ECONOMIC ANALYSIS ON ANIMAL MANURE; STATIC AND DYNAMIC APPROACHES, COX NON-NESTED TEST, AND OPTIMAL NITROGEN RATES FOR GRASSES

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ECONOMIC ANALYSIS ON ANIMAL MANURE; STATIC AND DYNAMIC APPROACHES, COX NON-NESTED TEST, AND OPTIMAL NITROGEN RATES FOR GRASSES

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Introduction

Animal population in Oklahoma has increased greatly during the past two decades. This increase is explained by a dramatic expansion of large confined animal feeding operations(CAFOs) in the Oklahoma Panhandle and other locations. The Oklahoma Panhandle is one of the leading swine producing regions in the U.S (Lowitt, 2006). Since easing restrictions on corporate farming in 1991 [Oklahoma Senate Bill 518], swine production increased dramatically in the Oklahoma Panhandle. Over the past seventeen years, swine production has grown exponentially from 10,000 units in 1991 to 1,640,000 units in 2007 (NASS, 2007). Along with beef cattle, swine production has an economic importance in the Oklahoma Panhandle. In 2008, the swine industry generated $636.7 million in revenue and was the major source of employment, providing nearly 16,000 jobs within this area (Oklahoma Pork Council, 2009, unpublished data).

This rapid growth in animal population and density has heightened concerns over animal waste management (Williams, 2006). Swine waste, for instance, has increased from 2,834 MT in 1992 to over 178,313 MT in 2007 (Turner, 2005; NASS, 2007). In the

Oklahoma Panhandle, nearly all of the swine waste is stored in open air lagoon systems (Carreira et al., 2006). When properly applied and remunerative, swine lagoon effluent (SE) can be used as manure with minimal environmental and nuisance concerns such as odor (Al-Kaisi and Waskom, 2002). Swine manure benefits producers by reducing waste management costs and the need for chemical fertilizers, as SE contains multiple essential crop nutrients (McAndrews et al., 2006). By recycling nutrients, animal manure enhances sustainable agriculture and improves overall animal production efficiency (Adeli et al., 2005).

Land application of animal waste has been widely adopted by livestock operators to utilize nutrients in manure in this region because it is cost effective relative to manure treatment and produces feedstuffs for the animals. Thus, available land for manure application is an important limited factor for livestock operations. The applied manure nitrogen content is largely affected in two primary ways: method of storage and handling; additionally the timing of soil application greatly influences the amount of nitrogen that can become plant available. Regionally, most swine manure is collected, stored, and applied as a liquid where most of the nitrogen is ammoniacal; ammonia (NH_3) is a volatile nitrogen compound that has the potential to be volatilized and lost to the atmosphere during handling and storage resulting in nuisance problems (i.e. odor) in addition to unrealized profit losses (Zhang 2003).

Significant positive benefits can be realized when the application of animal manures is adopted where soil fertility, tilth, soil aeration, and beneficial microorganisms can be maintained or enhanced. Additionally, soil and wind erosion can be reduced or prevented when soil properties are favorable and constructive. Manure can substitute for commercial fertilizers by supplying the multiple essential crop nutrients (such as N, P, K, S, Ca, Mg, and micronutrients) contained in animal wastes. The recent rapid increase in commercial fertilizer prices has made crop farmers take notice and renewed attention has been given to animal manures as an alternative to chemical fertilizers (Zhang 2003).

Despite the large potential economic benefit of manure as a substitute for commercial fertilizer, manure can not only degrade the quality of our water, soil, and air resource but also can impose additional handling costs on farmers, resulting in the possibility that costs could exceed benefits. Carreira (2004) mentioned five main environmental problems associated with animal waste management: 1) potential phosphorous accumulation in the soil receiving animal manure might create eutrophication problem in water sources, 2) groundwater in aquifer may be contaminated by nitrogen leaching from the soil, 3) a significant amount of nitrogen in animal manure can be lost to atmosphere through ammonia volatilization which may create offending odor issues among the population, 4) animal manure tends to increase soil salinity which can degrade the soil quality for crop production uses, and 5) potential risk of overflow of treatment lagoon and storage ponds exist under high rainfall events.

Moreover, all nutrients in animal manure are not available for plant uptake due to insolubility of nutrients and the nitrogen content in the manure applied to the land is largely affected by not only the method of storage and application but also the timing of land disposal (Zhang, 2003). Furthermore, the ratios of nitrogen, phosphorous, and potassium in manure do not match the relative quantities required by plants, so there is a tendency for nutrients like phosphorous to build up in the soil.

The Oklahoma Panhandle is a semi-arid region with varied and irregular rainfall, typically insufficient to support current crop production. Irrigation has been widely adopted to increase and stabilize agricultural production. Major crops such as maize and wheat are irrigated with mainly groundwater coming from the Ogallala Aquifer (Jensen, 2004; Stewart, 2003). Nearly all corn (98%) and some winter wheat (30%) in the region are under irrigation (NASS, 2007). About 40 % of the total cropland in this region is under irrigation (Almas et al., 2004). However, since the current extraction rate of the aquifer in this region is far beyond the recharge from precipitation, the fresh water in the aquifer as a depleting resource is becoming too expensive to be used profitability (Carreira, 2004). Therefore, it is important to recycle water and nutrients in the animal waste and to develop animal waste management practices to assist farmers to make decision in both water and manure management for the region.

Because of the regional importance of the swine industry, a study was conducted to assess the productivity of SE relative to the synthetic fertilizer, anhydrous ammonia (AA) and was compared to beef manure (BM) another readily available animal waste in the region. However, major differences between the two organic fertilizers are observed, mainly in the form handled and nutrient concentrations of the manures on an ‘as is’ basis. Swine effluent exists in a mixed solution of animal excrements and other components that have been flushed out of confined feeding and housing areas and stored in an outdoor retention structure, usually a facultative anaerobic lagoon. Most BM in this region is stock-piled in the feedlot prior to land application with approximately a 62 % dry matter content. Moreover, the ratio of the major nutrients N and P(e.g. $\frac{\mathrm{N}}{\mathrm{P}}$) are 3.8 and 1.2 for SE and BM, respectfully (Zhang and Hamilton, 2007).

Most previous studies (Castilho et al., 1993; Charistie and Beattie, 1989; Gao and Chang, 1996; Sharpley et al., 1993; Sommerfeldt and Chang, 1987; Stadelmann and Furrer, 1985) on the long-term application of animal manure were conducted in higher effective precipitation regions. There is limited research in semiarid agroecosystems on long-term, repeated applications of animal manures in irrigated maize production systems. Therefore, finding effective fertilizer management strategies that bring the largest farm income over the planning horizon is of high interest to livestock operators. The tipping point at which animal waste transitions from a cost (disposal) to a benefit (manure) is determined by both agronomic and economic factors. The recent increase in chemical fertilizer prices has placed renewed emphasis on using animal manure as a viable alternative to chemical fertilizers (Figure I-1). Research on competing types of nutrient recycling systems used in the Oklahoma Panhandle, i.e. SE and BM applied on irrigated corn, was conducted to assess their agronomic and economic benefits in relation to each other and to chemical fertilizers at equivalent NR.

Issues of Soil Nutrients

Nitrogen loss through volatilization and leaching

Historically, animal manure has played an invaluable role to maintain soil fertility because of its several effects on soil system such as a source of nutrients and improvement of soil structure. Nutrients in manure exist in two forms; inorganic and organic (carbon) compounds. Most inorganic forms of nutrients such as nitrogen, phosphorous, and potassium are consumed directly by plants while organic nutrients can be available for plant uptake through biological activity in soil.

Specifically, two kinds of nitrogen in manure are found; ammonium form of nitrogen (NO3 and NH4) and organic nitrogen (ON). Ammonium is also generated by mineralization of organic matter by microbes. According to nitrogen cycle, ammonium in soil may 1) be directly consumed by plant, 2) be transformed to ammonia (NH3), 3) become nitrate which is available for plant uptake through nitrification, and 4) be consumed by microbes to create organic compounds (immobilization).

Nitrogen losses take place via ammonia volatilization, leaching, denitrification, and plant uptake and removal in the harvested portion of the crop. Ammonia volatilization commonly happens in all ammonium type fertilizers like anhydrous ammonia, urea and swine effluent and is affected by various soil characteristics and weather conditions following application. Generally, potential for ammonia volatilization increases in high soil pH, temperature, crop residue, and soil moisture content and decreases when nitrogen fertilizers move below the soil surface through tillage incorporation and movement by irrigation and rain (Jones et al, 2007). Al-Kaiser et al.(2002) found that the percent of N lost through volatilization is not greatly affected by N concentration in effluent but that air temperature and wind speed are important factors for N loss.

Nitrogen also becomes unavailable for plant consumption via microbial processes in soil. Nitrate, an inorganic form converted from ammonium fertilizer, can be susceptible to leaching and denitrification. Potential nitrogen loss is greatly affected by N fertilizer form, soil temperature and soil moisture. Greater N loss takes place if soil temperature is warm and a more applied N is in a nitrate form. Thus, farmers should consider the following factors before providing supplemental nitrogen to the soil to meet the plant requirement; 1) amount of available nitrate in the soil, 2) the time of year length and time soils are saturated, 3) water movement through the soil, and 4) potential loss of crop yield from water damage (Sawyer 2007).

Phosphorous build up and loss

Manure is an unbalanced fertilizer unless farmers add nutrients like nitrogen to better match crop requirements. Manure has a fixed combination of nutrients so if manure application is on the basis of one nutrient, application of the other nutrients will be in excess or below plant needs. Historically, manure has been applied to land based on strategies to protect water resources from over-application of nitrogen. However, the N-P ratio in manure is less than the crop requirements so that the amount of phosphorous applied with manure is typically higher than the annual removal by plants. Phosphorous accumulation in soil over time is commonly found when the difference in N-P ratio between crop and manure is great. One typical instance is pasture systems applied with poultry litter. The maintenance ratio of nitrogen to phosphate for pasture is 20 to 1 while litter nitrogen to phosphate ratio is one according to University of Missouri, (Lory 1999).

Phosphorus in animal manure occurs in both inorganic and organic forms. Forty five to seventy percent of total phosphorous in manure is inorganic P which can be available for plant uptake. The remaining P is organic which is decomposed into inorganic P form through mineralization. This mineralization rate is greatly affected by temperature, soil pH, and soil moisture. The effectiveness of manure phosphorus is 80 to 100 percent of that of commercial P fertilizer. Thus, farmers can simply apply manure phosphorus to meet the crop P requirement as long as crop responds to additional P application. (Zhang et al, 2003).

Despite high water solubility and availability for plant uptake, inorganic P in animal manure becomes less available for plant consumption when manure is applied to land because of two main reactions; adsorption of phosphate by soil particles and chemical combination of phosphate with other minerals already present in soil like calcium (Ca), aluminum (Al), and iron (Fe). Soil texture greatly affects the ability of soil to capture phosphate. Fine clay soil has a higher capacity to adsorb phosphate than do medium to coarse soils. The creation of phosphorus compounds through chemical reactions with other minerals is affected by soil pH level. Calcium phosphates are formed in neutral and alkaline soils while aluminum and iron phosphates form in acid soils (Zhang et al, 2003).

Currently, most phosphorus loss from agricultural fields happens through surface runoff. Soil solution P increases and approaches to saturation as adsorbed and applied P increases. The P in soil solution is vulnerable to surface runoff during heavy rainfall. When the rainfall happens right after the manure application, the concentration of soluble phosphorous in the flash runoff is much higher than that in the normal runoff. Soil test phosphorous also is highly correlated with soluble phosphorus in the runoff (Zhang 2003). Two important factors affecting phosphorous loss from land receiving manure are soil test phosphorus (STP) and phosphorus transport to surface water (Lory 1999).

Objectives

The overall objective of this research is to provide an economic analysis of long-term data from an Oklahoma Panhandle research project involving applications of anhydrous ammonia, beef manure, and swine effluent to irrigated corn using two methods; ANOVA and deterministic dynamic optimization.

Specific objectives include:

ANOVA Analysis

1. Measure the effects of nitrogen source (NS) and nitrogen rate (NR) on irrigated corn yields and economic profitability.
2. Determine the sensitivity of large fluctuations in corn and fertilizer prices that occurred during the thirteen-year study period.
3. Determine the break-even prices of corn and AA prices.

Deterministic Dynamic Optimization

1. Estimate corn response functions, nutrient carryover (nitrogen and phosphorus), and soil pH relationship from long-term fertilizer experiments in the Oklahoma Panhandle.
2. Develop a deterministic dynamic optimization model that maximizes a net present value (NPV) of a stream of income in the future.
3. Determine optimal steady state levels of crop yield, amount of nitrogen applied, and residual soil nutrients such phosphorus and nitrogen, and soil pH over planning horizon for each source of N fertilizers.

4. Determine the sensitivity of optimal steady state levels due to a change in relative prices between corn and AA.

Hypotheses for a Dynamic Optimization.

This study is based on following hypotheses;

1. A representative farmer will maximize the net present value (NPV) of returns from irrigated continuous corn over some future period by applying nitrogen from either anhydrous ammonia (AA), beef manure (BM), or swine effluent (SE).
2. Total available nutrients (TAN-total available nitrogen, and TAP-total available phosphorus) to corn at a time is the sum of applied nutrients (NA-Nitrogen applied, and PA-Phosphorus applied) and soil nutrients (SN-soil nitrate-nitrogen and SP-soil phosphate) in the top 6 inches of the soil profile at the beginning of the crop year.
3. The prices of corn and other inputs are known over the planning horizon
4. No transportation cost was considered for the application of animal manure since manure assumed to be generated on farm.

Method and material

A long-term field experiment was conducted between 1995 and 2007 at the Oklahoma Panhandle Research and Extension Center (OPREC) near Goodwell, Oklahoma (36°35 N, 101°37 W) at elevation 992 m. Mean annual precipitation and temperature at the station are 435 mm and 13.2 °C. The experiment was established on a Gruver soil series (fine, mixed, superactive, mesic Aridic Paleustoll) with a 0-2% slope. Gruver soils are classified as very deep, well-drained, moderately slowly permeable calcareous soils. The calcareous nature of this soil increases risks associated with N losses due to ammonia volatilization that occurs under increased pH levels found in Gruver soils (Wu et al., 2003a, 2003b).

The experimental design was a randomized complete block with three replications of each of the main treatment effects, nitrogen source (NS) and NR. Each of three N sources, anhydrous ammonia (NH3) (AA), BM, and SE, were applied at equivalent NR of 0, 56, 168, and 504 kg N $ha^{-1}yr^{-1}$. The main treatment effects were arranged in a split-plot design, with NS on each of the main plots, and the equivalent NR on the corresponding subplots. Prior to the experiment, continuous wheat had been grown on the test plots for several years. Nutrient levels for macronutrients (P and K) and micronutrients (Mg, Ca, S, Fe, and Mn) were found to either meet or exceed plant requirements so additions of these nutrients were not made. Levels of major soil nutrients, N and P, along with soil pH are presented in Table I-1. Prior to the start of the experiment in 1995, soil phosphorus was found to be sufficient, with an initial value of 73 kg ha^{-1}, which exceeded the recommended P level of 60 kg ha^{-1} (Zhang and Raun, 2006). Soil N levels were 141 kg ha^{-1} prior to the start of the experiment, which were about 50 kg ha^{-1} below the recommended soil N level of 190 kg ha^{-1} (Zhang and Raun, 2006). Soil pH levels were not adjusted since they would interfere with one of the long-term objectives of the experiment, which was to evaluate the cumulative effects of repeated nutrient applications on both crop yields and soil properties across different NS.

Corn planting data, cultivar selection, seeding rate, and other management information are presented in Table I-2 for each year of the experiment. Annual corn planting dates varied from 13 April to 6 May, corresponding to when soil temperatures had reached 10°C at the 5cm depth (Table I-2). Field preparation consisted of a disk harrow with a double offset gang of notched disks that was later followed by a disk ripper in tandem with a chisel plow. Corn plant populations were between 76,570 and 81,510 plants ha^{-1} (Table I-2). Pioneer 3162 was used from 1995 through 2000 and Pioneer 33B51 was used for the last six years of the experiment (2001 through 2007). Study plots were irrigated under a center pivot system using the low energy precision application (LEPA) system. Approximately two weeks prior to planting, soil moisture levels were adjusted by 0.005 ha-m of irrigation water so that optimal germination would occur. Starting at approximately the V4 growth stage, 0.0103 ha-m of irrigation occurred every 7-10 days to all plots until the R6 growth stage was reached, typically 114 days after planting. Weeds were controlled with tillage during the off-season, between 1 October and 30 November. During the growing season, the test plots were scouted on a weekly basis for pest and weeds. Herbicides and insecticides were applied as required to control weeds and pests on each of the test plots (Table I-2).

Animal manures (beef and swine) were applied on an equivalent N basis as determined from nutrient analysis using Oklahoma State University Soil Testing Lab standard procedures (Turner, 2005). Manure samples were collected during plot applications and stored at 4˚C prior to nutrient analysis. SE was obtained from a commercial nursery lagoon, while BM was obtained from a local feedlot. The quantities of BM and SE applied were adjusted each year to meet the target level of N so that all three sources applied equivalent rates of N. Anhydrous ammonia (NH3) with approximately 82% N content, was injected into soil each year, on dates that varied between 9 January and 19 April. Beef manure was surface applied between 21 February and 8 April, and was immediately incorporated into the soil. Swine effluent was applied via irrigation at approximately the 6-leaf (V6) corn growth stage, which typically occurs about 3 weeks after seedling emergence. This stage varied between 20 April and 11 June (Table I-2).

Economic Data

Corn prices received by farmers in Oklahoma have varied during the twelve-year study period (1995-2007), from US \$76.77 and \$159.44 Mg^{-1}. The average of the last three years of the study (2005-2007) was used to calculate economic returns, US \$126.11 Mg^{-1}. Revenue was calculated using the observed corn yield data in each year of the field trial at the recent three-year average price of corn of US \$126.11 Mg^{-1}. The per unit (e.g. per kg) price of nitrogen also varied according to sources of nitrogen since beef and SE manure were presumed available on-farm, whereas AA was purchased commercially. The three-year average price (2005-2007) of AA used in the analysis \$0.53 N kg^{-1}.

Fertilizer application costs for the main effects of NS and equivalent NR are summarized in Table I-3. Anhydrous ammonia was the most costly NS across all three equivalent NRs of 56, 168, and 504 kg N ha^{-1}, with costs of \$76.26, \$135.62, and \$313.70 ha^{-1}. The higher costs of AA were largely explained by the need to purchase N, which was not required in the BM and SE treatments. Swine effluent had the lowest application costs across each of the equivalent NRs, with costs of \$12.12, \$24.19, and \$62.48 ha^{-1}. Lower costs were associated with SE since it was pumped through existing irrigation equipment, eliminating the need to purchase additional equipment. Both AA and BM required the purchase of application machinery, which adds fixed costs of \$27.31 ha^{-1} to

AA and \$34.15 ha^{-1} to BM. Because of the added fixed costs, BM had higher costs than SE, with application costs of \$75.42, \$87.64, and \$116.60 ha^{-1} across the NR of 56, 168, and 504 kg N ha^{-1}.

Sensitivity analysis was conducted to account for the large fluctuations in corn and fertilizer prices that occurred during the thirteen-year study period (Figure I-1). Since the last three years of the study, 2005-2007, occurred during a period of historically high AA prices, the model results based on the average prices from this period (2005-2007) overstate the cost of AA relative to the organic sources. Average corn and AA prices across all thirteen years of the field trials (1995-2007) were used to conduct a sensitivity analysis.

Literature Review

Effectiveness of animal manure compared to inorganic fertilizer

Previous studies have found various types of swine and beef manures to be equally effective as commercial fertilizers in supplying nutrients to row crops and forages. Field trials conducted in Mississippi found anaerobic SE and commercial fertilizer applied at comparable rates had similar effects on the cumulative dry matter yield and nutritive value of forages, including bermudagrass and johnsongrass (Adeli and Varco, 2001; Brink et al., 2003; and Adeli et al., 2005). On row crops, swine slurry and commercial fertilizer were also found to have similar effects on corn, soybean, and sorghum yields when of equivalent nitrogen application rates were applied (Kwaw-Mensah and Al-Kaisi, 2006; McAndrews et al., 2006; Loria et al., 2007; Paschold et al., 2008; Chantigny et al., 2008). Beef manure (BM) performed significantly better than commercial fertilizers in raising production levels at comparable Nitrogen (N) rates applied on corn silage in Nebraska (Ferguson et al., 2005). Similar results were reported when dairy cow manure was applied to corn and wheat in Wisconsin (Sanford et al., 2009).

Effects of the continuous application of animal manure on soil nutrients

Manure has been historically used as a source of soil nutrients to improve soil fertility for crop production. However, regions with high density of animal production have a higher potential of water pollution by nutrient accumulation and migration to water bodies.

Whalen and Chang (2001) determined the system-level phosphorus balance in irrigated and non-irrigated soil annually supplied with beef manure for 16 years in southern Alberta, Canada. Repeated annual applications of beef manure for barley production increased soil total and available phosphorus level at depths exceeding 60 cm. This was especially significant on plot treated with the higher rates of manure. However, no substantial phosphorus movement through soil profile was found due to the great capacity of soil (calcareous clay loam) to absorb phosphorus. King et al (1990) found similar results with soils treated annually with swine effluent. As the clay content increased, there was an increase in available soil phosphorus and a reduced downward transport of phosphorus.

Kingery et al. (1994) studied the effects of long-term (15 to 28 year) application of broiler litter on soil conditions in the Sand Mountain region of northern Alabama. Compared to untreated soils, significant accumulations of NO3-N and extractable soil phosphorus were found with higher nutrients like K, Ca, Mg, Cu and Zn in littered soils. This study also indicated that risks of potential adverse environmental impacts with intense poultry production increases over time.

Adeli and Varco (2001) conducted a study to measure the effects of comparable rates of nitrogen and phosphorus derived from anaerobic swine effluent and commercial fertilizer on yield and nitrogen and phosphorus accumulation and recovery by forage grasses(Bermudagrass and Johnson grass) grown on an acid and alkaline soils in Mississippi. Dry matter yields of grasses increased with increased rate of swine effluent and fertilizer but the application rate above 448 kg ha^{-1} did not effectively increase dry matter yield. No significant difference in the cumulative dry matter yield between nutrient sources was found. Findings showed that nitrogen accumulation was a function of both crop tissue nitrogen concentration and dry matter yield while phosphorus accumulation was primarily affected by an increase in dry mater yield.

Toth et al. (2006) examined the effects of N- vs. P-based manure applications on N and P uptake by alfalfa, corn for silage, and orchard grass, leaching below the root zone, and accumulation of P in soil. Four treatments were used; a) no nutrient input control, b) nitrogen based manure application, c) phosphorus based manure application, and d) phosphorus based manure application with the shortfall in N met using ammonium sulfate fertilizer. There was no significant difference nitrogen leaching below root zone between nutrient treatments. Average annual total P losses in leachate did not exceed 1 kg ha^{-1}. However, it was found that N-based fertilizer application strategy would lead to significant buildup of soil test P (STP) in the surface 5 cm of soil.

Crop response and nutrient carryover to animal waste

Martin et al. (2006) conducted a study to determine the effects of manure applied as fresh and composted, on alfalfa yield, soil nutrient contents, and the potential for nitrate leaching in southern Arizona. Fresh and composted manure were applied to meet the plant requirement of nitrogen. The application of fresh and composted manure ranged from 35 to 476 N kg ha^{-1} after each harvest. Soil tests revealed that total nitrogen under composted and fresh manure and control plots was 3000, 1750 and 1400 kg ha^{-1}, respectively. Results showed there was no significant difference in alfalfa yields receiving equivalent rates of N as composted or fresh manure. No significant N and P leaching was found in treated plots.

