ELECTRICAL CONDUCTIVITY AND SODIUM ADSORPTION RATIO CHANGES FOLLOWING ANNUAL APPLICATIONS OF ANIMAL MANURE AMENDMENTS

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LIST OF NOMENCLATURE AND SYMBOLS

AA	Anhydrous Ammonia
AWMFH	Animal Waste Management Field Handbook
AWMS	Animal Waste Management System
BM	Beef Manure
CAFO	Concentrated Animal Feeding Operations
CEC	Cation Exchange Capacity
DM	Dry Matter percentage
EC	Electrolytic or Electrical Conductivity of the saturated soil paste extract
EC_m	Electrolytic or Electrical conductivity of the animal manure
ESP	Exchangeable Sodium Percentage
ESR	Exchangeable Sodium Ratio
LEPA	Low Energy Precision Applicator
LSMEANS	SAS syntax for the least-squares means
MIII	Mehlich III
MIXED	SAS syntax for a mixed model analysis; i.e. A is fixed and B is random
NASS	National Agricultural Statistical Service
NEH	National Engineering Handbook
OPREC	Oklahoma Panhandle Research and Extension Center
pH	pH of the saturated soil paste extract
PROC	SAS syntax used to denote that a procedure follows; i.e. PROC MIXED
RCBD	Randomized Complete Block Design
SAR	Sodium Adsorption Ratio of the saturated soil paste extract
SAR_m	Sodium Adsorption Ratio of the animal manure
SAS	Statistical Analysis Software®, SAS, Institute
SE	Swine Effluent
SP	Saturation Percentage
USDA	United States Department of Agriculture
V6	Growth stage of corn where the sixth leaf is developed.
Ws	Weight of air-dried soil
Ww	Weight of added water
YR	Year

INTRODUCTION

Livestock production operations have increased in size and become more geographically concentrated because of improved technology and economic efficiencies. Not only is manure production being concentrated into fewer areas, it is also increasing in the volume produced nationally. Consequently, disposal of large amounts of manure annually are requisite. Land application of manure-derived nutrients generated by livestock-feeding operations has come under much scrutiny by local, state, and federal agencies due to elevated environmental awareness and concerns. These concerns include the quality and sustainability of the soil, water, air, plants, animals, and biology in regions geographically associated with land used for manure applications. Undoubtedly, these concerns overlap and are many times indivisible. One such concern is soil salinization; which salinization has the potential to drastically change whole ecologies.

The southern High Plains is a region where these concerns have been realized due to the significant number of livestock produced annually. According to the Jan 1, 2001 report from the Oklahoma Agricultural Statistics Service the Oklahoma panhandle had 750,000 feedlot cattle (*Bos taurus*) and calves, 110,000 rangeland cattle, and 1,465,000 hogs. In the High Plains swine (*Sus scrofus domesticus*) production has increased dramatically in the past several years. In the Oklahoma panhandle (Cimarron, Texas, Beaver, Harper and Ellis counties) of the High Plains swine production has grown rapidly to 1,465,000 animals in 2000, up 814% from 1995 (NASS). Access to feed processing and existing swine processing facilities in the area makes the region suitable for concentrated animal feeding operations (CAFO) as the producers attempt to lower production costs and maximize profits.

The increased number of swine, in addition to existing livestock, ultimately results in an increase of manure produced in the region. Currently, an estimated 18.57 Gt (Appendix I) of manure is produced annually in the Oklahoma panhandle region, most of which is stored in animal manure retention structures prior to land application as a nutrient source for crops in the area. Multiple essential plant nutrients (e.g. N, P, K, S, Ca, Mg, and micronutrients) are contained in the animal manures however much attention has been given to N and P since they are nutrients commonly deficient in plant growth and supplied as fertilizer inputs. Regulatory agencies concerned about eutrophication, olfactory sensitivity, human discomfort, recreation, and tourism monitor water quality, odor, or aesthetics; and have mandated restrictions relative to the amount of N and P leaving agricultural ecosystems. While N and P receive greater attention from regulatory agencies concerning these issues, a less visible, though potentially more long-term negative effect is secondary salinization of the land.

Secondary salinization is a function of minerals commonly added to livestock diets to enhance animal performance. When these minerals are added in quantities that exceed the daily requirement they are eventually excreted thus the manure may contain a high soluble salt content (OSU Extension Fact Sheets 3500 and F-1735). When animal manure is land-applied as part of a crop production system the quantity applied is determined as a function of the N or P needed in the system. However, soluble salts must also be accounted for in the animal waste management system (AWMS; USDA, 2000).

Soil salinity limits agricultural development (Rhoades *et al*., 1999) and commonly occurs in arid and semiarid areas (USDA, 1954). The semi-arid climatic conditions that occur in the Oklahoma panhandle may be susceptible to salt additions from recent agricultural developments. Therefore, particular attention needs to be made in respect to the practice of applying animal manures in the Oklahoma panhandle. Several studies have shown that repeated annual applications of animal manures with a high salt content have results in a buildup of soluble salts in the soil profile, sufficient to reduce productivity (Chang *et al*. 1991; Chang *et al*. 1993; Sutton *et al*. 1984; Sutton *et al*. 1986; Horton *et al.* 1981; Mathers and Stewart 1974; Pratt *et al.* 1978; Pratt *et al*. 1976). Beef feedlot manure applications have been found to increase soil electrical conductivity (EC) and sodium adsorption ratio (SAR) over time even under irrigation (Chang *et al*., 1990 and 1991). Murphy *et al*. (1972) reported depressed corn silage yields following large applications of feedlot manure, which was attributed to the accumulation of salts and toxic quantities of ammonium. Swine slurry has been found to increase exchangeable soil sodium with each year of application (Sutton *et al*., 1984) and increase swine effluent soluble salt accumulations (Liu *et al*., 1998).

Most previous long term manure application studies (Christie, 1987; Christie and Beattie, 1989; Sommerfeldt and Chang, 1985; Gao and Chang, 1996; Kingery *et al*., 1994; King *et al*., 1985; King *et al*., 1990; Sommerfeldt and Mackay, 1987; Marchesini *et al*., 1988; McGrath and Cegarra, 1991; N'Dayegamiye and Côté, 1989; N'Dayegamiye, 1990; Vitosh *et al*., 1973; Duijvenbooden and Waegeningh, 1987; Castilho *et al*., 1993; Schjønning *et al*., 1994; Sharpley *et al*., 1993; Stadelmann and Furrer, 1984) were conducted in high rainfall (>500 mm yr^{-1}) regions. The southern Great Plains region is a semi-arid moisture regime receiving 250-500mm of annual precipitation. Data from other manure application studies have remained unconfirmed in the unique, semi-arid agro-ecosystem of Oklahoma's panhandle (Hattey, 2001). And there is a research gap that exists for studies including soils in low rainfall (<500mm) areas that are amended with animal manures. Therefore, the effects of long-term animal manure applications in semi-arid agricultural environments need to be studied, specifically its relationship to salt accumulations and potential problems associated with reduced agronomic production.

Sustainable AWMS are needed for current agricultural production in the Oklahoma panhandle. Efficient use of animal manures without adverse effects on soil properties, plant growth, and air or water quality needs continued development. This will aide in providing safe, practical guides to reduce regional ecological risks. Because of the importance of the Great Plains to agricultural production, the research gap for semi-arid environments needs additional information, such as salinity and sodicity development, to effectively plan an adequate AWMS. In this low rainfall environment the effects of secondary salinization may occur at rates not found in these other studies mentioned; thus impeding the sustained production of agriculture. The objective of this research was to evaluate the effect of repeated annual applications of animal manures on soil salinity and sodium accumulation in conventionally tilled, continuously cropped corn in the Oklahoma panhandle.

MATERIALS AND METHODS

Site Description:

Field experiments were conducted at the Oklahoma Panhandle Research and Extension Center (OPREC) near Goodwell, OK (36°35 N, 101°37 W, and elevation 992 m). 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 Richfield clay loam (fine, smectitic, mesic, Aridic Argiustoll) on 0-2% slopes. The cumulative effects of repeated annual applications in 2000 are presented as the results and discussion; refer to Appendix II for the results of previous year's data. Selected soil chemical characteristics were determined using Mehlich-III (MIII, Mehlich, 1984) and 2M KCl (Mulvaney, 1996) extracts (Table 1). Total soil N and C were determined by the Dumas dry-combustion method (Nelson and Sommers, 1996 and Bremmer, 1996, respectfully) (Table 1) at 1350˚C and included carbonates at lower depths. Experimental plots were established under a center pivot irrigation system using LEPA nozzles. Monthly precipitation measured at OPREC during 1994-2000 is included in Table 2.

Experiment Design:

Established in 1995, a randomized complete block design with repeated measures was used to determine the effects of annual applications of beef manure (BM), swine effluent (SE), and anhydrous ammonia (AA) on soil properties. Corn (*Zea mays* L.) was planted annually, under conventional tillage methods. Beef manure, SE, and AA were applied to provide 0, 56, 168, and 504 kg N ha^{-1} yr^{-1}; beginning in 1995 and has continued annually to the same plots. The 0 N rates were used as a control due to the fact that initial soil SAR and EC were not measured. Anhydrous ammonia was soil injected in Feb.-Mar. of each year; while BM was applied and incorporated prior to annual planting, and SE was surface applied at approximately the 6-leaf (V6) growth stage of corn. Soil samples were obtained in the spring of each year prior to treatment application from 4.6 m by 9 m treatment plots.

Soil Sampling:

Soil profile samples, one per plot, were collected prior to annual manure applications using a Giddings® hydraulic probe, mounted on a Massey-Ferguson 60 Hp tractor, equipped with a 4.2 cm x 120 cm stainless steel probe. Samples were obtained to a depth of 0-120 cm then stored at 4ºC. Samples were removed from the tubes in 15 cm sections, resulting in depths of 0-15, 15-30, 30-45, and 45-60 cm depths. The 60 –120 cm depth was treated as a composite sample. All soil samples were then air-dried and ground to pass through a 2 mm stainless steel sieve. After grinding, samples were stored in airtight containers until a saturated soil paste was prepared, extracted and analysis preformed.

Manure Sampling:

Beef manure samples, collected in duplicate, were stored at 4˚C until analysis was preformed. Swine effluent samples were collected from a commercial nursery lagoon and BM used was obtained from a feedlot; the same facilities were used each year for SE and BM, respectfully. Moisture-content, pH, manure EC (EC_m), Na, Ca, Mg, K, P, total

N (TN), total carbon (TC), NH_4-N, and total dissolved solids (TDS) were determined from non-acidified samples (Table 3). Total K, P, Na, Ca, and Mg of manures were determined from nitric acid digestions (EPA 3050B) and are included in Table 3. Total dissolved salts (TDS) were calculated using the equation of Chang et al. (1983) and Hao and Chang (2003) (Eq. [1] Appendix I) to provide an estimate amount of salt contributing to soil EC. The quantity of manure and effluent as well as Na, Ca, Mg, K, and TDS applied annually for each manure treatment are listed in Table 4.

Analysis*:*

Sodium, Ca, Mg, K, HCO_3, EC, and pH_e were directly measured from saturated paste extracts obtained using methods outlined by Rhoades (1990 and 1996). Water saturation percentage (SP) of the saturated paste was determined using Eq. [2] where (W_s) is the weight of oven-dry soil and (W_w) is the weight of water added plus any water initially present in the soil sample.

$$SP = 100 * \frac{W_w}{W_s} \qquad [2]$$

The EC of soil-paste extracts were determined using an YSI® Model 3200 conductance meter; and Na, K, Ca, and Mg were determined from the extract by inductively coupled plasma (ICP) spectroscopy. Bicarbonate content was determined by titration with 0.02 N H_2SO_4 to a pH of 4.5. Since determination of exchangeable sodium percentage (ESP) is subject to numerous errors (Thomas, 1982), soil sodicity hazard is commonly defined and evaluated in the terms of SAR. The SAR was calculated using

Eq. [3] (Sposito and Mattigod, 1977), where the cation concentrations represented are in mmol L^{-1}.

$$\text{SAR} = \frac{\left[Na^{+}\right]}{\sqrt{[Ca^{+2}]+[Mg^{+2}]}} \qquad [3]$$

RESULTS

Cumulative Effects of Manure Additions:

Manure applied from 1994 through 2000, ranged from 4 to 37 Mg ha^{-1} for BM and from 73 to 527 m^3 ha^{-1} of SE annually (Table 4). At the highest loading rates BM and SE contributed 90 and 115 kg Na ha^{-1} yr^{-1}, respectfully. Total sodium additions ranged from 58 to 575 kg Na ha^{-1} after five annual manure applications, as a function of loading rate and manure source. Sodium additions per hectare were greater for SE applications relative to BM when applied at similar loading rates.

For other nutrients at similar loading rates, BM contributed more Ca, Mg and P per hectare than did SE; whereas SE contributed greater quantities of K and TDS when compared to BM (Table 4). Anhydrous ammonia was assumed to contribute only NH_3(g) to the soil system.

Sodium Adsorption Ratio:

Sodium adsorption ratios have been altered when sampled in 2000 following five cumulative, annual manure additions at the 0-15 cm depth (Table 5). Soil SAR increased linearly with SE additions; however it decreased linearly with additional AA loading, while BM loading remained unchanged with additional manure loading (Figure 1 and Table 5). Although SAR increased with additional SE loading, only at the high SE loading rate was the increase significantly greater than AA and BM at similar loading rates (Figure 1). The increase to the SAR from SE above BM at similar loading rates corresponds to a greater amount of Na being applied with SE applications (Table 4); whereas no Na was added with the AA applications.

The SAR of the high SE loading rate resulted in differences when compared to the low SE loading rate; however the SAR at the medium SE rate was not significantly different than the high rate (Table 6). Although SAR for the 168 kg ha^{-1} annual loading rate was not significantly less than the highest rate it followed the trend of increasing SAR with an increased SE loading rate. Sodium adsorption ratios, for soil following AA applications, were significantly lower than BM and SE treated soils at the high and medium loading rates at the 0-15 cm depth (Figure 1). However, SAR values for the low SE loading rate were comparable to high AA the rate; and the low AA rate was significantly higher than the high AA rate at this soil depth (0-15 cm) in 2000 (Table 6). Sodium adsorption ratio responses illustrated in Figure 1 demonstrate the loading rate influence on Na accumulation.

Sodium adsorption ratios for all AA, BM, and SE loading rates were compared to a control. Because initial data for SAR and EC were not measured (Table 1), the control equals the mean of all 0 N rates for 2000 at 0-15 cm. When SAR was compared to the control, only SE and AA at the high loading rate were distinguished from other treatments (Figure 2). The SAR trend was to increase with SE and decrease with AA applications. While the high SE and AA loading rates are the only treatments with SAR values significantly different from the control SAR, it is evident that if the trend is continued, the medium SE loading rate is at risk of increasing SAR above the control as well. This SAR trend may become greater each year at the 0-15 cm depth if annual applications continue.

Demonstrated SAR responses to increased loading rates from regression equations are found in Figure 1; however the SAR response information is for the cumulative annual applications in 2000. The SAR response as a function of the loading rate over time corroborates this information (Figure 3). The SAR responses in 1998-2000 found in Figure 3 indicate that SAR ranges seasonally; although, SAR still increased with SE applications, decreased with AA applications, and BM applications have maintained relatively level SAR values after five cumulative annual load rate applications as observed in Figure 1. The SAR responses to seasonal soil profile changes indicate that a comparison to a control may be needed to effectively evaluate ‘real’ SAR increases. While SAR had considerable range, the increasing separation of SAR values at these loading rates is evident. Only SAR’s at the high SE loading rate have increased above the control after five annual applications (approx.~2500 kg N ha^{-1}) at the 0-15 cm depth (Figure 3). While SAR changes were small and below the commonly held 13% where soil dispersion occurs, these changes can be used to evaluate potential declines to soil quality status.

