or altered the bedding management on the commercial farm from which the fresh manure applied in the spring of 2001 was obtained.

The ratio of ammonium-N to nitrate-N is sometimes used as an indicator of compost maturity (Mathur et al., 1993), with lower ratios indicative of greater decomposition. The \( \text{NH}_4^+ - \text{N} \) to \( \text{NO}_3^- - \text{N} \) ratio and the C content both suggest that the composted manure was more decomposed than the fresh manure overall, but that spring-applied amendments in 2001 were more similar to one another than at other application times (Table 2).

Each of the applied amendments contained a significant quantity of P (Table 2). Annual applications of livestock manure to fields in corn-soybean rotations at rates sufficient to meet corn N requirements have the potential to accumulate soil P (Jackson et al., 2000), due to higher P application rates than grain P removal rates. In our study, the P application rate ranged from 79 to 242 kg P ha\(^{-1}\) (Table 3) with mean P application rates of 121 and 188 kg P ha\(^{-1}\) for fresh and composted hoop manure, respectively, and 167 and 142 kg P ha\(^{-1}\) for fall and spring applied amendments, respectively (Table 3). During 2000-2001, corn and soybean yields in Boone, IA, averaged 9.7 and 2.7 Mg ha\(^{-1}\) (NASS, 2002) respectively, which would have removed an estimated 28 kg P ha\(^{-1}\) yr\(^{-1}\) for corn and 16 kg P ha\(^{-1}\) yr\(^{-1}\) for soybean (Voss et al., 1999). The combined P removal rate from one cycle of a corn-soybean rotation therefore would have removed 44 kg P ha\(^{-1}\). A comparison of the P applied in this study to the estimated P grain removal shows that one application of either fresh or composted hoop manure per corn-soybean rotation cycle would lead to soil P accumulation. However, it should be noted that fresh hoop manure had a higher N:P ratio (Table 3) which should slow soil P accumulation compared to composted hoop manure assuming equal P grain removal rates.
**Corn Emergence**

In 2000, corn emergence was adversely affected by fresh manure applied in both fall and spring (Table 4). Plant emergence reductions following high rates (100 Mg ha\(^{-1}\), wet weight) of spring-applied municipal solid waste compost (Mays et al., 1973) and fresh dairy manure (Motavalli et al., 1993) have also been observed. Mays et al. (1973) attributed these plant stand reductions to formation of a loose seed bed due to the high compost to soil ratio, and/or phytotoxic substances contained within the amendments. In our study, at corn planting in 2000, fresh manure clods were visible on the soil surface even after use of a disk and field cultivator. The combination of dry surface soil conditions, requiring a deeper (8 to 10 cm) than normal (4 to 6 cm) planting depth for seed to soil moisture contact, and the physical and/or chemical effects of the fresh-manure clods on the soil surface over the plant row were likely causes of the plant emergence effects in 2000. Fall-applied fresh manure reduced plant emergence less than spring-applied fresh manure in 2000 (Table 4). This was probably due a combination of degradation and/or dispersion of phytotoxic substances and the physical degradation of the fresh manure clods that occurred during the winter following fall application of amendments. Despite these stand reductions, plant population densities were not correlated with grain yields (Table 4). In 2001, plant emergence was not affected by amendment treatments (Table 4). Moist soil conditions throughout the spring of 2001 allowed for adequate fresh manure clod size reductions during tillage and thus eliminated the plant emergence problems observed in 2000.

**Late Spring Soil Nitrate**

The nitrate concentration in the surface 30 cm of soil when corn is 20-30 cm tall has been used in the midwestern and northeastern US to predict corn yield response to N
fertilizer (Blackmer et al., 1989; Magdoff, 1991). Although this method has been calibrated for synthetic N fertilizer sources and to a limited extent for soils amended with liquid swine manure (Hansen, 1999), it has not been calibrated for soils receiving solid livestock manures. It has had limited predictive success for soils where organic amendments are the main N source (Hansen, 1999). In both years of our study, soil nitrate concentrations were higher in plots receiving organic amendments than the unamended, fertilizer-free control (Table 4). A significant amendment form by application time interaction was detected for soil nitrate concentrations in 2000 (Table 4), in which the highest soil nitrate concentrations were found in plots treated with spring-applied composted manure followed by fall-applied composted manure then fall-applied fresh manure and the lowest in plots amended with spring-applied fresh manure. In 2001, low soil nitrate concentrations may have reflected the high soil moisture conditions prior to sampling, which could have caused nitrate leaching or denitrification losses. Blackmer et al. (1989) set the maximum soil nitrate concentration in the surface 30 cm at which to expect a yield response from applications of synthetic N fertilizer at 20 µg g⁻¹ and at 11 to 15 µg g⁻¹ for manured soils in years of excessively wet springs (i.e., 2001). In general, in our study soil nitrate concentrations accurately predicted corn responses to urea-N fertilizers, but did not predict the high yields of the fall applied manures (fresh and composted) in 2001 (Table 4 and Fig. 2). This supports the hypothesis that soils freshly amended with biologically active organic materials have more complex N dynamics than those amended with mineral N fertilizers (Magdoff, 1991; Cambardella et al., in press).
**Ear Leaf N and P Concentrations and Chlorophyll Meter Readings**

The chlorophyll meter nondestructively measures the degree of greenness of leaves and provides an indication of leaf N concentration (Varvel et al., 1997). Chlorophyll meters are useful for indicating N deficiencies, but not for determining excessive soil N availability (Schepers et al., 1992). Chlorophyll meter readings of corn ear leaves at growth stage R1 responded positively to urea application in both years (Table 5). A significant quadratic response to increasing rates of urea fertilizers \((p<0.001)\) was also found in 2000, possibly indicating that N was not limiting in the higher urea application rates \((120 \text{ and } 180 \text{ kg N ha}^{-1})\) at this point in the season (Table 5). Manure and compost treatments resulted in higher chlorophyll meter readings than the no amendment control in both years (Table 5). Eghball and Power (1999) found similar chlorophyll meter reading results when comparing composted and noncomposted beef feedlot manure to no amendment controls throughout the growing season. In our study in 2000, composted manure treatments (fall- and spring-applied) had higher chlorophyll readings than fresh manure (fall- and spring-applied), and the mean of all manure treatments was greater than the no amendment control (Table 5). A significant interaction was detected in 2001 between form of amendment and timing of application (Table 5). Spring-applied fresh manure treated plots in 2001 had the lowest chlorophyll readings among the manure treatments (Table 5).

Ear leaf tissue N concentration at plant growth stage R1 provides a relative measure of plant N status, but does not directly indicate plant N deficiency or excess soil N availability due to corn's capacity for luxury N uptake (Blackmer and Cerrato, 1991). Corn ear leaf N concentration at growth stage R1 responded positively to urea application in both years (Table 5). The slope of the response was greater in 2000 than in 2001. In 2000, the
mean ear leaf N concentration of all organic amendment treatments was higher than that of the control, but no difference between amendment treatments and the control was detected in 2001 (Table 5). The season of application was important in 2001, as fall applied manure generated higher ear leaf N concentrations than did spring applied manure (Table 5).

Both the corn ear leaf N concentrations and chlorophyll meter readings at growth stage R1 correlated well with final corn grain yield (Table 5). Eghball and Power (1999) also found strong correlations \((r>0.71)\) between chlorophyll meter readings and grain yield, except in a season of low precipitation. In our study, ear leaf N concentration and chlorophyll readings at R1 were also well correlated with each other (2000: \(r=0.54, P=0.0016\); 2001: \(r=0.64, P<0.0001\)).

Corn ear leaf P concentrations increased linearly with increasing rates of urea application in both years (Table 5). This may indicate that healthier plants in the higher urea treatments foraged for soil P more efficiently and/or that the hydrolysis of urea lowered soil pH, thus making more soil P plant available (Miller and Ohlrogge, 1958; Olson and Dreier, 1956). Differences in ear leaf P between years were may be due to differences in early season soil moisture, although many factors fertility and environmental factors interact to influence ear leaf P concentrations (Voss et al., 1970). In 2001, there were minimal differences between treatments (Table 5).

**Corn Grain Yields**

Corn grain yields increased in both years in response to increasing rates of urea application (Fig. 2; Table 6). The highest yields in response to urea application were similar in both years, but the yield of the control treatment was lower in 2000 than in 2001. This pattern was similar to that observed for the ear leaf N concentration and chlorophyll readings.
at R1 and is likely due to the influence of the previous year’s crop (oat prior to 2000 and soybean prior to 2001) (Crookston et al., 1991; Peterson and Varvel, 1989). The mean grain yield from amendment treatments was greater than the control in both years (Table 6; Fig. 2). In 2001, grain yields from composted manure treatments were greater than those from fresh manure treatments and fall applied manure treatments produced higher yields than did spring applied treatments. In 2000, no grain yield differences were detected due to the time of application nor the form of amendment (composted or fresh manure) (Table 6).