Dupuis (2006) examined crop yield, grain quality, soil fertility, and microbial activities in soil in wheat and corn agro-ecosystems using poultry litter or inorganic fertilizer in Ste.-Anne-de-Bellevue, Quebec, Canada. Wheat yields actually dropped and corn yields did not increase to additional nitrogen application due to the high initial soil N in study plots. Soil tests also showed that nitrogen fertilization led to higher nitrate concentration in the soils. However, better microbial activities such as biomass and respiration under corn system were found in manure treated plots than in inorganic plots.

Economic analysis of use of animal waste

Economic studies on animal manure have mainly focused on use of animal manure as a substitute for commercial fertilizer and the management decisions aimed to meet environmental regulations. Nunez and McCann (2004) found factors such as the awareness of other farmers using manure, off-farm income, location, transportation costs, and the odor were significant in determining farmers' willingness to use manure. Norwood et al. (2005) estimated the average willingness to pay for dry manure by crop producers was \$8.37 per ton when the value of fertilizer saved was \$15 and \$11.28 per ton when the value of fertilizer saved was \$ 25 per acre.

Potential economic effects of environmental regulations on farm management system have been of interest in previous researches. Generally, adoption of manure-nutrient standards results in higher costs of livestock operation. Some studies (Ribaudo and Agapoff 2005, Ribauldo et al. 2003) showed that production costs for diary and hog operations would increase by 0.5 %- 6.5% and by 5.5 %, respectively. Baerenklau et al (2007) also found that a representative dairy farm would lose profit by 12-19% and that large livestock producers would be more affected when a nitrogen-based NMP is implemented. Tradeoff of water-air regulations on livestock operations is also examined in recent researches (Aillery et al 2005; Baerenklau et al 2007).

Previous OSU research on animal waste and contribution

Kim (1997) evaluated the economics of alternative swine waste management systems. The most profitable swine production and waste management for representative swine operations in two counties (Texas and Seminole) of Oklahoma were determined in a mixed integer programming model. Economic effects of different environmental regulations on swine waste management system were also examined.

Carreira (2004) compared the profitability of two irrigation systems (sub-surface drip and center pivot sprinkler) using swine effluents with simulated EPIC data. A farmer's risk preference was also considered in a stochastic dynamic optimization approach. The results showed that surface drip system was economically more competitive than center pivot irrigation in Texas County, Oklahoma even under no financial incentive program. More land is irrigated with surface drip irrigation while a longer use of groundwater from Ogallala aquifer is found with center pivot irrigation.

Turner (2005) evaluated the effect of the long-term application of animal manure on soil electrical conductivity (EC) and sodium adsorption ratio (SAR) using the corn data from Experiment 701 conducted at the OSU Panhandle research station. Soil tests collected in 2000 were used to examine cumulative changes in soil EC and SAR after five-years of consecutive applications of nitrogen application from three N sources (AA, BM, and SE). Soil tests showed that the soil SAR increased lineally to SE application but decreased lineally to AA application. There was no change in the soil SAR under BM treated plots. Organic N fertilizers like BM and SE did not make a change in the soil EC but under the higher AA treatment has the soil EC increased.

Methodology

Static approach with ANOVA model

The experimental field data were analyzed using the SAS statistical software package (SAS Institute, 2002). An ANOVA model for corn yield was constructed using the PROC MIXED routine. Fixed effects included in the ANOVA model were NS and NR. Year (YR) and Block were included as a random effect in the model. Type III least-square means obtained from the PROC MIXED routine were used for mean comparison tests using the PDIFF option (SAS Institute, 2002). Model parameters and treatment differences were considered statistically significant at the $P < 0.05$ level.

The economic returns for each NS and equivalent NR were calculated on an average return per hectare basis using the OPREC field experiment results. The economic profitability of each NS was calculated as the return (price times yield) above specified costs, and then analyzed using an ANOVA model. The economic returns included application and other specified costs for AA, BM, and SE. The remaining costs, such as seed, pesticide, machinery, and irrigation costs, were maintained at constant levels across the main treatment effects of NS and NR and were not included in the economic returns. Fertilizer costs varied among the NS treatment effects since each NS required different types of machinery and demanded different levels of machinery, labor, and input use.

Machinery and labor costs required to apply AA and BM costs were developed using crop enterprise budget software to reflect actual costs incurred by producers in the Oklahoma Panhandle (Massey, 1998; Doye et al., 2009). The enterprise budgets estimated fertilizer costs based on machinery operating and ownership costs, labor requirements, and input use (such as fuel and lube). Technical coefficients describing the handling and application of BM (load capacity, transportation costs to field, speed of operation, and other factors) were obtained from previous research (Massey, 1998). SE requires less equipment and labor effort since it was applied through existing irrigation equipment (pivot). Costs for SE application costs were developed from previous research in the Oklahoma Panhandle that estimated SE costs (Carreira 2004). Crop enterprise budget software was used to update costs to current levels in 2009 (Doye et al., 2009).

Sensitivity analysis was conducted to account for the large fluctuations in corn and fertilizer prices that occurred during the thirteen-year study period (Figure I-1). Since the last three years of the study, 2005-2007, occurred during a period of historically high AA prices, the ANOVA model results based on the average prices from this period (2005-2007) overstate the cost of AA relative to the organic sources. Thus the ANOVA model of economic returns was rerun using average corn and AA prices across all thirteen years of the field trials (1995-2007). A break-even price analysis, which equated net economic returns between NSs at corn-AA price combinations, was also conducted (Kay et al., 2003). The break-even analysis considered four alternative price sets based on historical prices of corn and AA from 1995 through 2007. This analysis provided a representative range of corn and AA prices, including periods of relatively high (2005-2007), modest (1995-1997; 2001-2004), and low (1998-2000) prices of AA relative to corn prices. Break-even corn prices for BM and SE were calculated using the NR of 168 and 504 N kg^{-1}, which corresponded to the economically optimal N levels.

A dynamic optimization

The objective of deterministic optimization model is to maximize the net present value of a stream of net return from farm operation over the crop production horizon for each nitrogen fertilizer. A farmer's decision problem for each crop can be written as;

$$(1)\quad \max_{s,\ NA_t^s} NPV = \sum_{t=1}^{T} \delta^{t-1}(p \cdot \mathrm{E}(\mathrm{Y}_t^s) - r_s \cdot NA_t^s - TVC)$$

$$\begin{aligned}
\text{s.t}\quad & Y_t^s = f_t^s(TAN_t^s,\ TAP_t^s,\ pH_t^s),\\
& TAN_t^s = NA_t^s(1 - Nloss_t^s) + SN_t^s,\\
& TAP_t^s = PA_t^s + SP_t^s,\\
& SN_{t+1}^s = g_t^s(NA_t^s,\ SN_t^s, Y_t^s),\\
& SP_{t+1}^s = h_t^s(PA_t^s,\ SP_t^s),\\
& pH_{t+1}^s = q_t^s(pH_t^s,\ TAN_t^s),\\
& Nloss_{t+1}^s = j_t^s(pH_t^s,\ NA_t^s), \text{only for } s = 3\\
& NA_t^s = \xi^s PA_t^s\\
& NA_t^s,\ SN_t^s,\ PA_t^s,\ SP_t^s, \geq 0 \quad \forall\ t\ and\ s,\\
& s = 1 \text{ for AA, 2 for BM, and 3 for SE}
\end{aligned}$$

where s is the choice of crops, NPV is the present value of returns from crop production over the planning period, t is the year of the planning horizon, p is the price of corn (\$ kg^{-1}), r_s is the price (\$ kg^{-1}) of type s nitrogen fertilizer, NA_t^s is the amount (kg ha^{-1}) of type s nitrogen fertilizer in year t, TVC is total variable cost (\$ ha^{-1}) of all inputs except fertilizer, SN_t^s is the soil nitrate-nitrogen level (kg ha^{-1}) in year t under type s

nitrogen fertilizer, TAN_t^s is total available nitrogen for plant, TAP_t^s is total available phosphorus for plant, PA_t^s is amount of phosphorus applied, pH_t^s is soil pH level, $Y_t\ (\cdot)$ is crop response function, $g_t\ (\cdot)$, $h_t\ (\cdot)$, $q_t\ (\cdot)$ and $j_t^s(\cdot)$ are equations of nitrogen carryover, phosphorus carryover, pH carryover and nitrogen loss, respectively, δ is the discount factor, and ξ^s is a ratio of nitrogen and phosphorus in *s* fertilizer which is assumed to be constant over the planning period.

We are only interested in major plant nutrients such as nitrogen and phosphorus and soil pH levels in this study,. Therefore, the functional form for corn yield used in this study is a modified Mitscherilich-Baule function, thus,

(2)

$$Y_t = (\eta_{01} + \eta_{02}DBM + \eta_{03}DSE)\{1 - \exp(\eta_{11}TAN_t)\}\{1 - \exp(\eta_{21}TAP_t)\}\{1 - \exp(\eta_{31}pH_t)\} + \varepsilon_t$$

,

where $\eta_{01},\cdots,\eta_{31}$ are the parameters to be estimated. The input applications (*TAN*, *TAP*, and *pH*) assume to have negative parameters ($\eta_{11},\eta_{21},\eta_{31}$) to ensure a concave response function.

The parameter η_{01} means the maximum corn yield obtained with AA nitrogen fertilizer. DBM and DSE are dummy variables for BM and SE fertilizers. We expected two parameters for manure dummy variables (η_{02}, and η_{03}) to be positive, which means that higher corn yields are obtained in manure plots than in AA treated plots. ε_t is the error term, $\varepsilon_t \sim N\left(0, \ \sigma_\varepsilon^2\right)$

The nitrogen carryover function is defined as

$$SN_{t+1}^s = \lambda_0^s + \lambda_1^s NA_t^s + \lambda_2^s SN_t^s + \lambda_3^s Y_t + \vartheta_t^s \tag{3}$$

and we assume $\lambda_1^s > 0$, $\lambda_2^s > 0$, $\lambda_3^s < 0$ and the underlying distribution of the error term is $\vartheta_t^s \sim N\left(0, \exp(\phi_0^s + \phi_1^s NA_t^s\right)$. A parameter of the level of nitrogen applied in the variance equation is positive ($\phi_1^s > 0$) since we assume the nitrogen application level increases the variance of the error term.

The phosphorus available for plant uptake is the sum of phosphorus applied and soil phosphorus. Soil phosphorus in this study represents labile phosphorus although phosphorus is not a mobile nutrient in the soil like nitrogen. The phosphorus carryover function is defined as

$$SP_{t+1}^s = \delta_0^s + \delta_1^s PA_t^s + \delta_2^s SP_t^s + \varpi_t^s \tag{4}$$

where $\delta_0^s, \cdots, \delta_2^s, \ \kappa_0^s, and \ \kappa_0^s$ are parameters to be estimated, and the variance of error term (ϖ_t) for AA is $\varpi_t^s \sim N\left(0, \exp(\kappa_0^s)\right)$ and variances of error term for BM and SE are assumed to change according to phosphorus application levels, $\varpi_t^s \sim N\left(0, \exp(\kappa_0^s + \kappa_1^s PA_t^s\right)$.

The soil pH carry-over effect is defined as

$$pH_{t+1}^s = \gamma_0^s + \gamma_1^s pH_t^s + \gamma_2^s TAN_t^s + \xi_t^s \tag{5}$$

we also assume γ_1^s >0, because soil pH level in current period is positively affecting soil pH level in the next period. We also expect γ_2^s <0 because the level of total nitrogen tends to lower soil pH level in the next period. The underlying distribution of the error term is $\xi_t^s \sim N\left(0, \varphi_0^s + \varphi_1^s NA_t^s\right)$, which means the variance of error term in soil pH carryover function changes according to the level of nitrogen applied.

The actual nitrogen loss rate (%) through ammonia volatilization in the application of swine effluent was calculated using a mechanical model developed by Wu et al. (2003a) which considered the historical weather data such as wind, temperature, humidity and solar radiation. The nitrogen loss rate through ammonia volatilization is defined as

$$(6) \qquad Nloss_t = \psi_0 + \psi_1 pH_t + \psi_2 NA_t + \eta_t ,$$

we assume that nitrogen loss through ammonia volatilization in is positively related with both soil pH level and amount of nitrogen applied, i.e., ψ_1 >0. ψ_2 >0. The underlying distribution of the error term is $\eta_t \sim N\left(0, \exp(\tau_0 + \tau_1 NA_t\right)$, which means the variance of error term in the nitrogen loss function changes according to the level of nitrogen applied.

Results

ANOVA Analysis

Results

The ANOVA model results for the main treatment effects of NS and equivalent NR, the random effects of YR and plot replication (Block), and their interactions on corn yields are presented in Table I- 4. The ANOVA model found that both fixed effects, NS and NR, were statistically significant ($P \leq 0.05$). Only one of the random effects, YR, was found to be statistically significant ($P < 0.0001$), with the other, Block, being statistically insignificant ($P = 0.8745$). Since Block was found to be statistically insignificant, its data were pooled, and it was removed from the ANOVA model when comparing means. The results found two statistically significant interaction terms, one between NS and NR (NS×NR, P=0.0482), and the other between NR and YR (NR×YR, P=0.0293). The two remaining interaction terms were found to be statistically insignificant, those between NS and YR (NS×YR, P=0.9936) and among NS, NR, and YR (NS×NR×YR, P=0.5454).

Corn yields for the main treatment effects that were found to be significant in the ANOVA model (NS, NR, NS×NR, and YR) are presented in Table I- 5. For the main effect of NS, the ANOVA ranked both BM and SE as the highest yield performers. Beef effluent was found to have the highest yield, 7,041 kg ha^{-1}, but it was not significantly different at the $P<0.05$ level than the yield of SE, 6,941 kg ha^{-1}. However, both BM and SE were found to generate significant($P \leq 0.05$) higher corn yields than AA, whose yield was 6,438 kg ha^{-1}. There was less mean separation under the effect of NR, which ranked all three N rates (56, 168, and 504 kg N ha^{-1}) equally (Table I- 5). Hence, although the high N rate of 504 kg ha^{-1} generated the highest yield, 7,113 kg ha^{-1}, the difference was not significant at the $P<0.05$ level from both the medium N rate of 168 kg ha^{-1}, with a yield of 7,011 kg ha^{-1}, and the low N rate of 56 kg ha^{-1}, with a yield of 6,897 kg ha^{-1}. The ANOVA results found, however, that the three application rates of 56, 168, and 504 kg ha^{-1} did generate corn yields that were significantly different ($P\leq0.05$) from the control rate of 0 kg ha $^{-1}$ (CNTRL).

For the main interaction effect between NS and NR (NS×NR), the ANOVA model results found greater mean separation among NS as the NR was increased from 56 to 504 kg N ha^{-1} (Table I- 5). Under the low NR of 56 kg N ha^{-1}, no statistically significant effect of NS was seen on corn yield at the $P<0.05$ level. At 56 kg N ha^{-1}, the ANOVA model ranked corn yields at the $P<0.05$ level in the following order: AA=BM=SE. Statistically significant different corn yields among NSs were observed at the medium and high application rates of 168 and 504 kg N ha^{-1}. At the equivalent NR of 168 kg N ha^{-1}, the ANOVA model was able to separate the mean corn yields of BM from SE, but found no statistically significant difference between either BM and AA (BM×AA) or between SE and AA (SE×AA). Here, mean corn yields were ranked at the $P<0.05$ level as: SE>SE, with the other mean comparisons statistically insignificant at the $P<0.05$ level ,BM=AA and SE=AA. At the highest equivalent NR of 504 kg N ha^{-1}, the ANOVA model found a much different ranking, with the clearest separation of mean yields among the NSs. Here, SE was found to generate the highest corn yield, followed by BM, then AA. Thus, at 504 kg N ha^{-1}, the ANOVA model ranked corn yields in the following order at the $P<0.05$ level: SE>BM>AA.

The random effect of YR was found to be highly statistically significant in the ANOVA model ($P<0.0001$) as corn yields varied from as low as 3,110 kg ha^{-1} in 1996 to as high as 10,242 kg ha^{-1} in 2007 (Table I- 5). Across all years, the average corn yield was 6,807 kg ha^{-1}. The interaction term between NR and YR was also significant ($P\leq0.05$). In 2006, for instance, higher yields were found in the higher NR of 168 kg N ha^{-1} and 504 kg N ha^{-1} than in the 56 kg N ha^{-1} rate. There were also three years (1996, 1997, and 2003) when corn yields in the control plots (0 kg N ha^{-1}) were nearly as large as yields on the N applied plots.

Discussion

Swine effluent manure was ranked highest at the NR of 504 kg N ha^{-1}, but performed weak in the low and medium N application levels (56 and 168 kg N ha^{-1}) where it ranked behind, or no better than, BM and AA. The ANOVA results also found that SE's yields went down between the low (56 kg N ha^{-1}) and medium (168 kg N ha^{-1}) NR, falling from 6,997 to 6,581 kg ha^{-1}, although the difference was not found to be statistically significant at the $P<0.05$ level. These results are likely explained by the greater extent of ammonia volatilization in SE than in either of the other two sources, BM or AA. SE is prone to N losses following application efficiency due to ammonia volatilization (Al-Kaisi and Waskom, 2002). The hot and arid conditions, as well as calcareous soils high in pH, which are found in the Oklahoma Panhandle exacerbate the problem of ammonia volatilization (Wu et al., 2003a, 2003b).

At the highest application rate of 504 kg N ha^{-1}, the superior performance of SE relative to BM and AA can potentially be explained by several factors. One is that AA and BM are likely over-applying N at this level, which is much larger than those used by corn producers in the Oklahoma Panhandle. The excess N in the AA and BM plots is likely to result in N burning, particularly in the below-average production years when plant uptake of N is reduced. Although a major source of N to corn production, excess NH4 can result in toxicity symptoms during plant growth (Vines and Wedding 1960; Givan 1979; van der Eerden 1982; Fangmeier et al. 1994; Gerendas et al. 1997; Britto and Kronzucker 2002). Another factor is that the SE is applied during the crop growing season through the irrigation system as a liquid, which enhances soil moisture by providing additional water to the soil profile as well as increasing water retention through the solids contained in the mixture.

Beneficial effects of manure on corn yield are associated with increased soil nutrients, such as phosphorous and micronutrients. These effects could potentially explain the higher yields of BM and SE relative to AA since the AA plots had no additions of P or other soil micronutrients. In this experiment, however, soil P levels remained sufficient across all NS, including AA (Table I- 1). Although BM and SE had higher P soil values throughout the experiment than AA, sufficient P levels above 60 kg ha^{-1} remained on the AA plots (Zhang and Raun, 2006). Between 1995 and 2005, average P soil levels increased on the AA plot even without the addition of P, from 73 to 114 kg ha^{-1}, but this is likely due to soil testing error, which can be as high as 33% (Hailin Zhang, Personal communication). The increase in AA’s soil P levels is likely due to the high P soil levels found in the Gruver soils that provided adequate P throughout the experiment. Hence, it is more likely that the significant yield differences between the manures and AA are explained by the addition of micronutrients and organic matter from BM and SE.

Previous research by Sutton et al.(1986) found that micronutrients contained in manure significantly increased corn yields compared to chemical fertilizers. Similarly, Culley et al.(1981) found that the addition and long-term effects of organic matter from liquid dairy manure also significantly increased yields over chemical fertilizers.

The effect of NR was found to be statistically significant ($P \leq 0.05$), but the response of corn yield within the NR of 56, 168, and 504 N kg ha^{-1} was not found to be significant at the $P<0.05$ level. The flat response across increasing N applications is also explained by the high levels of ammonia volatilization and the over application of N under the high NR of 504 kg ha^{-1}. The ammonia volatilization on the SE plots reduced the effect of N, particularly between the low and medium application levels, whereas the excess N reduced yields on the AA and BM plots in going from the low to high N application levels. Thus, their combined effect was to reduce the effectiveness of N across the entire range of N fertilizer applications from 56 to 504 kg N ha^{-1}.

The random effect of YR was found to be highly significant ($P<0.0001$), with a fairly large variation in yields (Table I- 5). Although irrigation is able to reduce the more significant sources of risk in the region, such as low rainfall and frequent drought, other external factors beyond experimental control were present. In some years hail damage was reported, while in others pest damage was also encountered. Since the interaction of NS and YR (NS×YR) was statistically insignificant at the $P<0.05$ level, the main findings related to which NS provided the highest yields was not affected by random effects from year-to-year variability. The interaction term between NR and YR (NR×YR) was statistically significant ($P \leq 0.05$), but this result is likely explained by N having only a minimal effect on years of low yields, since in those types of years other external effects prevented N from having a significant effect on raising corn yields.

Because no statistically significant ($P \leq 0.05$) yield benefits occurred from the organic fertilizers when compared with AA at the lower N application rates (56 and 168 ha^{-1}), these results indicate that the organic NSs are potentially viable as substitutes for commercial fertilizers such as AA. At the highest NR of 504 kg N ha^{-1}, SE provided significant yield benefits over AA (N504×SE×AA; $P<0.001$), as did BM (N504×BM×AA; $P=0.0337$). These results suggest that both manure sources (SE and BM) could be the best NS at high N application rates with significant yield benefits over commercial fertilizer. Economic profitability of the NSs is tested in the next section.

The findings of the ANOVA model, that organic sources of N fertilizer generate higher crop yields than commercial fertilizers, are in agreement with previous studies about the effect of the long-term application of animal manure on crop productivity. Lithourgidis et al. (2007) found that yields of both corn grain and silage in the manure treatment significantly increased relative to the control and were equivalent to commercial fertilizer treatments. Shen et al. (2007) also reported higher yields in manure-treated plots than in the chemical fertilizer-treated plots by 2–5% and 6–14% for rice and wheat, respectively.

Economic returns

The ANOVA model results for the main treatment effects of NS and equivalent NR, the random effects of YR and plot replication (Block), and their interactions on economic returns are presented in Table I- 4. The ANOVA model found only one of the fixed effects, NS, significant (*P* <0.0001), with the other, NR, not significant (*P* =0.1921). Only one of the random effects, YR, was found to be statistically significant (*P* < 0.0001), with the other, Block, being not significant (*P* =0.8797). Since Block was found to be not significant, its data was pooled, and it was removed from the ANOVA model when comparing mean economic returns. The results found two statistically significant interaction terms, one between NS and NR (NS×NR, *P*<0.0001), and the other between NR and YR (NR×YR, *P*=0.0286). The two remaining interaction terms were found to be statistically insignificant - those between NS and YR (NS×YR, *P*=0.9935) and among NS, NR, and YR (NS×NR×YR, *P*=0.5555).

Corn returns for the main treatment effects that were found to be significant in the ANOVA model (NS, NS×NR, and YR) are presented in Table I- 6. For the main effect of NS, the ANOVA ranked both BM and SE as the most profitable alternatives. Swine effluent SE was found to generate the greatest economic return, \$477.88 ha^{-1}, but it was not significantly different at the *P*<0.05 level than the economic return of BM, \$445.43 ha^{-1}. However, both SE and BM were found to generate statistically significantly ($P \leq 0.05$) higher economic returns than AA, as the ANOVA model ranked economic returns in the following order at the *P*<0.05 level : SE=BM>AA. The effect of NR was statistically insignificant at the *P*<0.05 level , and provided no separation of mean economic returns across NRs including the control rate of 0 kg ha^{-1} (CNTRL) at the *P*<0.05 level. Thus, for NR, the ANOVA model ranked economic returns in the following order: N56=N168=CNTRL=N504.