Sodium adsorption ratios responses to AA applications have also decreased the pH_e (Table 5) with a corresponding increase in the amount of soluble Ca and Mg in the extract solution. This is similar to findings by Bouman *et al*. (1995) where they looked at soil acidification from long-term use of AA. However, a difference between this study and that of Bouman *et al*. (1995) is that they looked at the 7.5-15 cm depths at 3, 6, and 26 days after AA applications. Lindsey (1979) indicated Ca and Mg solubility would increase with decreasing pH. Consistent with these findings, decreasing SAR for AA applications was facilitated by increasing quantities of soluble Ca and Mg while maintaining Na levels (Table 5). Additionally, SAR responded to the high AA loading rate applications because soil Ca and Mg increased greater than four-fold (~4.4) relative to the found with the SE and BM treatments at similar loading rates (Table 5). The SAR of AA applications also have increased in NH_4-N (Table 5), which has likely facilitated the replacement of exchangeable Na, according to lyotrophic substitution (Havlin *et al.*, 1999).

Sodium adsorption ratios, at the 0-15 cm depth, have required five cumulative annual applications to observe a response to animal manure applications (Table 6); but only at the high loading rate did significant differences exist. The soil SAR below 0-15 cm increased with increasing depth; however the SAR increases from 15-120 cm were not confounded by source or rate interactions in 2000. The SAR responses differed from the 0-15 cm depth only at the 45-120 depths and no SAR increase with depth was distinct from the adjacent depth. Sodium adsorptions ratio responses below the 0-15 cm depth are included in Appendix II; however this paper has focused on the 0-15 cm because of its agronomic importance. The SAR responses to AA, BM, and SE at all loading rates observed in the 0-15 cm depth were similar at lower profile depths only although the magnitude of SAR values increased. No SAR responses were observed after 3 or 4 cumulative annual applications of animal manures or anhydrous ammonia at the 0-15 cm soil depth (Table 6 and Appendix II).

Electrical Conductivity:

The electrical conductivity of BM and SE averaged 14.8 and 9.5 dS m^{-1}, respectfully (Table 3); however, TDS loading was greater for SE when compared to BM on a dry-weight basis (Table 4).

Electrical conductivity increased following five cumulative annual AA applications in 2000 at the 0-15 cm depth (Figure 4). The greatest EC increase was observed at the high AA loading rate (Figure 5); however EC for the low and medium AA rates were similar to all loading rates of BM and SE at the 0-15 cm depth (Table 5). The EC increase at the high AA loading rate was 2.35 dS m^{-1}, greater than any other treatment and is approaching tolerance levels detailed by Mass (1984 and 1986). However, EC for applications of BM and SE at all loading rates were non significant in 2000 at the 0-15 cm (Table 7).

This soil EC change when AA was applied corresponds to a lowering of pH, a decrease of SAR and HCO_3, and an increase in soluble Mg, Ca, and K at the same depth (Table 5). Additionally, as EC increased at the high AA loading rate in the 0-15 cm depth so did NH_4-N and NO_3-N, while Mehlich-III extractable P, K, and Mg (Table 5) have remained similar to levels found in the soil prior to any loading rate application (Table 1). The EC changes at the high AA loading rates are likely influenced due to the fact that there have been no additional elemental additions other than NH_3, unlike the manure treatments. Beef manure at the high N loading rate has increased Mehlich-III extractable P, K, Ca, and Mg, as well as TN and TC at this depth. Swine effluent at this high N loading rate has increased Mehlich-III extractable P and K, while lowering Ca. Soil pH has increased following annual applications of SE and BM.

Soil EC has not changed in relation to cumulative TDS applied in 2000 at the 0-15 cm depth, because there was no EC response to either BM or SE additions (Table 7). Although no leachate was collected to determine soluble salt losses, EC changed relatively little to a depth of 120 cm (Appendix II).

DISCUSSION

Manure loading rates for this study were generally less that other manure applied studies (Lui *et al*, 1998; Evans *et al*, 1977; Sutton *et al*, 1984; King *et al*, 1985 and 1990; Chang *et al*, 1990, 1991, and 1993; Hao and Chang, 2003; Pratt, 1984; Mathers and Stewart, 1974); however significant differences were observed after five cumulative annual applications of manures. Hao and Chang (2003) were careful to point out that other studies (Bonciarelli, 1977; and Clark *et al*., 1998) may have differences due to lower applications rates, shallower sampling depth, shorter experimental time, and higher amounts of precipitation (and irrigation) than occured in their studies. This experiment includes the cumulative effects of five annual manure applications at the 0-15 cm depth; while most authors referred to in this discussion have conducted experiments for periods ranging from 11 to 25 years (Chang *et al*., 1990, 1991 and 1993; Hao and Chang, 2003).

The increase in SAR as a result of annual applications of SE could pose a long-term problem for this production system. If SAR increases above the level of 13 then other soil properties like dispersion, structure, and hydraulic conductivity can be impacted. Soil SAR was used in this study to assess sodium relationships in the soil profile. US Agricultural Handbook 60 (USDA, 1954) and Soil Survey Staff (Soil Taxonomy, 1999) refer to an exchangeable sodium ratio (ESR) boundary of 15 (approx~13 for SAR) where soil dispersion occurs enough to limit hydraulic conductivity. Carter *et al.* (2000) found in Oklahoma soils that ESR and SAR are strongly correlated; Carter's linear relationship was very similar to correlations found by the Soil Survey Staff (USDA, 1954), validating its applicability to this study. Because of equilibrium relationships that exist between soil solution and exchangeable cations in soil, Na should be related to soil CEC; this relationship is known as ESR. This information helps clarify understanding and validates that while SAR is really a measure of salinity or sodicty in aqueous samples and not a measure of soil ESR that they have a strong correlation to each other. With this correlation we can extrapolate soil SAR values and infer ESR, the correct measure of Na accumulation in soil. SAR was determined because all possible exchangeable cations were not measured. The SAR was measured for this study to determine if soil dispersion was a needed parameter to include in planning when animal wastes were applied. While changes to SAR were seen, they are much lower than 13 percent SAR value that has been correlated to dispersion (USDA, 1954). Continued evaluation of soil SAR is needed for this study because of local interest in manure applications.

Sodium adsorption ratio changes at the high SE loading rate for this study were similar to Na increases observed by King *et al*. (1990) following six annual applications of SE. Two differences in the study and King et al. (1990) are a higher rainfall regime and a greater nutrient loading rate before Na increases were observed. This would suggest that in the more humid environment, natural precipitation was moving Na through the profile decreaseing the rate of accumulation in the soil profile. In the semi-arid climate for the southern Great Plains, there is higher probability of Na accumulation in the upper portion of the soil profile due to the lack of precipitation to transport it to lower depths. Due to the reduced precipitation, the rate of Na accumulation in the soil profile surface horizon could be of significant concern for biological activity in the future. Sodium adsorption ratio or Na increases were observed in other studies following BM and SE applications (Evans *et al*, 1977; Sutton *et al*, 1984; King *et al*, 1985 and 1990; Chang *et al*, 1990, 1991, and 1993; Hao and Chang, 2003; Mathers and Stewart, 1974). The current study however found that applications of SE and BM did not alter soil SAR nor Na in a similar fashion. In this study neither SAR nor Na levels increased following BM loading while SE increased SAR and Na levels with increasing loading rates. The different responses to SAR and Na increases observed in this study contrasted to these other studies were likely due to two factors: different moisture regimes and loading rates.

Chang *et al*. (1991) in a semi-arid moisture regime also found that soil SAR in both irrigated and non-irrigated settings were increased with increased BM loading rates over an eleven year period. They further stated that application rates above 30 and 60 Mg ha^{-1} yr^{-1} (wet weight) for non-irrigated and irrigated, respectfully, was not advisable because of low precipitation and high potential evaporation. However in high rainfall regimes (Lui *et al*, 1998; King *et al*, 1990) a considerable increase of manure loading was needed before SAR or Na increased in the 0-15 cm of soil. This study, for the SE applications, agrees with Chang *et al*. (1990 and 1991) in that SAR is increasing with manure additions and that soils in this semi-arid region could become sodic in the distant future with repeated annual applications. In this study, the specific rate (average change per unit of manure applied per year) of increase to SAR for the high SE loading rate was 0.075 m^3 yr^{-1} X 10^{-3}; while the high BM loading rate has a specific rate of increase of 0.219 Mg yr^{-1} X 10^{-3}. Therefore, without increased water applications, the distant future is in order of decades and not years; whereas without water applications SAR will increase at a rate much higher than this study found under irrigated conditions. While others have observed a significant change in soil SAR values following repeated applications of BM it was not observed in this study. There are several possible explainations why the soil SAR did not change as aresult ofBM additions including fewer applications over a shorted period of time (Hao and Chang, 2003), lower BM loading rates relative to other studies (Evans *et al*., 1977; Chang *et al*., 1990, 1991, and 1993; Hao and Chang, 2003; Pratt, 1984; Mathers and Stewart, 1974), alteration of the cation suite relative to the other studies (Mathers and Stewart, 1974; Pratt, 1984; Chang *et al*., 1991), an increase in CEC (Gao and Chang, 1996; N'Dayegamiye and D.Côté, 1989; Summerfeldt and Chang, 1985; Stadelmann and Furrer, 1984; Schjønning *et al*, 1994), and increased saturated hydraulic conductivity (Miller *et al*., 2002; Williams and Cooke, 1961; Anderson *et al*., 1990; Tiarks *et al*., 1974; and Benbi *et al*., 1998) which tended to increase sodium leaching downward in the soil profile. Chang *et al*. (1991), Liu *et al*. (1998), Mathers and Stewart, (1974), and Sutton *et al*. (1984) as well as our results indicate evidence of Na leaching out of the sampled profile however they were either not reported or measured in any of these experiments. Sodium and SAR will change with soil depth (Chang *et al*., 1991, King *et al*. 1990, and Sutton *et al*., 1984). Increasing SAR with soil depth has been attributed to irrigation along with annual precipitation, which corresponded with an increase of exchangeable ions at lower soil profile depths when compared to non-irrigated conditions (Chang *et al*., 1991). Chang *et al*. (1991) and this study both utilized irrigation in a semi-arid moisture regime.

Deacreasing SAR with increasing AA loading rates as observed in this study have been previously observed (Bouman *et al*., 1995). As SAR decreased there was a corresponding decrease in pH_e and HCO_3; whereas the concentration of Na, Ca, Mg, K, and NH_4-N in soil solution increased. The SAR response to AA loading could be a result of the decrease in soil pH; increasing ammonia concentrations are driving the pH down which intern is altering the SAR. Continued loading rates of AA introduced free H+ as the ammonium was converted to nitrate. The result of five repeated applications at 504 kg N ha^{-1} supplied adequate acidity to decrease the soil pH to 4.77 (Table 5). As a result of the decreaseing soil solution pH it is very possible the cation suite present on the colloid surface was altered as the soil pH decreased from 7.18 to 4.77 following the five annual applications (Table 5). This is supported by the decreasing SAR and the increasing concentrations of NO_3-N, NH_4-N, P, Ca, Mg, Na, and K in soil solution and the saturated paste extract (Table 5). As the cation exchange sites were saturated by additional acidity, it replaced existing soil cations. In this system which is a calcium carbonate rich system, there was a significantly larger proportion of Ca and Mg displaced from the exchange sites resulting in a lower SAR; which increased the saturation extract concentrations of Ca, Mg, Na, and K, while lowering the HCO_3 levels (Table 5). The SAR of the high AA loading rate increased Na 1.6 times above the control; while a four-fold increase of Ca and Mg in solution contributed greatly to the decrease in SAR values.

Increasing the Ca and Mg in soil solution could enhance plant uptake thus altering the SAR. To check this, the plant nutrient uptake for this study was calculated from the elemental concentration of mature corn grain estimates of Jones *et al*. (1990) and USDA-NND (2004). When corn yield was accounted for, the nutrient removeal from grain harvest was minimal (Table 8) relative to the nutrient loading from BM and SE (Table 4). Corn yields from AA loading were below BM and SE corn yields; according to grain elemental concentration estimates AA loading removed less nutrients when compare to BM and SE removal (Table 8). Because of low quantities of Ca in mature corn grain (Table 8), the Na content of mature corn grain would need to increase dramatically in order to offset the additions of Ca and Mg in soil solution as solubility increased. According to grain removal estimates the decrease to SAR from AA loading is not a result of excess Na removed in mature corn grain (Table 8). Sodium adsorption ratios may have been influenced by corn Mg uptake (Table 9); however the bulk of Na and Ca applied can be accounted for in the soil. It does not appear that in this particular study that plant uptake of cations had a significant impact on the SAR.

The total salt accumulation in the soil, as measured by EC, varies similar to SAR. High manure applications can result in accumulation of soluble salts in the soil profile (Chang *et al*, 1990, 1991, and 1993; Hao and Chang, 2003; Mathers and Stewart, 1974; Vitosh *et al*., 1973). Repeated applications of BM and SE did not have a significant affect on EC however at the highest loading rate of AA the EC was significantly altered relative to other treatements. High AA loading has increased soil EC to 3.55 dS m^{-1} above 0.75 dS m^{-1} for the control; this increase in approaching 5.9 dS m^{-1}, a level where relative yield for crop production may be reduced 50% (Mass, 1986). Corn, a moderately salt sensitive crop, has a yield reduction of 12% per dS m^{-1} above 1.7 dS m^{-1} (Mass, 1986).

The stable EC for the BM and SE treatments is somewhat different than what others have found, where using animal manures as a soil amendment has contributed to an increasing soil EC. Chang *et al*. (1991) found that soil EC in both irrigated and non-irrigated settings increased with increasing rates of BM applications over an eleven year period. They further stated that application rates above 30 and 60 Mg ha^{-1} yr^{-1} (wet weight) for non-irrigated and irrigated, respectfully, was not advisable due to soil EC increases. Chang *et al*. (1991) also found linear increases to EC over time and were not reversed using irrigation suggesting that it would be difficlt to sufficiently leach soluble salts from the soil profile. However in 2000, this study indicated that soluble salts had been sufficiently leached below the 0-15 cm depth to maintain soil EC levels following application of animal manures.

A possible difference between the study of Chang *et al*. (1991) and the present one is related to water movement throught the profile. It is possible that mobile soluble salts had been transported out of the 0-15cm soil depth at the sampling time as described by Rhoades *et al*., (1981) and Miyamoto, (1985). They found that soil water depletion and solute movement affected soluble ions location in the profile between water additions; thus Rhoades *et al*., (1981) advises caution in the semi-arid regions like the High Plains, where agriculture consumes large quantities of irrigation water. In the future, the soil EC of this study may increase with continued manure applications and should be monitored.

Chang *et al*. (1993) found that high salinity from manure applications severely reduced barley (*Hordeum vulgare* L.) yields. Data, for this study, from manure treatments indicate EC was relatively unchanged at lower loading rates and only increased slightly at high N loading rates. Therefore, soil EC changes are not likely to affect crop yields similar to findings by Chang *et al* (1993) when manure loading rates are closer to the low and medium manure loading rates that this study used.

CONCLUSIONS

Manure EC averaged 12.7 and 9.5 dS m^{-1} for BM and SE, respectfully. At the highest loading rates BM and SE contributed 90 and 115 kg Na ha^{-1} yr^{-1}, respectfully. Sodium was added in greater quantities when SE was used as an N source when compared to BM; however BM contributed more divalent cations to the soil system.

Sodium adsorption ratios increased linearly with SE additions; however AA decreased SAR linearly with increasing loading rates, while BM has remained unaffected by loading rates. The trend for SAR to increase with SE loading and decrease with AA loading is a cause for concern.

If SAR continues to increase above the control with SE loading these soils will become sodic in the future. However, if SAR continues to decrease with AA loading these soils may become severely acidic; additionally, soluble nutrient leaching may occur under irrigation while maintaining repeated loading rate applications. The slow increase of SAR above the control in SE amended treatments can be deterred by management practices such as increased water infiltration to enhance Na leaching.

The soil EC increase of 2.35 dS m^{-1} at the high AA loading rate above all other treatments was of co-result of soil pH decreases and NH_4-N accumulations; which tended to increase Ca, Mg, K, and Na in solution. Soil EC was not significantly affected by BM and SE at current loading rates.

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Table 1 Initial soil characteristics of a Richfield clay loam for experiments located at OPREC, Goodwell, OK at the 0-15 cm depth†.