**Nitrogen Fertilizer Equivalency Value**

A quadratic equation was fit to the yield results from urea application treatments in each year (Fig. 2). Although only the linear trend was statistically significant (Table 6), the quadratic function produced a better fit to the data, and we judged it to be more biologically realistic (see Blevins et al., 1990; Barbarick and Ippolito, 2000). Based on each quadratic urea response curve, N fertilizer equivalency values were calculated for each amendment treatment mean (Table 7). Nitrogen supply efficiency (defined as the N fertilizer equivalency value per unit of N applied in an amendment) is an useful parameter for determining the economic value of an amendment’s effects in the first year after application (Barbarick and Ippolito, 2000), although the soil quality and crop performance benefits resulting from a single application of soil amendments may be long-term (Khaleel et al., 1981). Data shown in Table 7 indicate that, on average, fall application was superior to spring application and composted manure provided more consistent yield benefits than did fresh manure on a per N unit basis. At the application rate used in this experiment, spring-applied fresh manure produced inconsistent yield benefits.
The time of application was expected to influence the net N mineralization pattern relative to the crop N demand, due to seasonal variation in microbial decomposition of the soil amendments. Monitoring of soil N losses and net N mineralization in response to the timing of amendment application should help to clarify if the observed N use efficiencies were due to N effects. Alternatively, any phytotoxic substances contained in the amendments may have been degraded or dispersed with the increased time between application and crop planting with the fall application versus the spring application.

**Fall Stalk Nitrate**

Nitrate concentration in the lower portion of a corn stalk (the section between 15 to 35 cm above the soil surface) at plant maturity has been used as an indicator of late season soil \( \text{NO}_3^-\) concentrations and/or environmental stress (Binford et al., 1992). A stalk \( \text{NO}_3^-\) concentration of \(>2000\ \mu g \ \text{g}^{-1}\) indicates excessive soil nitrate or stress, whereas concentrations \(<200\ \mu g \ \text{g}^{-1}\) indicate insufficient inorganic soil N for maximum economic grain yield (Binford et al., 1992). In our study, urea application resulted in positive stalk nitrate responses in both years (Table 5). The curvilinear responses that were observed typically occur as plant-available soil N becomes greater than the plant's ability to assimilate \(\text{NO}_3^-\) into amino acids (Binford et al., 1992). In both years all amendment treatments resulted in stalk \( \text{NO}_3^-\) concentrations \(<500\ \mu g \ \text{g}^{-1}\), and the mean stalk nitrate concentration of all organic amendment treatments was not different from the control treatment (Table 5). In 2001, fresh manure applications resulted in higher stalk \( \text{NO}_3^-\) concentrations than composted manure applications and fall applications gave higher stalk nitrate concentrations than did spring-applied manure. The relationship of stalk nitrate concentration to grain yield followed closely those of Binford et al. (1992) in 2000, but this pattern was not as distinct in
2001 (figure not shown). It is unclear if this was due to limited available soil N or increased nitrate assimilation efficiencies. For example, in 2001, despite having similar yields, the fall application of composted manure resulted in lower stalk nitrate concentrations than did the 120 and 180 kg N ha$^{-1}$ urea-N treatments. This may suggest that other factors in addition to N effects may have contributed to the grain yield response to organic amendments.

**Conclusions and Recommendation for Future Research**

At the rates applied in this study, spring application of fresh hoop manure resulted in inconsistent yields, lower N-use efficiencies, and problems with plant emergence. Although not always significantly, the soil and plant N status parameters measured in each year (soil nitrate concentrations at plant growth stage V6 and apparent ear leaf chlorophyll and N contents at growth stage R1) indicated that spring-applied fresh manure supplied less N to the plants prior to and during plant flowering, than the other amendment treatments. Thus N deficits may have contributed to the lower yields in response to the spring-applied fresh manure compared to the other amendment treatments. Increasing spring-applied fresh hoop manure application rates to meet crop N demands may be detrimental to plant emergence and possibly cause greater soil N immobilization and therefore is not recommended.

In 2001, stalk nitrate concentrations in response to the manure treatments were low (<500 µg g$^{-1}$) (Table 5) compared to the stalk nitrate concentrations of urea-N treatments with similar grain yields. This pattern suggests that additional late-season plant available soil N would have increased grain yields in the organic amendment treated plots. Hanway (1962) found that corn seasonal N uptake patterns can differ in response to N fertility levels. A more detailed examination of the seasonal N mineralization and crop N uptake patterns in
response to fresh or composted hoop manure needs to be conducted to determine when and if supplemental N fertilizers may increase N use efficiencies.

The poor yield response to spring-applied fresh manure was more pronounced in 2001, a season of cooler and moister early season soil conditions. In Wisconsin, similar results were found in wet-cool springs if fresh solid dairy manure was applied immediately before corn planting (Talarczyk et al., 1996). Talarczyk et al. (1996) attributed this result to a slower than normal manure-N mineralization pattern. Fall application of solid manure organic amendments in Talarczyk et al.'s (1996) study and in our study resulted in more consistent yield benefits than did spring applications. This is may be due to the benefits of a more timely net N mineralization period relative to plant N demand and/or the degradation of phytotoxic substances with fall application versus spring application.

Given the estimated N losses during composting of fresh hoop manure (41%, Garrison et al., 2001), our results show that fall-applied fresh manure is more desirable for whole-farm N conservation, at least during the first year after application than spring applied compost. Nitrogen losses prior to crop demand from plots treated with fall-applied amendments need to be studied however, for a more complete whole-farm N budget. Based on these results, the optimum management strategies would be to apply fresh manure in the fall rather than composting it for spring application, and to compost fresh manure removed from hoops in the spring for fall application. An economic comparison of manure management alternatives may indicate a tradeoff between composting costs, hauling distance to the field with the associated reduction in compost volume, and crop yield benefits. If swine manure is applied at rates sufficient to meet N requirements of continuous corn or a corn-soybean rotation, then soil P will accumulate in the receiving soils due to the difference
in N:P removal ratio of these crops relative to the ratios of swine hoop manure or compost used in this study. Therefore, work is needed on the interactions of hoop manure form (compost or fresh), application rates, timing of application, and supplemental N fertilizer (either synthetic or legume-derived) within more diverse crop rotations.

References


Manure nutrients relative to the capacity of cropland and pastureland to assimilate nutrients: Spatial and temporal trends for the United States. Publ. nps00-0579.


Table 1. Soil fertility parameters of the surface 20 cm taken prior to treatment applications, near Boone, IA.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density, g cm$^{-3}$</td>
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<td>1.2</td>
</tr>
<tr>
<td>Total organic C, Mg ha$^{-1}$</td>
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<td>46.7</td>
</tr>
<tr>
<td>Total organic N, Mg ha$^{-1}$</td>
<td>3.8</td>
<td>4.1</td>
</tr>
<tr>
<td>Nitrate-N, kg ha$^{-1}$</td>
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<td>19.3</td>
</tr>
<tr>
<td>Ammonium-N, kg ha$^{-1}$</td>
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<td>1.8</td>
</tr>
<tr>
<td>Mehlich-I P, kg ha$^{-1}$</td>
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<td>113</td>
</tr>
<tr>
<td>Mehlich-I K, kg ha$^{-1}$</td>
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<td>Electrical conductivity, µS</td>
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Table 2. Composition of organic amendments.

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<th>H₂O</th>
<th>Ash</th>
<th>P</th>
<th>K</th>
<th>C</th>
<th>N</th>
<th>C:N</th>
<th>NH₄⁻-N</th>
<th>NO₃⁻-N</th>
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<th>EC§</th>
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<td>406</td>
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<td>28.6</td>
<td>11.3</td>
<td>3496</td>
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<td>8.8</td>
<td>4.6</td>
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<td></td>
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<td>10.7</td>
<td>497</td>
<td>818</td>
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<td>2770</td>
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<td>5.7</td>
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<tr>
<td></td>
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<td>726</td>
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<td>15.4</td>
<td>144</td>
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<td>16.3</td>
<td>12.7</td>
<td>944</td>
<td>136</td>
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† Moisture content is expressed on a wet weight basis and all other concentration parameters are expressed on a dry matter basis.

§ Electrical conductivity (EC) and pH were determined on 5:1 water to amendment slurry.
Table 3. Loading rates of organic amendments.