The interaction effect between NS and equivalent NR (NS×NR) was better able to separate mean economic returns than either of the individual main effects, NS or NR

(Table I- 6). For instance, the main effect of NS had a relatively weak ranking at the $P<0.05$ level : SE=BM>AA, which could only separate the organic sources from AA, but not from each other. The interaction term (NS×NR), however, found that this ranking changed as the NR was increased. Within the low NR of 56 kg N ha^{-1}, the ANOVA model found even less separation among economic returns, with only SE significantly greater than AA. Here, mean economic returns were ranked at the $P<0.05$ level as: SE>AA, with the other mean comparisons statistically insignificant at the $P<0.05$ level , SE=BM and BM=AA. While the middle N168 of 168 kg N ha^{-1} had the same ranking as the individual effect of NS, SE=BM>AA at the $P<0.05$ level, at the high NR of 504 kg N ha^{-1}, the interaction effect (NS×NR) ranked economic returns at the $P<0.05$ level as: SE>BM>AA. Thus, SE was found to generate the greatest profit at the highest equivalent N504 application of 504 kg N ha^{-1}, followed by BM, then AA.

Similarly, the main effect of NR (NR) was not able to separate mean economic returns, with a ranking across the equivalent NRs at the $P<0.05$ level as : N56=N168=N504. While SE and BM were not able to separate means, AA was found to have the most complete separation of mean economic returns. Within AA, economic returns were ranked at the $P<0.05$ level as: N56=N168>N504.

When mean economic returns are compared across the interaction effects of NS×NR, rather than within either of the individual effects, NS or NR, the ANOVA model found that SE×N504 generated the highest economic return of \$560.57 ha^{-1}. No statistically significant difference at the $P<0.05$ level occurred, however, between SE×N504 and two other treatment effects, SE×N56 and BM×N168 (Table I- 6). The ANOVA model of economic returns also found that SE applied with the high level of equivalent N (SE×N504) was ranked higher than six other treatment effects, with a ranking at the $P<0.05$ level as : SE×N504 > BM×N56=SE×N168= =BM×N504=AA×N56= AA×N168> AA×N504. Two of the treatment effects, SE×N56 and BM×N168, although not statistically different at the $P<0.05$ level than SE×N504, were ranked higher than all three of the AA treatment effects. Anhydrous ammonia had the lowest ranked treatment effects, AA×N504, and generated the lowest economic return of $65.37.

Sensitivity analysis

The ANOVA model of economic returns was rerun using the thirteen-year average of corn and AA prices, which contained a higher relative price between corn and AA than the three-year average price (2005-2007) used in the preceding section (Table I- 4). The ANOVA results of economic returns under the sensitivity scenario found no difference in the statistical significance of the main effects or their interactions. NS, YR, and the interactions between NS and NR (NS×NR) and between NR and YR (NR×YR) were the only statistically significant factors ($P \leq 0.05$). The remaining effects of NR (NR), replication plot, (Block), and the interactions between NS and YR and among NS, NR, and YR (NS×NR×YR) were all found to be statistically insignificant at the $P<0.05$ level .

The ANOVA model found only modest changes in the ranking of the main effects of NS and NR and their interaction (NS×NR), with AA remaining as the least profitable alternative (Table I- 7). Across NS, the ANOVA model of economic returns ranked the alternatives at the $P<0.05$ level as: SE>BM>AA. Across the interaction of NS and NR (NS×NR), the ANOVA model was able to separate SE and BM from AA at the same NR found previously (Table I- 6). The ANOVA model ranked economic returns at the $P<0.05$ level as: SE×N504=SE×N56=BM×N168>AA×N56= AA×N168> AA×N504. Hence, the main finding that both organic sources of N, SE and BM, generated statistically significantly greater economic returns than AA was robust to the change in corn and AA prices. The ranking of economic returns across NR was also unchanged under the new prices, with an equal ranking across each of the NR given at the $P<0.05$ level as : at 56 kg N ha^{-1} SE=BM>AA, at 168 kg N ha^{-1} BM=SE>AA, at 504 kg N ha^{-1} SE>BM>AA.

The break-even price analysis found that SE would remain the most profitable NS, even during the cheap energy period of the late 1990's (1998-2000) when the price of AA was lowest (Figure I-1; Figure I- 2). The break-even corn price of SE was found to be \$57.23 MT^{-1}, substantially lower than the average corn price of \$80.34 MT^{-1} that prevailed during this period (Figure I- 2). Beef manure was found to have higher break-even corn prices than SE, with an average difference of \$48.93 ha^{-1}. Even with a higher break-even corn price, BM would still be more profitable than AA in each of the periods except for the period of low AA prices (1998-2000), where its break-even corn price would be \$21.85 MT^{-1} higher than the average corn price during this period of \$80.34 MT^{-1}. During the modest periods of AA prices (1995-1997; 2001-2004), the break-even corn price of BM was close to the actual corn prices, rendering it profitable for producers with on-farm sources of BM but it was unlikely to be adequately remunerative over even short distances due to transportation costs.

The most expensive period of AA prices (2005-2007) had the lowest break-even corn prices for BM (\$46.84 MT^{-1}) and SE (\$6.83 MT^{-1}). The substantial gaps between the actual observed corn price during this period and the break-even corn prices of the manures generates both increased profitability for producers as well as increased economic viability of marketing BM as a commercial fertilizer. In the Oklahoma Panhandle, the price of BM averages \$2 MT^{-1}, with a shipping cost of \$0.81 km^{-1} (J.C. Banks, Personal Communication). With these prices, BM would be able to profitably transport up to 47 km from its point of origin. Swine effluent, although it was found to have a break-even price of only \$6.83 MT^{-1}, would remain too bulky to transport off-farm to other producers, but would remain a highly profitable substitute for AA for on-farm applications.

A dynamic approach

Econometric estimation

The irrigated corn yield response function to total available nitrogen, total available phosphorus, and soil pH was estimated using PROC NLMIXED procedure in SAS. The maximum likelihood estimation method based on an asymptotic normal distribution was used. The functional form for the yield function in this study was a modified Mitscherlich-Baule function, which is nonlinear in both the parameter and variables. We expected the parameters associated with inputs to be negative to ensure a concave yield response function with respect to input levels. The parameter estimates for the corn yield are presented in Table I- 8.

All parameters have expected sign. The marginal effect of each variable on corn yield is not equal to the parameter estimates of the input variable, as the first partial derivative of corn yield with respect to the input variable of interest is a function of other variables as well as parameters. SAS Proc NLMIXED procedure reports parameter estimates along with approximate P-values with the Gauss-Newton Method.

Parameter estimates for maximum attainable corn yield for AA, total available nitrogen, and soil pH were significantly different than zero at the one percent significance level. Parameter estimates for total available phosphorus were not significantly different than zero. There are parameter estimates corresponding to two dummy nitrogen source variables (η_{02}, and η_{03}). The parameter estimates for both nitrogen source dummy variables were not statistically significant at the five percent significance level. The positive sign for both dummy variables indicates that the potential corn yield under animal manure application is higher than under the inorganic fertilizer (i.e. AA), which is consistent with our initial assumption that organic nitrogen fertilizers generate a higher corn yield than inorganic fertilizer. However, the insignificant yield benefit for organic fertilizers over that for AA is not in accordance with the information obtained from the experiment in which significantly higher corn yields were observed with organic fertilizers.

The function for soil nitrogen carryover was estimated with the maximum likelihood using SAS PROC AUTOREG, given assumption of heteroskedasticity due to the amount of nitrogen applied. The parameter estimates for a nitrogen carryover by each nitrogen source are presented in Table I- 9.

The normality assumption was rejected with less than p=0.0001 in all three soil nitrogen carryover functions, which means that the distribution of errors in the soil nitrogen equation was not normal. However, statistical tests based on the normality assumption are asymptotically valid because the asymptotic normality assumption was used in the estimation of regression parameters. The Lagrangean multiplier test of heteroskedasticity test for soil nitrogen carryover functions showed that the homoskedasticity assumption was rejected at the 5 percent significance level.

All parameter estimates of soil nitrogen carryover function for AA were significantly different from zero. Also, a positive significant slope parameter in the variance equation indicates that the variance of soil nitrogen increased with the amount of nitrogen applied. For BM, only parameters (λ_0^s and λ_1^s)for intercept and lag of nitrogen applied were significantly different from zero. A positive sign of slope in the variance equation for BM was obtained but insignificant. For SE, All parameter estimates except lag of nitrogen applied were significantly different from zero. A negative sign for the slope in the variance equation for SE was obtained but was insignificant.

The soil phosphorus carryover function was estimated with maximum likelihood using SAS Proc AUTOREG. The heteroskedasticity assumption due to amount of phosphorus applied was accounted in soil phosphorus carryover functions for BM and SE. The parameter estimates for a soil phosphorus carryover function by each fertilizer are presented in Table I- 10.

Both normality and homoskedasticity assumptions for soil phosphorus levels were rejected at the 5 percent significance level. The expected positive sign of slope in the variance equation was obtained in the phosphorus carryover function in BM, indicating that variance of soil phosphorus under BM plots increases with the level of phosphorus applied. However, a negative sign for the slope in the variance equations was found on the contrary to our expectation, which the heteroskedasticity of soil phosphorus declines with the level of phosphorus applied. All parameter estimates of soil phosphorus carryover function for AA were significantly different from zero. For BM, all the parameters except the intercept were significantly different from zero. For SE, all parameter estimates except the intercept and lag of phosphorus applied were significantly different from zero at the 5 percent significance level.

The soil pH carryover function was also estimated with maximum likelihood using SAS Proc AUTOREG. The heteroskedasticity assumption due to amount of phosphorus applied was accounted in this carryover function. The parameter estimates for a soil pH carryover function by each fertilizer are presented in Table I- 11. All parameter estimates for AA were significantly different from zero at the 1 percent significance level. For BM and SE, all parameters except for the lag of total available nitrogen were statistically significant. The parameter estimates for the variance equation for AA and BM were statistically significant, indicating the variance of soil pH increases with the level of nitrogen applied. However, the negative sign of a parameter estimate for the heteroskedasticity equation was obtained for SE but is not statistically significant.

The nitrogen loss equation through ammonia volatilization in the application of swine effluent was estimated through maximum likelihood method (Table I- 12). Both the normality and heteroskedasticity assumptions were rejected at the 5 percent significance level. All expected signs for both soil pH level and amount of nitrogen applied were obtained. A negative parameter in the variance equation was determined, which means that the variance of nitrogen loss rate declines with the level of nitrogen applied.

Optimization results

The deterministic optimization procedure was implemented using the Microsoft Excel Solver with following assumptions a) a thirty-year planning horizon; b) five percent discount rate; c) no uncertainty regarding nutrients in the manure. In addition, it was assumed in this study that the ration of nitrogen to phosphorus was 1.2 to 1 and 3 to 1 for BM and SE, respectively, which means that if you apply 1.2 kg of nitrogen in BM then you apply one kg of phosphorus. Other minor nutrients such as K, and Ca were not considered in this study despite their presence in animal manure.

Compared to animal manure, it was optimal to apply less amount of nitrogen with anhydrous ammonia on a per hectare basis (Figure I- 3). The optimal cumulative amount over the 30 year period were 656 kg/ha for AA, 2,071 kg/ha for BM, and 1737 kg/ha for SE. The optimal steady state levels of nitrogen applied during much of the production horizon were 24, 71, and 59 kg/ha for AA, BM, and SE respectively.

Lower soil nitrogen levels per hectare were optimal with animal manure than for AA fertilizer. The levels of soil nitrogen for all three nitrogen sources reached a steady state and remained constant during much of the planning period (Figure I- 4), which means that the amount of nitrogen applied was close to the amount of nitrogen removed by corn yield and ammonia. The drop at the first three years of the planning horizon is explained by initial high soil nitrogen levels due to the previous experiments. The steady state level of soil nitrogen was 69 kg/ha for AA, 52 kg/ha for BM, and 57 kg/ha for SE.

The higher soil phosphorus level occurred with BM while soil phosphorus levels with AA and SE were lower and nearly equal over the planning horizon (Figure I- 5). This result concurred with our expectation because of lower ratio of nitrogen and phosphorus in BM than in SE. Soil phosphorus levels for all three nitrogen sources reached stable levels. The steady level of soil phosphorus was 98 kg/ha for AA, 198 kg/ha for BM, and 98 kg/ha for SE. Stable soil phosphorus level in swine effluent-treated plot in our study does not agree with the results of Carreira (2004), in which soil phosphorus level from an EPIC simulated model continuously increased over the planning horizon both under pivot and subsurface irrigation systems.

Lower soil pH levels were obtained with AA application during the entire planning horizon. Soil pH levels for all three nitrogen sources were stable during much of the planning period. The steady state level of soil pH was 7.6 for AA, 7.9 for BM, and 7.8 for SE. A sharp drop in soil pH under AA for the first two years was due to the high soil nitrogen level (Figure I- 6).

The optimal irrigated corn yield per hectare was higher for organic fertilizers during the entire planning horizon (Figure I- 7). This higher corn yield from animal manure can be explained by the enhanced water retention capability and other added soil nutrients such as phosphorus and potassium due to the application of manure. The steady state level for corn yield was 7,057 kg/ha for AA, 7,129 kg/ha for BM, and 7,116 kg/ha for SE.

The summary of results for the deterministic optimization model is presented in Table I-13. The highest net present value over the planning horizon is observed in SE, which is $9,269. However, the net present value using BM is $ 8,288, slightly less than with AA which is $8,474 (Table I-13). This result is not consistent with that of static analysis using the ANOVA model. This is possibly explained that the higher steady state level of nitrogen amount applied for BM was determined in the model which produces higher application cost of nitrogen rather than other nitrogen sources despite the highest corn yield level for BM. The deterministic optimization model also found that the nitrogen alternative that generated the highest net present values was swine effluent as did the static analysis.

Sensitivity analysis results for deterministic optimization

The deterministic optimization procedure was again implemented with thirteen-year average of corn and AA prices, which contained a higher relative price between corn and AA than the three-year average price (2005-2007) in order to examine the effect of a change in relative prices between corn and AA on variables in the model

As with the previous dynamic results, less nitrogen was applied with AA than with animal manure on a per hectare basis (Figure I-8), cumulatively over time (719 kg/ha for AA, 1,976 kg/ha for BM, and 1628 kg/ha for SE). The steady state levels of nitrogen applied were reached after four years and remained stable during much of the production horizon at 26, 68, and 55 kg/ha for AA, BM, and SE respectively. As the relative price of AA to two organic fertilizers was lowered both the cumulative amount of and a steady state level of nitrogen applied with AA increased while the cumulative amount of and steady state level of nitrogen applied with the two organic fertilizers decreased.

Lower optimal soil nitrogen levels per hectare were observed with animal manure compared to AA fertilizer. The levels of soil nitrogen for all three nitrogen sources reached a steady state and remained constant during much of the planning period (Figure I- 9). The drop at the first three years of the planning horizon is explained by initial high soil nitrogen levels due to the previous experiments. The steady state level of soil nitrogen was 70 kg/ha for AA, 52 kg/ha for BM, and 57 kg/ha for SE. There was a slight increase in soil N level with AA due to the increased amount of N applied while soil N levels with two organic fertilizers remained constant.

Higher soil phosphorus level also occurred in BM rather than in AA and SE over the planning horizon (Figure I-10). There was no great difference in soil phosphorus levels between AA and SE. Soil phosphorus levels for all three nitrogen sources reached stable levels. The steady level of soil phosphorus was 98 kg/ha for AA, 194 kg/ha for

BM, and 98 kg/ha for SE. a lower soil phosphorus level with BM is explained by a reduced amount of beef manure applied corresponding to the amount of N applied with BM.

Soil pH levels for all three nitrogen sources were very stable during the much of planning period. The optimal steady state level of soil pH was 7.6 for AA, 7.9 for BM, and 7.8 for SE. There was no effect of a change in relative price between corn price and AA on steady state levels of soil pH for three N sources.(Figure I-11).

Higher yields of irrigated corn per hectare were also found in organic fertilizers during the entire planning horizon (Figure I-12). The optimal steady state level for corn yield was 7,065 kg/ha for AA, 7,126 kg/ha for BM, and 7,112 kg/ha for SE. As more nitrogen is applied with AA, a higher steady state level of irrigated corn yield was obtained with AA.   On the other hand, lower steady state levels of corn yield were determined due to the slightly reduced amount of nitrogen applied with two organic fertilizers.

The summary of results for the sensitivity analysis is presented in Table I-14. There was no change in the rank of N sources in terms of net present values. The highest net present value over the planning horizon is also observed in SE, which is $6,969. The net present value using BM is $ 5,984, slightly less than with AA which is $6,241 (Table I-14). A lower corn price in the sensitivity analysis produced lower net present value from the stream of future income for all three N sources. As described earlier, a relatively cheaper price of AA resulted in a slight increase in steady state levels of N applied, soil N, and corn yield under AA. In addition, Table I-15 showed the comparison of optimal steady state variables under two different price scenarios.

Summary and Conclusions

The long-term experiment of animal manure to irrigated corn fields in the semi-arid agro-ecosystem of Oklahoma Panhandle has been conducted. Results from ANOVA models found that the two organic fertilizers tested in the experiment, BM and SE, produced higher yields and generated higher economic returns than a chemical fertilizer, AA. These findings were generally robust across the wide range of prices encountered during the experiment, although BM would not have been as profitable as AA during the cheap energy prices experienced in the late 1990's (1998-2000). Hence, this study is in agreement with previous studies that also found animal manures to be adequate, and often remunerative, substitutes for chemical sources of N. Results from a dynamic optimization also showed that the organic nitrogen fertilizer with swine effluent provided the highest NPV of returns over a 30-year planning horizon.

Table I-16 shows the best Nitrogen management strategies derived from static and dynamic analysis with two price scenarios. Results indicate that swine effluent can be a nitrogen source that brings the highest economic return. However, there is a big difference in the application rate of nitrogen; 504 N kg ha^{-1} under ANOVA and 59 or 55 kg ha^{-1} under dynamic optimization. This gap is explained by whether the existence of soil residual nitrogen is considered in the analysis or not. ANOVA approach failed to consider the nitrogen carryover effect by assuming that nitrogen fertilizer in excess of crop needs is lost from the cropland while the dynamic optimization approach assumed that the accumulation of soil nitrate-nitrogen in sufficient quantity affects crop yields and, in turn, that soil residual nitrogen at a certain period is a function of applied nitrogen and soil residual nitrogen in previous period. The inter-temporal carryover effect of soil residual nitrogen should be considered in developing a proper effluent management for improved economic benefit of crop production and for prevention of degrading soil and water quality.

Some caution should be taken in interpreting results. Nitrogen application optimal rules derived here are only applicable to a limited circumstance and should be evaluated on a field-by-field basis in that ; a) the availability of animal manure should be considered due to relatively high hauling costs of manure; b) nutrient values in animal manure are highly affected by forms of manure, kind of ration, manure handling method, and moisture contents.

More farmers have considered animal manure as a viable alternative to a commercial fertilizer as the price of commercial fertilizer has continued to go up for recent years. Results in this paper support the economic feasibility of animal manure within both a static and the dynamic optimization structure. However, better nutrient management in animal manure is necessary to improve the substitutability of animal manure.

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Figure

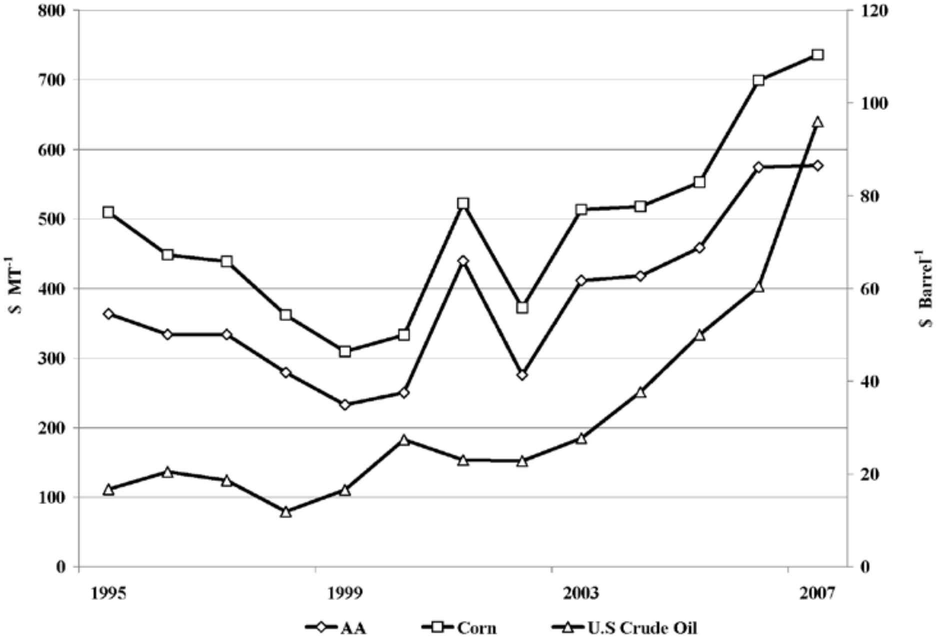

Figure I-1. Price trend of corn, anhydrous ammonia (AA), and U.S crude oil.