Characteristics‡		Continuously cropped, conventionally tilled system
pH		7.18
NH_4-N	mg kg^{-1}	10.7
NO_3-N	mg kg^{-1}	55.4
P	mg kg^{-1}	34.3
K	mg kg^{-1}	634
Mg	mg kg^{-1}	747
Ca	mg kg^{-1}	2512
TN	g kg^{-1}	1.2
TC	g kg^{-1}	12.3

† Data over all depths is included in Table 8 of the appendix.

‡ Soil pH using glass electrode with a 1:2 soil: H_2O ratio; NH_4-N and NO_3-N from 2M KCl extracts; P, K, Mg, and Ca from Mehlich III extracts; Leco CN2000 dry-combustion analysis at 1350°C; Soil electrical conductivity for forage cropping system used a 1:2 soil: H2O ratio; all others used a saturated paste extract.

Table 2 Precipitation amounts from 1994-2000 as measured by NOAA† at OPREC, Goodwell, OK.

	Precipitation							
Month	1994	1995	1996	1997	1998	1999	2000	LTMEAN‡
	mm							
Jan.	6	2	TR	TR	TR	15	4	8
Feb.	1	TR	TR	4	13	13	TR	12
Mar	19	16	TR	TR	59	46	110	22
Apr	43	14	TR	67	20	106	48	33
May	51	90	TR	39	TR	56	26	69
Jun	46	58	61	38	TR	60	46	62
Jul	50	95	117	55	157	3	43	69
Aug	49	60	138	84	78	26	TR	60
Sep	20	62	TR	28	2	10	TR	41
Oct	TR	8	16	19	148	56	128	32
Nov	13	TR	11	TR	TR	TR	TR	15
Dec	15	13	TR	8	9	8	TR	11
Yearly Total	312	418	343	341	488	400	405	435

† National Oceanographic and Atmospheric Administration accessed thru the National Climatic Data Center.

‡ Long-term mean of data collected since 1910 (90 years).

§ TR indicates a trace of or no precipitation, snowfall, or snow depth.

Table 3 Selected characteristics of beef manure (BM) and swine effluent (SE) used over five years on experiments located at OPREC, Goodwell, OK.†

		BM (16)‡		SE (298)	
pH		8.02	±0.17	8.19	±0.13
EC_m§	dS m^{-1}	14.84	±1.19	9.46	±0.98
SAR_m¶		.	.	5.21	±0.54
Moisture content#	kg Mg^{-1}	658.9	±27.8	7.5	±1.2
Na	mol Mg^{-1}	161	±8	1267	±133
Ca	mol Mg^{-1}	785	±70	360	±67
Mg	mol Mg^{-1}	203	±15	200	±40
K	mol Mg^{-1}	443	±20	3000	±80
P	mol Mg^{-1}	178	±15	280	±13
TDS††	kg Mg^{-1}	33.9	±2.3	8.4	±0.5
TN	kg Mg^{-1}	31	±2	136	±4
TC	kg Mg^{-1}	344	±30	261	±16
NH_4-N	mmol L^{-1}	.	.	45.3	±1.3

† Numbers based on manure dry-weight, except NH_4-N.

‡ Number of samples.

§ Electrical conductivity of manure (EC_m). BM required a1:2 manure: H_2O ratio.

¶ Sodium adsorption ratio of animal manures (SAR_m).

Moisture content is equal to kg solids Mg^{-1} manure.

††Total dissolved salts (TDS) based on Hao and Chang (2004) calculations.

Table 4 Annually applied animal manures to a conventionally tilled, continuously cropped corn production system located at OPREC, Goodwell, OK.

			Application Amount					
Source†	N		Na	Ca	Mg	K	P	TDS‡
	kg ha^{-1}	Mg ha^{-1}	kg ha^{-1}					
BM	56	4	10	83	13	46	15	413
	168	12	30	253	40	137	44	1239
	504	37	90	756	119	422	134	3716
		m^3 ha^{-1}						
SE	56	73	16	8	3	64	5	1827
	168	176	38	19	6	155	11	4430
	504	527	115	56	19	464	34	13277

† BM=beef manure and SE=swine effluent.

‡ Total dissolved salts applied in manure.

Table 5 Cumulative soil characteristics in 2000 after five annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) of continuously cropped, conventionally tilled corn production system, located at OPREC, Goodwell, OK.†

			--------------------Saturated paste extract--------------------								----2M KCl‡ ----		------------MIII§------------				--LECO¶--	
Source	N	DEPTH	pH_e	EC	SAR	HCO_3	Na	Mg	Ca	K	NH_4-N	NO_3-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}			dS m^{-1}		--------------mmol L^{-1}-------------					---------------------mg kg^{-1}----------------------						---g kg^{-1}---	
AA	0	0-15	7.18	0.75	1.16	.#	1.81	0.97	1.47	1.02	3.07	7.17	36	691	909	2457	1.25	11.02
		15-30	7.18	0.64	1.10	.	1.64	0.84	1.37	0.57	2.87	5.50	22	561	882	2539	0.96	7.93
		30-45	7.05	0.61	1.23	.	1.71	0.71	1.22	0.26	2.60	3.07	21	465	977	3840	0.65	4.99
		45-60	7.30	0.54	1.29	.	1.71	0.57	1.19	0.19	2.23	2.43	32	347	887	5054	0.53	4.27
		60-120	7.20	0.49	1.41	.	1.70	0.42	1.03	0.19	3.33	2.80	24	317	787	18023	0.38	8.91
	56	0-15	7.87	0.95	1.56	0.78	2.63	1.15	1.67	0.98	3.67	12.77	26	588	783	2189	1.11	10.35
		15-30	7.84	0.81	1.21	0.76	2.00	0.99	1.77	0.40	3.80	9.80	16	482	937	2812	0.79	6.74
		30-45	7.99	0.76	1.43	0.55	2.17	0.77	1.53	0.23	3.13	9.53	19	500	1109	3223	0.61	4.86
		45-60	7.97	0.81	1.82	0.47	2.70	0.67	1.52	0.26	2.33	7.67	29	339	802	7053	0.53	5.45
		60-120	7.92	0.77	1.88	0.38	2.70	0.61	1.44	0.30	1.87	3.97	27	346	722	16263	0.35	9.66
	168	0-15	6.86	1.13	1.23	0.79	2.38	1.54	2.18	1.13	4.10	26.23	38	646	837	2340	1.24	10.68
		15-30	7.02	0.95	1.02	0.42	1.96	1.38	2.29	0.46	2.03	21.20	27	460	902	2589	0.95	7.71
		30-45	7.17	1.03	0.95	0.31	1.87	1.38	2.48	0.27	2.77	31.00	19	376	1000	2824	0.66	4.70
		45-60	7.47	1.02	1.20	0.43	2.23	1.12	2.35	0.26	3.20	36.17	23	311	888	11085	0.54	6.44
		60-120	7.33	1.03	1.51	0.51	2.72	0.93	2.30	0.25	2.17	28.23	19	266	737	12828	0.35	7.22
	504	0-15	5.94	3.55	0.83	0.09	3.00	5.13	7.82	2.07	140.00	151.57	45	623	802	2252	1.38	9.26
		15-30	6.40	2.60	0.75	0.27	2.34	3.59	6.04	1.40	77.73	112.40	32	505	732	2174	1.03	7.30
		30-45	7.72	2.17	0.74	0.50	2.29	3.30	6.22	0.59	0.70	91.30	30	502	1055	5914	0.72	5.02
		45-60	7.66	2.26	0.84	0.39	2.68	3.36	6.76	0.42	1.27	90.53	17	398	1101	13458	0.61	10.16
		60-120	7.55	2.20	0.90	0.34	2.90	2.46	7.94	0.43	0.97	73.33	26	276	667	15165	0.41	9.70

† Data for 1998 and 1999 are found in the appendix.

‡ 2 Molar KCl extraction for NH_4-N and NO_3-N.

§ Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

¶ Total N and Total C from Leco CN2000 dry-combustion analysis at 1350°C.

Data Not Available

Table 5 Cont.—beef manure†

			Saturated paste extract								2M KCl‡		MIII§				LECO¶	
Source	N	DEPTH	pH_e	EC	SAR	HCO_3	Na	Mg	Ca	K	NH_4-N	NO_3-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}			dS m^{-1}		mmol L^{-1}					mg kg^{-1}						g kg^{-1}	
BM	0	0-15	7.71	0.98	1.36	1.01	2.49	1.39	1.99	1.13	1.77	9.00	35	736	963	2658	1.25	11.03
		15-30	7.58	0.83	1.32	0.70	2.28	1.14	1.86	0.55	0.87	6.70	26	500	830	2464	0.96	7.71
		30-45	7.68	0.71	1.53	0.52	2.24	0.75	1.38	0.23	2.27	2.23	18	446	979	3096	0.70	5.01
		45-60	7.62	0.63	1.55	0.56	2.03	0.54	1.19	0.17	1.90	2.23	33	322	845	5850	0.61	4.81
		60-120	7.60	0.63	1.65	0.44	2.14	0.50	1.20	0.18	1.43	1.23	26	289	732	16158	0.49	12.75
	56	0-15	7.29	0.96	1.29	1.22	2.30	1.30	1.88	1.26	3.10	10.87	62	680	878	2428	1.27	11.53
		15-30	7.20	0.77	1.48	0.83	2.28	0.93	1.44	0.65	1.63	5.40	28	551	831	2307	0.88	7.66
		30-45	7.31	0.87	1.79	0.66	2.92	0.97	1.69	0.35	1.27	3.50	19	404	878	2526	0.65	5.19
		45-60	7.31	0.61	1.60	0.47	2.17	0.62	1.23	0.19	0.60	2.80	22	305	830	5756	0.54	4.62
		60-120	7.55	0.53	1.65	0.52	2.04	0.41	1.11	0.13	2.07	1.77	17	235	603	15885	0.36	7.24
	168	0-15	7.68	1.00	1.42	1.16	2.50	1.25	1.88	1.45	4.00	17.93	70	773	899	2582	1.21	11.68
		15-30	7.53	0.84	1.77	0.71	2.75	0.97	1.46	0.59	3.80	4.40	27	549	872	2540	0.84	7.66
		30-45	7.48	0.72	1.90	0.54	2.63	0.72	1.19	0.29	3.27	3.63	25	479	997	2977	0.60	5.05
		45-60	7.61	0.72	2.09	0.64	2.98	0.67	1.36	0.24	5.73	5.33	35	334	874	5448	0.50	5.24
		60-120	7.75	0.75	1.85	0.49	2.79	0.62	1.64	0.21	1.20	6.87	25	288	750	16873	0.37	9.56
	504	0-15	7.29	1.01	1.39	0.86	2.38	1.19	1.73	2.22	4.03	26.63	156	914	905	2889	1.64	14.12
		15-30	7.35	0.91	1.51	0.94	2.53	1.09	1.73	1.03	2.43	10.13	35	681	892	2512	0.93	7.70
		30-45	7.20	0.73	1.84	0.34	2.66	0.77	1.31	0.24	2.80	7.87	20	417	988	2746	0.64	4.85
		45-60	7.34	0.71	1.95	0.29	2.71	0.67	1.26	0.21	4.50	6.20	39	328	870	4630	0.52	3.73
		60-120	7.40	0.69	1.62	0.64	2.37	0.63	1.51	0.23	2.30	5.17	21	267	639	16645	0.32	6.00

† Data for 1998 and 1999 are found in the appendix.

‡ 2 Molar KCl extraction for NH_4-N and NO_3-N.

§ Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

¶ Total N and Total C from Leco CN2000 dry-combustion analysis at 1350˚C.

Table 5 Cont. —swine effluent†

			Saturated paste extract								2M KCl‡		MIII§				LECO¶	
Source	N	DEPTH	pH$_e$	EC	SAR	HCO$_3$	Na	Mg	Ca	K	NH$_4$-N	NO$_3$-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}			dS m^{-1}		mmol L^{-1}					mg kg^{-1}						g kg^{-1}	
SE	0	0-15	7.56	0.83	1.38	1.46	2.24	1.04	1.58	0.93	2.47	8.30	22	667	908	2467	1.11	10.29
		15-30	7.45	0.66	1.43	0.84	2.06	0.77	1.31	0.39	2.70	5.27	15	535	941	2807	0.88	7.62
		30-45	7.49	0.74	1.85	0.66	2.75	0.77	1.44	0.26	2.33	2.40	22	475	1047	3233	0.59	4.80
		45-60	7.63	0.70	2.09	0.56	2.84	0.60	1.24	0.24	2.00	1.87	15	384	959	10770	0.52	7.07
		60-120	8.16	0.68	1.87	0.48	2.65	0.78	1.23	0.25	1.03	0.77	30	281	703	15652	0.31	9.22
	56	0-15	7.43	0.76	1.30	.#	1.98	0.93	1.40	0.94	2.47	6.93	32	740	981	2916	1.13	9.59
		15-30	7.37	0.72	1.46	.	2.19	0.84	1.43	0.44	1.93	4.43	14	564	991	2660	0.84	6.76
		30-45	7.39	0.67	1.78	.	2.49	0.68	1.28	0.22	2.17	3.13	10	452	1020	3481	0.60	4.42
		45-60	7.53	0.61	1.64	.	2.21	0.59	1.21	0.18	2.23	2.70	13	366	1030	8603	0.53	5.55
		60-120	7.39	0.62	1.88	.	2.35	0.47	1.09	0.20	0.47	1.13	24	330	861	15525	0.38	11.89
	168	0-15	7.58	1.09	1.62	1.22	3.13	1.29	2.46	1.60	3.13	11.60	33	876	1013	3077	1.16	9.83
		15-30	7.56	0.84	1.58	0.78	2.64	1.05	1.74	0.50	2.33	7.23	20	502	903	2740	0.91	7.22
		30-45	7.49	0.73	1.73	0.80	2.59	0.77	1.48	0.22	2.77	4.47	24	425	1023	2296	0.67	4.93
		45-60	7.56	0.53	1.86	0.62	2.23	0.46	0.98	0.17	2.77	3.37	33	310	840	6802	0.53	5.27
		60-120	7.70	0.53	1.89	0.46	2.28	0.41	1.04	0.18	1.60	1.93	23	262	654	15755	0.35	7.25
	504	0-15	7.92	1.20	2.18	0.86	3.73	1.14	1.79	2.37	3.70	8.20	81	888	766	2143	1.16	10.99
		15-30	7.90	0.96	1.99	0.89	3.42	1.14	1.81	1.05	2.10	10.67	27	663	836	2402	0.83	7.58
		30-45	7.77	1.23	2.24	0.70	4.22	1.17	2.38	0.42	1.93	10.97	17	542	1117	4634	0.62	5.04
		45-60	7.95	0.82	1.80	0.49	2.97	0.87	1.86	0.22	2.80	9.83	22	351	955	8032	0.51	5.14
		60-120	7.40	1.03	2.30	0.35	3.91	0.72	2.16	0.19	1.57	8.17	19	245	656	17458	0.31	6.70

† Data for 1998 and 1999 are found in the appendix.

‡ 2 Molar KCl extraction for NH$_4$-N and NO$_3$-N.

§ Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

¶ Total N and Total C from Leco CN2000 dry-combustion analysis at 1350˚C.

Data Not Available

Table 6 Statistical summary of sodium adsorption ratio (SAR) from 0-15 cm for a conventionally tilled, continuously cropped corn production system located at OPREC, Goodwell, OK during 1998-2000.

					SAR	
	1998-2000			2000	1999	1998
	DF	*F*	DF	--------*F* < P--------		
Rate	3	NS†	3	NS	NS	NS
Source	2	**	2	*	NS	NS
Rate*Source	6	*	6	*	NS	NS
Year	2	***	--	--	--	--
Rate*Source*Year	22	NS	--	--	--	--
<u>CONTRASTS</u>‡						
CONTROL_vs_ ALL OTHERS		--	1	NS	NS	NS
CONTROL_vs_ SE 504		--	1	**	NS	NS
BM 56_vs_ SE 504		--	1	**	NS	NS
BM 168_vs_ SE 504		--	1	*	NS	NS
BM 168_vs_ AA 168		--	1	NS	NS	*
BM 168_vs_ AA 504		--	1	*	NS	*
BM 504_vs_ SE 504		--	1	*	NS	NS
SE 56_vs_ SE 504		--	1	**	NS	NS
SE 168_vs_ AA 504		--	1	**	NS	NS
SE 504_vs_ AA 56		--	1	*	NS	NS
SE 504_vs_ AA 168		--	1	**	NS	NS
SE 504_vs_ AA 504		--	1	***	*	NS
AA 56_vs_ AA 504		--	1	*	NS	NS
<u>SLICES</u>						
Rate*Source AA		--	3	NS	NS	NS
Rate*Source BM		--	3	NS	NS	NS
Rate*Source SE		--	3	*	NS	NS
Rate*Source	0	--	2	NS	NS	NS
Rate*Source	56	--	2	NS	NS	NS
Rate*Source	168	--	2	NS	NS	NS
Rate*Source	504	--	2	***	*	NS

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectfully.