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<tr>
<td>Fall 1999</td>
<td>Fresh manure</td>
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<td>Composted manure</td>
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<tr>
<td>Spring 2000</td>
<td>Fresh manure</td>
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<tr>
<td></td>
<td>Composted manure</td>
<td>336</td>
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<tr>
<td>Fall 2000</td>
<td>Fresh manure</td>
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<tr>
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<td>Composted manure</td>
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<tr>
<td>Spring 2001</td>
<td>Fresh manure</td>
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<td></td>
<td>Composted manure</td>
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</table>

DM represents dry matter.
Table 4. Treatment means, analysis of variance, and correlation to yield for plant population and late spring soil nitrate concentration during 2000 and 2001 near Boone, IA.

<table>
<thead>
<tr>
<th></th>
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<td>Side-dressed (at V6)</td>
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<td>63252</td>
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Table 4. (continued)

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<thead>
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<th>Source of Variation</th>
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<th>Soil Nitrate</th>
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<tr>
<td></td>
<td>2000</td>
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<td>Treatment contrasts</td>
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<td>Urea fertilizer linear response</td>
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<td>Urea fertilizer cubic response</td>
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<tr>
<td>Control vs. all organic amendments</td>
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<td>Among amendments (fresh vs. composted)</td>
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<td>Time of Application (A)</td>
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<td>Amendments (fall vs. spring)</td>
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<td>Amendments (fresh vs. composted) X (fall vs. spring)</td>
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<td>ns</td>
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<tr>
<td>Correlation to Yield (r)</td>
<td>-0.20&lt;sup/ns&lt;/sup&gt;</td>
<td>-0.11&lt;sup/ns&lt;/sup&gt;</td>
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†, *, **, and *** represent significance at the P<0.1, 0.05, 0.01, and 0.001 probability level, respectively.
Table 5. Treatment means, analysis of variance, and correlation to grain yield for SPAD chlorophyll meter readings and corn ear leaf N and P concentrations at growth stage R1, and fall stalk nitrate concentrations in 2000 and 2001, Boone, IA.

<table>
<thead>
<tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td>kg N ha⁻¹</td>
<td>g kg⁻¹</td>
<td>g kg⁻¹</td>
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<td>g kg⁻¹</td>
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<tr>
<td>Side-dressed (at V6)</td>
<td>Urea</td>
<td>60</td>
<td>60.4</td>
<td>24.5</td>
<td>2.9</td>
<td>2.2</td>
<td>4.5</td>
<td>4.3 (25)</td>
<td></td>
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<tr>
<td>Side-dressed (at V6)</td>
<td>Urea</td>
<td>120</td>
<td>61.2</td>
<td>26.5</td>
<td>3.1</td>
<td>2.1</td>
<td>26.0</td>
<td>23.3 (566)</td>
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<tr>
<td>Side-dressed (at V6)</td>
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<td>27.0</td>
<td>3.3</td>
<td>2.2</td>
<td>77.7</td>
<td>37.9 (1491)</td>
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<tr>
<td>Fall</td>
<td>Fresh manure</td>
<td>336</td>
<td>58.0</td>
<td>24.1</td>
<td>3.5</td>
<td>2.2</td>
<td>10.1</td>
<td>18.3 (402)</td>
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<tr>
<td>Fall</td>
<td>Composted manure</td>
<td>336</td>
<td>60.1</td>
<td>24.6</td>
<td>3.0</td>
<td>2.2</td>
<td>9.6</td>
<td>6.5 (52)</td>
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<tr>
<td>Spring</td>
<td>Fresh manure</td>
<td>336</td>
<td>57.2</td>
<td>23.1</td>
<td>3.4</td>
<td>2.1</td>
<td>5.3</td>
<td>8.0 (66)</td>
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<tr>
<td>Spring</td>
<td>Composted manure</td>
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<td>60.0</td>
<td>25.5</td>
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Table 5. (continued)

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<tr>
<td>Urea fertilizer linear response</td>
<td>*** ***</td>
<td>*** **</td>
<td>*** †</td>
<td>*** *** ***</td>
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<td>*** ***</td>
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<td>Urea fertilizer quadratic response</td>
<td>*** ns</td>
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<td>Control vs. all organic amendments</td>
<td>*** **</td>
<td>*** ns</td>
<td>*** *</td>
<td>ns ns</td>
<td></td>
<td>*** ns</td>
<td>ns ns</td>
<td>ns ns</td>
</tr>
<tr>
<td>Among amendments (fresh vs. composted)</td>
<td>*** **</td>
<td>ns †</td>
<td>ns ns</td>
<td>ns ns</td>
<td></td>
<td>ns ns</td>
<td>ns ns</td>
<td>ns ns *</td>
</tr>
<tr>
<td>Time of Application (A)</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Amendments (fall vs. spring)</td>
<td>ns ***</td>
<td>ns **</td>
<td>ns ns</td>
<td>ns ns</td>
<td></td>
<td>ns ns</td>
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<tr>
<td>Amendments (fresh vs. composted) X (fall vs. spring)</td>
<td>ns *</td>
<td>ns †</td>
<td>† ns</td>
<td>ns</td>
<td></td>
<td>ns</td>
<td>ns †</td>
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<tr>
<td>Correlation to Yield (r)</td>
<td>0.70***</td>
<td>0.51**</td>
<td>0.44*</td>
<td>0.55**</td>
<td>0.25 ns</td>
<td>0.35*</td>
<td>0.54**</td>
<td>0.37*</td>
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†, *, **, and *** represent significance at the P<0.1, 0.05, 0.01, and 0.001 probability level, respectively.

§ Analysis of variance conducted on square root transformed data. Data in parentheses are means of raw data.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>P&gt;F</th>
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<td>Treatment Contrasts</td>
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<td>Forms (F)</td>
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<td>Urea fertilizer linear response</td>
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<td>Urea fertilizer quadratic response</td>
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<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Urea fertilizer cubic response</td>
<td></td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Control vs. all organic amendments</td>
<td></td>
<td>***</td>
<td>**</td>
</tr>
<tr>
<td>Among amendments (fresh vs. composted)</td>
<td></td>
<td>ns</td>
<td>***</td>
</tr>
<tr>
<td>Time of Application (A)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amendments (fall vs. spring)</td>
<td></td>
<td>ns</td>
<td>**</td>
</tr>
<tr>
<td>F X A</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Amendments (fresh vs. composted) X (fall vs. spring)</td>
<td></td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

†, *, **, and *** represent significance at the P<0.1, 0.05, 0.01, and 0.001 probability level, respectively.
Table 7. Estimated N fertilizer equivalency values of amendments and the N supply efficiency, based on corn yield response to side-dressed (at V6) urea fertilizer, in Boone, IA, 2000 and 2001.

<table>
<thead>
<tr>
<th>Time of Application</th>
<th>Form</th>
<th>N fertilizer equivalency value</th>
<th>N supply efficiency†</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>2000</td>
<td>2001</td>
</tr>
<tr>
<td>Fall</td>
<td>Fresh Manure</td>
<td>103</td>
<td>60</td>
</tr>
<tr>
<td>Fall</td>
<td>Composted Manure</td>
<td>96</td>
<td>137</td>
</tr>
<tr>
<td>Spring</td>
<td>Fresh Manure</td>
<td>79</td>
<td>-6</td>
</tr>
<tr>
<td>Spring</td>
<td>Composted Manure</td>
<td>97</td>
<td>71</td>
</tr>
</tbody>
</table>

† N supply efficiency defined as the N fertilizer equivalency value expressed as a percentage of the total N applied (336 kg N ha⁻¹).
Figure 1. Monthly total precipitation (a) and average daily temperature (b) for 2000, 2001, and the 50-year average recorded from an automated weather station located <1 km for fields sites.
a. Mean Monthly Air Temperature (°C)

- 50-year ave.  ■ 1999  □ 2000  □ 2001

b. Monthly precipitation totals (mm month⁻¹)

- 50-year ave.  ■ 1999  □ 2000  □ 2001
Figure 2. Grain yield from urea-N rates side-dressed at plant growth stage V6 and manure treatments from 2000 and 2001, near Boone, Iowa. Error bars represent plus/minus one standard error. Grain yields presented are adjusted to a moisture content of 155 g kg\(^{-1}\). Treatment contrasts are presented in Table 6.
2000

\[ Y = -0.0714x^2 + 35.723x + 6659.4 \]

\[ R^2 = 0.996 \]

2001

\[ Y = -0.0897x^2 + 30.589x + 8132.9 \]

\[ R^2 = 0.999 \]
CHAPTER 3. GROWTH RESPONSES OF CORN (ZEA MAYS L.) TO COMPOSTED AND FRESH SOLID SWINE (SUS SCROFA L.) MANURE