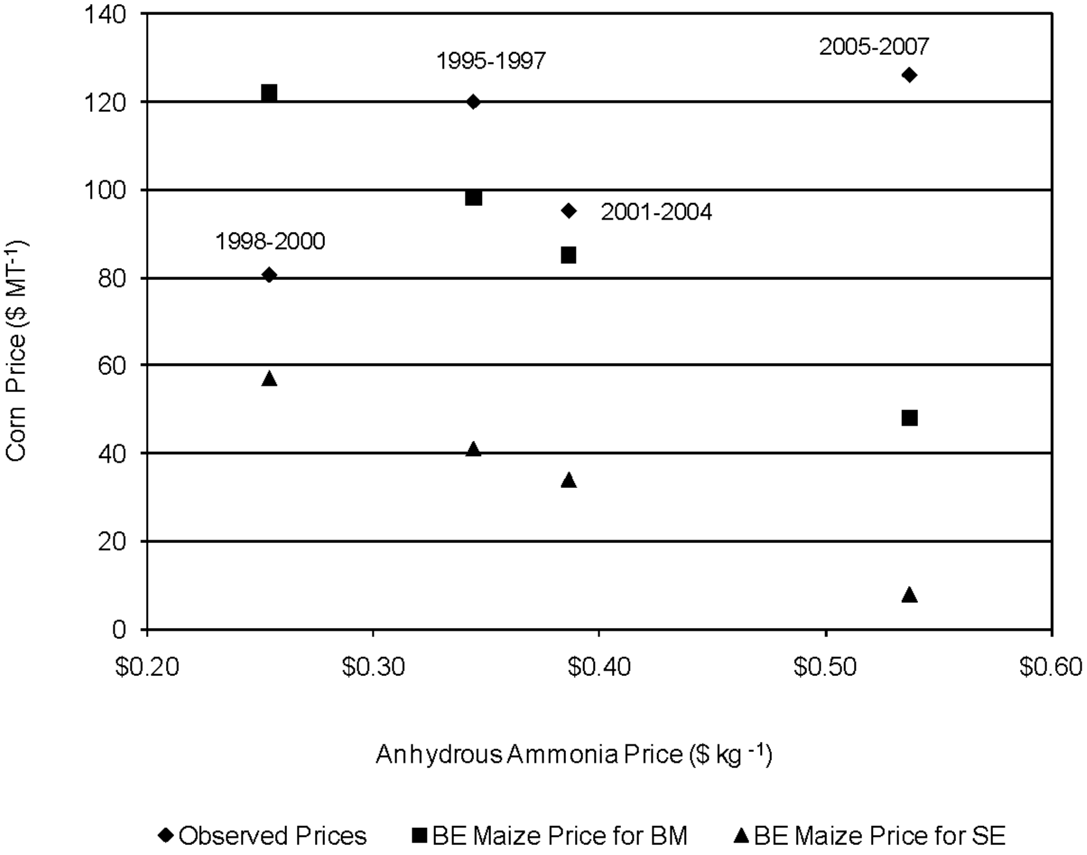

Figure I-2. **Break-even corn prices for beef manure and swine manure.**

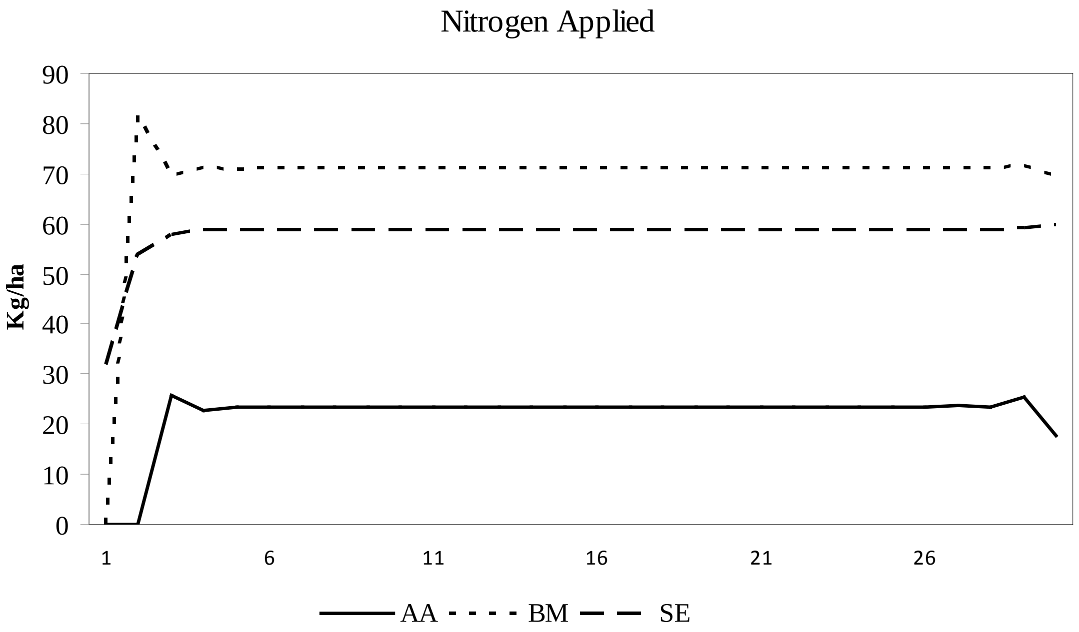

Figure I-3. **Projected amount of nitrogen applied with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure**

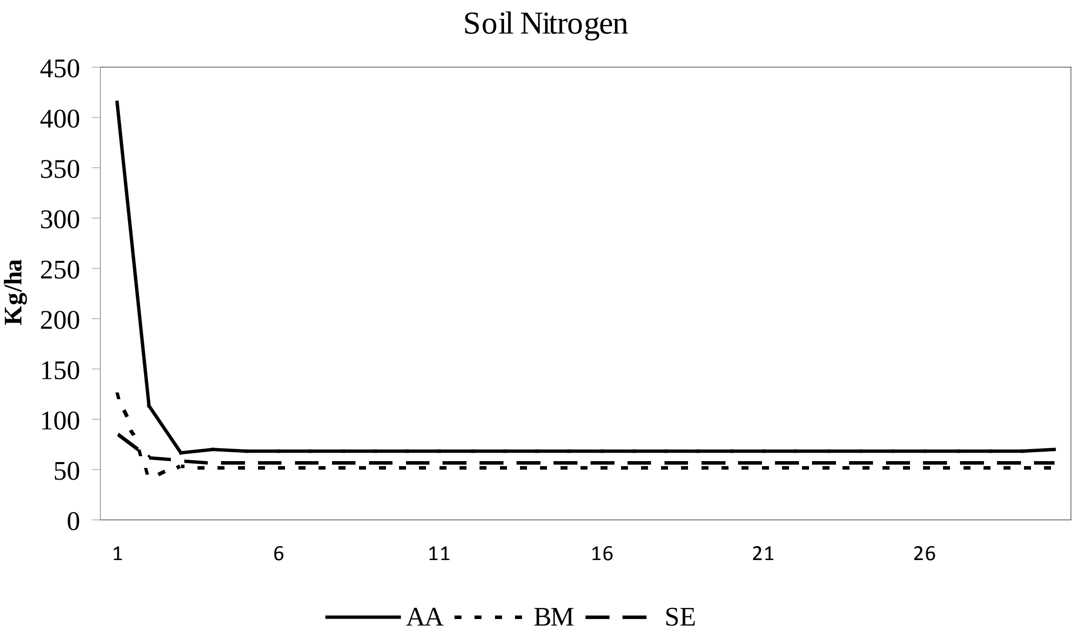

Figure I-4. **Projected soil nitrogen with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure**

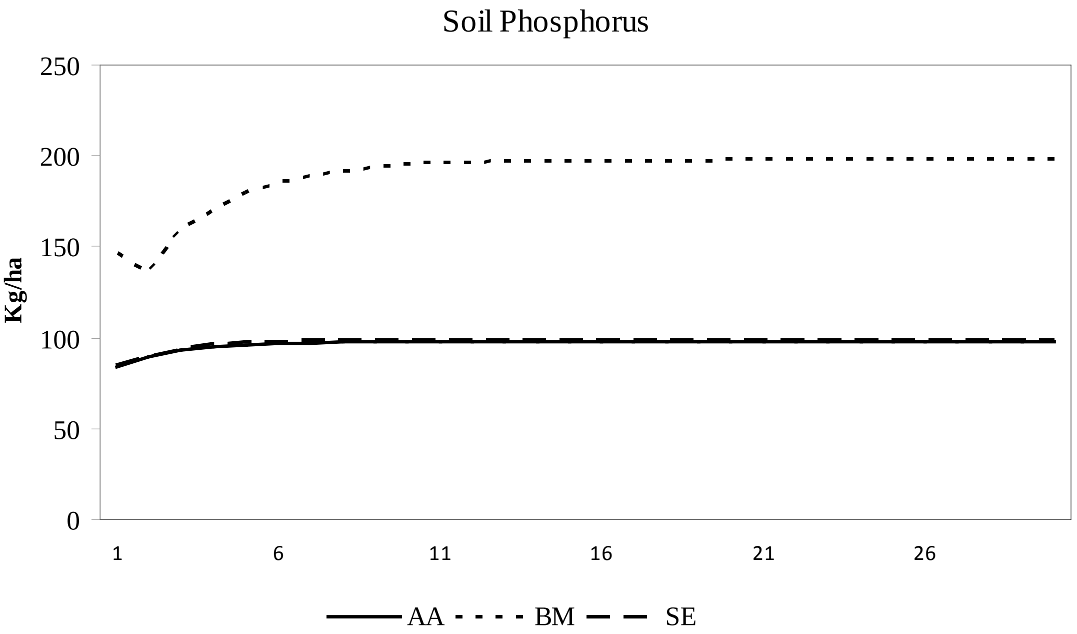

Figure I-5. Projected soil phosphorus with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure

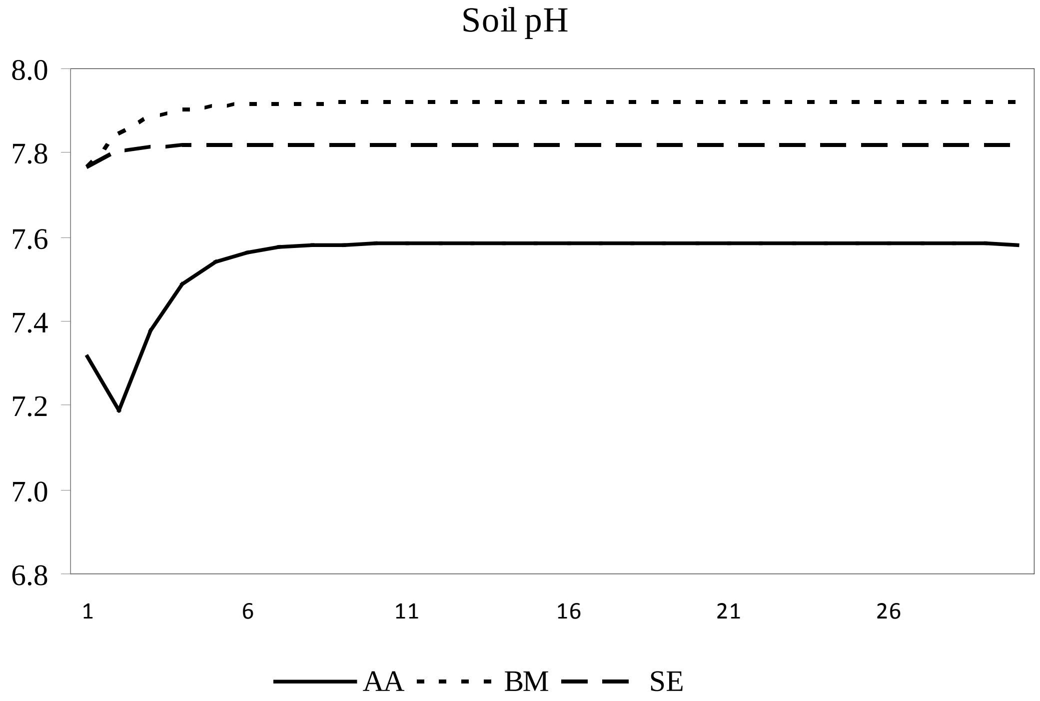

Figure I-6. **Projected soil pH with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure**

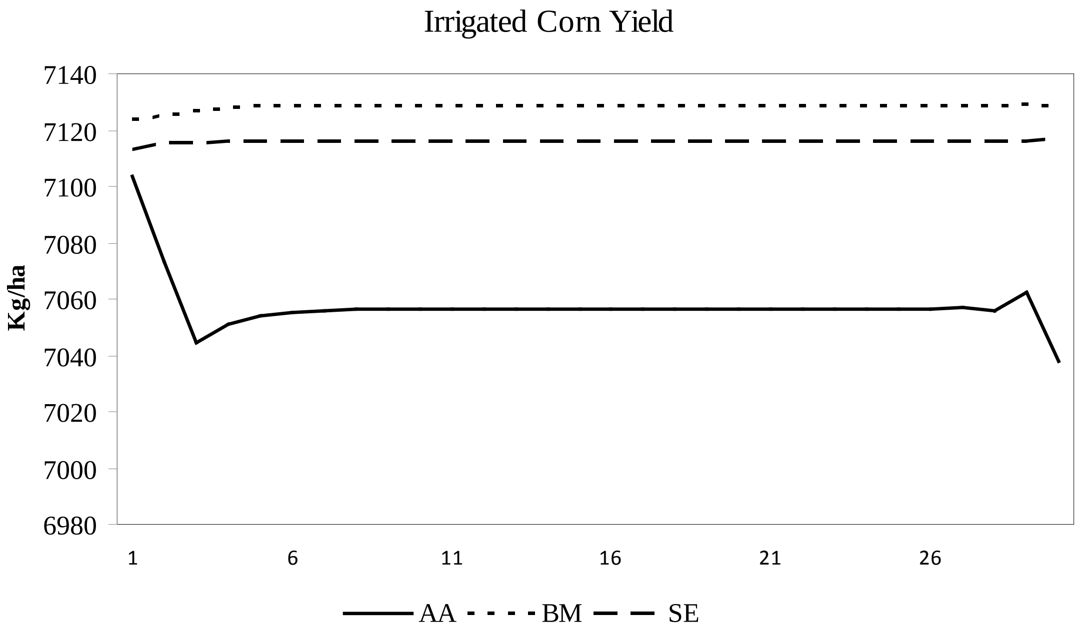

Figure I-7. Projected irrigated corn yield with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure

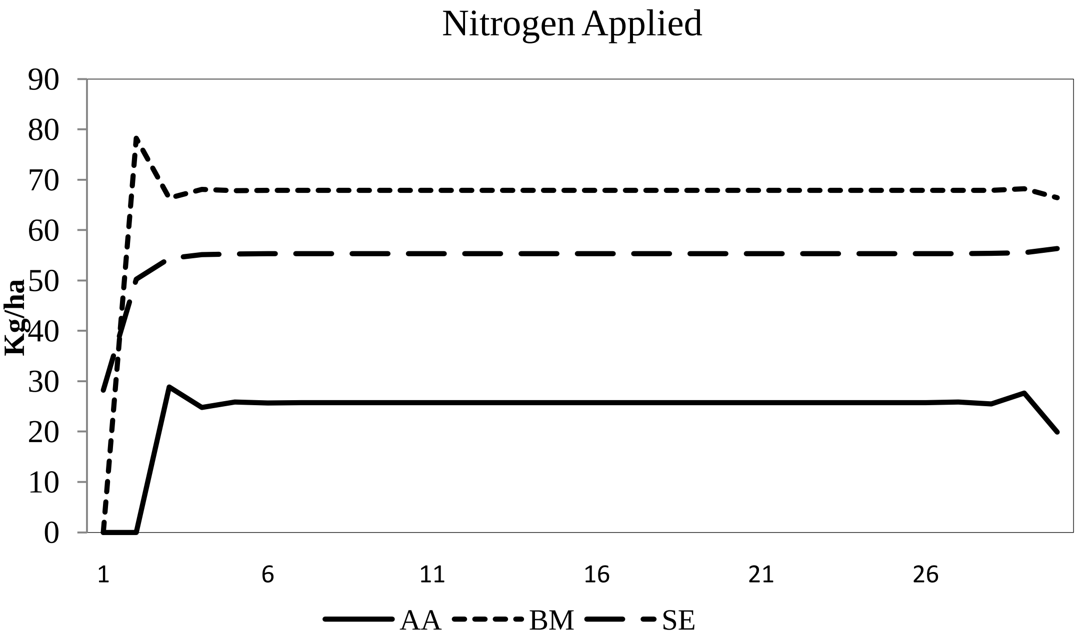

Figure I-8. Projected amount of nitrogen applied with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure (sensitivity analysis)

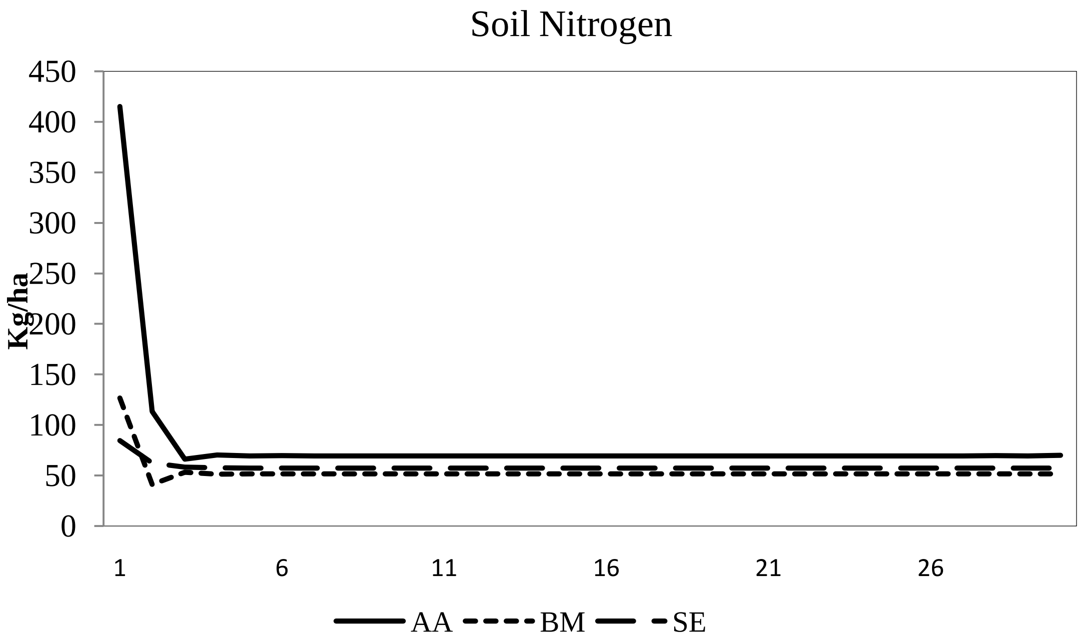

Figure I-9. **Projected soil nitrogen with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure (sensitivity analysis)**

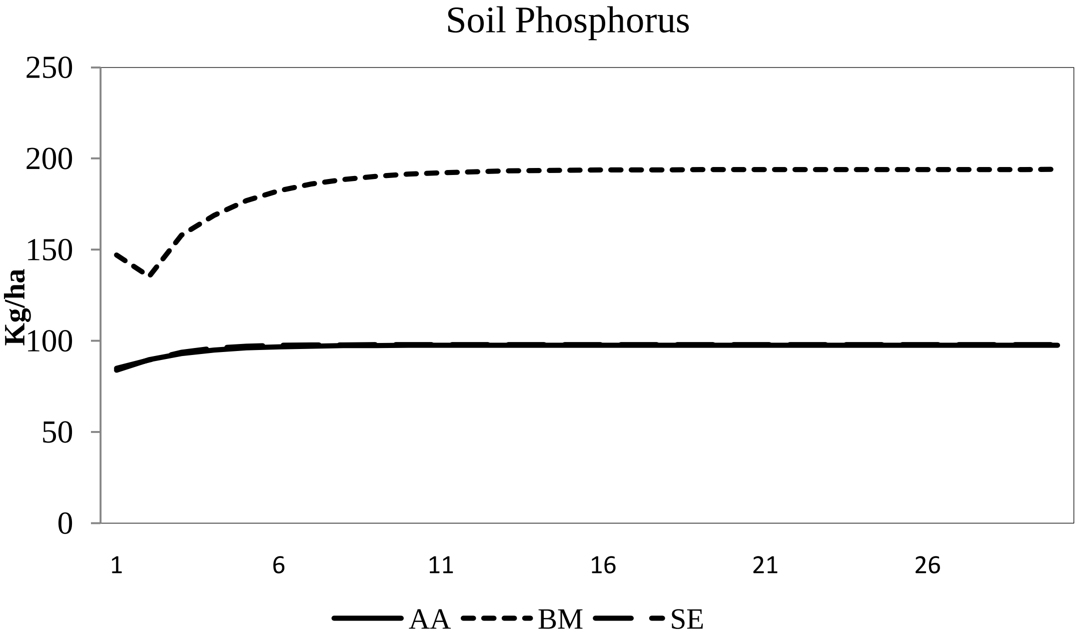

Figure I-10. Projected soil phosphorus with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure (sensitivity analysis)

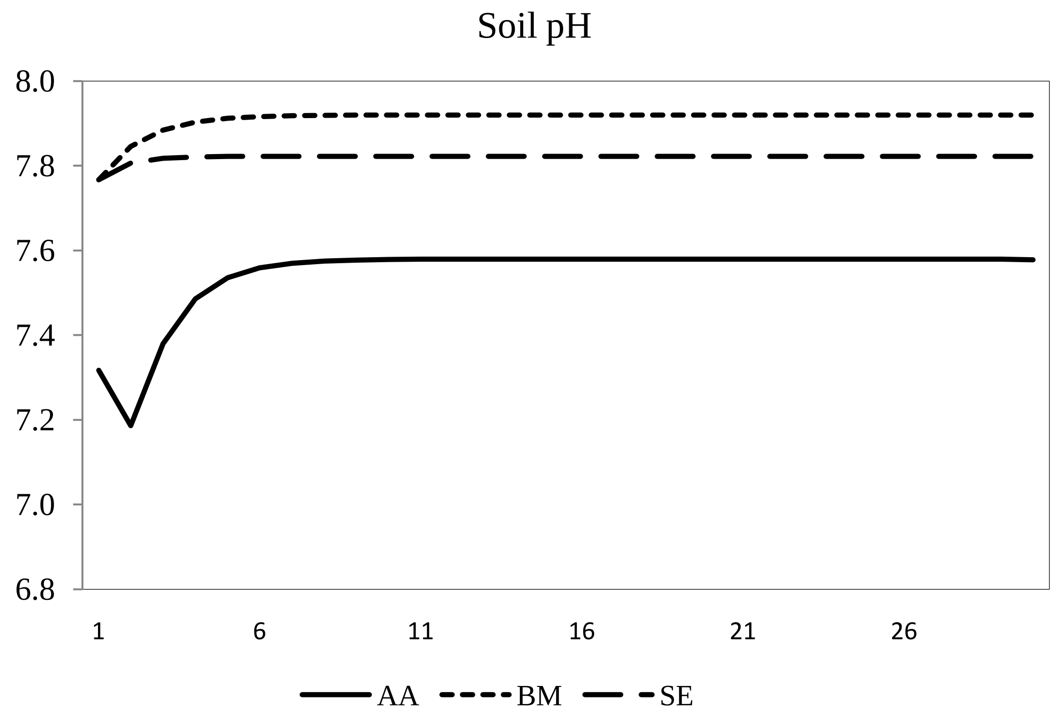

Figure I-11. **Projected soil pH with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure (sensitivity analysis)**

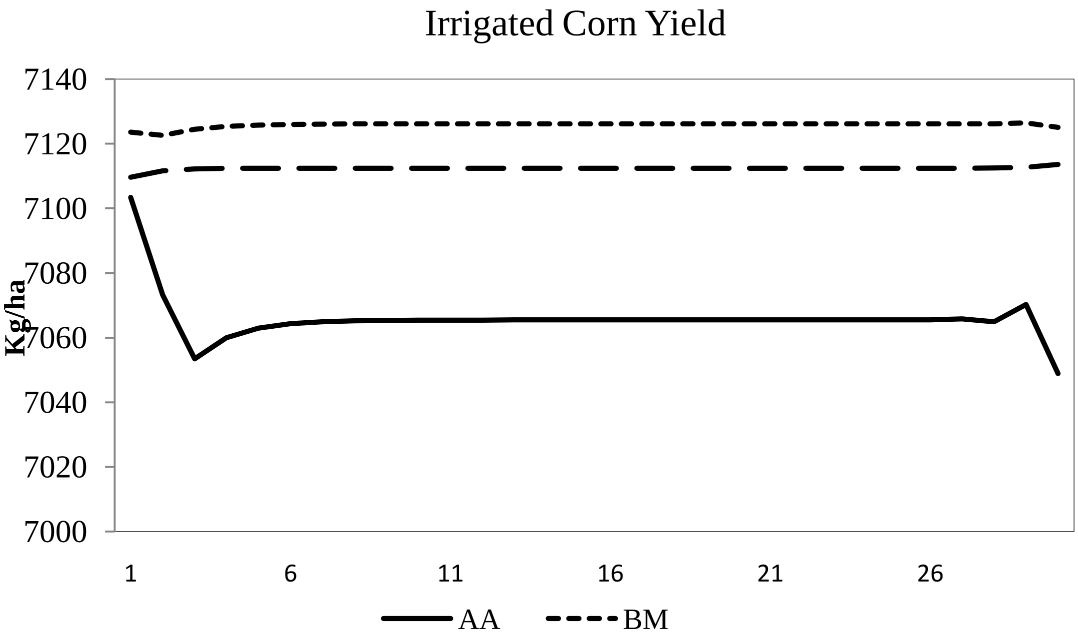

Figure I-12. **Projected irrigated corn yield with three nitrogen sources for the 30-year production horizon using the deterministic optimization procedure (sensitivity analysis)**

Table I-1. Soil N and P and soil pH levels at top 15 cm in depth.