† NS, non significant at the 0.05 level.

‡ All other possible single degree contrasts were non significant.

¶ SLICE option can produce what are known as tests of simple effects (Winer 1971). For example, suppose that Rate*Source is significant and you want to test for the effect of Rate within each level of Source. This code tests for the simple main effects of Rate for Source, which are calculated by extracting the appropriate rows from the coefficient matrix for the Rate*Source LSMEANS and using them to form an *F*-test as performed by the CONTRAST statement.

Table 7 Statistical summary of electrical conductivity (EC) from 0-15 cm where beef manure (BM), swine effluent (SE), and anhydrous ammonia (AA) have had five annual applications applied to a conventionally tilled, continuously cropped corn production system located at OPREC, Goodwell, OK during 2000.

						EC	
		1998-2000			2000	1999	1998
		DF	*F*	DF	--------*F* < P--------		
Rate		3	***	3	***	NS†	***
Source		2	***	2	**	NS	**
Rate*Source		6	***	6	***	NS	**
Year		2	***	--	--	--	--
Rate*Year		6	**	--	--	--	--
Source*Year		4	**	--	--	--	--
Rate*Source*Year		22	**	--	--	--	--
CONTRASTS‡							
CONTROL_vs_	ALL OTHERS		--	1	NS	NS	NS
CONTROL_vs_	AA 504		--	1	***	NS	***
BM 56_vs_	AA 504		--	1	***	NS	***
BM 168_vs_	AA 504		--	1	***	NS	***
BM 504_vs_	AA 56		--	1	NS	*	NS
BM 504_vs_	AA 168		--	1	NS	*	NS
BM 504_vs_	AA 504		--	1	***	NS	***
SE 56_vs_	AA 504		--	1	***	NS	***
SE 168_vs_	AA 504		--	1	***	NS	***
SE 504_vs_	AA 504		--	1	***	NS	***
AA 56_vs_	AA 504		--	1	***	NS	***
AA 168_vs_	AA 504		--	1	***	NS	**
AA_vs_	BM		--	1	**	NS	**
AA_vs_	SE		--	1	**	NS	**
BM_vs_	SE		--	1	NS	NS	NS
SLICES¶							
Rate*Source	AA		--	3	***	NS	***
Rate*Source	BM		--	3	NS	NS	NS
Rate*Source	SE		--	3	NS	NS	NS
Rate*Source		0	--	2	NS	NS	NS
Rate*Source		56	--	2	NS	NS	NS
Rate*Source		168	--	2	NS	NS	NS
Rate*Source		504	--	2	***	NS	***

*, **, *** Significant at 0.05, 0.01, and 0.001 probability levels, respectfully.

† NS, non significant at the 0.05 level.

‡ All other possible pair-wise single degree treatment contrasts were non significant.

¶ SLICE option can produce what are known as tests of simple effects (Winer 1971). For example, suppose that Rate*Source is significant and you want to test for the effect of Rate within each level of Source. This code tests for the simple main effects of Rate for Source, which are calculated by extracting the appropriate rows from the coefficient matrix for the Rate*Source LSMEANS and using them to form an *F*-test as performed by the CONTRAST statement.

Table 8 Maximum corn yields and elemental uptake and removal in grain at maturity after repeated annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) for a continuously cropped, conventionally tilled corn study, located at OPREC, Goodwell, OK (n=3).† Values represent the maximum yield and potential nutrient removal from 1995-2000 harvested grain yields.

	Max Yield	Na	Ca	Mg	K	P	Mn	Cu	Zn	Fe
	kg ha^{-1}						g ha^{-1}			
AA	9750	3.41	0.68	12.38	27.98	20.47	47.77	30.22	215.47	264.22
BM	11106	3.89	0.78	14.10	31.87	23.32	54.42	34.43	245.44	300.97
SE	10932	3.83	0.77	13.88	31.37	22.96	53.57	33.89	241.59	296.25
SED	519	0.18	0.04	0.66	1.49	0.62	2.54	1.61	11.41	14.01

† Elemental concentrations of corn grain adapted from Jones et al. (1990) and USDA-NND (2004) sources.

Table 9 Nutrient usage in corn grain at maturity after repeated annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) for a continuously cropped, conventionally tilled corn study, located at OPREC, Goodwell, OK (n=3).†

		Elemental Use Efficiency‡				% Uptake§			
		Na	Ca	Mg	K	Na	Ca	Mg	K
		%				%			
BM	56	2.70	0.065	7.55	4.82	23.87	0.575	66.62	42.55
	168	1.26	0.030	3.43	2.26	8.32	0.197	22.63	14.93
	504	0.50	0.012	1.37	0.88	2.85	0.068	7.83	4.99
SE	56	0.88	0.351	16.99	1.80	15.08	6.034	291.91	30.92
	168	0.51	0.202	11.63	1.02	6.49	2.595	149.09	13.04
	504	0.27	0.112	5.97	0.55	2.25	0.923	49.38	4.57

† Elemental concentrations of corn grain adapted from Jones et al. (1990) and USDA-NND (2004) sources.

‡ Relative percent increase above the 0 N loading rate removed in corn grain[†].

§ Percent of applied nutrient removed in corn grain[†].

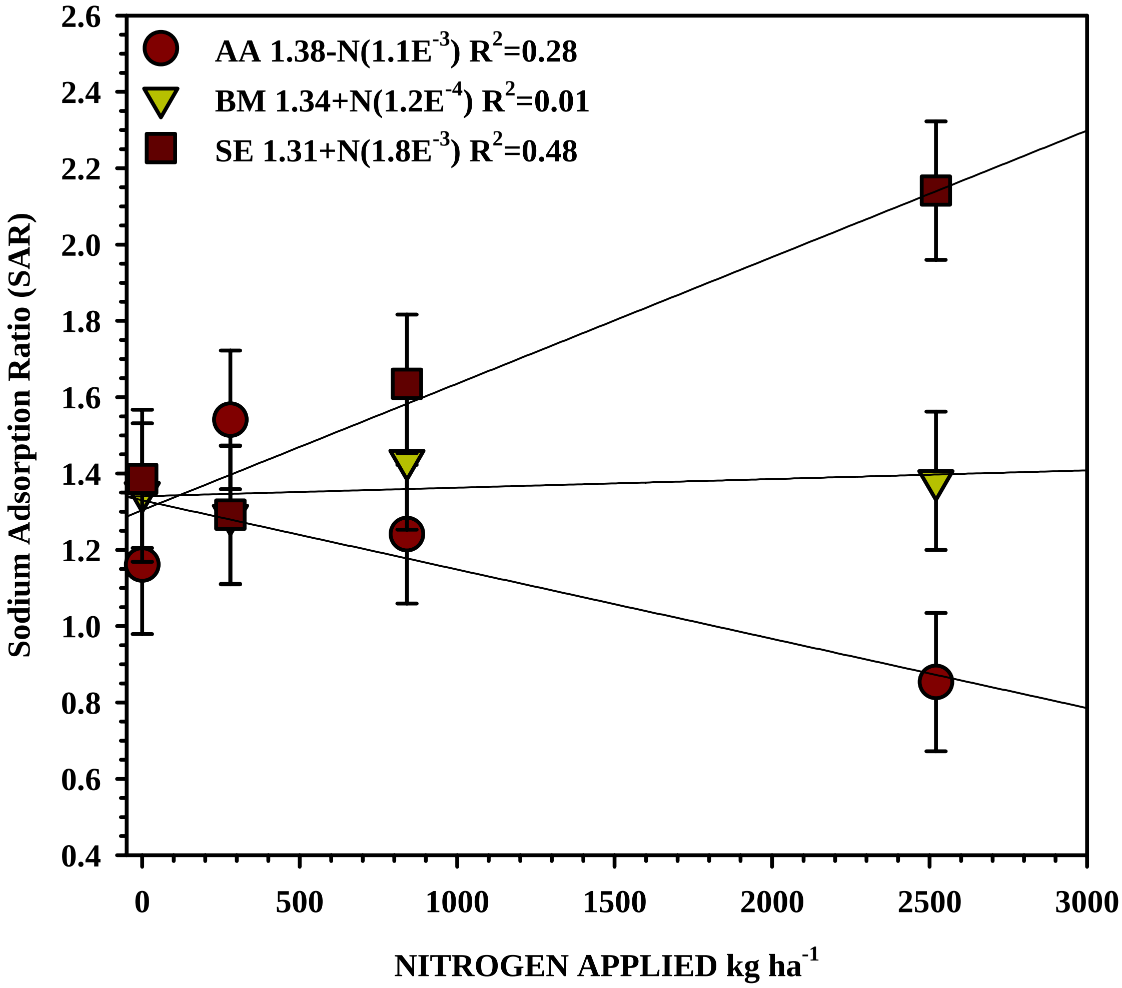

Figure 1 Sodium adsorption ratio (SAR) at 0-15 cm depth in 2000 as a function of cumulative annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) in a continuously cropped, conventionally tilled corn production system located at OPREC, Goodwell, OK (n=3).

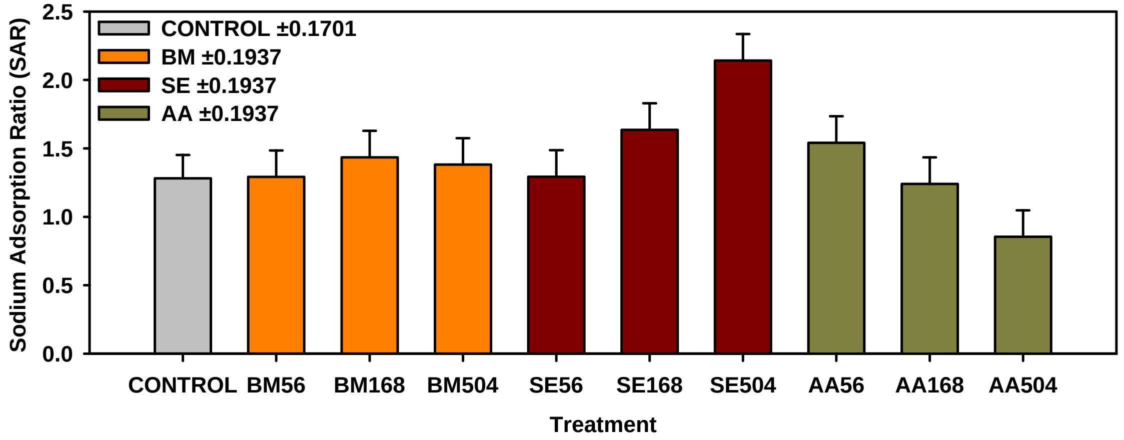

Figure 2 The cumulative effect of five annual applications of beef manure (BM), swine effluent (SE), and anhydrous ammonia (AA) at 56, 168, and 504 kg N ha^{-1} yr^{-1} on sodium adsorption ratio (SAR) at the 0-15 cm depth when compared to the control plot. The control is the average of all 0 N rates.

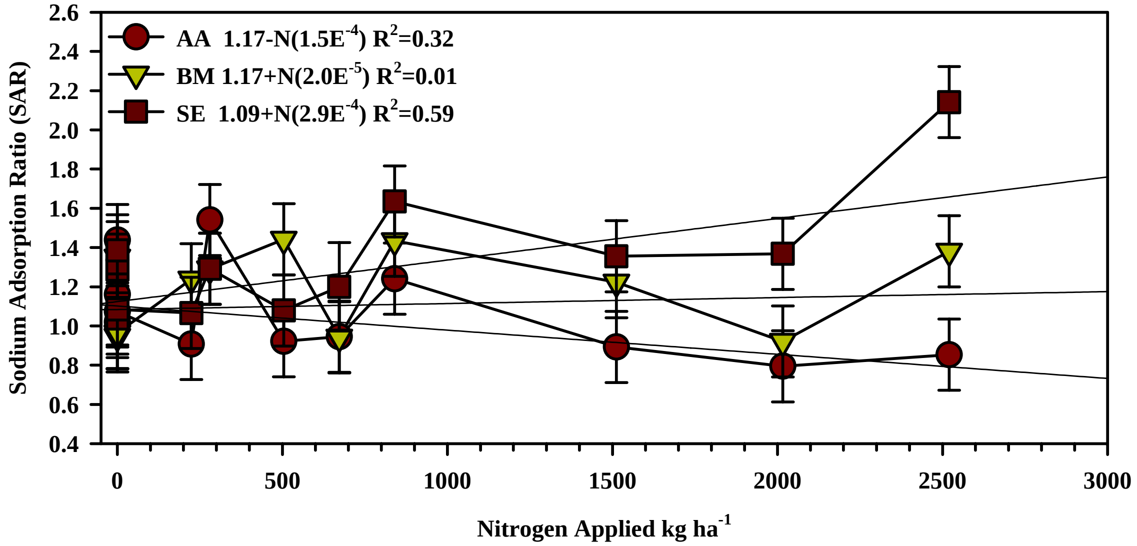

Figure 3 Sodium adsorption ratio (SAR) at the 0-15 cm depth as a function of cumulative annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) in a continuously cropped, conventionally tilled corn production system located at OPREC, Goodwell, OK (n=3). Annual applications were from 1995 thru 2000, but only data from 1998 thru 2000 was plotted.

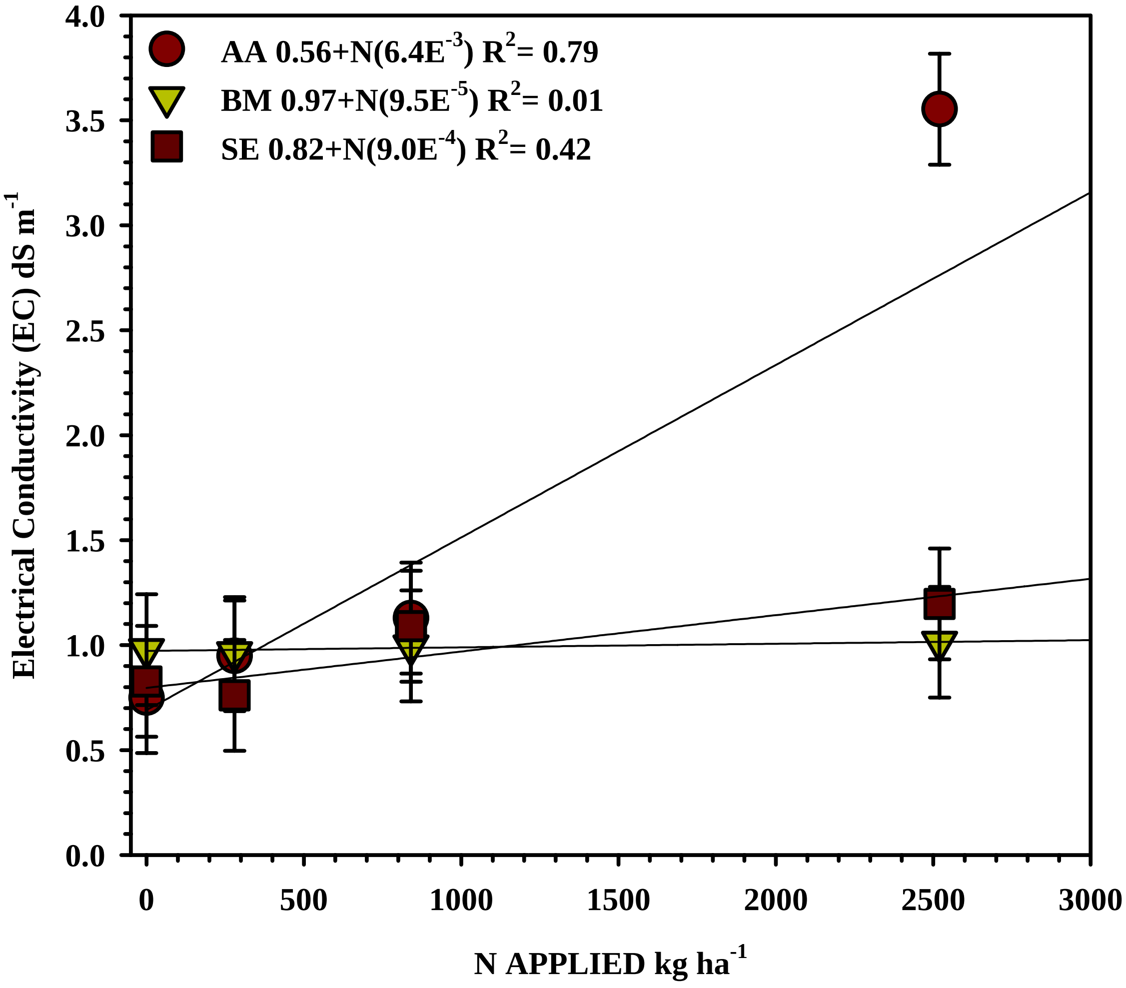

Figure 4 Electrical conductivity (EC) at 0-15 cm depth in 2000 as a function of cumulative annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) in a continuously cropped, conventionally tilled corn production system located at OPREC, Goodwell, OK (n=3).