A paper to be submitted to Crop Science

Terrance Loecke, Matt Liebman, Cynthia A. Cambardella, and Thomas L. Richard

Abstract

Use of fresh and composted livestock manure as soil amendments can inhibit or stimulate plant growth beyond levels explainable by decreases or increases in nutrient supply. Swine (Sus scrofa L.) production in hoop structures is relatively new deep-bedded swine finishing system in which manure can be field applied fresh or piled for composting prior to field application. We conducted field-plot trials near Boone, IA, during two growing seasons to determine the effects of spring-applied fresh and composted swine hoop manure on corn (Zea mays L.) growth responses. Amendments were applied at a total N rate of 336 kg N ha$^{-1}$, and a functional growth analysis approach using frequent plant harvests was used to monitor total aerial dry matter production and leaf area development. In 2000, fresh manure had phytotoxic effects on corn seedlings in the field and on annual ryegrass (Lolium multiflorum L.) seedlings in the laboratory. No treatments differences were detected in aerial dry matter production efficiencies or morphological partitioning patterns. In both 2000 and 2001, composted manure treated plots produced significantly larger plants than did the fresh manure treatment, but the time of treatment separation differed between years. In 2000, size differences were evident early in the season, whereas in 2001, size differences became
evident near plant flowering. The time of treatment separation in both years coincided with
the driest soil conditions of the season. Plant growth stimulating substances and/or
phytotoxic substances appeared to be important factors affecting corn growth responses to
the composted and fresh swine hoop manure.

Introduction

Application of animal manure to agricultural fields is a widely used method of
increasing soil organic matter, aggregate stability, water holding capacity, and fertility
(Khaleel et al., 1981). Most solid livestock manures can be applied directly to crop fields or
piled for composting (Rynk et al., 1992). Composting solid animal manure can reduce field
application costs by increasing bulk density and reducing volume. Composting can also
increase application uniformity due to a reduction in particle size, and decrease densities of
viable weed seeds (Wiese et al., 1998) contained in manure or manure/bedding mixtures.
Composted manure can be safely stored until land application (Rynk et al., 1992), which
creates substantial flexibility in timing of application. Phytotoxic substances contained in
fresh solid swine manure decrease with time of composting (Tiquia and Tam, 1998).

Disadvantages of composting manure are potentially large losses of C and N, and
greater requirements for labor and capital associated with extra handling. Nitrogen losses
during composting of animal manures have typically ranged from 20 to 70% (Martins and
Dewes, 1992; Rao Bhamidimarri and Pandey, 1996; Eghball et al., 1997; Tiquia et al., 2002).

Field trials comparing manures to the composts derived from them have been limited,
but are critical for determining best manure management practices. Several factors influence
crop responses to soil organic amendments, including (1) differences in the timeliness and
quantities of plant available nutrients from each amendment in relation to the crop demand.
for those nutrients (Magdoff, 1995), (2) phytotoxic effects associated with the degree of humification (Zucconi et al., 1985), (3) the presence of microbially-derived plant growth promoting substances (Hoitink and Kuter, 1986), (4) the spatial distribution of the amendments that may influence crop-stand evenness, and (5) soil quality characteristics such as water holding capacity (Hornick, 1988). Mineralization rates of organic amendments in soil are influenced by soil physical conditions, including temperature, moisture content, and aeration (Honeycutt et al., 1988, 1991; Griffin and Honeycutt, 2000; Doel et al., 1990), and the material quality, primarily C:N ratios and the carbon constituents (especially lignin quantities) (Swift et al., 1979; Tian et al., 1997). The synchrony of net nutrient mineralization from organic amendments and crop demand for those nutrients is a key to optimal crop production and prevention of environmental contamination.

Field trials comparing composted to fresh animal manures have demonstrated similar corn yields (Brinton, 1985; Ma et al., 1999; Eghball and Power, 1999), with equivalent (Ma et al., 1999) or lower N use efficiencies (Brinton, 1985; Eghball and Power, 1999) from the composts. The lower N use efficiency of compost is typically attributed to increased humification of the compost relative to its feedstock, fresh manure. A more humified organic material is more resistant to microbial degradation, thus the release of the nutrients contained in that material will be slower than those from less humified materials when applied to soil (Stevenson and He, 1990). Comparing sunflower (Helianthus annuus L.) seedling growth response to composts at increasing stages of humification, Baca et al. (1995) found phytotoxic inhibition from immature composts and nutrient deficiencies with more mature composts. Phytotoxicity and nutrient limitation effects are clearly important, but a substantial number of studies have also demonstrated that animal manure, composts, and
compost extracts can increase plant growth beyond levels explainable by increases in nutrient supply (Cooke, 1979; Chen and Aviad, 1990). These stimulatory effects also warrant consideration.

Swine production in hoop structures is a relatively new husbandry system, in which manure is handled as a solid that can be composted (Tiquia et al., 2000; Honeyman et al., 2001). A direct comparison of the effects of composted and fresh swine hoop manure on crop performance is possible and relevant to producer decision making concerning best management practices for utilizing manure. Field studies using quantitative growth analysis (Evans, 1972; Hunt, 1982) have been used to examine physiological responses to corn plant spacing (Bullock et al., 1988), P fertility levels (Plenet et al., 2000), above-optimal fertility levels (Karlen et al., 1988), and other factors, but corn growth response to compost maturity has not been studied using this approach. The objective of this study was to use quantitative growth analysis to examine corn response to spring-applied composted and fresh hoop manure under field conditions.

Materials and Methods

Site, Experimental Design and Management

The experiment was conducted on adjacent fields during 2000 and 2001 on Iowa State University’s Agronomy and Agricultural Engineering Research Farm, near Boone, IA (42°01' N, 93°45' W). Both field sites were in a soybean-corn-oat rotation with no animal manure application history in the previous 10 years. The soil of the 2000 site was a Nicollet loam (fine-loamy, mixed, superactive, mesic Aquic Hapludolls), whereas the 2001 site was mainly a Webster silty clay loam (fine-loamy, mixed, superactive, mesic, Typic Endoaquolls) mixed with some Nicollet loam. Air temperature and precipitation data were collected from
an automated weather station located within 1 km of the field site. Soil moisture content in the surface 20 cm was determined every seven to 21 days throughout the growing seasons gravimetrically from three 20 cm by 4.4 cm i.d. soil cores taken from each plot.

A randomized complete block design with four replications was used in both years. Plots consisted of five rows spaced 0.76 m apart, and were 61 m and 73 m long in 2000 and 2001, respectively. On 21 April 2000 and 24 April 2001, fresh and composted hoop manure were applied to appropriate plots with a John Deere® model-40 manure spreader equipped with a drum-beater modified by adding additional beater tines. Application rates were based on the moisture and total N content of samples taken 10 to 14 days prior to application. Rates were set at 336 kg of total N ha\(^{-1}\) based on the assumption that approximately one third of the total N would be plant-available in the first year after application (Eghball and Power, 1999). The manure spreader was calibrated by adjusting tractor and spreader-gear speeds to apply the desired mass of each amendment to a tarp of known area. The amendments were incorporated into the surface 15 cm of soil within 6 h of application with a disk. In 2000, two passes with a cultipacker were also necessary for adequate seedbed preparation. All of the fresh and composted hoop manure was produced on the Iowa State University Rhodes Research Farm in Marshall County, IA, except for the fresh manure applied in the spring of 2001, which was came from a commercial farm in Story County, IA.

Amendment characteristics were determined on 4 L composite samples collected from twenty 0.18-m\(^2\) plastic trays placed inside the spreader path in each plot at the time of application. All amendment samples were handled, processed, and characterized as described in Chapter 2.
A corn hybrid (Pioneer 35P12, Pioneer Hybrid International Inc., Johnston, IA) was planted at 140 000 seeds ha\(^{-1}\) on 5 May 2000 and 9 May 2001 and then thinned to an evenly-spaced population of 71 000 plants ha\(^{-1}\) at plant growth stage V2 (Hanway, 1963). Weed control was achieved with a preplant incorporated application of metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-(2-methoxy-1-methylethyl) acetamide] at 1.5 kg a.i. ha\(^{-1}\), interrow cultivation at plant growth stage V6, and hand weeding.