NS	RATE	1995[†]	1998	1999	2000	[‡] 2002	2003	2004	2005
				Soil N (Kg ha^{-1})					
CTRL	0	141	79	26	23	64	63	44	29
AA	56	141	81	36	35	278	90	33	27
	168	141	317	51	65	348	112	39	29
	504	141	1186	119	622	493	267	70	39
BM	56	141	94	92	30	58	47	48	33
	168	141	145	31	47	90	71	77	45
	504	141	167	53	65	113	117	96	103
SE	56	141	85	23	20	120	61	47	31
	168	141	90	25	31	92	76	52	30
	504	141	102	31	25	96	80	42	35
				Soil P (Kg ha^{-1})					
CTRL	0	73	78	72	66	162	93	82	107
AA	56	73	79	82	55	128	95	95	117
	168	73	92	66	82	104	108	103	109
	504	73	80	92	97	123	102	132	121
BM	56	73	124	132	132	148	161	180	226
	168	73	117	163	150	223	213	511	438
	504	73	253	241	333	298	733	813	1257
SE	56	73	81	81	70	91	100	76	89
	168	73	99	92	70	102	95	85	114
	504	73	107	133	173	198	152	128	173
				Soil pH					
CTRL	0	7.8	7.8	7.9	7.9	7.6	7.7	7.7	7.8
AA	56	7.8	7.3	7.6	8.0	7.6	7.7	7.1	8.0
	168	7.8	7.2	7.3	6.9	7.5	7.4	6.9	7.7
	504	7.8	7.0	5.8	4.8	5.4	6.6	6.3	7.4
BM	56	7.8	7.9	8.2	8.1	8.2	7.6	7.7	7.8
	168	7.8	7.7	8.1	8.2	7.9	7.8	7.4	7.8
	504	7.8	7.8	8.1	8.1	8.0	7.7	7.5	7.8
SE	56	7.8	7.9	8.3	8.1	7.7	7.8	7.5	8.1
	168	7.8	7.8	8.3	8.2	8.2	7.8	7.6	8.0
	504	7.8	7.7	7.6	7.9	7.6	7.5	7.6	8.2

[†] The same values are an average of three soil samples from the entire field, not from each plot.

[‡] No soil sampling was made in 1996, 1997 and 2001.

Table I-2. Management and Production Practices for Irrigated Corn in Nitrogen Source and Nitrogen Rate Study Established on Oklahoma Panhandle Research and Extension Center (OPREC), 1995 through 2007.

Item	1995	1996	1997	1998	1999	2000	2001
Plant Date	20 Apr	16 Apr	17 Apr	22 Apr	6 May	13 Apr	19 Apr
Variety	Pioneer 3162	Pioneer 3162	Pioneer 3162	Pioneer 3162	Pioneer 3162	Pioneer 3162	Pioneer 33B51 (YGCB)
Plant Density (ha^{-1})	76,935	77,382	78,642	80,924	81,483	76,570	77,873
Fertilization							
AA	19 Apr	8 Apr	7 Apr	6 Apr	1 Mar	15 Mar	1 Nov†
BM	6 Apr	8 Apr	7 Apr	6 Apr	1 Mar	21 Feb	4 Apr
SE	20 Apr	22 Apr	30 Apr	5 Jun	10 Jun	6 Jun	11 Jun
Harvest Date	11 Sep	22 Oct	16 Oct	21 Sep	23 Sep	15 Sep	15 Sep
Sprays‡					4	1,2,3,6	
Cont'd	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	
Plant Date	15 Apr	18 Apr	20 Apr	19 Apr	20 Apr	30 Apr	
Variety	Pioneer 33B51 (YGCB)	Pioneer 33B51 (YGCB)	Pioneer 33B51 (YGCB)	Pioneer 33B51 (YGCB)	Pioneer 33B51 (YGCB)	Pioneer 33B51 (YGCB)	
Plant Density (ha^{-1})	78,385	79,184	76,698	78,486	79,774	81,510	
Fertilization							
AA	17 Feb	20 Nov†	9 Jan	15 Mar	16 Mar	19 Mar	
BM	19 Mar	17 Mar	17 Mar	15 Mar	16 Mar	17 Mar	
SE	11 Jun	20 May	25 May	8 Jun	5 Jun	2 Jun	
Harvest Date	27 Sep	30 Sep	1 Oct	30 Sep	27 Sep	10 Sep	
Sprays		7		5			

† Application was made in previous year.

‡ 1: Glyphosate (CAS# 38641-94-0), 2: Leadoff (CAS # 1912-24-9,163515-14-8), 3: Frontier (CAS# 81674-68-8), 4: Basic Gold (CAS# 1912-24-9,122931-48-0, 111991-09-04), 5:ATZ (CAS#1912-24-9,163515-14-8), 6: LOrsban (CAS# 2921-88-2), 7: Honcho.

Table I-3. Fertilizer Application Costs for Anhydrous Ammonia (AA), Beef Manure (BM), and Swine Manure (SE).

	Equivalent Nitrogen Rate (kg ha^{-1})								
	Anhydrous Ammonia			Beef manure			Swine Manure		
Item	56	168	504	56	168	504	56	168	504
	$ ha^{-1}								
Operating Costs									
Nitrogen Fert.	29.68	89.04	267.12	0[‡]	0	0	0	0	0
Fuel and lube	5.08	5.08	5.08	18.41	26.97	47.28	6.30	17.51	55.17
Labor	2.16	2.16	2.16	7.84	11.49	20.15	5.82	6.68	7.31
Repair	9.02	9.02	9.02	11.27	11.27	11.27	0.00	0.00	0.00
Fixed Costs[†]									
Depreciation	13.22	13.22	13.22	16.53	16.53	16.53	0	0	0
Interest	14.09	14.09	14.09	17.62	17.62	17.62	0	0	0
Insurance	3.01	3.01	3.01	3.76	3.76	3.76	0	0	0
Total	76.26	135.62	313.70	75.42	87.64	116.60	12.12	24.19	62.48

[†] Tractor fixed costs not included since tractor is not exclusively required for fertilizer operations.

[‡] Anhydrous requires applicator and beef manure requires spreader; no special equipment required to apply swine manure.

Table I-4. Analysis of Variance for Corn Yield and Economic Returns.

Name and Type of Effects	df	Yield	Economic Returns	Economic Returns (Sensitivity Scenario)
Fixed Effects		*P*> F	*P*> F	*P*> F
NS (Nitrogen Source)	2	0.0002	<0.0001	<0.0001
NR (Nitrogen Rate)	3	0.0247	0.1921	0.2323
Random Effects				
YR (Year)	12	<0.0001	<0.0001	<0.0001
Block	2	0.8745	0.8797	0.8745
Interaction Terms				
NS×NR	6	0.0482	<0.0001	<0.0001
NS×YR	24	0.9936	0.9935	0.9936
NR×YR	36	0.0293	0.0286	0.0293
NS×NR×YR	72	0.5454	0.5555	0.5572

Table I-5. Main Effects of Nitrogen Source (NS) and Equivalent Nitrogen Rates (NR) and Their Interaction (NS×NR) on Irrigated Corn Yield.

Effect	All Years	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
	-- kg ha^{-1} --													
Nitrogen Source (NS)														
AA	6438B†	3094	2376	8543	8321	8648	2156	3921	9845	7181	8595	4435	6690	9890
BM	7041A	5144	3646	8973	9436	8752	2894	5222	8788	7476	8874	5352	7122	9856
SE	6941A	4843	3419	8477	8909	7817	2628	5106	10201	7290	9031	5399	6229	10 877
Nitrogen Rate (NR)														
CTRL	6206B	3702	2734	8173	8317	7491	2022	4050	9220	7169	8761	4355	5692	8987
56	6897A	4596	3052	8481	9138	8712	2688	4869	9931	7406	9167	5128	6277	10 216
168	7011A	4480	3220	8858	9163	8875	2441	5083	10035	7195	8398	5289	7287	10 821
504	7113A	4489	3323	9278	9084	8658	2785	4851	9459	7530	9152	5352	7457	11 048
NS×NR														
CTRL	6205Ae‡	3723	2647	8129	8307	7628	1988	4089	9134	6974	8537	4398	5858	9259
AA×56	6600Acde	4315	2876	8483	8749	8255	2227	4593	9386	7078	8526	4846	6370	10 099
BM×56	7094Abc	4625	3363	8779	9174	8748	2860	5089	9993	7520	9234	5352	6913	10 565
SE×56	6997Abcd	4497	3202	8787	9170	8780	2793	4853	9897	7493	9083	5239	6751	10 414
AA×168	6903ABbcd	4359	3169	8537	9084	8718	2523	4938	9793	7277	8834	5227	6796	10 482
BM×168	7550Aab	5020	3768	9436	9593	9185	3173	5440	10417	8007	9401	5786	7735	11 189
SE×168	6581Bcde	4219	2889	8627	8688	8262	2243	4578	9402	6892	8251	4804	6556	10 139
AA×504	6314Cde	3985	2646	8271	8341	7752	2073	4189	8786	6825	8349	4603	6318	9946
BM×504	7135Bbc	4593	3414	9139	9215	8870	2825	4969	10081	7524	9211	5255	6967	10 697
SE×504	7889Aa	5251	4073	9747	9971	9595	3536	5838	10512	8317	9749	6233	8162	11 571
Year (YR)														
Year	6807	4335	3110	8683	8910	8422	2516	4729	9640	7321	8854	5044	6679	10 242

† Within a column, means followed by a different capital letter are significantly different at $P \leq 0.05$.

‡ Within a column, means followed by a different capital letter are significantly different at $P \leq 0.05$ within each nitrogen rate. Means followed by a lowercase letter are significantly different at $P \leq 0.05$ across the interaction term of NS×NR.

Table I-6. **Main Effects of Nitrogen Source (NS) and Equivalent Nitrogen Rates (NR) and Their Interaction (NS×NR) on Economic Returns.**

Effect	All Years	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
		---------- kg ha^{-1} ----------												
Nitrogen Source (NS)														
AA	263.06B†	-49.75	-208.62	499.93	529.76	472.50	-282.30	0.79	620.00	322.31	515.91	40.93	252.28	706.04
BM	445.43A	132.62	-26.25	682.30	712.13	654.87	-99.93	183.16	802.37	504.68	698.28	223.30	434.65	888.41
SE	477.88A	165.07	6.20	714.75	744.58	687.32	-67.48	215.61	834.82	537.13	730.73	255.75	467.10	920.86
Nitrogen Rate (NR)														
CTRL	394.57A	81.76	-77.11	631.44	661.27	604.01	-150.79	132.30	751.51	453.82	647.42	172.44	383.79	837.55
56	427.27A	114.46	-44.41	664.14	693.97	636.71	-118.09	165.00	784.21	486.52	680.12	205.14	416.49	870.25
168	414.43A	101.62	-57.25	651.30	681.13	623.87	-130.93	152.16	771.37	473.68	667.28	192.30	403.65	857.41
504	345.56A	32.75	-126.12	582.43	612.26	555.00	-199.80	83.29	702.50	404.81	598.41	123.43	334.78	788.54
NS×NR														
CTRL	394.67Acd‡	79.37	-58.09	638.68	661.67	576.44	-141.49	126.05	766.18	490.91	689.23	165.32	351.76	783.39
AA×56	337.63Bcd	46.46	-135.08	576.98	610.52	547.96	-217.07	82.50	692.01	398.73	583.25	115.02	309.41	778.49
BM×56	446.59ABbc	133.16	-26.99	662.06	711.13	656.62	-91.41	191.58	814.61	501.37	717.98	225.34	424.19	886.01
SE×56	497.59Aab	180.35	16.21	725.60	773.34	723.20	-36.82	225.81	865.65	560.83	762.39	274.38	467.26	930.46
AA×168	318.24Bd	-4.34	-155.71	527.49	594.89	547.67	-237.49	68.11	685.07	366.72	564.30	104.97	304.75	770.68
BM×168	492.35Aab	171.51	12.55	732.01	752.33	700.09	-63.05	224.67	856.37	550.86	728.77	268.37	514.04	952.02
SE×168	432.69Abc	132.15	-36.18	691.64	700.49	645.94	-118.00	177.95	791.17	473.58	647.33	207.25	429.08	882.57
AA×504	65.37Ce	-231.25	-400.71	313.49	323.43	249.30	-473.57	-204.16	381.76	130.30	323.99	-152.13	65.17	524.14
BM×504	410.74Bbcd	88.39	-61.79	664.56	675.18	630.51	-136.56	136.24	784.26	460.97	674.22	172.78	389.80	861.06
SE×504	560.57Aa	226.68	76.65	796.87	825.26	776.86	8.16	300.07	895.22	615.61	798.04	349.64	592.89	1025.47
Year (YR)														
Year	395.45	82.64	-76.23	632.32	662.15	604.89	-149.91	133.18	752.39	454.70	648.30	173.32	384.68	838.43

† Within a column, means followed by a different capital letter are significantly different at $P \leq 0.05$.

‡ Within a column, means followed by a different capital letter are significantly different at $P \leq 0.05$ within each nitrogen rate. Means followed by a lowercase letter are significantly different at $P \leq 0.05$ across the interaction term of NS×NR.

Table I-7. Main Effects of Nitrogen Source (NS) and Equivalent Nitrogen Rates (NR) and Their Interaction (NS×NR) on Economic Returns.

Effect	All Years	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
	------ kg ha^{-1} ------													
Nitrogen Source (NS)														
AA	154.34C†	-199.66	-275.65	377.18	353.61	388.30	-298.93	-112.12	514.97	232.99	382.70	-57.73	181.01	519.76
BM	296.26B	95.41	-63.17	500.79	549.78	477.36	-142.78	103.70	481.22	342.31	490.28	117.45	304.80	594.26
SE	330.84A	108.76	-41.90	493.46	539.21	423.59	-125.65	136.68	676.00	367.84	552.16	167.70	255.56	747.54
Nitrogen Rate (eNR)														
CTRL	263.1AB	-1.89	-104.42	471.34	486.59	399.13	-179.78	34.90	582.24	365.07	533.63	67.23	208.69	557.58
56	284.47A	40.86	-122.58	452.14	521.73	476.65	-161.06	69.85	605.62	338.32	524.78	97.18	218.82	635.81
168	274.29AB	6.36	-127.00	469.83	502.05	471.57	-209.48	70.21	594.35	293.74	421.05	92.01	303.49	677.60
504	220.07B	-57.70	-181.11	449.23	428.75	383.67	-238.06	-19.40	468.45	264.23	435.95	33.71	256.55	636.67
NS×NR														
CTRL	263.10Acd‡	0.43	-114.57	466.26	485.57	415.15	-183.85	39.41	572.34	342.49	507.64	72.15	228.04	589.24
AA×56	207.73Bde	-35.76	-186.28	406.90	434.71	382.64	-254.38	-5.32	502.92	258.51	412.55	22.00	184.39	577.61
BM×56	296.31Abc	35.06	-98.27	476.41	516.70	471.10	-152.26	83.49	602.59	342.13	521.96	111.80	277.77	663.54
SE×56	349.36Aab	85.04	-51.49	539.54	578.76	536.66	-96.32	123.07	655.67	401.98	569.71	163.28	324.45	711.32
AA×168	197.20Be	-71.40	-197.68	372.30	427.33	387.58	-265.62	-11.70	502.52	237.96	402.50	19.11	185.82	574.88
BM×168	332.40Aab	65.19	-67.18	531.94	549.13	505.35	-130.15	109.39	635.46	381.22	529.96	145.69	349.29	715.89
SE×168	293.27Abc	42.37	-97.53	508.31	516.29	470.64	-165.50	80.67	591.88	327.94	473.32	105.39	289.83	668.90
AA×504	7.20Cf	-240.55	-381.36	213.54	222.39	161.01	-442.12	-217.29	272.00	61.18	222.59	-174.29	6.50	389.98
BM×504	259.57Bcde	-8.85	-134.17	470.49	479.88	442.18	-196.47	31.09	570.26	301.74	478.86	61.64	242.21	635.55
SE×504	393.44Aa	115.74	-9.45	590.28	613.96	573.26	-66.71	176.20	672.91	439.47	591.83	217.22	418.87	781.14
Year (YR)														
Year	260.48	-0.64	-130.11	458.77	482.69	431.15	-192.84	40.95	559.85	314.83	476.82	74.28	247.01	623.50

† Within a column, means followed by a different capital letter are significantly different at $P \leq 0.05$.

‡ Within a column, means followed by a different capital letter are significantly different at $P \leq 0.05$ within each nitrogen rate. Means followed by a lowercase letter are significantly different at $P \leq 0.05$ across the interaction term of NS×NR

Table I-8. Maximum Likelihood Parameter Estimates of Irrigated Corn Yield Function Computed with the Gauss-Newton Method in SAS Proc NLMIXED..

Variables	Symbol	Parameter Estimates	P-Values
Maximum corn yield for AA fertilizer	η_{01}	7220*	<0.0001
Adjustment of η_{01} for BM fertilizer	η_{02}	4.88	0.9903
Adjustment of η_{01} for SE fertilizer	η_{03}	2.23	0.9956
Total available nitrogen	η_{11}	-0.0513*	<0.0001
Total available phosphorus	η_{21}	-0.2160	0.4717
Soil pH	η_{31}	-0.5639*	0.0074
Variance	σ_{ε}^{2}	6453680*	<0.0001

Note: * Parameter significant at the 1 percent significance level. N=

Table I-9. Soil Nitrogen Carryover Function Maximum Likelihood Parameter Estimates Computed in SAS Proc AUTOREG (kg/ha/year)

	Regression Coefficient Estimates (P-values in brackets)		
	AA	BM	SE
Intercept (λ_0^s)	122.56 (0.0001)	52.23 (0.0015)	69.58 (<.0001)
Lag of nitrogen applied (λ_1^s)	0.4234 (0.0350)	0.0892 (0.0120)	-0.0162 (0.6568)
Lag of soil nitrogen(λ_2^s)	0.2234 (0.0221)	-0.0387 (0.7939)	0.3253 (0.0011)
Corn yield(λ_3^s)	-0.0128 (0.0048)	-0.0004 (0.8270)	-0.0048 (0.0060)
Variance intercept (ϕ_0^s)	60.54 (<.0001)	31.93 (<.0001)	34.66 (<.0001)
Variance due to N applied (ϕ_1^s)	0.0065 (<.0001)	0.0004 (0.6672)	-0.0033 (0.1001)

Note: *N*=72 for AA, BM, and SE, respectively

Table I-10. Soil Phosphorus Carryover Function Maximum Likelihood Parameter Estimates Computed in SAS Proc AUTOREG (kg/ha/year)

	Regression Coefficient Estimates (P-values in brackets)		
	AA	BM	SE
Intercept (δ_0^s)	41.33 (0.0027)	27.83 (0.1968)	46.18 (0.1553)
Lag of phosphorus applied (δ_1^s)	--	0.5201 (0.0068)	0.3243 (0.0911)
Lag of soil phosphorus(δ_2^s)	0.5766 (<.0001)	0.7093 (<.0001)	0.4502 (<.0001)
Variance intercept (κ_0^s)	37.29 (<.0001)	50.59 (<.0001)	96.74 (<.0001)
Variance due to P applied (κ_1^s)	--	0.0082 (<.0001)	-0.0147 (<.0001)

Note: *N*=72 for AA, BM, and SE, respectively

Table I-11. Soil pH Carryover Function Maximum Likelihood Parameter Estimates Computed in SAS Proc AUTOREG (kg/ha/year)

	Regression Coefficient Estimates (P-values in brackets)		
	AA	BM	SE
Intercept (γ_0^s)	3.97 (<.0001)	3.68 (0.0021)	5.65 (<.0001)
Lag of soil pH (γ_1^s)	0.4959 (<.0001)	0.5359 (0.0004)	0.2822 (0.0061)
Lag of total available nitrogen(γ_2^s)	-0.0008 (0.0005)	-0.0008 (0.6285)	-0.0003 (0.5133)
Variance intercept (φ_0^s)	0.4367 (<.0001)	0.2412 (<.0001)	0.4083 (<.0001)
Variance due to N applied (φ_1^s)	0.0039 (<.0001)	0.0007 (0.0241)	-0.0010 (<.1125)

Note: *N*=72 for AA, BM, and SE, respectively

Table I-12. Maximum Likelihood Parameter Estimates of Nitrogen Loss Function through Ammonia Volatilization in Application of Swine Effluent Using SAS Proc AUTOREG

Variables	Symbol	Parameter Estimates	P-Values
Intercept	ψ_0	-156.36	<0.0001
Soil pH	ψ_1	25.11	<0.0001
Nitrogen applied	ψ_2	0.0311	0.0387
Variance intercept	τ_0	28.45	0.0013
Variance due to N applied	τ_1	-0.0060	<0.0001

Note: N= 72

Table I-13. Summary Solution for Deterministic Model When Price of Corn =\$126.11 MG^{-1} and Price of AA=\$0.53 N kg $^{-1}$.

		Nitrogen Sources		
Variables	Unit	AA	BM	SE
Nitrogen Applied				
Annual average	kg/ha	22	69	58
Steady state level	kg/ha	24	71	59
Lifetime application	kg/ha	656	2071	1737
Soil Nitrogen				
Average over time	kg/ha	82	54	58
Steady state level	kg/ha	69	52	57
Soil Phosphorus				
Average over time	kg/ha	97	190	98
Steady state level	kg/ha	98	198	99
Soil pH				
Average over time	kg/ha	7.5	7.9	7.8
Steady state level	kg/ha	7.6	7.9	7.8
Corn Yield				
Average over time	kg/ha	7,058	7,128	7,116
Steady state level	kg/ha	7,057	7,129	7,116
Lifetime yield	kg/ha	211,725	213,850	213,479
Net Present Value				
Lifetime NPV	$	8474.07	8288.32	9269.08

Table I-14. Summary Solution for Deterministic Model When Price of Corn =$105.88 MG^{-1} and Price of AA=$0.38 N kg $^{-1}$.

		Nitrogen Sources		
Variables	Unit	AA	BM	SE
Nitrogen Applied				
Annual average	kg/ha	24	66	54
Steady state level	kg/ha	26	68	55
Lifetime application	kg/ha	719	1976	1628
Soil Nitrogen				
Average over time	kg/ha	82	54	59
Steady state level	kg/ha	70	52	57
Soil Phosphorus				
Average over time	kg/ha	97	187	97
Steady state level	kg/ha	98	194	98
Soil pH				
Average over time	kg/ha	7.5	7.9	7.8
Steady state level	kg/ha	7.6	7.9	7.8
Corn Yield				
Average over time	kg/ha	7,066	7,126	7,112
Steady state level	kg/ha	7,065	7,126	7,112
Lifetime yield	kg/ha	211,976	213,776	213,371
Net Present Value				
Lifetime NPV	$	6240.65	5984.31	6969.20

Table I-15. Comparison of Steady State Values under the Change in Prices of Both Corn and Anhydrous Ammonia.