APPENDICES

Appendix I
Manure Calculations

Hog and Beef manure Calculations based on animals in CAFO's:

A. 1,465,000 hogs in the Oklahoma panhandle (Oklahoma Agricultural Statistics Services 2000).

B. 750,000 cattle in the Oklahoma panhandle (Oklahoma Agricultural Statistics Services 2000).

C. 1,800 kg yr^{-1} hog wastes produced (Springer, T. L. 1999. High Plains Animal Waste Conf. Proc. Agronomic Uses of Animal Waste on Irrigated Buffalograss).

D. 1.4 gal day^{-1} volume of hog manure produced sow (OSU Ext-F-1735).

E. 0.9 gal day^{-1} volume of hog manure produced finishers (OSU Ext-F-1735).

F. 58.2 kg 1000kg^{-1} day^{-1} Beef manure produced ~ 450-500 lb animal (USDA Agricultural Waste Management Field Handbook).

<u>Hog waste produced in Oklahoma's panhandle counties:</u>

$$= \frac{1800 \cdot kg \cdot waste \cdot * \cdot 1.465 \times 10^{6} \cdot hogs}{hog \cdot yr} = \frac{2.637 \times 10^{9} \cdot kg \cdot waste}{yr}$$

<u>Feedlot cattle waste produced in Oklahoma's panhandle counties:</u>

$$= \frac{58.2 \cdot kg \cdot waste \cdot * \cdot 7.5 \times 10^{5} \cdot feedlot \cdot cattle \cdot * \cdot 365 \cdot day}{1000 \cdot lb \cdot animal \cdot day \cdot \cdot yr} = \frac{1.593 \times 10^{10} \cdot kg \cdot waste}{1000 \cdot lb \cdot AU \cdot \cdot yr}$$

Total dissolved salts (TDS) calculated based on the equation:

$$TDS = 765.1 \cdot EC^{1.087} \qquad \text{Eq.[3]}$$

(where TDS is in mg L^{-1} and EC is in dS m^{-1}) by Chang et al. (1983) and the water content of manure at which the EC measurements were obtained.

SWINE EFFLUENT

SODIUM

$$\frac{218mg\cdot Na}{L_{SE}}\times\frac{{}^{*}L_{SE}}{kg_{SE}}\times\frac{1000kg_{SE}}{Mg_{SE}}\times\frac{Mg_{SE}}{7.5kg\cdot SOLIDS}=\frac{29067mg\cdot Na}{kg\cdot SOLIDS}$$

$$\frac{29067mg\cdot Na}{kg\cdot SOLIDS}\times\frac{g\cdot Na}{1000mg\cdot Na}\times\frac{mol}{22.98977g}\times\frac{1000kg\cdot SOLIDS}{Mg\cdot SOLIDS}=\frac{1264.33mol\cdot Na}{Mg\cdot SOLIDS}$$

*ASSUMING ρ=1.0 FOR SE.

CALCIUM

$$\frac{107mg\cdot Ca}{L_{SE}}\times\frac{{}^{*}L_{SE}}{kg_{SE}}\times\frac{1000kg_{SE}}{Mg_{SE}}\times\frac{Mg_{SE}}{7.5kg\cdot SOLIDS}=\frac{14267mg\cdot Ca}{kg\cdot SOLIDS}$$

$$\frac{14267mg\cdot Ca}{kg\cdot SOLIDS}\times\frac{g\cdot Ca}{1000mg\cdot Ca}\times\frac{mol}{40.078g}\times\frac{1000kg\cdot SOLIDS}{Mg\cdot SOLIDS}=\frac{355.97mol\cdot Ca}{Mg\cdot SOLIDS}$$

*ASSUMING ρ=1.0 FOR SE.

MAGNESIUM

$$\frac{36mg\cdot Mg}{L_{SE}}\times\frac{{}^{*}L_{SE}}{kg_{SE}}\times\frac{1000kg_{SE}}{Mg_{SE}}\times\frac{Mg_{SE}}{7.5kg\cdot SOLIDS}=\frac{4800mg\cdot Mg}{kg\cdot SOLIDS}$$

$$\frac{4800mg\cdot Mg}{kg\cdot SOLIDS}\times\frac{g\cdot Mg}{1000mg\cdot Mg}\times\frac{mol}{24.305g}\times\frac{1000kg\cdot SOLIDS}{Mg\cdot SOLIDS}=\frac{197.49mol\cdot Mg}{Mg\cdot SOLIDS}$$

*ASSUMING ρ=1.0 FOR SE.

POTASSIUM

$$\frac{880mg\cdot K}{L_{SE}}\times\frac{{}^{*}L_{SE}}{kg_{SE}}\times\frac{1000kg_{SE}}{Mg_{SE}}\times\frac{Mg_{SE}}{7.5kg\cdot SOLIDS}=\frac{117333mg\cdot K}{kg\cdot SOLIDS}$$

$$\frac{117333mg\cdot K}{kg\cdot SOLIDS}\times\frac{g\cdot K}{1000mg\cdot K}\times\frac{mol}{39.0983g}\times\frac{1000kg\cdot SOLIDS}{Mg\cdot SOLIDS}=\frac{3000.98mol\cdot K}{Mg\cdot SOLIDS}$$

*ASSUMING ρ=1.0 FOR SE.

PHOSPHORUS

$$\frac{65mg\cdot P}{L_{SE}}\times\frac{{}^{*}L_{SE}}{kg_{SE}}\times\frac{1000kg_{SE}}{Mg_{SE}}\times\frac{Mg_{SE}}{7.5kg\cdot SOLIDS}=\frac{8667mg\cdot P}{kg\cdot SOLIDS}$$

$$\frac{8667mg\cdot P}{kg\cdot SOLIDS}\times\frac{g\cdot P}{1000mg\cdot P}\times\frac{mol}{30.97376g}\times\frac{1000kg\cdot SOLIDS}{Mg\cdot SOLIDS}=\frac{279.81mol\cdot P}{Mg\cdot SOLIDS}$$

*ASSUMING ρ=1.0 FOR SE.

BEEF MANURE

SODIUM

$$\frac{2435mg \cdot Na}{kg_{BM}} \times \frac{1000kg_{BM}}{Mg_{BM}} \times \frac{Mg_{BM}}{658.9kg \cdot SOLIDS} = \frac{3696mg \cdot Na}{kg \cdot SOLIDS}$$

$$\frac{3696mg \cdot Na}{kg \cdot SOLIDS} \times \frac{g \cdot Na}{1000mg \cdot Na} \times \frac{mol}{22.98977g} \times \frac{1000kg \cdot SOLIDS}{Mg \cdot SOLIDS} = \frac{160.75mol \cdot Na}{Mg \cdot SOLIDS}$$

CALCIUM

$$\frac{20725mg \cdot Ca}{kg_{BM}} \times \frac{1000kg_{BM}}{Mg_{BM}} \times \frac{Mg_{BM}}{658.9kg \cdot SOLIDS} = \frac{31454mg \cdot Ca}{kg \cdot SOLIDS}$$

$$\frac{31454mg \cdot Ca}{kg \cdot SOLIDS} \times \frac{g \cdot Ca}{1000mg \cdot Ca} \times \frac{mol}{40.078g} \times \frac{1000kg \cdot SOLIDS}{Mg \cdot SOLIDS} = \frac{784.82mol \cdot Ca}{Mg \cdot SOLIDS}$$

MAGNESIUM

$$\frac{2435mg \cdot MG}{kg_{BM}} \times \frac{1000kg_{BM}}{Mg_{BM}} \times \frac{Mg_{BM}}{658.9kg \cdot SOLIDS} = \frac{3696mg \cdot MG}{kg \cdot SOLIDS}$$

$$\frac{3696mg \cdot MG}{kg \cdot SOLIDS} \times \frac{g \cdot MG}{1000mg \cdot MG} \times \frac{mol}{24.305g} \times \frac{1000kg \cdot SOLIDS}{Mg \cdot SOLIDS} = \frac{160.75mol \cdot MG}{Mg \cdot SOLIDS}$$

POTASSIUM

$$\frac{11417mg \cdot K}{kg_{BM}} \times \frac{1000kg_{BM}}{Mg_{BM}} \times \frac{Mg_{BM}}{658.9kg \cdot SOLIDS} = \frac{17327mg \cdot K}{kg \cdot SOLIDS}$$

$$\frac{17327mg \cdot K}{kg \cdot SOLIDS} \times \frac{g \cdot K}{1000mg \cdot K} \times \frac{mol}{39.0983g} \times \frac{1000kg \cdot SOLIDS}{Mg \cdot SOLIDS} = \frac{443.17mol \cdot K}{Mg \cdot SOLIDS}$$

PHOSPHORUS

$$\frac{3624mg \cdot P}{kg_{BM}} \times \frac{1000kg_{BM}}{Mg_{BM}} \times \frac{Mg_{BM}}{658.9kg \cdot SOLIDS} = \frac{5500mg \cdot P}{kg \cdot SOLIDS}$$

$$\frac{5500mg \cdot P}{kg \cdot SOLIDS} \times \frac{g \cdot P}{1000mg \cdot P} \times \frac{mol}{30.97376g} \times \frac{1000kg \cdot SOLIDS}{Mg \cdot SOLIDS} = \frac{177.57mol \cdot P}{Mg \cdot SOLIDS}$$

Appendix II

SAR and EC in a Conventionally Tilled, Continuously Cropped Corn Production Experimental Design

Table 10 Initial soil characteristics of a continuously cropped, conventionally tilled corn system, measured prior to manure applications in 1995. All studies are located at OPREC, Goodwell, OK.

Study	Depth	pH†	NH_4-N	NO_3-N	P	K	Mg	Ca	TN	TC
	cm		———————mg kg^{-1} soil———————						—g kg^{-1}—	
Continuously cropped, conventionally tilled corn system	0-15	7.18	10.67	55.40	34.28	634	747	2512	1.2	12.3
	15-30	7.60	9.90	51.09	13.96	525	867	2628	1.0	8.7
	30-45	7.76	6.73	24.63	25.19	534	867	2980	0.9	6.7
	45-60	7.70	7.11	25.24	25.44	510	833	7938	0.6	12.1
	60-120	8.14	5.24	34.61	22.90	394	720	16708	0.6	19.9

† Soil pH using glass electrode with a 1:2 soil: H_2O ratio; NH_4-N and NO_3-N from 2M KCl extracts; P, K, Mg, and Ca from Mehlich III extracts; Leco CN2000 dry-combustion analysis at 1350˚C; Soil electrical conductivity for forage cropping system used a 1:2 soil: H2O ratio; all others used a saturated paste extract.

Table 11 Cumulative soil characteristics in 1999 after four annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) of a continuously cropped, conventionally tilled corn production system, located at OPREC, Goodwell, OK.

			---------------------Saturated paste extract---------------------								----2M KCl† ----		------------MIII‡------------				--LECO§--	
Source	N	DEPTH	Ph_e¶	EC	SAR	HCO_3	Na	Mg	Ca	K	NH_4-N	NO_3-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}	cm		Ds m^{-1}		--------------mmol L^{-1}-------------					---------------------mg kg^{-1}----------------------						---g kg^{-1}---	
AA	0	0-15	7.79	0.52	1.02	0.30	1.44	1.18	0.75	0.58	7.46	6.98	33	688	948	3615	0.95	8.73
		15-30	7.52	0.50	1.17	0.45	1.57	1.07	0.66	0.24	4.25	4.93	21	520	1076	4121	0.72	6.18
		30-45	7.99	0.53	1.50	0.62	1.97	1.13	0.60	0.18	5.42	4.07	49	459	1088	4702	0.58	4.60
		45-60	7.90	0.55	1.09	0.82	1.49	1.24	0.72	0.44	5.17	4.79	21	601	1051	14180	0.71	11.43
		60-120	7.70	0.56	1.57	0.43	1.92	1.03	0.44	0.17	2.27	2.46	23	368	733	16031	0.32	10.55
	56	0-15	7.56	0.44	0.91	0.97	1.34	1.29	0.90	0.80	8.54	8.40	38	739	995	3556	1.21	9.97
		15-30	7.76	0.54	1.40	0.84	1.98	1.21	0.79	0.33	9.99	6.32	19	515	1141	3938	0.91	6.76
		30-45	7.83	0.54	1.74	0.62	2.28	1.05	0.71	0.26	7.17	5.05	17	471	1141	4150	0.74	5.05
		45-60	7.75	0.58	1.56	0.51	2.19	1.27	0.65	0.24	7.60	4.75	57	492	1037	4623	0.65	4.16
		60-120	7.48	1.05	1.85	0.30	3.62	2.58	1.18	0.38	7.39	14.09	23	458	810	22755	0.51	13.88
	168	0-15	7.22	0.46	0.95	0.30	1.25	1.02	0.70	0.67	13.93	10.17	31	806	933	3383	1.03	9.86
		15-30	7.85	0.51	1.14	0.31	1.48	1.00	0.67	0.53	8.63	5.03	23	554	953	3733	0.77	7.47
		30-45	7.71	0.55	1.34	0.48	1.76	1.14	0.65	0.22	7.49	6.10	34	472	1038	3874	0.56	5.38
		45-60	7.57	0.72	1.46	0.42	2.22	1.68	0.81	0.18	7.36	12.14	24	383	909	7252	0.47	5.96
		60-120	7.35	1.56	1.50	0.25	3.59	4.61	1.52	0.30	5.64	42.84	18	349	708	23994	0.36	10.91
	504	0-15	6.33	0.73	0.79	0.10	1.26	1.40	1.07	0.88	25.61	29.99	43	888	1038	3564	1.35	10.15
		15-30	6.32	0.68	0.81	0.12	1.31	1.53	0.99	0.51	21.31	29.92	31	666	1072	4036	0.99	7.14
		30-45	7.46	0.91	0.76	0.54	1.52	2.63	1.44	0.27	4.86	30.45	21	569	1352	5956	0.81	8.43
		45-60	7.52	1.15	1.06	0.53	2.25	3.54	1.61	0.23	7.25	40.55	11	557	1302	20960	0.55	7.36
		60-120	7.52	1.40	1.12	0.35	3.09	6.27	1.96	0.30	4.60	71.24	21	433	964	31829	0.41	14.07

[†] 2 Molar KCl extraction for NH_4-N and NO_3-N.

[‡] Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

[§] Total N and Total C from Leco CN2000 dry-combustion analysis at 1350°C.

¶Soil Ph using a glass electrode in a 1:2 soil: H_2O ratio.