**Phytotoxicity Bioassay**

Phytotoxicity bioassays were conducting using a germination method modified from one given by Zucconi et al. (1981). Seventy g dry-weight equivalent of homogenized organic amendment was combined with 700 g of distilled water, shaken for 15 h at 22°C, passed through cheesecloth, and centrifuged at 3000g for 30 minutes. The supernatant was then diluted to a 5% concentration by mass with distilled water and centrifuged at 4900g for 10 minutes at 22°C. This 5% supernatant was used as the test extract. Thirty seeds of cress (*Lepidium sativum* L.) or annual ryegrass (*Lolium multiflorum* L.) were placed on two layers of Fisher Qualitative P5 filter paper (Fisher Scientific, Brightwaters, NY) in sterile petri dishes (100 x 15 mm) and 2.5 ml of 5% extract was filtered through a 0.45 µm Cameo Syringe Filter (Minnetonka, MN) and applied onto the seeds. Five petri dish replicates of each species were incubated in a completely randomized arrangement in alternating conditions of 30°C (16 h of light) and 20°C (8 h of dark). After four days, growth was terminated by applying a 50% ethanol solution, and radicle length was measured. A radicle length of less than 0.5 mm was recorded as zero. Percent radicle length inhibition (RI%) was calculated as:
\[ RI\% = \frac{(RL_{water} - RL_{amendment})}{RL_{water}} \times 100 \]

where \(RL_{water}\) is the mean radicle length from a distilled water control treatment, and \(RL_{amendment}\) is the mean radicle length from the 5% aqueous organic amendment extract. Results are reported such that a positive RI% indicates inhibition and a negative RI% indicates stimulation as compared to seeds treated with the distilled water control. Two sets of bioassays were conducted for each amendment sample.

**Plant Sampling Procedures**

All measurements in the field experiments were taken from the center three rows of each plot. At plant growth stage V2 each plot was divided into subplots for aerial dry matter harvests and grain harvest. Thirty-nine randomly selected well-bordered subplots were established for aerial dry matter harvests (DMH). One three-row-by-9.1 m and two three-row-by-11.0 m well-bordered grain yield harvest subplots were randomly located within each plot in 2000 and 2001, respectively. Repeated harvests of three DMH subplots, each containing four bordered plants, were conducted every 7 to 16 d from growth stages V2 to R6 in each plot. There were 13 harvest dates in 2000 and 11 in 2001. Plants were separated into two components in the field: leaf (blade only) and nonleaf (stalk, leaf sheath, and reproductive parts). Leaf area was determined using a benchtop leaf area meter (LI-3100 Area Meter, LI-COR, Inc., Lincoln, NE) within three hours of harvest. Both leaf and nonleaf components were then dried at 60°C in paper bags for a minimum of four days and weighed. Starting at plant growth stage R1 the wet weight of the complete nonleaf component was determined, but only a representative sample (approximately equal to two plants in mass and
composition) was dried and used in subsequent analyses. Grain yield subplots were harvested with a combine and moisture content was determined with an on-board moisture meter. Grain samples were taken from each plot and dried to a constant weight. Grain yields presented are adjusted to a moisture content of 0 g kg⁻¹ for ease of comparison to other dry matter plant parameters. All dried plant tissues (leaf, nonleaf, and grain) were ground to pass a 0.85-mm screen and sent to a commercial laboratory (Harris Laboratory, Lincoln, NE) for mineral analysis. Total N was determined by Kjeldahl digestion procedures. Fifteen stalk samples (20 cm in length) were collected 15 cm above the soil surface from each plot at grain harvest, dried at 60°C for 4 d, ground to pass a 0.85 mm screen, and analyzed for NO₃⁻-N (Binford et al., 1992).

The functional approach to growth analysis (Hunt, 1982) was used to estimate aerial dry matter per plant (W) and leaf area per plant (A) in a manner similar to methods used by Bullock et al. (1988) and Liebman et al. (1995). Briefly, the approach involves using the relationship between plant growth parameters (W and A) at different points during the growing season (represented by the accumulated growing degree (GDD) days after corn planting) to generate plot-specific curves. The GDD is defined as:

\[ GDD = \left(\frac{T_{\text{max}} + T_{\text{min}}}{2}\right) - T_B \]

where \( T_{\text{max}} \) is the daily maximum air temperature, \( T_{\text{min}} \) is the daily minimum air temperature, and \( T_B \) is equal to 10°C (the physiological minimum base temperature for corn growth). From these curves, predicted values were generated, converted to a land area basis and subjected to analysis of variance (ANOVA). Hunt (1982, p. 52-53) and Vernon and Allison
(1963) have provided justification for these statistical procedures and Russelle et al. (1984) have described the rationale for using GDD rather than calendar date as a predictor variable.

Specific details of the analysis presented here are as follows. After examination of several possible functions (Hunt, 1982) for goodness of fit and systematic biases, the Gompertz (Sit, 1994) function was fitted to \( W \) and a weighted third order polynomial was fitted to \( A \). \( W \) was fitted using PROC NONLIN in SAS (SAS Institute, 1999) with programming code from Sit (1994). \( A \) was fitted with PROC REG in SAS with a weight inversely proportional to the GDD. This weighted least squares procedure was used to offset the observed increase in variation associated with increasing leaf area through time. A third order polynomial was fitted to the leaf N concentrations and was subjected to the same analysis as \( A \) and \( W \) using PROC REG in SAS. Predicted \( W \), \( A \), and leaf N concentration values were calculated for each replicate plot at approximately the same GDD at which they were harvested.

From these predicted plant growth parameters, equations provided by Hunt (1982) were used to examine plant growth rates, efficiencies, and morphological patterns. In this paper we examine the crop growth rate (CGR) (defined as the first derivative of \( W \) with respect to GDD, expressed on an area basis) and the net assimilation rate (NAR), which is a measure of how efficient the crop is at producing new aerial dry matter with its leaf area. We also examine the leaf area ratio (LAR), which is a means of expressing the proportion of the aboveground plant dry matter that is partitioned into leaf area.

**Statistical Analysis**

Analysis of variance (ANOVA) was conducted using the PROC GLM routine of SAS (SAS Institute, 1999) to test for main and interaction effects of blocks, years, and treatments...
on plant growth parameters. If year by treatment interactions were nonsignificant then the sums of squares attributed to this component of the ANOVA was pooled with the experimental error sums of squares to test for significant year and treatment effects (Underwood, 1997, p. 268-273). Phytotoxicity bioassay data were tested for treatment by trial interactions by ANOVA and homogeneity of between-trial error variances was tested using Cochran’s procedure (Underwood, 1997, p. 183-184). Means from the phytotoxicity bioassays were separated by Fischer’s least significant difference (LSD) procedure. Correlations between compost parameters were made on an experimental unit basis using PROC CORR in SAS.

Results and Discussion

Weather Conditions

The cumulative growing degree days (GDD) after corn planting were similar between years until approximately 70 days after planting (DAP), when a 20 d long cool period began in 2000 compared to 2001 (Fig. 1). This period in 2001 (DAP 70 to 90) was marked by two 6 d long periods (DAP 70 to 76 and 84 to 90) of very warm conditions (Fig. 1). Plant flowering occurred during this 20 d period in both years, with 50% silk emergence estimated at 76 and 74 DAP in 2000 and 2001, respectively, as indicated by the arrows on Figures 1 through 5. Soil moisture content of the surface 20 cm indicated dry conditions early in the growing season and after flowering in 2000, and before and during flowering in 2001 (Fig. 2). Moist soil conditions characterized the early part of the 2001 growing season (Fig. 2). Total growing-season cumulative precipitation was greater in 2001 than 2000 (Fig. 2), although both years’ precipitation was lower than the 50-year average (Chapter 2). There
were no significant differences in soil moisture in the surface 20 cm due to amendment treatments at any time in either year (Fig. 2).

**Amendment Characteristics**

Carbon to N ratios of applied amendments ranged from 11.0 to 13.3 with means of 12.8 and 11.8 for fresh and composted manures, respectively (Table 1). Materials with C:N ratios of less than 20 are generally thought not to immobilize soil N following application and soil-incorporation (Mathur et al., 1993). Although short-term immobilization has been observed with partially composted hoop manure with C:N ratios of 12 to 15 (Cambardella et al., in press). The composition of the fresh manure was similar in both 2000 and 2001, with the exception of a more than two-fold higher NH$_4^+$-N concentration in 2000 compared to 2001. The C content of the compost applied in 2001 was much greater than that applied in 2000. This was probably due to colder than normal weather conditions during the composting period of winter 2000-2001, which may have slowed decomposition compared to the warm winter of 1999-2000. The higher NO$_3^-$-N and ash concentrations in the compost applied in 2000 also indicate that the 2000 compost was more decomposed than the 2001 compost.