		Nitrogen Sources					
	Unit	AA		BM		SE	
		A	B	A	B	A	B
Steady State Variables							
Nitrogen Applied	kg/ha	24	26	71	68	59	55
Soil Nitrogen	kg/ha	69	70	52	52	57	57
Soil Phosphorus	kg/ha	98	98	198	194	99	98
Soil pH	kg/ha	7.6	7.6	7.9	7.9	7.8	7.8
Corn Yield	kg/ha	7,057	7,065	7,129	7,126	7,116	7,112
Net Present Value							
Lifetime NPV	$	8,474	6,241	8,288	5,984	9,269	6,969

Note: A is when price of corn is $126.11 per MT and price of AA is $ 0.53 per N kg. B is when price of corn is $105.88 per MT and price of AA is $0.38 per N kg.

Table I-16. Optimal Recommended Nitrogen Management Strategies with Two Approaches

	A		B	
	NS	NR	NS	NR
ANOVA	SE	504	SE	504
Optimization	SE	59	SE	55

Note: A is when price of corn is $126.11 per MT and price of AA is $ 0.53 per N kg. B is when price of corn is $105.88 per MT and price of AA is $0.38 per N kg.

PAPER II

A COX NON-NESTED TEST USING A FAST DOUBLE BOOTSTRAP

Introduction

The functional form of empirical production functions have taken much attention due to different elasticity estimates under the different specifications (Dameus et al., 2002). Ackello-Ogutu et al. (1985) argued polynomial specification of crop response function to fertilizer nutrients such as nitrogen (N), phosphorous (P), and potassium (K) generated a higher optimal level of fertilizer, which leads to environmental damage from the over use of fertilizer.

The von Liebig function was regarded as an alternative to polynomial functions to arrive at a more accurate optimal application level of fertilizer because variability and randomness can be included in this specification (Katibie et al., 2007). A multiple logistic model of forage response to applied nitrogen, phosphorous, and potassium was developed and extended to include plant uptake of N, P, and K (Overman et al.,1990; 1995).

Previous model selection tests regarding a crop functional form have been done through different statistical procedures. Ackello-Ogutu et al. (1985) tested a von Liebig crop response function against a polynomial specification using C-test by Davidson and

MacKinnon (1981) for the computational simplicity. Paris (1992) used a nonnested P-test between a nonlinear von Liebig switching regression model and a nonnested Mitscherllich-Baule function. Katibie et al. (2007) adopted a Cox parametric bootstrap method to select between two functional forms of the von Liebig livestock production; a switching regression and a linear response function with a stochastic plateau function. A test for functional forms is also considered a test between competing theories since a production model is derived based on theoretical assumptions (Katibie et al., 2007).

A non-nested test that has been widely used is to calculate a bootstrap P value which is simply the proportion of the simulated log likelihood ratio statistics that are more extreme than the actual log likelihood ratio statistics (Davison and MacKinnon 2007). Although several previous studies (Davidson and MacKinnon 1999; MacKinnon 2002; Park 2003) also showed that bootstrap test yields more reliable inferences than asymptotic test, Goddfrey (2007) argued that using estimated parameters, the bootstrap values have too large a variance, which results in an asymptotically invalid significance test. There are some solutions suggested for the problem of the asymptotic validity of a bootstrap method. One appropriate approach to improve the reliability of nonnested test with bootstrap method is to use the fast double bootstrap but there is no research on non-nested test using this approach.

This paper tests production theory using a dry-matter yield of grass fertilized with swine effluent. The specification for model is first tested and then the Cox non-nested test with both a bootstrap and fast double bootstrap method is used to test among two competing production functional forms. In addition, for each model, the expected optimal nitrogen level is calculated with the random deviates for parameter estimates in each model. Finally, the expected profits for the two functions are compared to one another.

Production Theory

A simple neoclassical production function for a single output and *n* variable inputs is written as

(1) $y = f(x_1, \cdots, x_n)$

where y is the output quantity and x_i is the quantity of i^{th} variable input. Four main assumptions for equation (1) are specified by Chambers (1988): a) finite real inputs i.e. nonnegative $(x_i \geq 0)$, which implies that any finite, nonnegative combination of inputs is possible, b) finite, nonnegative single valued output for all possible combinations of inputs, c) $f(x_1, \cdots, x_n)$ is a continuously first and second differentiable function, and d) $f(x_1, \cdots, x_n)$ shows diminishing returns to the increase in input.

The existence of the negative marginal productivity is challenged by some writers (Samuelson, 1983; Chambers, 1988) but is found in the circumstance where uncertainty matters. Empirically, when we use data in which an actual output decreases at the higher input level the estimation of a production function with a constant or never decreasing output even at higher input rate (i.e. logistic function) is biased (Hall, 1998).

One advantage of neoclassical production theory is that various production functions are allowed with assumptions mentioned above. A production model with a single input variable (x_1), a special case of equation (1), is considered in this paper as,

$$(2) \qquad y = f(x_1 \mid x_2^0, \cdots x_n^0)$$

where $x_2^0, \cdots x_n^0$ are other given input variables.

Although the possible substitution among inputs cannot be analyzed with a function with a single input variable, a simplified model is still useful in examining agronomic experimental data in which output changes according to different treatment levels in a single input.

Nonnested Hypotheses Test

Bootstrap

Two models are said to be nonnested when one regression model can not be expressed as a special case of the other. Two competing nonnested models (Model A and B) with the same set of independent variables from the same observation are presented. The nonnested hypotheses for two models under the null hypothesis that model A is the true functional form can be written as follows;

$$(3) \qquad \begin{array}{l} H_0 : Y = f(X,\ \beta_0,\ \sigma_0^2) \\ H_1 : Y = g(X,\ \beta_1,\ \sigma_1^2) \end{array}$$

where *Y* is a vector of dependent variables, X is a matrix of independent variables, β_0 and β_1 are parameter vectors under the null and alternative hypotheses, and σ_0^2 and σ_1^2 are variances of the error term under the null and alternative hypotheses.

Cox's nonnested test is based on a likelihood ratio but it does not have a χ^2 distribution. The Cox's test statistic is based on a log likelihood ratio and its expected value (Cox, 1962). The Cox test statistic is the difference between the log-likelihood ratio and the expected value of the log-likelihood ratio. The Cox test statistic for testing the null hypothesis against the alternative hypothesis is written as

$$(4) \qquad T_0 = L_{01} - E_0(L_{01})$$

where L_{01} is the log-likelihood ratio which is the difference in the estimated maximum log-likelihoods under the null and alternative hypotheses ($L_{01} = L_0(\hat{\beta}_0) - L_1(\hat{\beta}_1)$), $E_0(L_{01})$ is the expected value of the log-likelihood ratio under the null and alternative hypotheses, $\hat{\beta}_0$ and $\hat{\beta}_1$ are the maximum likelihood parameter estimates of the null and alternatively hypotheses, respectively, and T_0 is a Cox test statistic under the null hypotheses, which is asymptotically distributed with mean zero and variance φ_0^2 (Cox,1962) . The Cox statistic for testing the alternative hypotheses against the null hypotheses is written as $T_1 = L_{10} - E_1(L_{10})$.

While the log likelihood ratio is relatively easy to calculate, difficulty is found in calculating the expected value of the log-likelihood ratio and its variance. To address this problem, several approaches including stochastic simulation (Pesaran and Pesaran, 1993; 1995), and Monte Carlo hypothesis testing procedures (Lee and Brorsen, 1994; Coulibaly and Brorsen, 1999) have been developed.

The Cox's nonnested test with a parametric bootstrap was adopted in this paper since it can have the correct size and high power in both small and large sample sizes (Coulibaly and Brorsen, 1999). The parametric bootstrap generates Monte Carlo samples with same number of observations as the original data using parameters estimated under the hull hypothesis (Katibie et al., 2007).

The model selection procedure, using the Cox test with a parametric bootstrap, is as follows according to Dameus et al.(2002): a) two competing models are estimated with actual observation, b) an actual log-likelihood ratio is calculated with two log-likelihood values for each model, c) under the null hypothesis, a large number of Monte Carlo samples are generated with the distribution assumption, d) two models are estimated for each generated sample and a corresponding log-likelihood ratio for each sample is calculated, e) the p-value is obtained with a percentile method which compares the actual log-likelihood ratio and the simulated log-likelihood ratio, and f) this test needs to be implemented for each null hypothesis, in our case, one for the null hypothesis that a quadratic function is true and the other for the null hypothesis that a logistic model is a true model.

The ordinary bootstrap p-value here is based on the Cox test by Coulibaly and Brorsen (1999):

$$(5) \qquad p\text{ - value} = \frac{\left(numb[L_0(\hat{\theta}_{0j}, y_j) - L_1(\hat{\theta}_{1j}, y_j) \leq \hat{L}_{01}] + 1\right)}{NS + 1}$$

where $numb[\cdot]$ is the number of realizations for which the specified relationship is true. NS is the number of generated samples with N observation, $\hat{L}_{01}$ is an actual log-likelihood ratio calculated under the null and alternative hypotheses, $L_0(\cdot)$ - $L_1(\cdot)$ is a log-likelihood ratio for each generated sample with the null and alternative hypotheses. The value one is added to both numerator and denominator to correct small sample problems. The small *p*-value forces us to reject the null hypothesis because the obtained p-value means the area to the left of the Cox test statistic (Coulibaly and Brorsen, 1999).

Fast double bootstrapping

Beran (1988) introduced the double bootstrapping method. The double bootstrap can be a reliable test which produces more accurate p values than ordinary bootstrap p values. However, the double bootstrapping method is costly in terms of computation since it requires generating second-level bootstrap samples for each first-level bootstrap sample in the same way as the first-level bootstrap samples were obtained from the actual sample. Therefore, the fast double bootstrap, or FDB, was proposed by Davidson and MacKinnon (2001). The computational demand can be greatly reduced with FDB, which only needs one second-level bootstrap sample for each first-level bootstrap sample. However, for FDB to be valid, the distribution of statistics from the second-level bootstrap samples must be independent of the distribution of statistics from the first-level bootstrap samples.

The calculation of a p-value with Cox nonnested test using an ordinary bootstrap in equation 5 can be rewritten as

$$(6)\quad p^*(\hat{L}_{01}) = p\text{-value} = \frac{1}{B+1}[\sum_{j=1}^{B} I(L^*_{01,j} < \hat{L}_{01}) + 1]$$

where $p^*(\hat{L}_{01})$ is the bootstrap P value, $I(\cdot)$ is a indicator function that take a value 1 when the specified relationship is true. B is the number of generated samples for $j = 1, \cdots, B$. $\hat{L}_{01}$ is an actual log-likelihood ratio calculated under the null and alternative hypotheses, $L^*_{01,j}$, which is $L_0(\cdot) - L_1(\cdot)$, is a log-likelihood ratio for the jth generated sample of the first-level bootstrap with the null and alternative hypotheses.

The P-value based on a Cox-nonnested test using the fast double bootstrap can be easily calculated:

$$(7)\quad p_F^{**}(\hat{L}_{01}) = \frac{1}{B+1}[\sum_{j=1}^{B} I(L^{*}_{01,j} < \hat{Q}_B^{**}(p^{*}(\hat{L}_{01})) + 1]$$

where $p_F^{**}(\hat{L}_{01})$ is the fast double bootstrap P value, $\hat{Q}_B^{**}(p^{*}(\hat{L}_{01}))$ is the $p^{*}(\hat{L}_{01})$ quantile of $L^{**}_{01,j}$ which is a log-likelihood ratio for the j^{th} generated sample of the second-level bootstrap with the null and alternative hypotheses.

Data

Dry-matter yields of Bermudagrass were obtained from an experiment conducted at the Oklahoma Panhandle Research and Extension Center (OPREC) near Goodwell, OK (36°35 N, 101°37 W, and elevation 992 m) from 1997 to 2005. Mean annual precipitation and temperature at the station are 435 mm and 13.2 °C, respectively. The predominant soil series at this site is a Gruver soil series (fine, mixed, superactive, mesic Aridic Paleustoll) on 0-2% slopes.

Swine-effluent was obtained from a local anaerobic single stage lagoon near the research station and the urea was obtained from a fertilizer dealer. Effluent and urea rates of 56 and 168 kg N ha^{-1} were applied after the first monthly cutting, during the June harvest. The 504 kg N ha^{-1} rate was split into two applications, the first after the June harvest and the second after the July harvest. All plots were fully irrigated under a center-pivot irrigation system.

Soil residual nitrogen levels were measured in 1997 and 2001. The actual level of applied nitrogen from the effluent is used instead of the intended nitrogen level to ensure the variability of nitrogen value in the manure. Figure II- 1 shows the relationship between dry matter yield of bermudagrass and levels of total available nitrogen which is sum of soil residual nitrogen and amount of nitrogen actually applied.

The price of bermudagrass hay is assumed to be \$35 per ton according to Kopp (2007). The market value of nitrogen in the swine effluent is assumed to be \$0.15 per kg (Carreira 2004). Total operating costs other than fertilizers are assumed to be \$575 per ha (Brees and Carpenter, 2006). The average soil residual nitrogen is 87.17 kg per ha based on the experimental data.

Objective Function

Assume a farmer who wants to maximize expected profit from growing Bermudagrass using swine effluent as a nitrogen fertilizer. Since a production function is provided to a farmer, his decision problem regarding an optimal nitrogen level with a quadratic production hypothesis can be represented as

$$(8) \qquad \max_{NA} \mathrm{E}(\pi) = p \cdot \mathrm{E}[f(TAN)] - r \cdot NA - TOC$$

$$f(TAN) = \alpha + \beta(TAN) + \rho(TAN)^2 + \varepsilon$$

$$TAN = NA + SN$$

$$NA, \text{and } SN \geq 0,$$

where π is the profit (\$/ha), p is the price of grass (\$/Mg), r is the price of swine effluent(\$/kg), $f(TAN)$ is a quadratic production function (Mg/ha), TOC is total operating costs, TAN is the total available nitrogen to plant(Kg/ha), NA is the amount of nitrogen in swine effluents applied(kg/ha), SN is the soil residual nitrogen(kg/ha), and $\alpha,\ \beta,$ and ρ are the parameters to be estimated, and ε_i is the error term, $\varepsilon \sim N\left(0,\ \ \sigma^2\right)$.

A farmer's decision problem regarding an optimal nitrogen level with a logistic production hypothesis can be represented as,

$$\text{(9)} \qquad \max_{NA}\ \mathrm{E}(\pi) = p \cdot \mathrm{E}[\mathrm{g}(TAN)] - r\ \cdot NA - TOC$$

$$g(TAN) = \frac{A}{1 + \exp(\gamma - \eta(TAN))} + \varpi$$

$$TAN = NA + SN$$

$$NA, \text{and } SN\ \geq\ 0\,,$$

where π is the profit (\$/ha), p is the price of grass (\$/Mg), r is the price of swine effluent(\$/kg), $g(TAN)$ is a logistic production function (Mg/ha), TOC is total other costs, TAN is the total available nitrogen to plant(Kg/ha), NA is the amount of swine effluents applied(kg/ha), SN is the soil residual nitrogen(kg/ha), and A is a maximum dry matter yield (Mg/ha), γ is an intercept parameter for dry matter yield, η is a response coefficient (ha/kg), and ϖ is the error term $\varpi \sim\ N\left(0,\ \ \sigma^2_{\varpi}\right)$,

Model Validation

The well specified model can produce unbiased and consistent estimation, leading to a reliable conclusion. Individual misspecification tests have a limitation in that a test is valid only when no other source of misspecification exists. McGuirk et al. (1993) argue that misspecification sources are easily identified by performing both individual and joint misspecification tests. Individual and joint misspecification tests for the quadratic and logistic models are described in Table II- 1.

A joint conditional mean test for a quadratic function is implemented with the following artificial regression;

$$(10) \qquad \hat{\varepsilon}_{it} = \beta' X + \gamma_0 T_t + \gamma_1 \hat{Y}_{it}^2 + v_{it}$$

where $\hat{\varepsilon}_{it}$ is a residual from the quadratic regression, β is a vector of parameters corresponding to X which is a matrix containing explanatory variables, T_t is a binary variable indicating the structural change over time, $\hat{Y}_{it}^2$ is a RESET2 variable for non-linearity, and v_{it} is an error term $v_{it} \sim N(0, \sigma_v^2)$.

The null and alternative hypotheses for a conditional mean test are as follows.

$$(11) \qquad \begin{array}{l} H_0 : \gamma_0 = \gamma_1 = 0 \\ H_1 : \gamma_0 \neq 0 \quad \text{or } \gamma_1 \neq 0 \end{array}$$

A joint conditional variance test for a quadratic function uses the following artificial regression;

$$(12) \qquad \hat{\varepsilon}_{it}^2 = \beta' X + \phi_0 T_t + \phi_1 \hat{Y}_{it}^2 + \psi_{it}$$

where $\hat{\varepsilon}_{it}^2$ is a squared residual, β is a vector of parameters corresponding to X which is a matrix containing explanatory variables, T_t is a binary variable indicating the structural change over time, $\hat{Y}_{it}^2$ is a RESET2 variable for static-heteroskedasticity, and ψ_{it} is an error term, $\psi_{it} \sim N(0, \sigma_\psi^2)$.

The null and alternative hypotheses for a conditional variance test for a quadratic function are as follows.

(13) $$H_0 : \phi_0 = \phi_1 = 0$$
$$H_1 : \phi_0 \neq 0 \quad \text{or}\ \phi_1 \neq 0$$

A joint conditional mean test for a logistic function is implemented with the following artificial regression;

(14) $$\hat{\varepsilon}_{it} = \alpha' \hat{F} + \gamma_0 T_t + v_{it}$$

where $\hat{\varepsilon}_{it}$ is a residual, α is a vector of parameters corresponding to $\hat{F}$ which is a matrix containing the derivatives of a logistic function with respect to unknown parameters(β) for each observation evaluated at parameter estimates($\hat{\beta}$), T_t is a binary variable indicating the structural change over time, and v_{it} is an error term $v_{it} \sim N(0, \sigma_v^2)$.

Expected Optimal Nitrogen Level

Given the hay price (*p*), nitrogen cost (*r*), and the average soil nitrogen (*Sn*), the optimal nitrogen level for the quadratic function is

(18) $$NA_Q^* = -\frac{pb_1 + 2pb_2Sn}{2pb_2} - r$$

where b_1 and b_2 are parameter estimates in the quadratic function.

The optimal nitrogen level for the logistic function is

(19) $$NA_L^* = \frac{b - cSn - \log(\frac{PAc - 2r - \sqrt{P^2A^2c^2 - 4pAcr}}{2r})}{c}$$

where A, b and c are parameter estimates in the logistic function.

The random deviate generation method for parameter estimates in each function is used to get N optimal nitrogen levels and then the expected optimal nitrogen level for each function and its standard deviation are obtained. The expected optimal solutions for two functions are

$$(20) \qquad \overline{NA}_Q^* = \frac{\sum_{i=1}^{N} NA_{Q\,i}^*}{N} \qquad \overline{NA}_L^* = \frac{\sum_{i=1}^{N} NA_{L\,i}^*}{N} \qquad (i = 1, \cdots, N)$$

where $\overline{NA}_Q^*$ and $\overline{NA}_L^*$ are expected optimal nitrogen levels for the quadratic and the logistic function, respectively, and $NA_{Q\,i}^*$ and $NA_{L\,i}^*$ are optimal nitrogen levels at the i^{th} generated sample for the quadratic and the logistic function, respectively.

The standard deviations of expected optimal solutions for two functions are

$$(21) \qquad s.e(\overline{NA}_Q^*) = \frac{\sum_{i=1}^{N} (NA_{Q\,i}^* - \overline{NA}_Q^*)^2}{N} \qquad s.e(\overline{NA}_L^*) = \frac{\sum_{i=1}^{N} (NA_{L\,i}^* - \overline{NA}_L^*)^2}{N}$$

where $s.e(\overline{NA}_Q^*)$ and $s.e(\overline{NA}_L^*)$ are standard deviations of expected optimal solutions for the quadratic and logistic function, respectively.

The paired difference t-test is used to test the difference between the expected optimal level and the one obtained from actual data for each functional form. The hypothesis for the quadratic function is

$$(22) \qquad \begin{aligned} &H_0 : \overline{NA}_Q^* = NA_Q^* \\ &H_1 : \overline{NA}_Q^* \neq NA_Q^* \end{aligned}$$

where $\overline{NA}_Q^*$ is the expected optimal nitrogen level, and NA_Q^* is the optimal nitrogen level drawn from actual data for the quadratic function.

The hypothesis for the logistic function is

$$(23) \qquad \begin{aligned} &H_0 : \overline{NA}_L^* = NA_L^* \\ &H_1 : \overline{NA}_L^* \neq NA_L^* \end{aligned}$$

where $\overline{NA}_L^*$ is the expected optimal nitrogen level, and NA_L^* is the optimal nitrogen level obtained from actual data for the logistic function.

Results

Misspecification Test and Model Estimation

The results of the individual and joint misspecification tests for the quadratic and logistic production models in Table II- 2 show that both functional forms (quadratic and logistic) are quite satisfactory. The individual hypothesis for normality, static heteroskedasticity, and parameter stability are not rejected. In terms of the RESET2 test for functional forms, results only for a quadratic function are obtained, showing that a quadratic form is adequate to explain Bermudagrass dry matter response to TAN. Similarly, the joint tests show that misspecification problems for two functional forms are not of concern.

The dry matter response to *TAN* for two functional forms was estimated using PROC NLMIXED in SAS. All parameter estimates except for a squared term (TAN^2) in the quadratic function are statistically significant at the 5% confidence level and expected sign for all coefficients are obtained (Table II- 3). Figure II- 2 also shows actual dry matter yield and predicted dry matter yield with two estimated response functions with respect to *TAN*.

Cox's Nonnested Test with a bootstrap

500 Monte Carlo samples with 32 observations were generated with the parametric bootstrap. Results of the Cox test are given in Table II- 4. For three samples, convergence problems were encountered in estimating a logistic form, leading to re-estimating a model by changing starting values and rescaling for each of samples with convergence problems. However, a quadratic function was estimated for all samples without any convergence problems.

For an ordinary bootstrap, the *p*-value is 0.8303 if a quadratic function is the null hypothesis while the *p*-value is 0.1446 when a logistic function is the null hypothesis. For the fast double bootstrap, the *p*-value is 0.9238 when a quadratic function is assumed to be true. The p-value is 0.1578 when a logistic function is assumed to be true. Results suggests that we fail to reject the null hypothesis that a quadratic function is true and that we also fail to reject the null hypothesis that a logistic function is true. Therefore, the Cox nonnested test with the bootstrap demonstrates that both models fit the data.

Optimal Nitrogen Level

10,000 optimal nitrogen levels for each functional form are used to get the expected optimal nitrogen levels. Optimal nitrogen level, expected profit, and expected yields for two response functions are described in Table II- 5. The expected optimal nitrogen level for the quadratic function is less than one drawn from actual data. However, the expected optimal nitrogen level for the logistic model is larger than the one drawn from actual data. The standard deviation of the expected optimal value for the quadratic function is much larger than that for the logistic function. In terms of the expected profit, the logistic functional form has a higher value than the quadratic form in both actual data and simulated data.

Summary and Conclusion

Misspecification tests and the Cox nonnested test with both a parametric bootstrap and fast double bootstrap are adopted to check the fitness of two production models (quadratic and logistic) to the data. Results show that either function well represents the dry matter response of Bermudagrass to nitrogen. This is also justified by the graph in Figure II- 2, where no significant difference between two curves is noticed. As described earlier, the advantage of fast double bootstrap is to provide an asymptotically valid bootstrap solution. However, the logistic model provides higher expected yield and profits than the quadratic model when both the expected optimal nitrogen level and the optimal nitrogen level drawn from actual experimental data are used.