Table 11 Cont. —beef manure

			---------------------Saturated paste extract---------------------								-----2M KCl[†] -----		------------MIII[‡]------------				--LECO[§]--	
Source	N	DEPTH	pH_e	EC	SAR	HCO_3	Na	Mg	Ca	K	NH_4-N	NO_3-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}	cm		dS m^{-1}		-------------mmol L^{-1}-------------					---------------------mg kg^{-1}---------------------						---g kg^{-1}---	
BM	0	0-15	7.81	0.47	0.95	1.01	1.53	1.50	1.04	0.84	5.62	7.73	43	602	869	3601	1.20	10.32
		15-30	7.70	0.34	1.36	0.73	1.88	1.16	0.76	0.34	5.87	5.27	22	521	1080	3752	0.89	7.39
		30-45	7.61	0.36	1.60	0.65	1.87	0.85	0.52	0.17	4.86	3.63	31	442	1131	4070	0.65	4.95
		45-60	7.75	0.45	1.93	0.65	2.33	0.97	0.55	0.14	6.19	3.46	46	378	980	6248	0.58	4.93
		60-120	7.72	0.62	1.96	0.46	2.88	1.52	0.65	0.20	5.04	2.52	26	359	787	20408	0.42	13.22
	56	0-15	7.83	0.75	1.24	1.11	2.03	1.64	1.09	1.28	36.62	6.58	62	916	940	3562	1.16	11.22
		15-30	7.14	0.30	1.44	0.74	2.05	1.23	0.79	0.53	5.00	5.21	30	630	994	3543	0.75	7.30
		30-45	7.73	0.42	1.67	0.70	2.11	1.03	0.60	0.23	3.88	3.65	28	454	1057	3915	0.58	5.17
		45-60	7.88	0.46	2.00	0.62	2.75	1.26	0.63	0.20	3.35	3.38	28	402	925	6543	0.41	6.19
		60-120	7.70	0.49	1.49	0.46	1.95	1.26	0.42	0.14	3.57	2.47	21	327	627	17010	0.32	8.96
	168	0-15	7.91	0.63	0.94	1.07	1.40	1.33	0.91	1.05	7.53	7.03	76	860	1030	3704	1.17	11.58
		15-30	7.80	0.58	1.58	0.86	2.06	1.06	0.70	0.45	5.86	6.00	22	588	1045	3571	0.84	7.41
		30-45	7.76	0.54	1.98	0.69	2.37	0.94	0.52	0.16	4.69	4.57	25	415	1102	3852	0.59	5.30
		45-60	7.54	0.45	1.64	0.42	2.40	1.42	0.74	0.19	5.58	8.73	17	580	1055	6165	0.50	6.20
		60-120	7.59	0.92	1.86	0.38	3.23	2.02	0.99	0.28	5.75	10.11	39	425	1099	18383	0.50	18.20
	504	0-15	7.68	1.07	0.92	1.89	1.74	2.76	1.93	2.20	12.59	12.04	113	1125	1019	4584	1.55	14.14
		15-30	7.84	0.55	1.65	0.50	2.11	0.99	0.64	0.77	5.85	5.22	27	717	1028	3628	0.91	7.51
		30-45	7.69	0.46	1.79	0.56	2.46	1.17	0.70	0.25	6.33	5.34	16	459	1099	5440	0.67	5.06
		45-60	7.57	0.75	1.77	0.46	2.85	1.73	0.91	0.22	6.28	8.17	31	392	954	16156	0.55	5.64
		60-120	7.22	1.35	1.90	0.25	4.35	3.83	1.64	0.30	6.41	29.04	25	404	920	24891	0.32	9.47

[†] 2 Molar KCl extraction for NH_4-N and NO_3-N.

[‡] Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

[§] Total N and Total C from Leco CN2000 dry-combustion analysis at 1350˚C.

¶Soil pH using a glass electrode in a 1:2 soil: H_2O ratio.

Table 11 Cont. —swine effluent

			---------------------Saturated paste extract---------------------								-----2M KCl[†] -----		------------MIII[‡]------------				--LECO[§]--	
Source	N	DEPTH	pH_e	EC	SAR	HCO_3	Na	Mg	Ca	K	NH_4-N	NO_3-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}	cm		dS m^{-1}		-------------mmol L^{-1}-------------					---------------------mg kg^{-1}----------------------						---g kg^{-1}---	
SE	0	0-15	7.73	0.75	1.04	0.68	1.87	2.00	1.33	1.00	5.80	2.43	26	849	1031	3534	1.31	10.60
		15-30	7.66	0.70	1.51	0.78	2.53	1.88	1.13	0.58	4.64	2.34	23	597	1008	3985	0.90	7.46
		30-45	7.75	0.48	1.48	0.39	1.79	0.95	0.50	0.21	6.90	1.24	41	504	1092	4259	0.69	5.20
		45-60	7.90	0.53	1.91	0.41	2.59	1.20	0.64	0.17	3.66	1.28	19	499	1091	11394	0.58	7.19
		60-120	7.63	0.69	2.01	0.39	2.74	1.27	0.60	0.25	3.12	0.88	29	448	850	14812	0.41	17.98
	56	0-15	7.42	0.72	1.07	1.01	1.68	1.63	1.04	0.81	5.42	5.37	38	855	949	3817	1.11	10.07
		15-30	7.81	0.39	1.07	0.74	1.51	1.20	0.75	0.50	6.79	6.44	28	617	982	3530	0.87	7.30
		30-45	7.20	0.52	1.71	0.56	2.22	1.10	0.59	0.27	7.72	4.48	16	530	1070	4027	0.63	5.06
		45-60	7.86	0.61	1.54	0.59	2.10	1.26	0.60	0.21	7.33	4.38	38	481	997	8194	0.57	5.40
		60-120	7.54	0.69	1.60	0.44	2.32	1.48	0.62	0.20	4.19	3.24	23	566	918	20116	0.34	14.01
	168	0-15	7.75	0.58	1.21	0.64	1.66	1.11	0.77	1.08	5.88	5.75	43	965	1000	3577	1.15	10.33
		15-30	7.74	0.66	1.69	0.74	2.42	1.28	0.77	0.46	8.10	4.99	22	586	995	4889	0.88	7.98
		30-45	7.64	0.53	2.06	0.60	2.42	0.87	0.51	0.28	5.39	3.61	26	589	1062	3662	0.71	5.71
		45-60	7.82	0.47	1.79	0.49	2.38	1.16	0.61	0.25	7.35	3.25	26	473	1017	8143	0.61	6.31
		60-120	7.36	0.80	1.72	0.37	2.74	1.90	0.72	0.23	6.50	3.56	20	363	726	20519	0.42	12.82
	504	0-15	7.26	0.59	1.37	0.62	1.75	0.98	0.66	1.48	5.85	8.89	62	1048	1095	7573	1.25	10.18
		15-30	7.69	0.65	1.53	0.65	2.26	1.35	0.84	0.78	5.90	6.84	30	813	1040	4115	0.92	7.51
		30-45	7.87	0.35	1.74	0.66	2.25	1.08	0.59	0.22	4.91	5.27	20	484	1119	5519	0.69	4.51
		45-60	7.82	0.43	2.09	0.44	2.47	0.95	0.43	0.15	4.39	3.77	44	338	817	15254	0.70	6.29
		60-120	7.59	0.54	2.04	0.34	2.43	1.03	0.39	0.14	5.84	2.61	21	291	632	22695	0.41	8.12

[†] 2 Molar KCl extraction for NH_4-N and NO_3-N.

[‡] Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

[§] Total N and Total C from Leco CN2000 dry-combustion analysis at 1350°C.

¶Soil pH using a glass electrode in a 1:2 soil: H_2O ratio.

Table 12 Cumulative soil characteristics in 1998 after three annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) of a continuously cropped, conventionally tilled corn production system, located at OPREC, Goodwell, OK (n=3).

			---Saturated paste extract---								-----2M KCl[†] -----		---MIII[‡]---				--LECO[§]--	
Source	N	DEPTH	pH_e	EC	SAR	HCO_3	Na	Mg	Ca	K	NH_4-N	NO_3-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}	cm		dS m^{-1}		---mmol L^{-1}---					---mg kg^{-1}---						---g kg^{-1}---	
AA	0	0-15	7.89	0.84	1.44	0.94	2.27	1.68	0.99	0.97	17.87	18.35	40	396	730	2367	0.92	9.95
		15-30	7.76	0.64	1.03	0.78	1.54	1.45	0.84	0.38	11.84	8.47	22	266	739	2224	0.69	7.24
		30-45	8.02	0.64	1.25	0.63	1.83	1.37	0.77	0.16	11.74	5.68	26	207	838	2545	0.53	5.00
		45-60	8.02	0.74	1.37	0.64	2.14	1.64	0.81	0.16	9.07	5.16	34	210	817	5881	0.45	7.28
		60-120	7.92	0.44	1.41	0.50	2.16	1.64	0.75	0.18	6.70	2.50	26	192	734	13930	0.37	13.81
	56	0-15	7.89	0.84	1.07	1.02	1.87	2.03	1.16	1.07	13.75	24.00	37	522	709	2312	1.00	10.41
		15-30	7.95	0.88	1.07	1.02	1.96	2.22	1.21	0.45	10.18	25.49	16	348	810	2535	0.70	6.97
		30-45	8.00	1.09	1.19	1.02	2.38	2.71	1.32	0.37	10.75	39.60	19	316	864	2875	0.53	4.72
		45-60	7.86	1.04	1.32	1.19	2.49	2.51	1.07	0.32	10.50	38.42	31	313	770	5619	0.43	4.89
		60-120	7.94	1.10	1.50	0.82	2.65	2.19	0.91	1.28	25.32	25.91	27	284	686	13411	0.34	9.68
	168	0-15	7.42	1.88	0.92	0.65	2.26	4.78	2.72	1.47	44.63	103.86	43	422	692	2511	1.08	10.26
		15-30	7.62	1.03	0.86	0.34	1.65	2.26	1.46	0.52	12.44	48.01	29	288	715	2142	0.78	7.45
		30-45	7.79	1.03	0.98	0.40	2.20	3.29	1.82	0.26	10.67	61.34	21	206	820	2513	0.54	4.70
		45-60	7.54	1.31	1.29	0.32	2.85	3.38	1.55	0.24	9.59	56.79	25	187	714	7122	0.43	6.61
		60-120	7.59	1.00	1.47	0.40	2.72	2.39	1.00	0.21	12.87	32.07	24	171	653	10982	0.37	11.12
	504	0-15	5.87	4.14	0.89	.¶	4.05	15.93	5.89	2.94	337.89	217.77	37	429	596	5447	1.33	9.99
		15-30	6.02	4.38	0.74	1.03	3.22	14.90	6.47	1.77	203.62	243.09	26	389	710	2319	1.08	7.21
		30-45	7.51	3.69	0.82	0.70	3.62	14.30	5.24	0.72	11.69	203.62	16	340	883	3172	0.69	6.69
		45-60	7.42	3.20	0.98	0.58	3.88	12.23	3.58	0.52	8.35	169.28	11	321	823	10430	0.59	8.20
		60-120	7.79	2.58	1.12	0.73	3.90	9.95	2.73	0.40	9.46	153.48	19	262	713	14338	0.51	16.26

[†] 2 Molar KCl extraction for NH_4-N and NO_3-N.

[‡] Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

[§] Total N and Total C from Leco CN2000 dry-combustion analysis at 1350˚C.

¶ Data Not Available

Table 12 Cont. —beef manure

			---------------------Saturated paste extract---------------------								-----2M KCl† -----		------------MIII‡------------				--LECO§--	
Source	N	DEPTH	pH_e	EC	SAR	HCO_3	Na	Mg	Ca	K	NH_4-N	NO_3-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}	cm		dS m^{-1}		-------------mmol L^{-1}-------------					--------------------mg kg^{-1}---------------------						---g kg^{-1}---	
BM	0	0-15	7.70	0.86	0.96	0.10	1.65	1.79	1.18	0.99	14.76	32.30	44	551	775	2483	1.01	10.69
		15-30	7.85	0.69	1.26	.¶	1.84	1.33	0.83	0.39	13.05	16.59	27	372	761	2320	0.74	7.48
		30-45	7.70	0.75	1.65	.	2.48	1.54	0.78	0.18	11.92	7.78	20	288	804	2680	0.50	4.81
		45-60	7.97	0.69	1.49	.	2.15	1.47	0.65	0.15	11.13	4.02	25	270	718	4627	0.43	4.49
		60-120	8.02	0.72	1.57	0.50	2.41	1.64	0.62	0.20	10.15	2.24	23	272	684	11488	0.36	14.48
	56	0-15	7.99	0.88	0.96	1.04	1.60	1.67	1.10	1.24	15.91	28.38	58	595	751	2608	1.08	11.26
		15-30	7.41	0.81	1.30	.	2.06	1.53	0.93	0.57	16.00	14.14	37	415	749	2394	0.78	7.71
		30-45	7.51	0.82	1.25	.	1.95	1.55	0.87	0.29	10.83	9.91	22	340	824	2601	0.54	5.06
		45-60	7.23	1.03	1.25	.	2.27	2.42	1.09	0.22	11.87	6.40	18	259	732	5554	0.42	4.59
		60-120	7.38	0.85	1.18	.	1.98	2.01	0.78	0.17	11.53	3.60	19	208	582	13268	0.33	8.10
	168	0-15	7.84	1.16	1.44	1.48	2.76	2.12	1.44	1.70	27.28	40.74	55	650	737	2899	1.10	11.64
		15-30	7.96	1.01	1.49	0.97	2.71	1.94	1.29	0.51	23.13	21.81	26	351	750	2278	0.73	7.33
		30-45	8.06	0.97	1.33	0.81	2.52	2.18	1.23	0.20	12.32	13.10	21	268	806	2631	0.53	5.16
		45-60	7.95	0.88	1.36	0.62	2.30	1.97	0.92	0.16	11.32	7.32	28	257	771	5145	0.44	6.62
		60-120	7.95	0.84	1.50	0.50	2.46	1.86	0.79	0.17	16.74	4.13	22	247	716	14081	0.41	13.72
	504	0-15	7.92	1.54	1.22	1.26	2.63	2.89	1.90	2.81	13.97	64.37	119	682	784	3228	1.48	15.35
		15-30	7.88	1.15	1.44	0.60	2.78	2.44	1.26	0.57	12.83	36.22	29	324	714	2211	0.73	7.03
		30-45	7.71	1.32	1.25	0.65	2.67	3.15	1.55	0.31	10.60	29.64	29	226	725	2413	0.51	4.59
		45-60	7.74	1.21	1.16	0.64	2.30	2.86	1.25	0.33	9.17	27.41	20	199	623	7925	0.42	4.84
		60-120	7.79	1.13	1.06	0.48	2.06	2.82	0.95	0.19	11.72	22.68	23	164	519	12140	0.32	6.36

†2 Molar KCl extraction for NH_4-N and NO_3-N.

‡Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

§Total N and Total C from Leco CN2000 dry-combustion analysis at 1350˚C.