Each of the amendments stimulated cress radicle growth compared to the distilled water control treatment, with the fresh manure applied in 2001 being the most stimulatory (Table 1). Fresh manure applied in 2000 inhibited ryegrass radicle growth compared to the other organic amendments and the distilled water control. Cress and ryegrass germination and radicle growth have been used as bio-maturity indicators to detect the presence of phytotoxins that may temporarily or permanently inhibit crop growth (Iannotti et al., 1994; Pare et al., 1997). However, these parameters may not provide complete information about
compost phytotoxicity and maturity (Zucconi et al., 1981). Cress and ryegrass radicle length inhibition correlated with electrical conductivity (cress: r=0.76, P=0.0006; ryegrass: r=0.52, P=0.040), indicating that these species are potentially sensitive to the salt contents of the amendments.

**Aerial Dry Matter**

Significant treatment by GDD by year interactions occurred for aerial dry matter responses, so plant growth parameters are presented separately by year. In both years, the compost treatment resulted in more total aerial biomass accumulation than did the fresh manure treatment (Fig. 3). Compost stimulated dry matter production early in 2000 and later in the 2001 growing seasons relative to fresh manure. In 2000, the slower early season CGR of fresh manure treated plots corresponded to the ryegrass phytotoxicity results compared to composted manure (Table 1 and Fig. 3). In contrast, no bioassay phytotoxic effects were detected for the 2001 amendments and no in-field corn plant growth treatment differences were observed in the early portion of the 2001 season (Table 1 and Fig. 3).

In 2000, dry surface soil conditions (Fig. 2) required a deeper (8 to 10 cm) than normal (5 to 6 cm) planting depth for adequate seed-soil contact. Also due to these dry soil conditions from the time of amendment application until after planting in 2000, clods of fresh manure persisted on the soil surface after disking and cultivation. The slower CGR of fresh manure treated plots (Fig. 3) may have been related to the combination of dry soil conditions and the physical/chemical effects of the fresh manure clods on the soil surface inhibiting seedling emergence compared to the composted manure treated plots. In a similar experiment on an adjacent field a 10% reduction in crop density following spring applied fresh hoop manure was observed (Chapter 2) at the same application rates used in this study.
Motavalli et al. (1993) also found poorer plant emergence in dry soils with increasing application rates of fresh dairy manure. In 2001, the moister soil conditions allowed for normal planting depth and the fresh manure clods were broken apart more easily by preplant tillage. In both years, we chose to thin to a consistent plant density, discarding the weakest seedlings to guarantee an even stand for the remainder of the study. As a result, we may have inadvertently reduced the severity of the early season treatment differences.

In 2000, the timing and magnitude of the maximum CGR (Fig. 3) and the leaf N concentrations (Fig. 4) were similar for each treatment indicating that the treatments probably had no effect on the timing of plant transition from vegetative to reproductive stages. The LAI of compost treated plots was greater than that of the fresh manure treated plots throughout 2000 growing season (Fig. 5). As a result of the parallel increase in dry matter production, the treatments were equally efficient at producing biomass from a given LAI as represented by the NAR (Fig.5).

In 2001, composted manure produced a greater and slightly later maximum CGR than did the fresh manure, leading to greater late season biomass production. This late season production was maintained through a longer leaf area duration as indicated by the treatment differences in LAI at the last measurement date (Fig. 5) and the trend for leaf N concentration to be greater in the composted treatment at that point in the season (700 to 950 GDD) (Fig. 4). This period of treatment separation in 2001 coincided with plant flowering and the driest and warmest conditions of the season.

Leaf area ratio (LAR), the plant partitioning ratio of LAI to aerial dry matter, remained consistent across treatments in both years (data not shown), indicating that the treatments did not alter this morphological characteristic.
Grain Yield, Fall Stalk Nitrate, and Dry Matter Harvest Index

Analysis of variance conducted for grain yield, fall stalk nitrate concentration, and dry matter (DM) harvest index indicated no significant treatment by year interaction (Table 2). In this study, composted manure applications resulted in greater corn grain yields than did fresh manure (Table 2), although there was a significant year effect: yields were higher in 2000 than in 2001. These yield results are consistent with those of a concurrent experiment conducted with the same amendments, application rates, corn hybrids, and tillage system on the same farm (Chapter 2).

The equivalent harvest indices and parallel CGR values during and after plant flowering observed in 2000 may indicate that the treatments were equally effective at filling the kernels pollinated. Given the cool weather conditions and adequate soil moisture during the time period bracketing plant flowering (Fig. 1 and 2), moisture or heat related stress would not have been expected to inhibit fruit set. Using N deficiency treatments to temporarily slow CGR in the early stages of maize development (VE to V7) Girardin et al., (1987) reported decreased final kernel number and attributed this decline to one of two possible factors: the potential number of ovules or the CGR at flowering. In our study, the CGR (Fig. 3) was similar for each treatment at flowering and beyond in 2000, but lower in the fresh manure treated plots than in composted treated plots early in the growing season (200 to 400 GDD) (Fig. 3). It is possible that the grain yield treatment differences in 2000 may have been due to a difference in the number of ovules available to be pollinated and not the crop’s ability to pollinate the available ovules and carry those kernels through maturity. If grain yield components (kernel weight and number) had been measured this hypothesis could have been tested. Regardless of the precise yield determination mechanism, the larger
plants and greater LAI in the compost treated plots should have had a greater assimilate capacity than the smaller plants in the fresh manure treated plots.

In 2001, the increased leaf area duration (discussed above) allowed compost treated plants to maintain photosynthesis later into the season than fresh manure treated plants as indicated by the greater late season CGR (Fig. 3). This increase in photosynthesis duration probably allowed compost treated plants to pollinate more ovules and carry more of those kernels to maturity than did fresh manure treated plants. The time period bracketing maize flowering is the most sensitive period in maize grain yield development to stress events such as drought or N deficiency. Both water deficits (Westgate and Thomson Grant, 1989) and N deficiencies (Uhart and Andrade, 1995) during this time can result in plants with reduced leaf area duration and CGR. We observed leaf area duration and CGR treatment differences in 2001 that resemble those commonly described as either water or N stress, although no treatment differences were detected in the plant-available soil N (Fig. 2A) or the soil moisture contents (Fig. 2) in the surface 20 cm at any sampling date during 2001. However, this period bracketing plant flowering in 2001 was marked by the warmest (Fig. 1) and the driest (Fig. 2) conditions of the season. If plant water or N status contributed to the treatment separation in growth then the compost treated plants were either more efficient at water and/or N uptake and use from the surface 20 cm of soil or the zone of active water and/or N uptake differed between treatments.

Chen and Aviad (1990) have suggested that humic acids derived from composts promote root growth more than shoot growth. Increased root growth may explain the apparent increased drought tolerance or drought avoidance of composted manure treated plants compared to fresh manure treated plants. In addition, more humified organic
amendments (such as composted manure) have been shown to provide greater plant protection from pathogens (Hoitink and Kuter, 1986) and to contain microbially-derived plant growth promoting substances (Hoitink and Kuter, 1986; Valdrighi et al., 1996), both of which may have influenced plant root system exploration depth and health. If compost treated plant roots were under less pathogen pressure than fresh manure treated plants then less root turnover would have been expected, thus possibly improving root water uptake and N use efficiencies.

Corn stalk samples (20 cm segment, 15 cm off of the soil surface) taken at physiological maturity (growth stage R6) have been used to indicate late season soil nitrogen availability or plant stress (Binford et al., 1992). In Iowa, Binford et al. (1992) set a stalk nitrate NO$_3^-$-N concentration of $>2000$ µg g$^{-1}$ to indicate excessive soil nitrate and/or stress, and $<200$ µg g$^{-1}$ as an indicator of insufficient inorganic soil N for maximum grain yield. We found no stalk nitrate concentration differences between treatments, but a trend for higher stalk nitrate concentrations in 2000 than in 2001 (Table 2). Two-year average stalk nitrate concentration treatment means are in the marginal category of 200 to 700 µg g$^{-1}$ (Table 2), implying that additional plant available soil N would have increased grain yields (Binford et al., 1992).

No treatment differences were detected in the aerial dry matter harvest indexes in either year (Table 2). These data imply that the form of manure did not affect grain production efficiencies relative to the quantity of aerial biomass (Table 2) at the plot-scale, although at the individual plant-scale treatment effects may have been inconsistent. We visually observed smaller and more evenly distributed composted manure particles relative to the clods of applied fresh manure. An alternative hypothesis to explain the treatment
responses presented here is that the spatial uniformity of the application of the amendments (not measured in this study) may have influenced crop stand evenness. In this study, we measured the height, stem diameter, and apparent chlorophyll content of each plant harvested. Analyzing the variances in these three parameters within treatments, we conclude that plants in each treatment were equally uniform in their height, stem diameter, and apparent chlorophyll contents (data and analysis not shown). This may indicate that the plants did not perceive any differences in the spatial distribution of the amendments on the individual plant-scale.