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Table II-1. Individual and Joint Misspecification Tests

Tested	Quadratic	Logistic
Individual tests		
Normality	Omnibus test	Omnibus test
Functional Form	RESET2	NA
Static Heteroskedasticity	RESET2 type	RESET2 type
Parameter Stability	Chow test	Chow test
Joint tests		
Conditional mean	Parameter Stability Functional Form	Parameter Stability NA
Conditional variance	Static Heteroskedasticity Parameter Stability	Static Heteroskedasticity Parameter Stability

Table II-2. Results of Individual and Joint Misspecification Tests: P-values for Quadratic and Logistic Production Functions

Tested	Quadratic	Logistic
Individual tests		
Normality	0.1051	0.1199
Functional Form	0.1687	NA
Static Heteroskedasticity	0.2881	0.3950
Parameter Stability	0.3362	0.4931
Joint tests		
Overall mean test	0.1102	0.5895
Overall variance test	0.3316	0.3984

Table II-3. Dry Matter Yield Response (Mg/ha) of Bermudagrass to Total Available Nitrogen (Kg/ha) for Two Models

Explanatory Variables	Coefficients	p-value
Quadratic		
Intercept	7.4353	0.0107
Total Available Nitrogen(TAN)	0.06087	0.0061
TAN Squared	-0.00004	0.1879
Variance	27.7545	<.0001
Log likelihood	-98.6	
Logistic		
a maximum dry matter yield	32.5603	<.0001
Intercept	1.0229	0.0014
Total Available Nitrogen(TAN)	0.00633	0.0298
Variance	28.3428	0.0004
Log likelihood	-98.9	

Table II-4. Cox Parametric Bootstrap Test Statistics for Quadratic and Logistic Functions with Dry Matter Yield as a Function of Total Available Nitrogen

Test Statistic	Data	Estimated Model	Test Values
Log Likelihood	Actual Data	Quadratic	-98.6
Log Likelihood	Actual Data	Logistic	-98.9
Difference			0.30
Mean Log Likelihood	Ho: Quadratic	Quadratic	-96.451
Mean Log Likelihood	Ho: Quadratic	Logistic	-96.445
Difference			-0.006
Mean Log Likelihood	Ho: Logistic	Quadratic	-96.921
Mean Log Likelihood	Ho: Logistic	Logistic	-97.360
Difference			0.439
Ordinary Bootstrap			
p-value		Ho: Quadratic	0.8303
p-value		Ho: Logistic	0.1446
FDB			
p-value		Ho: Quadratic	0.9238
p-value		Ho: Logistic	0.1578
Test result		Fail to reject both functions.	

Table II-5. Optimal Nitrogen Levels, Expected Profits, and Expected Yield for Quadratic and Logistic for Production Functions.

	Quadratic	Logistic
Optimal nitrogen level		
With actual data (kg/ha)	597	594
Expected profit ($/ ha)	520.88	565.16
Expected yield (Mg/ha)	30.36	31.39
With generated data (kg/ha)	431	681
(Standard deviation)	(18,430)	(377)
Expected profit ($/ ha)	481.62	559.45
Expected yield (Mg/ha)	28.24	31.87

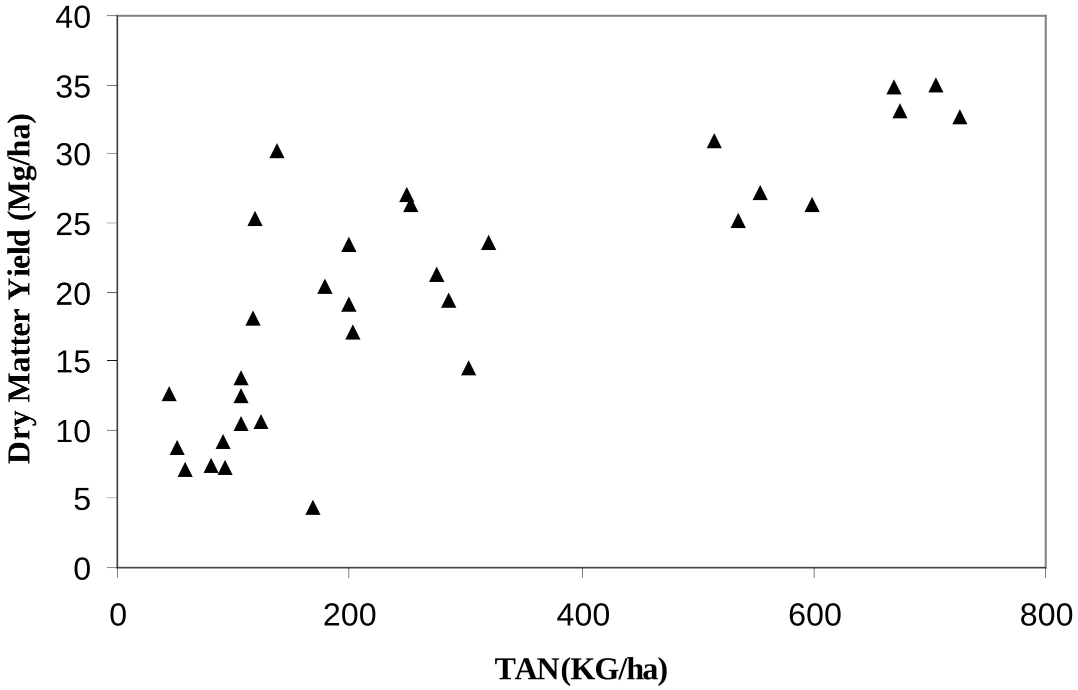

Figure II-1. Dry matter yield response of bermudagrass to total available nitrogen (TAN)

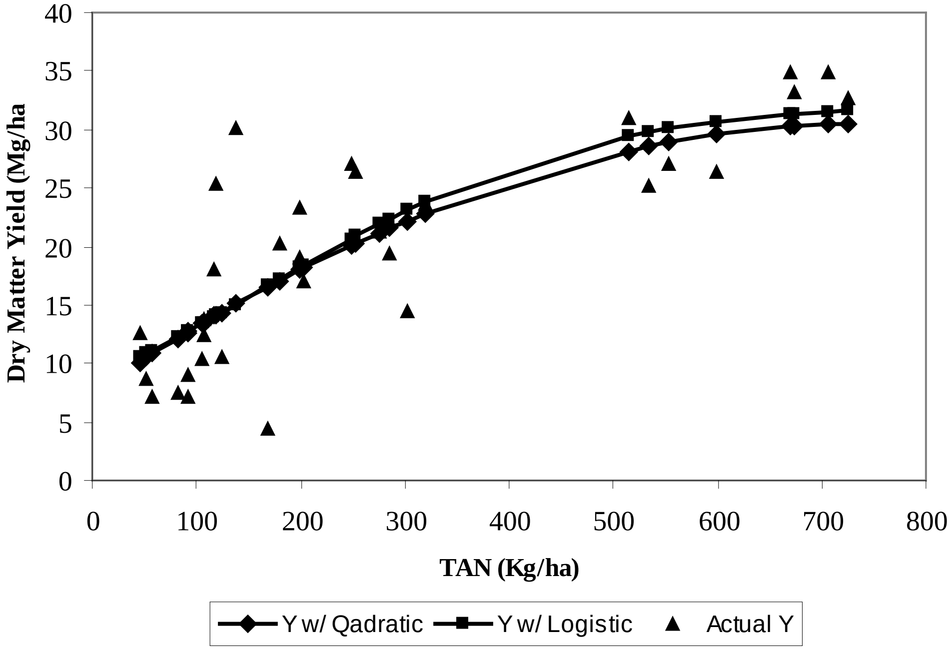

Figure II-2. **Actual dry matter yield and predicted dry matter yield with two response functions.**

PAPER III

OPTIMAL FERTILIZER RATES OF IRRIGATED GRASSES

Introduction

The Oklahoma Panhandle is one of the leading swine producing regions in the U.S. (Lowitt 2006). Confined swine production facilities in this region produce massive amounts of manure that are typically flushed into anaerobic lagoons to facilitate decomposition. Crop and grassland close to swine production facilities are mainly irrigated with swine effluent. There are multiple plant nutrients such as nitrogen, phosphorus, and potassium in the effluent (Sutton et al. 1982). Also, the application cost of nitrogen in swine effluent is very low (Carreira 2004) since it is typically delivered to crop land through an existing irrigation system.

Crop production in this region has used groundwater pumped from Ogallala aquifer at rates that have far exceeded recharge for many years. Groundwater will not be always available for supporting the current irrigated agriculture in this region and adoption of water conservation policies is important (Allen et al., 2005). Animal production and crop production compete for the use of the limited water resources (Carreira 2004). Manure can be a valuable production asset by recycling water and nutrients in it.

The role of improved forage systems in the Oklahoma Panhandle is important since grasses can reduce water and chemical use with decreased variable costs (Allen et al., 2005). The Panhandle region was originally grassland and is suited to cattle grazing with better adapted cultivars of grasses in an improved forage system, resulting in higher per acre yields and profits (Krall and Schuman, 1996).

This paper examines the variance covariance structures of the error term with repeated measures data and then tests for the existence of systematic changes in the parameters of response functions. Finally, optimal nitrogen application rates for each of four grasses with two nitrogen sources are determined with estimated dry matter response functions.

Material and Method

Forage dry matter yields and soil nitrogen data between 1999 and 2005 were obtained from experimental plots (or experiment 702) at the Oklahoma Panhandle Research and Extension Center (OPREC) near Goodwell, OK. Forage plots were arranged in a completely randomized split-plot design with four replications, where forage species was the whole plot unit and nitrogen source as the subplot unit. There were four grass species (Bermuda, Buffalo, Orchard and wheat), three nitrogen application rates (50, 150 and 450 N lb ac^{-1}) with swine effluent and urea, and control (0 N lb ac^{-1} rate) plots for each grass. Swine effluent was obtained from a local anaerobic single stage lagoon near the research station and the urea was obtained from a fertilizer dealer. Effluent rates of 56 and 168 kg N ha^{-1} were applied after the first monthly cutting, during June. The 504 kg N ha^{-1} rate was split into two applications, the first after the June harvest and the second after the July harvest (OPREC, 2005). Actual nitrogen application rates for swine effluent (Table III-1) were used for the estimation of response functional forms.

All plots were established and fully irrigated under a center-pivot irrigation system. Grasses were grown on a Gruver clay loam soil (fine mesic aridic Argiustolls). The cool-season forage species; orchardgrass and tall wheatgrass, were harvested in May, June, and September. The warm-season forage species; bermudagrass and buffalograss, were harvested in June, July, August, and September (OPREC, 2005).

The information about the prices of hay in Oklahoma was obtained from the USDA (NASS, 2007). The hay price used here was calculated by averaging hay prices in Oklahoma between 1999 and 2005. The price of grass hay is \$55 per MT (Kopp, 2007). The value of nitrogen in the swine effluent is assumed to be \$0.15 per N kg (Carreira, 2004). The average price of urea between 1992 and 2008 was \$ 0.65 per N kg (NASS, 2009). Total operating costs other than fertilizers are assumed to be \$575 per ha (Brees and Carpenter, 2006)

Analysis of Repeated Measures Data

There are two important facts in an experiment with data collected in a sequence of equally spaced time points from each experimental unit: treatment and time. Treatments are regarded as “the between-subject factor” because levels of treatment change only between subjects. Time is “a within-subject factor” because different measurements are taken from the same treatment subject at different times. A repeated measurement experiment is considered to be a split-plot experiment in that a treatment and a time factor are corresponding to the main plot and the sub plot factors in the split-plot experiment, respectively. However, there is a difference between a repeated measure experiments and a split-plot experiment. Levels of sub-plot factors in the split-plot experiment are randomly assigned to sub-plot unit within main-plot units while in the repeated measure experiments, responses from points close in time are usually more highly correlated than responses from points far apart in time. Therefore, an analysis of the correlation structure or the variance and covariance is unique for repeated measures data (Littel et al., 2006)

A statistical model for a repeated measure experiment is

(1) $Y_{ijk} = \mu + \alpha_i + \gamma_k + (\alpha\gamma)_{ik} + e_{ijk}$

where $Y_{ijk} = \mu + \alpha_i + \gamma_k + (\alpha\gamma)_{ik}$ is the mean for treatment *i* at time *k*, containing effects for treatment, time, and treatment ×time interaction, and e_{ijk} is the random error associated with the measurement at time *k* on the *j*th subject that is assigned to treatment *i*.

The random errors e_{ijk} for the same subjects are not independent since the time factors are not randomly assigned to units within subjects. Thus, additional assumptions on the variance and covariance structure of the errore_{ijk} s are made: 1) random errors e_{ijk} for the different subject are independent, which means $Cov\left[e_{ijk}, e_{i'j'k}\right] = 0$ if either $i \neq i'$ or $j \neq j'$, and 2) the variance of e_{ijk} changes by the measurement time k, and the covariance between the errors at two times, k and k', for the same subject, also changes over time, which is $\mathrm{Var}\left[e_{ijk}\right] = \sigma_k^2$ and $Cov\left[e_{ijk}, e_{ijk'}\right] = \sigma_{kk'}$ (Littel et al., 2006).

Candidate Variance Covariance Structures

Several commonly used variance covariance structures were compared based on the criteria of fit to assess the various models. Four models were selected: variance component, unstructured, compound symmetry, and first order autoregressive (Littel et al., 2006).

1) Variance Component

The simplest mode with the independent covariance model, where the within-subject error correlation is zero, a variance covariance matrix for a subject $(\sum)=\sigma^2 \mathbf{I}$

2) Unstructured covariance model

The most complex model, where within-subject errors for each pair of times have their own unique correlation.

$$\sum=\sigma^2\begin{bmatrix} \sigma_1^2 & \sigma_{12} & \sigma_{13} & \cdots & \sigma_{1K} \\ & \sigma_2^2 & \sigma_{23} & \cdots & \sigma_{2K} \\ & & \sigma_3^2 & \cdots & \sigma_{3K} \\ & & & \ddots & \vdots \\ & & & & \sigma_K^2 \end{bmatrix}$$

3) Compound Symmetry

The simplest model with correlation, in which correlation is constant regardless of the lag between pairs of repeated measurements.

$$\Sigma=\sigma^2\begin{bmatrix} 1 & \rho & \rho & \cdots & \rho \\ & 1 & \rho & \cdots & \rho \\ & & 1 & \cdots & \rho \\ & & & \ddots & \vdots \\ & & & & 1 \end{bmatrix}$$

4) The first order autoregressive, AR(1).

The model where a correlation between observations is a function of their lag in time and adjacent observations tend to be more highly correlated than observations farther part in time.

$$\Sigma=\sigma^2\begin{bmatrix} 1 & \rho & \rho^2 & \cdots & \rho^{K-1} \\ & 1 & \rho & \cdots & \rho^{K-2} \\ & & 1 & \cdots & \vdots \\ & & & \ddots & \rho \\ & & & & 1 \end{bmatrix}$$

Selecting Covariance Structure with Experimental Data

Plot, grass type, nitrogen source, nitrogen rate, year were used in the ANOVA model as classification factors. The experiment year variable was used as a repeated factor in the model. Year was treated as a repeated measure since measurements were taken for yield each year of the study from the same plot.

Selecting an appropriate covariance model is important because a very simple model might underestimate standard error, increasing the Type I error rate and because too complex of a model will sacrifice power and efficiency. Guerin and Stroup (2000) showed that repeated measures analysis is robust as long as the covariance model used is approximately correct.

Table III-2 shows output from PROC MIXED of SAS including -2 Residual Log Likelihood, and three information criteria (AIC, AICC, and BIC). According to the residual log likelihood, an unstructured model with the lowest value is considered best among competing models. However, the residual log likelihood criterion is not reliable because the log likelihood always increases as more parameters are added to the model as does the R^2 in multiple regression. The three information criteria use penalties by addition parameters to the model, which means that information criteria is -2 Residual Log Likelihood plus -2 times a function involving the number of covariance model parameters (Littel et al., 2006). AIC tends to choose more complex model than BIC (Guerin and Stroup, 2000). Therefore, AIC is considered as a fitting criterion of choice when Type I error is of interest, while BIC is preferred when losing power matters. Generally, the close values of AIC, AICC, or BIC indicates that the simpler model is preferred. An unstructured model is better fitted than other three model based on AIC and AICC. However, the AR(1) covariance model is selected according to BIC in Table III-2 and the interest of using a parsimonious model. (Littel 2006).

Main effects including grass(G), nitrogen rate(NR), and year(YR) were found to be significant at the 1 percent significance level across models (Table III-3). Some interaction terms including NR× G, YR×G, NR×YR, and NR×YR×G were also found to be significant at the 1 percent significance level across models. Nitrogen source (NS) and an interaction term between NR and NS and G were found to be significant at the 5 percent significance level only in the variance component model. The least squared means of grass yields of main effects-grass types, nitrogen source, and nitrogen rates, and their interaction terms were presented in Table III-4. The highest dry matter yield was obtained in bermudagrass at 504 N kg ha^{-1} with urea.

Test of a Systematic Change in Parameters

A functional form of a dry matter yield response for all grasses is assumed to be quadratic based on Figure III-1. Now, we examine the existence of a systematic change in parameters of a response function over year. Since grass was found to be a significant factor according to Table III-3, a model with systematically varying parameter was developed for each grass. A quadratic function with systematically varying parameters can be written as

(2) $Y_t = \beta_{0t} + \beta_{1t} NA + \beta_{2t} NA^2 + e_t$

s.t.

(3) $\beta_{0t} = \alpha_0 + \alpha_1 Year$

(4) $\beta_{1t} = \gamma_0 + \gamma_1 Year$

(5) $\beta_{2t} = \delta_0 + \delta_1 Year$

We can rewrite function (2) by incorporating (3) to (5) restrictions as

$$(6)\ Y_t = \alpha_0 + \alpha_1 Year + \gamma_0 NA + \gamma_1 YearNA$$
$$+\delta_0 NA^2 + \delta_1 YearNA^2 + e_t$$

Table III-5 showed estimates of varying parameters for each grass and results of log likelihood ratio test with the null hypothesis , ($H_0: \alpha_1 = \gamma_1 = \delta_1 = 0$). Tests showed that varying parameters are significant only in bermudagrass and orchardgrass at the 5 percent significance level. Only an incept parameter (α_1) for bermudagrass was found to be significant at the 5 percent significance level. Now, we test a time trend ($\alpha_{1)}$ by dropping (4) and (5) restrictions. The modified response function is ‘

$$(7)\ Y_t = \alpha_0 + \alpha_1 Year + \beta_1 NA + \beta_2 NA^2 + e_t$$

Table III-6 showed that there is an uptrend over time for warm-season grasses (bermudagrass and buffalograss). The uptrend for bermudagrass was found to be significant but that for buffalograss was not. There is a significant downtrend for cool season grasses including orchardgrass and wheatgrass.

Estimation of Response Function

Based on results in previous sections, we can define a function form of a dry matter yields response to applied nitrogen levels for each grass type with different nitrogen sources. A dry matter yield response to applied nitrogen with the first autocorrelation can be written as

$$(8)\ Y_t = \alpha_0 + \alpha_1 Year + \beta_1 NA + \beta_2 NA^2 + v_t$$

$$v_t = \rho v_{t-1} + \varepsilon_t \qquad \varepsilon_t \sim N(0, \sigma_\varepsilon^2)$$

$$\alpha_1 = 0 \text{ for Buffalograss}$$

Parameter estimates of a dry matter response function for four grasses were reported in Table III-7. There were only two significant squared terms of applied nitrogen (NA^2) for orchardgrass and wheatgrass treated with swine effluent. In addition, a lag effect (ρ) was found to significant only for wheatgrass with swine effluent. Parameters were re-estimated by dropping both an insignificant squared term of applied nitrogen (NA^2) and a lag effect (ρ). All parameter estimates in Table III-8 were significant at the 1 percent significance level. .Bermudagrass shows a significant uptrend over time while two cool season grasses including orchardgrass and wheatgrass showed a downtrend over time.

Optimal Nitrogen Rate

Optimal nitrogen application rates were calculated within the range of nitrogen applied in the experiment, that is, 0 to 504 N kg ha^{-1}. Table 9 and 10 show profits and optimal nitrogen rates of each year for warm-season and cool-season grasses, respectively. Optimal nitrogen rates for bermudagrass and buffalograss treated with swine effluent is 504 N kg ha^{-1}. For warm-season grasses treated with urea, optimal nitrogen rates are 504 and 0 N kg ha^{-1} for bermudagrass and buffalograss, respectively. Optimal nitrogen rates for cool-season grasses treated with swine effluent are 455 and 378 N kg ha^{-1} for orchardgrass and wheatgrass, respectively. However, the zero nitrogen rate was considered optimal for cool season grasses treated with urea. Given prices of hay and nitrogen fertilizers, the best forage chosen out of four grasses is bermudagrass applied with swine effluent based on the average profits per hectare. Swine effluent is also considered a better nitrogen source that brings a higher profit due to its cheap price of nitrogen relative to urea.

Summary and Conclusion

Statistical approaches including analysis of repeated measure data and systematical change in parameters in a dry matter response function were used to determine optimal nitrogen application rates for four grasses receiving two nitrogen sources (swine effluent and urea). A variance covariance structure with a first degree autoregressive, AR(1), was considered to be fitted to our experimental data and the existence of a trend over year was found. Finally, the same optimal nitrogen rates were found in effluent treated warm-season grasses and a higher optimal nitrogen rates was obtained in orchardgrass rather than wheatgrass when plots were treated with swine effluent.

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Table

Table III-1. Actual Amount of Nitrogen Applied for Swine Effluent (N kg ha^{-1})

Expected N rate (N kg ha^{-1})	1999	2000	2001	2002	2003	2004	2005*
56	44.58	42.83	65.31	29.94	51.45	55.16	48.21
168	133.73	128.50	195.93	89.82	154.36	165.48	144.63
504	401.18	385.51	587.78	269.46	463.07	496.43	433.90

Note: * Average values from 1999 to 2004 were used in 2005

Table III-2. Statistics from PROC MIXED procedure

Model	-2 Res Log Likelihood	AIC	AICC	BIC
Variance Component (VC)	3349.4	3351.4	3351.4	3354.1
Unstructured(UN)	3150.1	3206.1	3209.0	3282.2
Compound Symmetry(CS)	3273.3	3277.3	3277.3	3282.7
AR(1)	3270.3	3274.3	3274.3	3279.7

Table III-3. Test of Fixed Effects (P-values)

Fixed Factors	VC	UN	CS	AR(1)
GRASS(G)	<.0001	<.0001	<.0001	<.0001
Nitrogen Rate(NR)	<.0001	<.0001	<.0001	<.0001
NR× G	<.0001	<.0001	<.0001	<.0001
Nitrogen Source(NS)	0.0112	0.1115	0.1115	0.0693
NS× G	0.0374	0.3401	0.3401	0.2249
NR×NS	0.5930	0.8174	0.8174	0.7683
NR×NS× G	0.0038	0.2441	0.2441	0.1157
YEAR(YR)	<.0001	<.0001	<.0001	<.0001
YR×G	<.0001	<.0001	<.0001	<.0001
NR×YR	<.0001	<.0001	<.0001	<.0001
NR×YR×G	<.0001	<.0001	<.0001	<.0001
NS×YR	0.9606	0.9222	0.9177	0.8543
NS×YR×G	0.5953	0.2044	0.2480	0.2200
NR×NS×YR	0.8682	0.3195	0.6768	0.5537
NR×NS×YR×G	0.9423	0.7078	0.6553	0.9137

Table III-4. Least Squared Mean of Dry Matter Yields for Four Grasses (MT ha^{-1})

	Bermudagrass	Buffalograss	Orchardgrass	Wheatgrass
Control	10.25	9.57	7.21	8.83
Swine effluent				
56	13.21	11.65	8.74	9.73
168	17.20	15.60	11.08	10.20
504	23.73	21.01	13.21	13.67
Urea				
56	10.41	12.01	9.55	9.92
168	15.70	15.03	10.52	10.28
504	24.03	17.35	13.14	13.64

Table III-5. Estimates of Varying Parameters for Four Grasses (p-values) and Log Likelihood Ratio Test

Parameters	Bermudagrass	Buffalograss	Orchardgrass	Wheatgrass
α_1	<.0001	0.2179	0.7771	0.0583
γ_1	0.7774	0.2073	0.1107	0.1176
δ_1	0.8506	0.1820	0.2071	0.1190
LLR test (P-value)	<.005	<0.10	<.005	>0.10

Table III-6. Test of a Varying Parameter for the Intercept for Four Grasses

	Bermudagrass		Buffalograss		Orchardgrass		Wheatgrass	
	Estimates	P	Estimates	P	Estimates	P	Estimates	P
α_1	1.7598	<.0001	0.1188	0.5088	-0.4482	<.0001	-0.7998	<.0001

Table III-7. Parameter Estimates of a Response Function for Four Grasses (MT ha^{-1}).