¶ Data Not Available

Table 12 Cont.—swine effluent

			---------------------Saturated paste extract---------------------								-----2M KCl[†] -----		------------MIII[‡]------------				--LECO[§]--	
Source	N	DEPTH	pH$_e$	EC	SAR	HCO$_3$	Na	Mg	Ca	K	NH$_4$-N	NO$_3$-N	P	K	Mg	Ca	TN	TC
	kg ha^{-1}	cm		dS m^{-1}		-------------mmol L^{-1}-------------					--------------------mg kg^{-1}---------------------						---g kg^{-1}---	
SE	0	0-15	8.06	0.91	1.29	1.16	2.26	1.97	1.20	0.96	10.67	17.40	25	420	757	2345	0.94	9.75
		15-30	7.67	0.74	1.06	1.75	1.74	1.71	0.99	0.46	11.83	10.30	12	305	783	2366	0.72	7.28
		30-45	7.80	0.74	1.19	1.14	1.97	1.85	0.92	0.25	12.42	6.76	11	262	850	2832	0.54	4.98
		45-60	7.82	0.77	1.46	1.22	2.37	1.88	0.81	0.26	10.83	4.61	12	250	799	6865	0.47	6.51
		60-120	7.80	0.82	1.39	0.86	2.37	2.05	0.83	0.23	9.25	4.30	23	240	784	14452	0.39	14.37
	56	0-15	8.03	0.99	1.08	1.22	2.01	2.08	1.31	1.19	12.68	27.22	38	456	738	2756	0.99	10.32
		15-30	8.07	0.92	1.32	0.87	2.41	2.17	1.13	0.46	12.95	15.76	16	288	768	2439	0.72	7.08
		30-45	8.09	0.98	1.54	0.77	2.79	2.22	1.11	0.21	9.90	12.02	19	227	847	2879	0.55	5.27
		45-60	8.05	0.85	1.65	0.54	2.71	1.90	0.83	0.18	12.24	6.41	22	224	804	8565	0.47	11.42
		60-120	8.07	0.72	1.99	0.46	3.50	2.18	0.90	0.23	13.40	4.70	20	237	746	12389	0.40	16.80
	168	0-15	7.96	0.98	1.08	0.96	1.96	2.06	1.24	1.52	15.20	27.16	46	482	729	2609	0.98	10.26
		15-30	8.01	0.85	1.46	0.84	2.48	1.84	1.04	0.46	11.41	19.52	21	265	774	2383	0.75	7.47
		30-45	8.04	1.01	1.50	1.34	2.82	2.40	1.11	0.26	9.90	13.82	18	217	788	2669	0.49	4.71
		45-60	7.85	0.94	1.47	0.33	2.63	2.28	0.89	0.22	8.54	11.20	29	193	708	5976	0.40	5.92
		60-120	7.69	0.80	1.73	0.35	2.72	1.80	0.68	0.19	11.84	6.50	21	184	642	11216	0.34	10.54
	504	0-15	7.76	1.08	1.36	1.16	2.43	2.00	1.29	1.71	14.74	33.27	50	868	692	2685	1.04	10.76
		15-30	7.81	1.06	1.76	0.81	3.06	1.99	1.21	0.44	10.55	23.38	26	420	776	2475	0.73	7.08
		30-45	7.82	1.86	1.74	0.68	3.58	2.79	1.55	0.30	12.58	29.57	19	329	805	2815	0.56	4.84
		45-60	7.82	1.48	1.73	0.54	3.72	3.41	1.33	0.27	9.58	31.58	15	300	680	6767	0.46	5.51
		60-120	7.76	1.22	1.66	0.37	3.27	2.77	0.88	0.13	11.13	25.95	19	242	547	12250	0.34	8.58

[†] 2 Molar KCl extraction for NH$_4$-N and NO$_3$-N.

[‡] Mehlich III extraction for phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca).

[§] Total N and Total C from Leco CN2000 dry-combustion analysis at 1350˚C.

[¶] Data Not Available

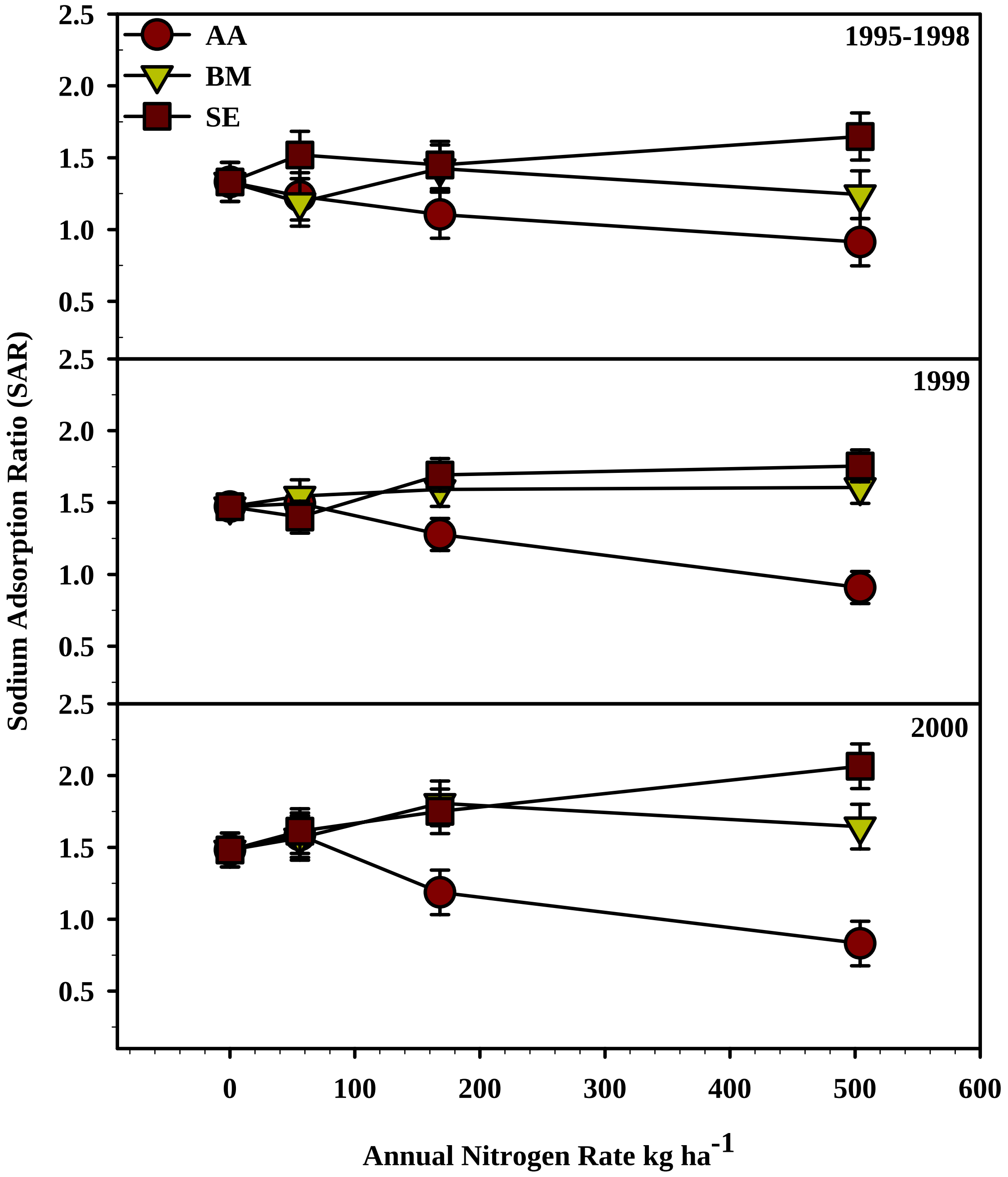

Figure 5 Sodium adsorption ratio (SAR) from 0-120 cm depth as a function of cumulative annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) in a continuously cropped, conventionally tilled corn production experiment located at OPREC, Goodwell, OK (n=15).

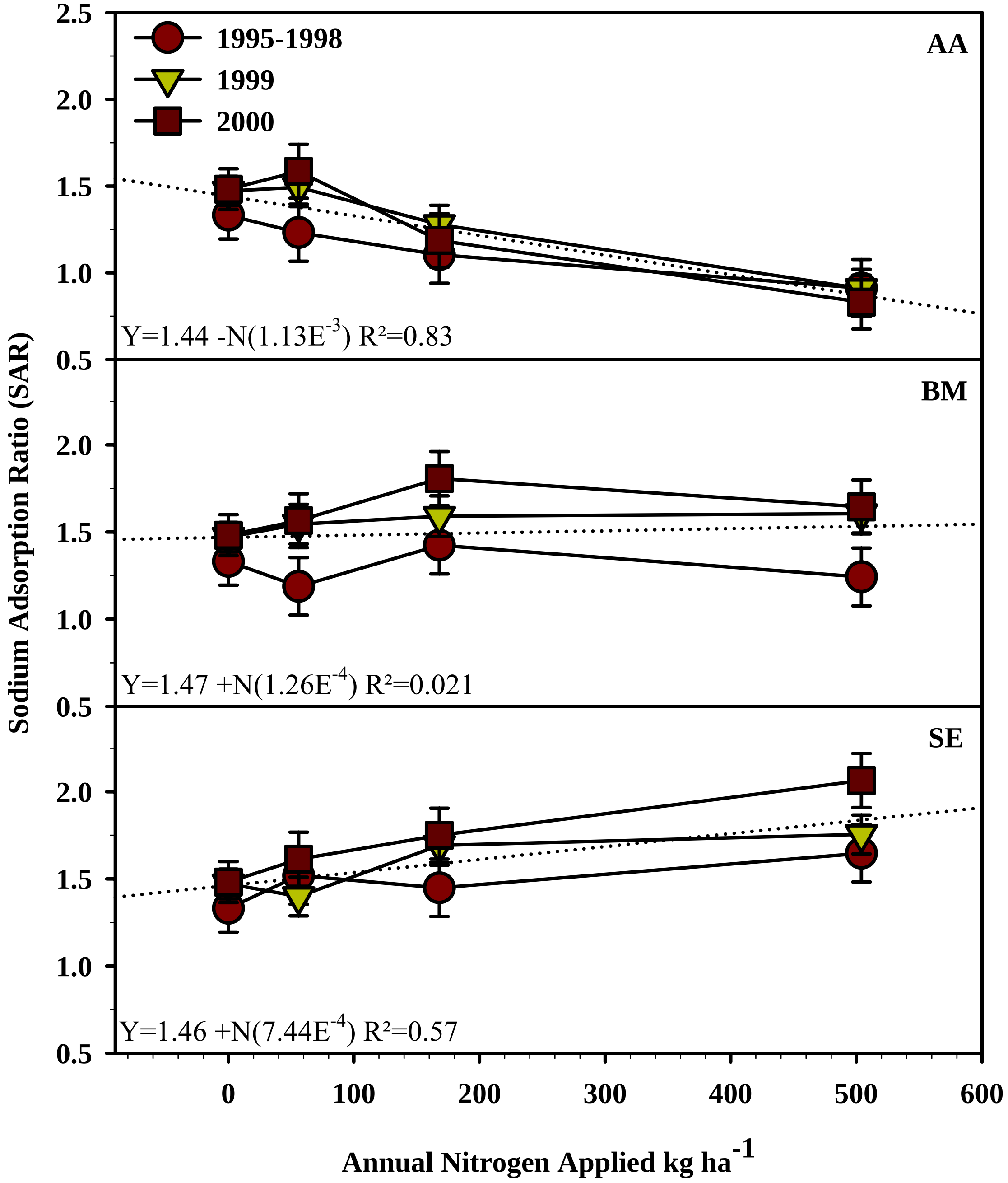

Figure 6 Increase to sodium adsorption ratio (SAR) from 0-120 cm as affected by annual loading rates of swine effluent (SE), beef manure (BM), and anhydrous ammonia (AA) to a long-term, continuously cropped, conventionally tilled corn production system measured at OPREC, Goodwell, OK (n=15).

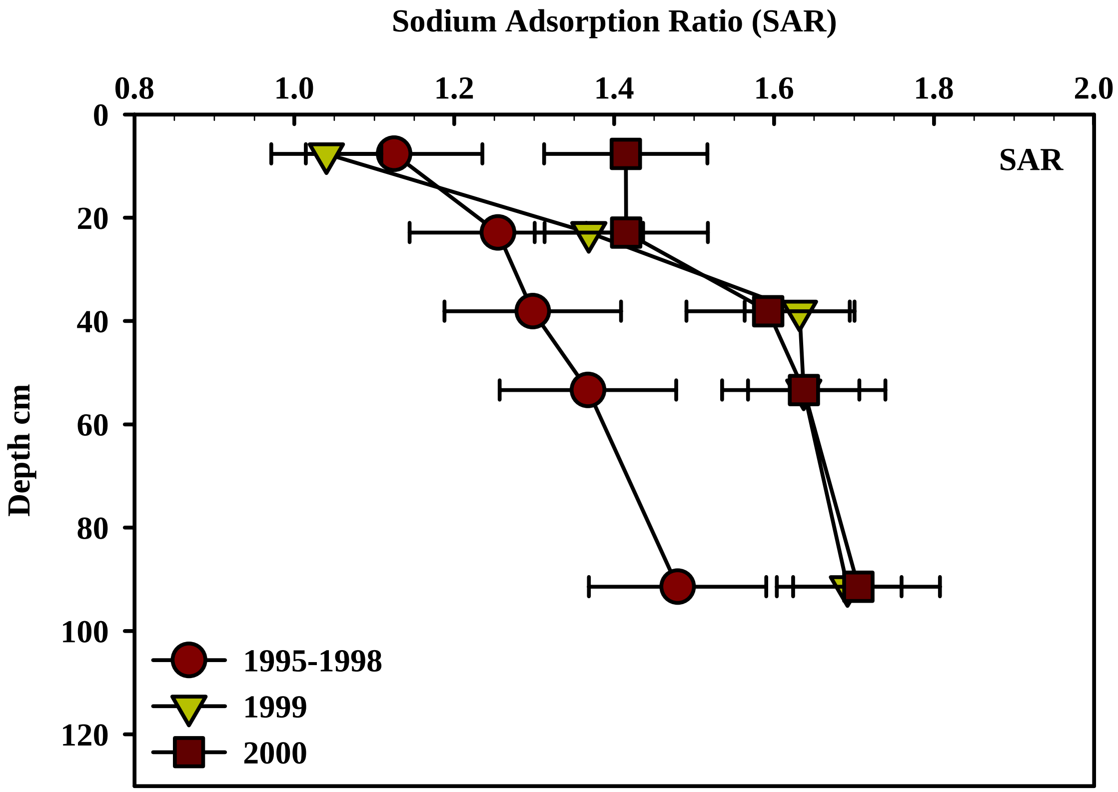

Figure 7 Sodium adsorption ratio (SAR) from 1995-2000 for 0-120 cm depths in a continuously cropped, conventionally tilled corn production system measured at OPREC, Goodwell, OK (n=36).

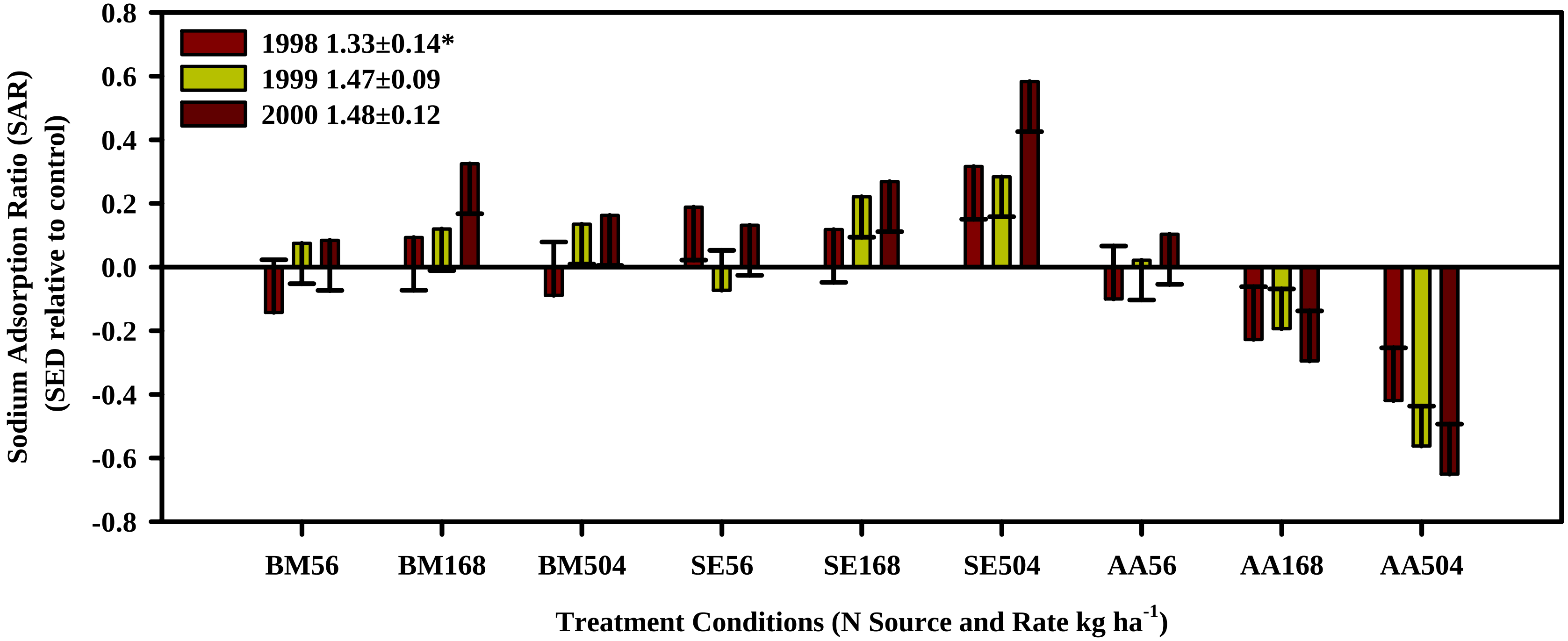

Figure 8 Sodium adsorption ratio (SAR) in 1998-2000 at 0-120 cm depths where treatment means were compared to a control (0 kg N ha^{-1} yr^{-1}) to examine the effects of cumulative annual applications of beef manure (BM), swine effluent (SE), and anhydrous ammonia (AA) at loading rates of 56, 168, and 504 kg N ha^{-1} yr^{-1}. *Treatment mean and standard error of differences (SED) based on the combined 0 N rate replications for that year (the Y axis 0 is equal to the mean and standard error of differences for the control of that particular year; this is a Dunnett's test).