**Conclusions**

In both years composted manure amended soils produced larger plants and greater grain yields than did fresh manure amended soils. These results run contrary to several studies showing similar yields with fresh and composted manure (Brinton, 1985; Ma et al., 1999; Eghball and Power, 1999), but may be related to the timing of amendment application. In a concurrent experiment with the study presented here, it was found that fall applied fresh and composted hoop manures resulted in similar yields, but that with spring-applied amendments (i.e., the same as in this study), composted manure treated plots resulted in greater yields than did spring-applied fresh manure treated plots (Chapter 2).

The functional approach to growth analysis indicated that the form of swine hoop manure (composted or fresh) did not affect plant growth efficiencies (NAR) or plant morphological patterns (HI and LAR), but it did suggest that the treatments affected the plants' ability to tolerate dry soil conditions. In both years, the time of the driest soil conditions in the surface 20 cm of soil coincided with the period in which compost treated plants gained their aerial dry matter advantage over fresh manure treated plants. Increased
root growth, stimulated by the humic acids contained within the compost (Chen and Aviad, 1990), may explain the apparent increase in drought tolerance or avoidance exhibited by composted manure treated plants compared to fresh manure treated plants. Phytotoxic effects exhibited by the fresh manure applied in 2000 may have inhibited early season growth relative to composted manure treated plants. It is likely that a combination of these two factors, phytotoxic substances (Zucconi et al., 1981) and growth promoting substances (Chen and Aviad, 1990) contributed to the resulting treatment difference. Plant available soil N (Table A1) and plant stand evenness did not seem to have contributed to these treatment differences.

A series of experiments is needed to determine if soils amended with composted solid livestock manure consistently provide greater drought-stress tolerance than fresh manure amended soils. The implications of increased drought tolerance are temporally and spatially variable, but are major production concerns worldwide.

References


Table 1. Selected chemical, physical, and biological parameters of organic amendments applied in 2000 and 2001, near Boone, IA.

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<th>Amendment parameters</th>
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<td>fresh</td>
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<tr>
<td>Water, g kg⁻¹</td>
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<td>485</td>
<td>547</td>
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<tr>
<td>Ash, g kg⁻¹</td>
<td>714</td>
<td>439</td>
<td>594</td>
<td>434</td>
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<tr>
<td>C, g kg⁻¹</td>
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<td>254</td>
<td>201</td>
<td>243</td>
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<tr>
<td>N, g kg⁻¹</td>
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<td>21.0</td>
<td>16.4</td>
<td>18.3</td>
</tr>
<tr>
<td>P, g kg⁻¹</td>
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<td>9.7</td>
<td>6.3</td>
<td>9.2</td>
</tr>
<tr>
<td>K, g kg⁻¹</td>
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<td>21.5</td>
<td>15.5</td>
<td>16.7</td>
</tr>
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<td>NH₄⁺-N, µg g⁻¹</td>
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<td>4980</td>
<td>596</td>
<td>2003</td>
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<tr>
<td>NO₃⁻-N, µg g⁻¹</td>
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<td>59</td>
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Phytotoxicity‡

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<td>fresh</td>
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<tr>
<td>Cress, %</td>
<td>-17.7a</td>
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<td>-46.8a</td>
<td>-102.6b</td>
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<td>Rye, %</td>
<td>-9.4b</td>
<td>13.7a</td>
<td>-8.6b</td>
<td>-20.1b</td>
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</table>

† Water content is expressed on a wet weight basis, all other concentration parameters are expressed on a dry weight basis.

‡ Phytotoxicity data presented as a percentages of inhibition as compared to distilled water control such that a negative results equals stimulation compared to the control and a positive result is an inhibition. Within rows, means followed by the same letter are not significantly different according to LSD (α=0.05).
Table 2. Analysis of variance and means of corn grain yields, fall stalk nitrate concentrations, and harvest indexes in response to fresh and composted swine manure applied during 2000 and 2001, Boone, IA.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Grain Yield†</th>
<th>Fall Stalk Nitrate</th>
<th>Harvest Index‡</th>
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<tr>
<td></td>
<td>kg ha⁻¹</td>
<td>NO₃⁻N (µg g⁻¹)</td>
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</tr>
<tr>
<td>2000</td>
<td></td>
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<tr>
<td>Composted manure</td>
<td>9288</td>
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<tr>
<td>Fresh manure</td>
<td>8604</td>
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</tr>
<tr>
<td>2001</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composted manure</td>
<td>8169</td>
<td>92</td>
<td>0.46</td>
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<tr>
<td>Fresh manure</td>
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<td>66</td>
<td>0.47</td>
</tr>
<tr>
<td>2-yr average</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Composted manure</td>
<td>8728</td>
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<td>0.46</td>
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<td>Fresh manure</td>
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<td>df</td>
<td></td>
<td>P&gt;F</td>
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<tr>
<td>Treatment (T)§</td>
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<td>0.495</td>
</tr>
<tr>
<td>Y X T</td>
<td>1</td>
<td>0.615</td>
<td>0.562</td>
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</table>

† Grain yield data are adjusted to a moisture content of 0 g kg⁻¹.

‡ Harvest index is the ratio between grain dry matter and total plant dry matter.

§ Treatment F test was conducted using the pooled error (T*B + T*Y*B).
Figure 1. Cumulative growing degree days (GDD) after corn planting as a function of days after corn planting and mean daily air temperature in 2000 and 2001, near Boone, IA. GDD are calculated as the cumulated average mean daily temperature minus a physiological base temperature (10°C for corn). The black arrow in each figure represents the time of 50% silk emergence, plant growth stage R1. Note the intense warm period at plant growth stage R1 in 2001 relative to 2000.
Days after planting (DAP)
Figure 2. Cumulative growing season precipitation (from 1 April to grain harvest) and moisture content of the surface 20 cm of soil during the 2000 and 2001 growing seasons, near Boone, IA. The black arrow in each figure represents the time of 50% silk emergence, plant growth stage R1.
Figure 3. Predicted corn aerial dry matter (DM) and crop growth rate (CGR) as functions of the cumulative growing degree days (GDD) after corn planting in 2000 and 2001, near Boone, IA. The P(DM) and P(CGR) symbols represent the probabilities of significant differences between corn response to composted swine hoop manure and fresh swine hoop manure. †, *, ** represent significance at the 0.1, 0.05, and 0.01 probability levels. The black arrow in each figure represents the time of 50% silk emergence, plant growth stage R1.
Figure 4. Predicted corn leaf N concentrations as functions of cumulative growing degree days (GDD) after corn planting in 2000 and 2001, near Boone, IA. The P(N) symbols represent the probabilities of significance differences between corn response to composted swine hoop manure and fresh swine hoop manure from similar origins. †, *, ** represent significance at the 0.1, 0.05, and 0.01 probability levels. The black arrow in each figure represents the time of 50% silk emergence, plant growth stage R1.
GDD after planting

Leaf N (mg g⁻¹)

2000
- Compost
- Fresh

2001
Figure 5. Predicted corn leaf area index (LAI) and net assimilation rate (NAR) as functions of the cumulative growing degree days (GDD) after corn planting in 2000 and 2001, near Boone, IA. The P(LAI) and P(NAR) symbols represent the probabilities of significant differences in corn responses to composted swine hoop manure and fresh swine hoop manure. †, *, ** represent significance at the 0.1, 0.05, and 0.01 probability levels. The black arrow in each figure represents the time of 50% silk emergence, plant growth stage R1.
Leaf Area Index (m² m⁻²)

GDD after planting

Composted
Fresh

LAI
NAR

Net Assimilation Rate (g m⁻² GDD⁻¹)

2000

2001
CHAPTER 4. GENERAL CONCLUSIONS

Executive Summary

Swine production in hoop structures is a relatively new deep-bedded husbandry system in which a solid manure/bedding pack accumulates. At the end of each swine production cycle, when the pigs are sold, the farmer faces a decision to haul the manure directly to the crop field or pile it for composting. Pigs and crops have different production cycles, so the season of application also warrants consideration. Currently, no guidelines are available to producers as to the optimal time (fall or spring) and form (composted or fresh) for applying hoop manure for the greatest crop performance and environmental protection.