Variable	Bermudagrass		Buffalograss	
	Swine Effluent	Urea	Swine Effluent	Urea
Intercept (α_0)	-3372*	-3687*	10.17*	10*
Year (α_1)	1.690*	1.846*	NA	NA
NA (β_1)	0.033*	0.058*	0.035*	0.038
NA^{2} ($\beta_{2)}$	-0.000007	-0.00005	-0.00002	-0.00005
Lag (ρ)	0.140	-0.160	0.082	0.024
Variance (σ_ε^2)	38.35*	24.42*	17.86*	31.92*

	Orchardgrass		Wheatgrass	
	Swine Effluent	Urea	Swine Effluent	Urea
Intercept (α_0)	647**	1138*	1975*	1733*
Year (α_1)	-0.320**	-0.564*	-0.982*	-0.8612*
NA (β_1)	0.031*	0.010	0.0254*	0.0002
NA^{2} ($\beta_{2)}$	-0.00004*	-0.000002	-0.00003**	0.00002
Lag (ρ)	-0.141	0.057	0.297*	0.066
Variance (σ_ε^2)	8.59*	10.96*	15.21*	10.97*

Note: *, and ** are significant at the 1, and 5 percent significance level, respectively.

Table III-8. Parameter Estimates of A Response Function for Four Grasses Using PROC MIXED Procedure.

Variable	Bermudagrass		Buffalograss	
	Swine Effluent	Urea	Swine Effluent	Urea
Intercept (α_0)	-3404*	-3642*	10.63*	12.25*
Year (α_1)	1.7062*	1.824*	NA	NA
NA (β_1)	0.030*	0.029*	0.024*	0.001*
NA^2 (β_2)	NA	NA	NA	NA
Lag (ρ)	NA	NA	NA	NA
Variance (σ_ε^2)	37.89*	25.24*	18.04*	32.17*

	Orchardgrass		Wheatgrass	
	Swine Effluent	Urea	Swine Effluent	Urea
Intercept (α_0)	786*	1067*	1975*	1673*
Year (α_1)	-0.389*	-0.529*	-0.982*	-0.832*
NA (β_1)	0.030*	0.008*	0.0254*	0.0089*
NA^2 (β_2)	-0.00003*	NA	-0.00003**	NA
Lag (ρ)	NA	NA	0.297*	NA
Variance (σ_ε^2)	8.61*	10.76*	15.21*	10.82*

Note: *, and ** are significant at the 1, and 5 percent significance level, respectively.

Table III-9. Profits and Optimal Nitrogen Rates (N kg ha^{-1}) for Warm-Season Grasses when the Price of Hay is $ 55.00 MT^{-1}.

Year	Bermudagrass		Buffalograss	
	Profit ($ ha^{-1})	Optimal N (Kg ha^{-1})	Profit ($ ha^{-1})	Optimal N (Kg ha^{-1})
Swine effluent				
1999	549	504	599	504
2000	643	504	599	504
2001	737	504	599	504
2002	831	504	599	504
2003	925	504	599	504
2004	1018	504	599	504
2005	1112	504	599	504
Average	831	504	599	504

Year	Bermudagrass		Buffalograss	
	Profit ($ ha^{-1})	Optimal N (Kg ha^{-1})	Profit ($ ha^{-1})	Optimal N (Kg ha^{-1})
Urea				
1999	131	504	99	0
2000	231	504	99	0
2001	332	504	99	0
2002	432	504	99	0
2003	532	504	99	0
2004	633	504	99	0
2005	733	504	99	0
Average	432	504	99	0

Table III-10. Profits and Optimal Nitrogen Rates (N kg ha^{-1}) for Cool-Season Grasses when the Price of Hay is $ 55.00 MT^{-1}.

Year	Orchardgrass		Wheatgrass	
	Profit ($ ha^{-1})	Optimal N (Kg ha^{-1})	Profit ($ ha^{-1})	Optimal N (Kg ha^{-1})
Swine effluent				
1999	227	455	320	378
2000	206	455	266	378
2001	185	455	212	378
2002	163	455	157	378
2003	142	455	104	378
2004	120	455	50	378
2005	99	455	-4	378
Average	163	455	158	378

Year	Orchardgrass		Wheatgrass	
	Profit ($ ha^{-1})	Optimal N (Kg ha^{-1})	Profit ($ ha^{-1})	Optimal N (Kg ha^{-1})
Urea				
1999	-51	0	-34	0
2000	-80	0	-80	0
2001	-109	0	-126	0
2002	-138	0	-172	0
2003	-167	0	-217	0
2004	-196	0	-263	0
2005	-225	0	-309	0
Average	-138	0	-172	

Figure

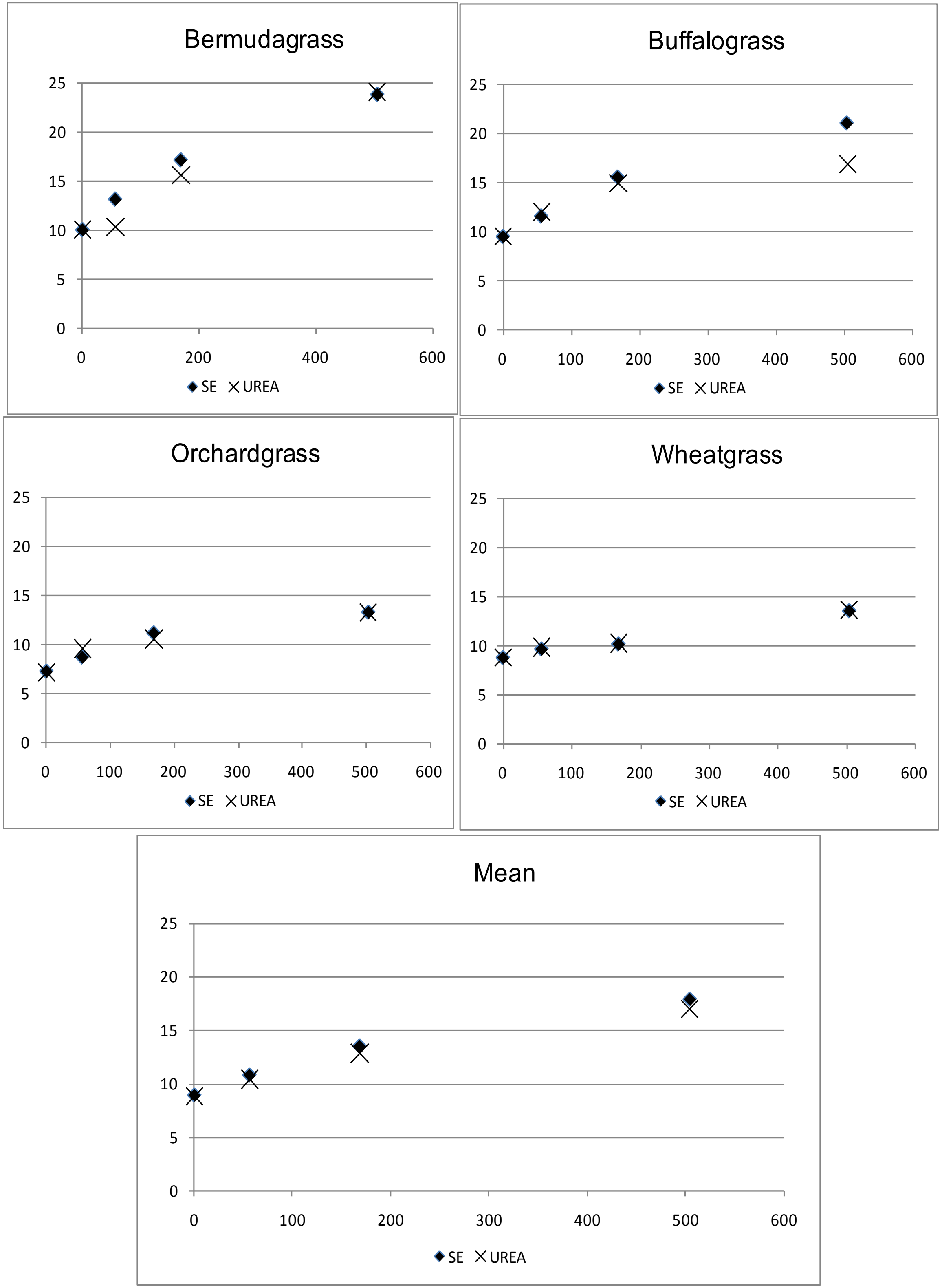
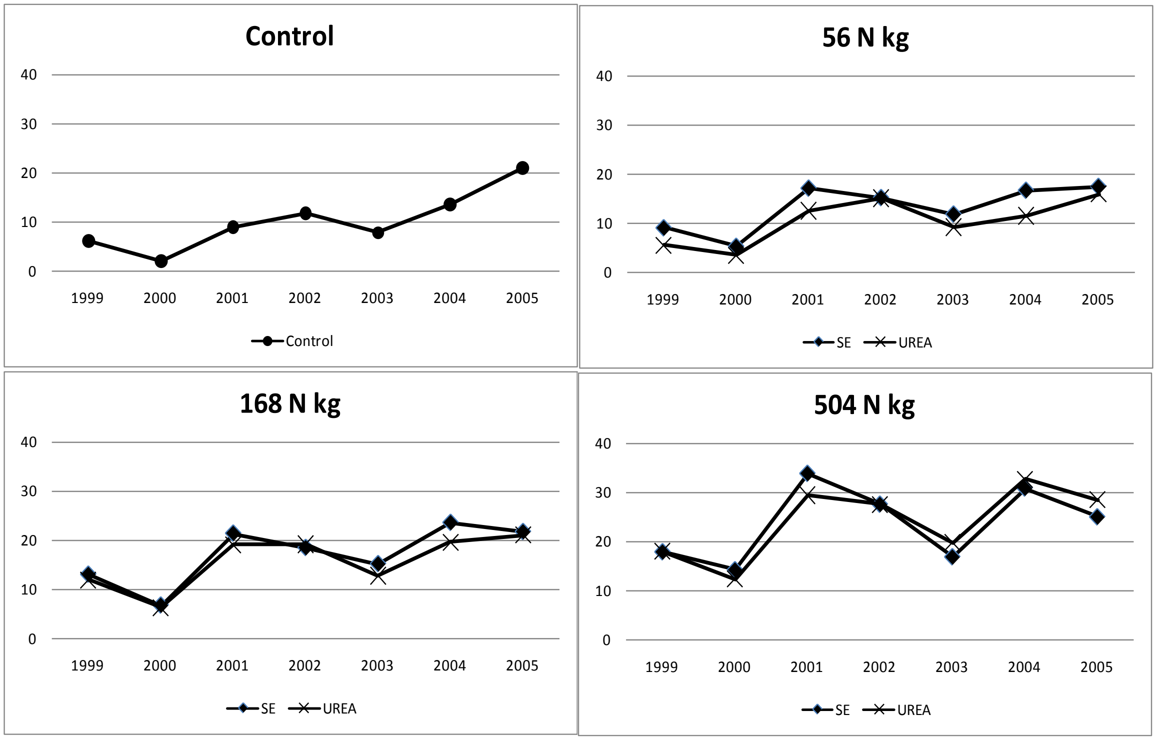


Figure III-1. Average dry matter response (MT ha^{-1}) to applied swine effluent and urea nitrogen (N kg ha^{-1}) by each grass from 1999 through 2005 at Goodwell, OK


Control

56 N kg

168 N kg

504 N kg

Figure III-2. Dry matter yield (MT ha^{-1}) of bermudagrass over 7 years

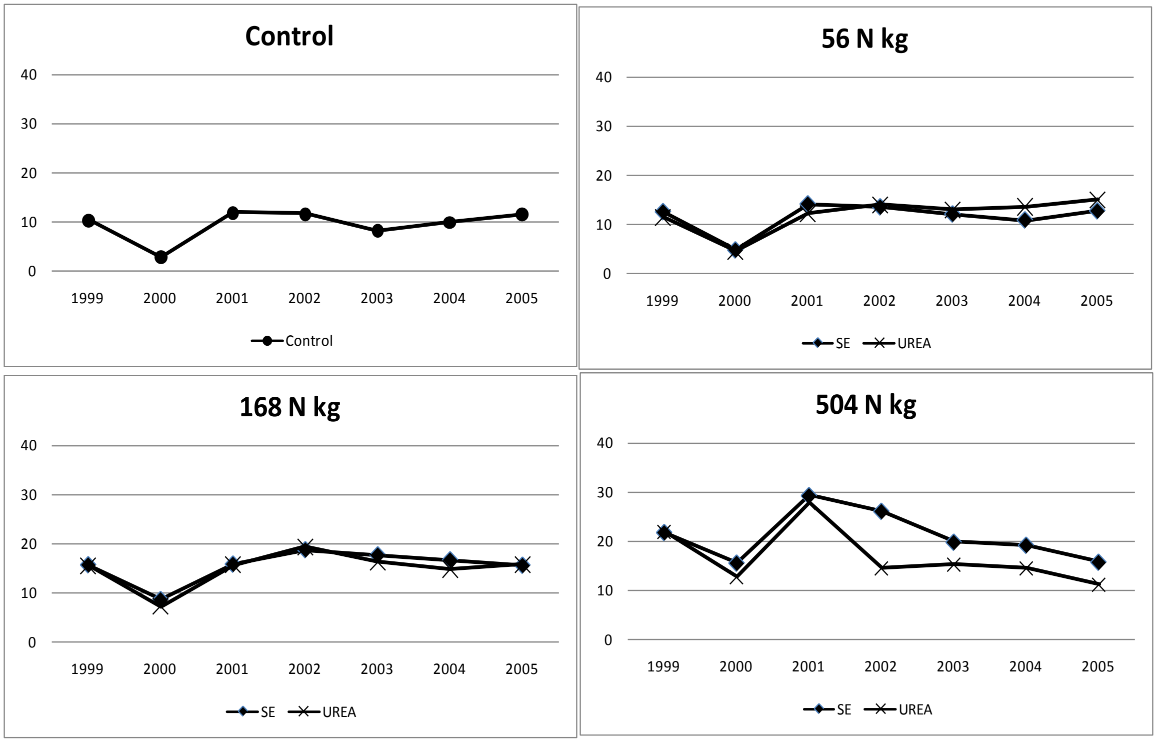


Figure III-3. Dry matter yield (MT ha^{-1}) of buffalograsss over 7 years

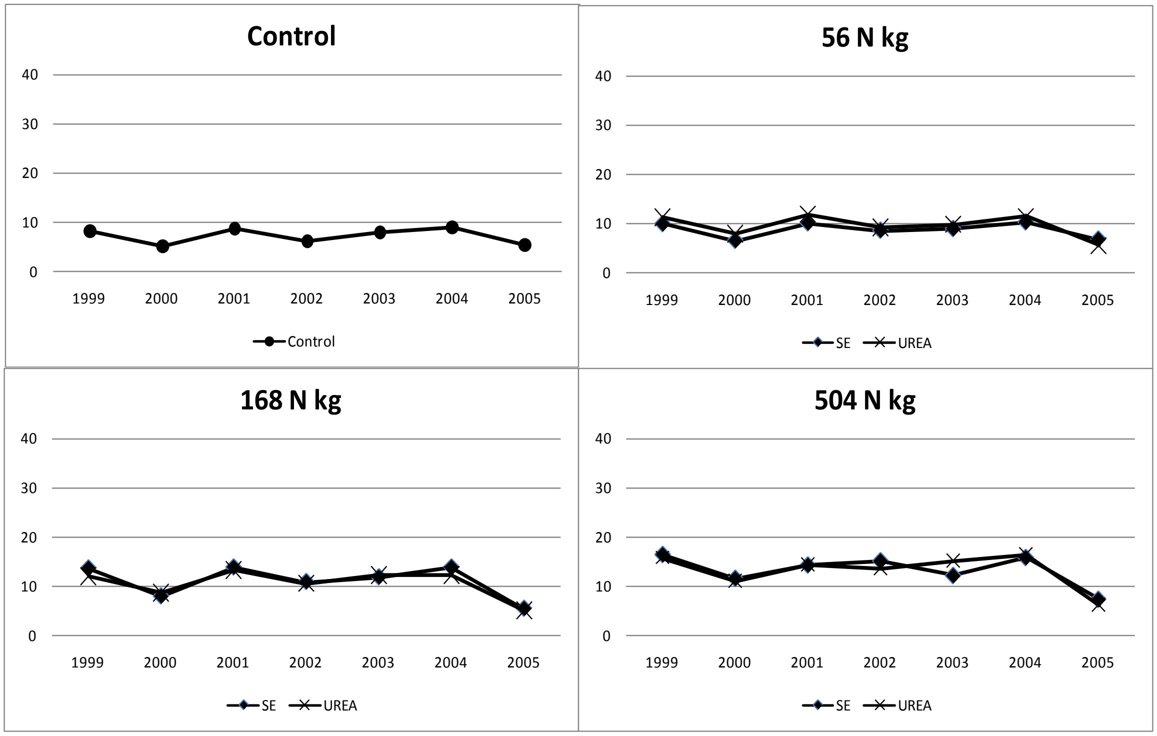


Figure III-4. Dry matter yield (MT ha^{-1}) of orchardgrass over 7 years

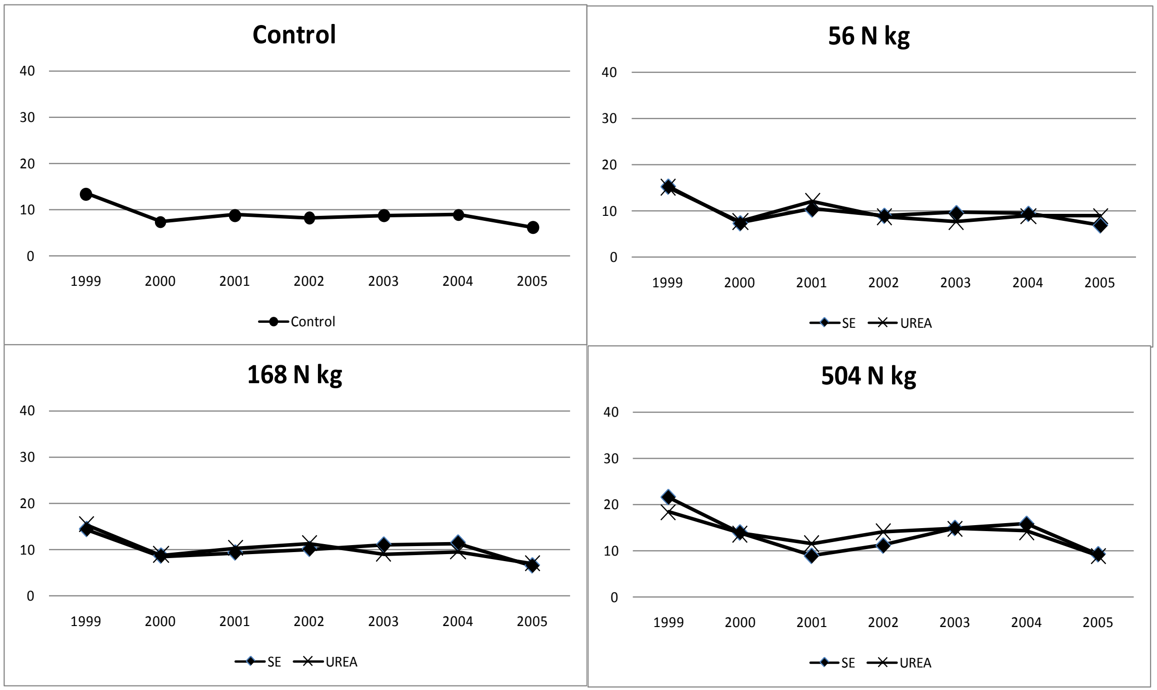


Figure III-5. Dry matter yield (MT ha^{-1}) of wheatgrasss over 7 years

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Doctor of Philosophy

Dissertation: ECONOMIC ANALYSIS ON ANIMAL MANURE; STATIC AND DYNAMIC APPROACHES, COX NON-NESTED TEST, AND OPTIMAL NITROGEN RATES FOR GRASSES

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Title of Study: ECONOMIC ANALYSIS ON ANIMAL MANURE; STATIC AND DYNAMIC APPROACHES, COX NON-NESTED TEST, AND OPTIMAL NITROGEN RATES FOR GRASSES

Pages in Study: 131 Candidate for the Degree of Doctor of Philosophy

Major Field: Agricultural Economics

Scope and Method of Study: This study consists of three sections. The purpose of first section is to determine an economic profitability of sustained application of swine lagoon effluent and beef feedlot manure relative to anhydrous ammonia in the Oklahoma Panhandle. Two approaches: ANOVA for a static analysis and an optimization for a dynamic analysis were obtained. The purpose of second section is to examine the fitness of two competing production functions (quadratic and logistic) to data. Misspecification tests and the Cox non-nested test with a parametric fast double bootstrap were adopted. The purpose of last section is to determine optimal nitrogen rates for each of four grasses with two nitrogen sources. The variance covariance structures of the error term with repeated measures data and the existence of systematic changes in parameters of response functions were studied.

Findings and Conclusions: For the first section, swine lagoon effluent was found to be the nitrogen source which provided the largest economic profits among three nitrogen sources (anhydrous ammonia, beef manure and swine effluent) in both approaches. A difference in optimal nitrogen rates between two approaches also indicates that the amount of nitrogen applied can be reduced significantly when the residual soil nitrogen level is considered. Animal manure can be an agronomically and economically viable substitute for commercial fertilizers. For the second section, two functional forms well represent the dry matter response of bermudagrass to total available nitrogen. A higher expected yield and profit was obtained in the logistic model than in the quadratic model. For the last section, the AR(1) variance covariance error structure was selected according to the selection criteria. The most profitable forage was bermudagrass fertilized with swine effluent. Swine effluent was a better nitrogen source that yielded higher profits than urea. The same nitrogen rate was optimal with buffalograss. A higher optimal nitrogen rate was obtained for orchardgrass rather than for wheatgrass when plots were treated with swine effluent.

ADVISER’S APPROVAL: Dr. Art Stoecker