The main objective of this research was to test the effects of composting and time of application on corn (Zea mays L.) dry matter production and grain yield. Two fieldplot experiments were conducted near Boone, Iowa, each during two growing seasons. Results indicated no difference in grain yields among the fall applied hoop amendments, but inconsistent yield results from the spring applied fresh manure. Parameters used to indirectly monitor plant and soil N status suggested that spring-applied fresh manure did not supply plants with N as effectively as the other hoop amendment treatments. However, an experiment designed to closely examine the temporal relationship between soil N derived from spring applied fresh and composted manure and plant N uptake indicated no treatment differences. Analyses of corn growth responses to the spring applied hoop amendments suggested that fresh hoop manure may sometimes exhibit phytotoxic effects on corn seedlings and that composted manure may aid in drought tolerance relative to the effects of spring-applied fresh hoop manure. Mean N supply efficiency, defined as N fertilizer
equivocality as a percentage of the total N applied, was greatest for fall-applied composted manure (34.7%), intermediate for fall-applied fresh manure (24.3%) and spring-applied composted manure (25.0%), and least for spring-applied fresh manure (10.9%). Based on these results, the optimum management strategies would be to apply fresh manure in the fall rather than composting it for spring application, and to compost fresh manure removed from hoops in the spring for fall application. These results are based on agronomic production only; economic and environmental implications of N losses associated with the time and form of application could affect these recommendations.

**Recommendations for Future Research**

One of the general themes of sustainable agriculture is the emphasis on diverse cropping rotations. The research presented in Chapters 2 and 3 was a first and simplified direct step to understanding crop responses to soil amendments produced in hoop structures used for swine husbandry. Research is now needed regarding amendment use in diverse cropping systems. Such research should incorporate strategies designed to conserve nutrients, increase crop productivity, and spread labor requirements throughout the year. The research recommendations outlined below are designed to investigate the use of hoop manure as a supplemental nutrient source, and to elucidate its role in stimulating or inhibiting plant growth within more diverse crop rotations.

1. As a source of plant nutrients within more diverse crop rotations, hoop amendments should be used to supply N to the crop with the greatest N requirement. For example, in a soybean-cereal/clover-clover-corn rotation the hoop amendment (either composted or fresh manure) could be applied to a field in clover to meet the N requirements for the following corn crop. Typically, clover residue decomposes quickly in the spring
resulting in larger spring soil nitrate concentrations than for soils following nonleguminous crops. Application of a more stabilized organic N source, like composted hoop manure, would ideally supply plant available N slightly later than would the legume residue, thus adding to plant available N during plant developmental stages most sensitive to N stress, i.e., flowering and grain filling. We have demonstrated that the timing and form of hoop amendment applications can influence crop response when applied as the sole applied N source. Hoop amendment application rates, form (composted or fresh manure), time of application, timing of tillage and/or clover kill, and clover crop biomass and quality should all interact with climatic conditions to produce the intended corn crop. Each of these factors should have an influence on both corn development and plant available N. Factorial experiments should be conducted with combinations of the aforementioned factors to develop management guidelines for the integrated use of hoop amendments and N-fixing leguminous in diverse crop rotations that include corn.

2. A major issue concerning the use of livestock manures as soil amendments is the rate of nitrate leaching from fields receiving these amendments. To better understand water quality and agronomic impacts of alternative management systems, the effects of time and rate of application and composting of hoop manure need to be compared with effects of liquid manure handling systems used in conventional swine confinement operations. Determining a basis for comparison is always an issue in designing this type of experiment. My recommendation would be to base the application rates on P content of each of the amendments (including the liquid manure sediment), regardless of the soil P tests.
3. We observed phytotoxic effects from the spring application of fresh hoop manure. This effect may be associated with the time and weather conditions after amendment application and before corn planting, which affect the dispersal and/or degradation of any phytotoxic substances contained in the fresh manure. Richard Thompson of Boone, Iowa (personal communication, 2000) shares this rule-of-thumb: Always apply fresh livestock manure at least 30 days in advance of planting to avoid plant emergence problems. I have observed several farmers applying relative fresh swine manure to plots immediately prior to planting with no adverse effects, which suggests that the phytotoxic effects of fresh hoop are inconsistent, perhaps related to a threshold concentration level, the application rate, and/or unpredictable soil conditions following application. To address these concerns a factorial experiment of time of application by manure/compost application rate is necessary over a wide range of environmental conditions. More mechanistic studies of phytotoxic compounds and relevant processes would greatly extend previous empirical research. For example, if a certain compound was isolated from fresh hoop manure that caused a majority of the phytotoxic effects, than manure handling processes may be altered to avoid its production or promote its degradation.

4. Reducing application rates of synthetic N fertilizer on soils amended with hoop manure is necessary for improving N use efficiencies and minimizing environmental contamination regardless of the crop rotation. An experiment is needed to find the optimal rates for hoop manure/compost and synthetic N fertilizer used in combination. One option would be to base the manure/compost application rate on the expected grain P removal rate of the rotation used and then find the appropriate synthetic N rate from that starting point. Recent concerns regarding soil P and K accumulation are only problematic if more P and
K are being imported onto the farm than are being exported. This nutrient imbalance at
the farm scale is typically only associated with intensive livestock production where the
feed for the animals fed on a farm is coming from a larger land area than the manure is
being spread on.

5. Possible drought tolerance benefits due to increased humification of manure amendments
should be explored. Greenhouse experiments where drought conditions can be imposed
on corn plants at various stages of development grown in soils amended with composts of
varying degrees of humification would be a first step in such research.

6. Methods to study in-situ N mineralization are necessary to examine the complex and
dynamic interactions that occur in soils amended with organic materials. An improved
understanding of the effects of varying soil conditions on the various in-situ methods is
necessary. Small in-lab $^{15}$N labeled experiments measuring CO$_2$ evolution, NO$_x$
emissions, NH$_3$ volatilization, and changes in NO$_3^-$ and NH$_4^+$ concentrations in the in-situ
vessels (polyethylene bags, PVC tubes with anion/cation exchange resin, etc.) compared
to standard soil incubation conditions would assist in the interpretation of results from in-
situ mineralization experiments.

Thesis Conclusions

This thesis addressed hoop structure manure management alternatives of when (fall or
spring) and in what form (fresh or composted manure) to apply hoop manure for the greatest
agronomic benefits. Based on the results presented within, the optimum management
strategies would be to apply fresh manure in the fall rather than composting it for spring
application, and to compost fresh manure removed from hoops in the spring for fall
application. These results and those of future research as outlined above should help
managers of integrated crop-livestock production systems to evaluate and improve the sustainability of their crop and livestock production systems.
Table 1A. Means and analysis of variance for end-of-the-season biomass and corn grain contents of N, P, and K in response to spring-applied composted and fresh hoop manure in 2000 and 2001, near Boone, IA.

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<th>Treatment</th>
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<td></td>
<td>Biomass</td>
<td>Grain</td>
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</tr>
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<tr>
<td>Compost</td>
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Figure 1A. Cumulative in-situ mineralized N as a function of days of the year (DOY) in response to spring-applied composted and fresh hoop manure in 2000 and 2001, near Boone, IA. In-situ mineralization was measured using a polyethylene bag method.
Figure 2A. Soil inorganic N (NO$_3^-$-N + NH$_4^+$-N) concentrations of the surface 30 cm of soil in response to spring-applied composted and fresh hoop manure in 2000 and 2001, near Boone, IA.
Figure 3A. Cumulative aerial plant N uptake in response to spring-applied composted and fresh hoop manure in 2000 and 2001, near Boone, IA.
2000

- Composted manure
- Fresh manure

N Uptake (kg N ha⁻¹)

apply planting silking harvest

DOY

2001

apply planting silking harvest

DOY
ACKNOWLEDGEMENTS

I would like to thank my major professor, Dr. Matt Liebman, for giving me the opportunity to pursue my Masters of Science degree. I am appreciative for his guidance, accessibility, high standards, professionalism, and commitment to sustainable agriculture. I would like to thank my graduate committee, Drs. Cynthia Cambardella, Tom Richard, Deborah Muenchrath, and Matt Liebman for their time, scientific insight, patience, and especially for keeping an open door. Research Associates, Dave Sundberg, for his long hours in the sun and patience, and Jody Ohmacht for her extreme patience with my messy and smelly lab experiments. I also want to thank my officemates, Adam Davis and Carlos Khatounian, Adam for his willingness and enthusiasm to share his diverse ideas and scientific knowledge, Carlos for his guiding insight into nature phenomena and both for their friendship. To Fabian Menalled, thanks for the ridiculous stories, they made the long runs not so long. For the farm crews at the Rhodes, Armstrong, and Ag Engineering Research Farms who are always there for consult and ready to lend a hand. For the PFI cooperators, who forced me to understand why this research was necessary. I can’t forget the toils of numerous undergraduate workers for whom without this research would not have been possible. And for many other graduate students who have challenged and supported me through their scholarship and friendship.

I want to thank my brothers, sisters-in-law, and parents for their unconditional support.