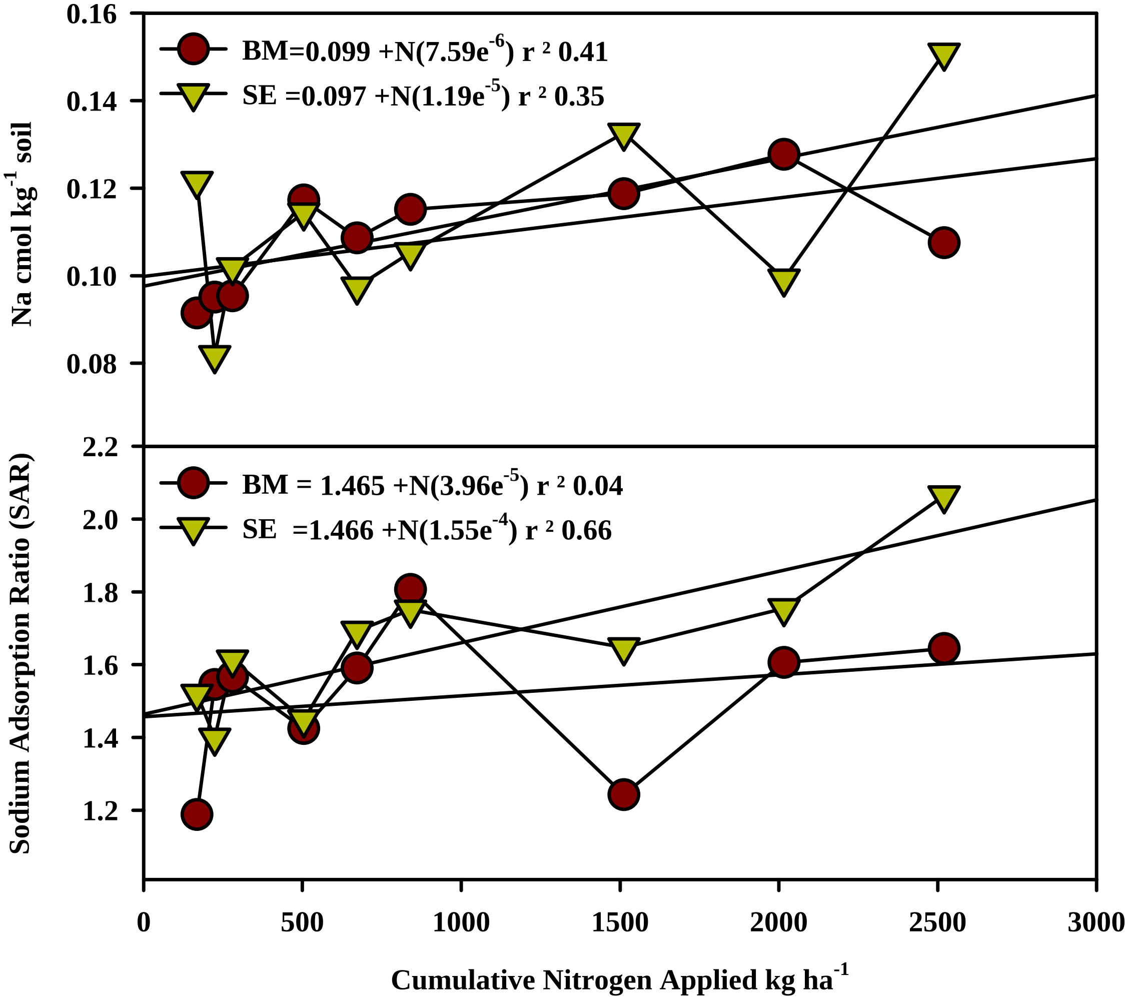

Figure 9 Sodium adsorption ratio (SAR) and Na compared to cumulative N added with beef manure (BM) and swine effluent (SE) at 56, 168, and 504 kg N ha^{-1} yr^{-1} in a conventionally tilled, continuously cropped corn production system, located at OPREC, Goodwell, OK.

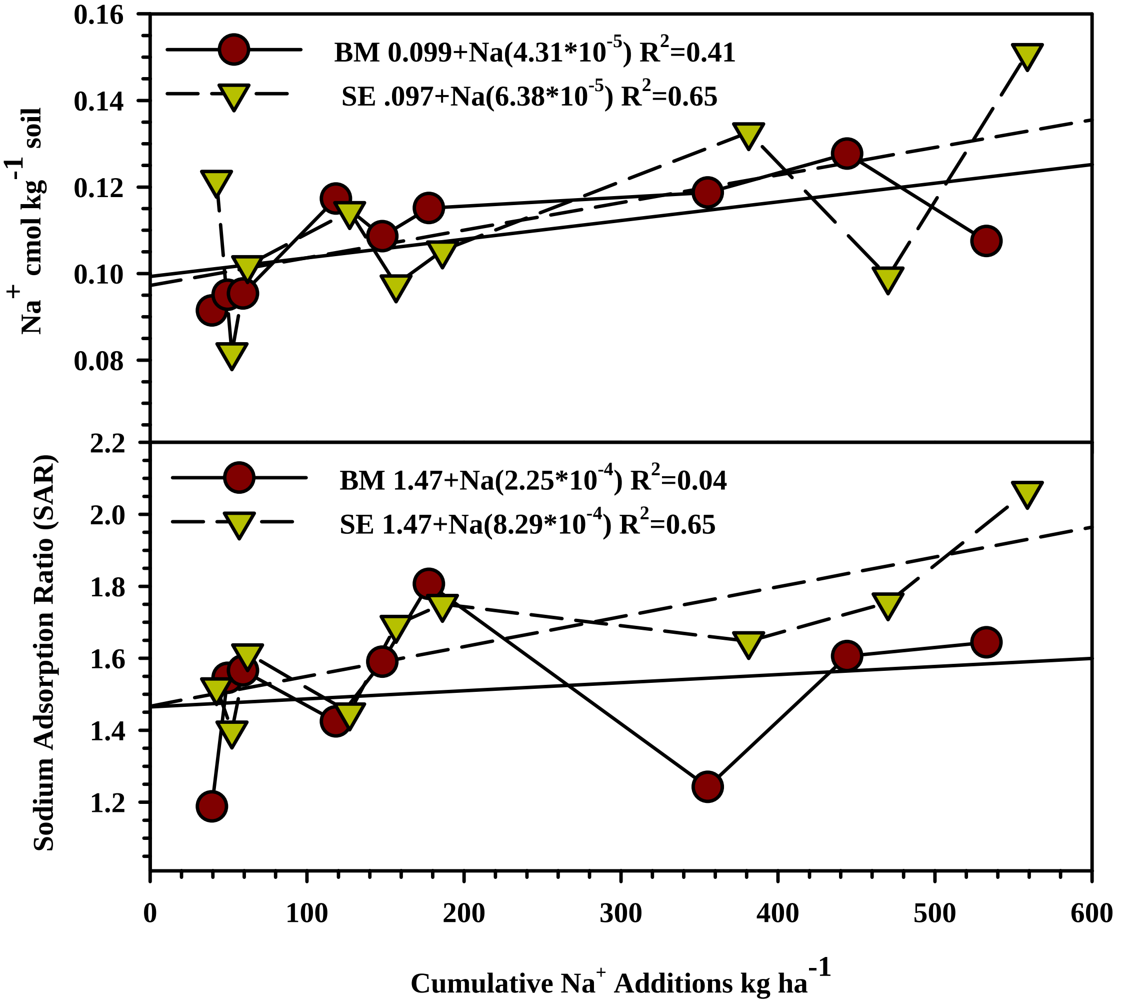

Figure 10 Sodium adsorption ratio (SAR) and Na compared to cumulative Na added with beef manure (BM) and swine effluent (SE) at 56, 168, and 504 kg N ha^{-1} yr^{-1} in a conventionally tilled, continuously cropped corn production system, located at OPREC, Goodwell, OK. This is similar to Figure 9, however Na loading has extended SE further out on the X axis.

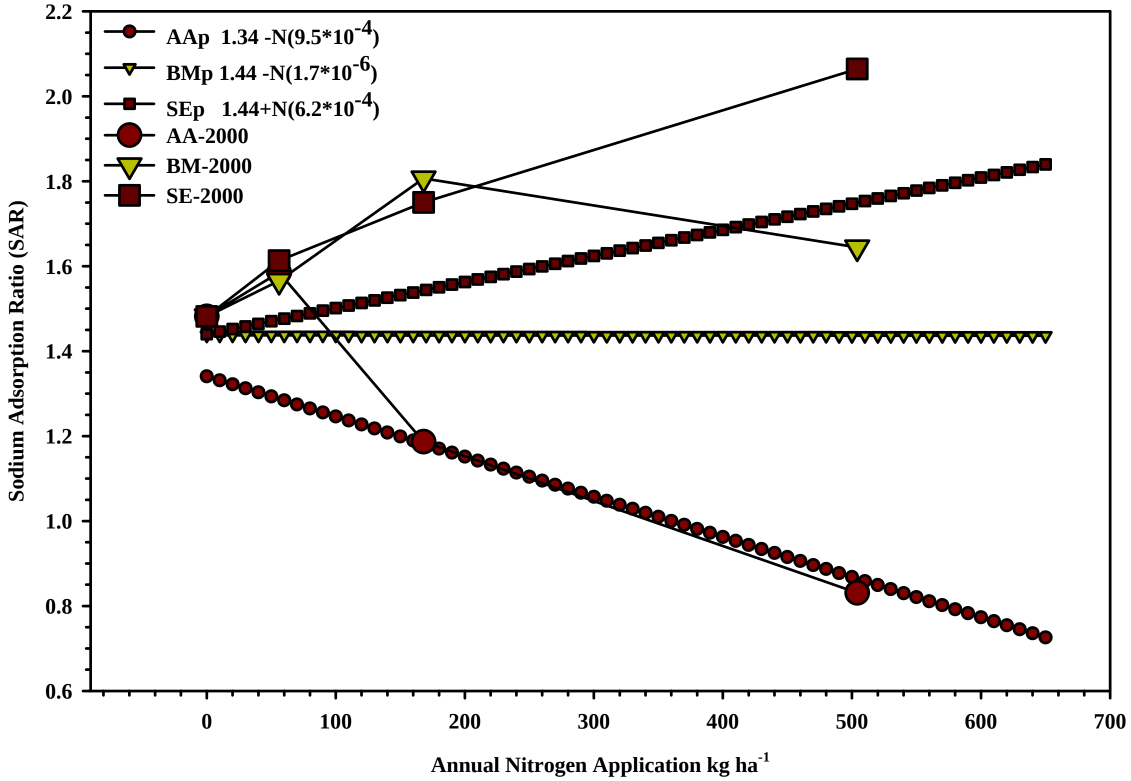

Figure 11 Regression curve for SAR averaged over the 0-120 cm from 1998-1999 data was used to predict SAR responses in 2000 for cumulative annual applications of anhydrous ammonia (AA-2000), beef manure (BM-2000), and swine effluent (SE-2000) in a continuously cropped, conventionally tilled corn study located at OPREC, Goodwell, OK (n=15). Predicted values for anhydrous ammonia (AAp), beef manure (BMp), and swine effluent (SEp).

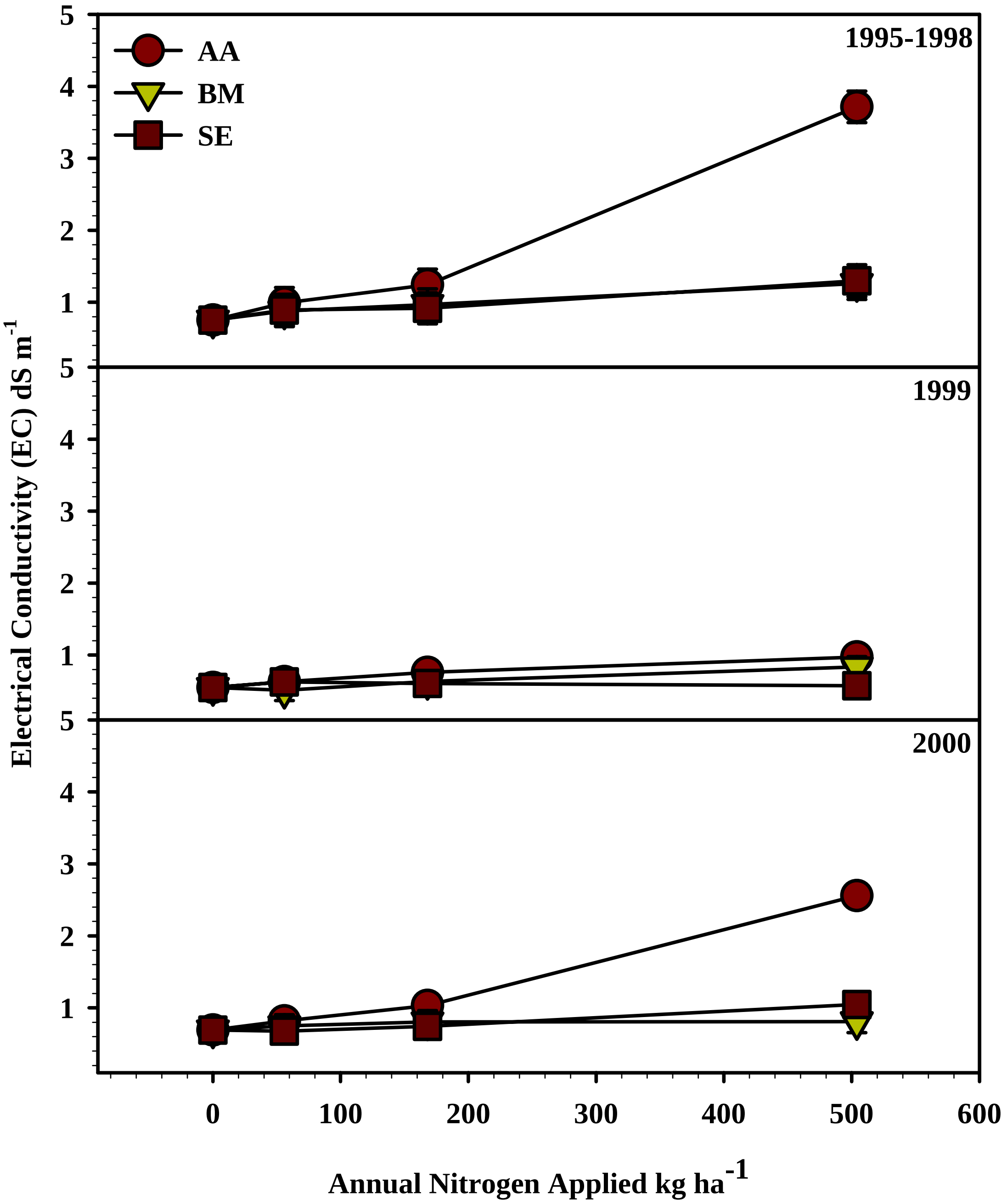

Figure 12 Electrical conductivity (EC) response to repeated annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) at loading rates of 0, 56, 168, and 504 kg N ha^{-1} yr^{-1} in a continuously cropped, conventionally tilled corn production experiment located at OPREC, Goodwell, OK (n=15). *Error bars are included.

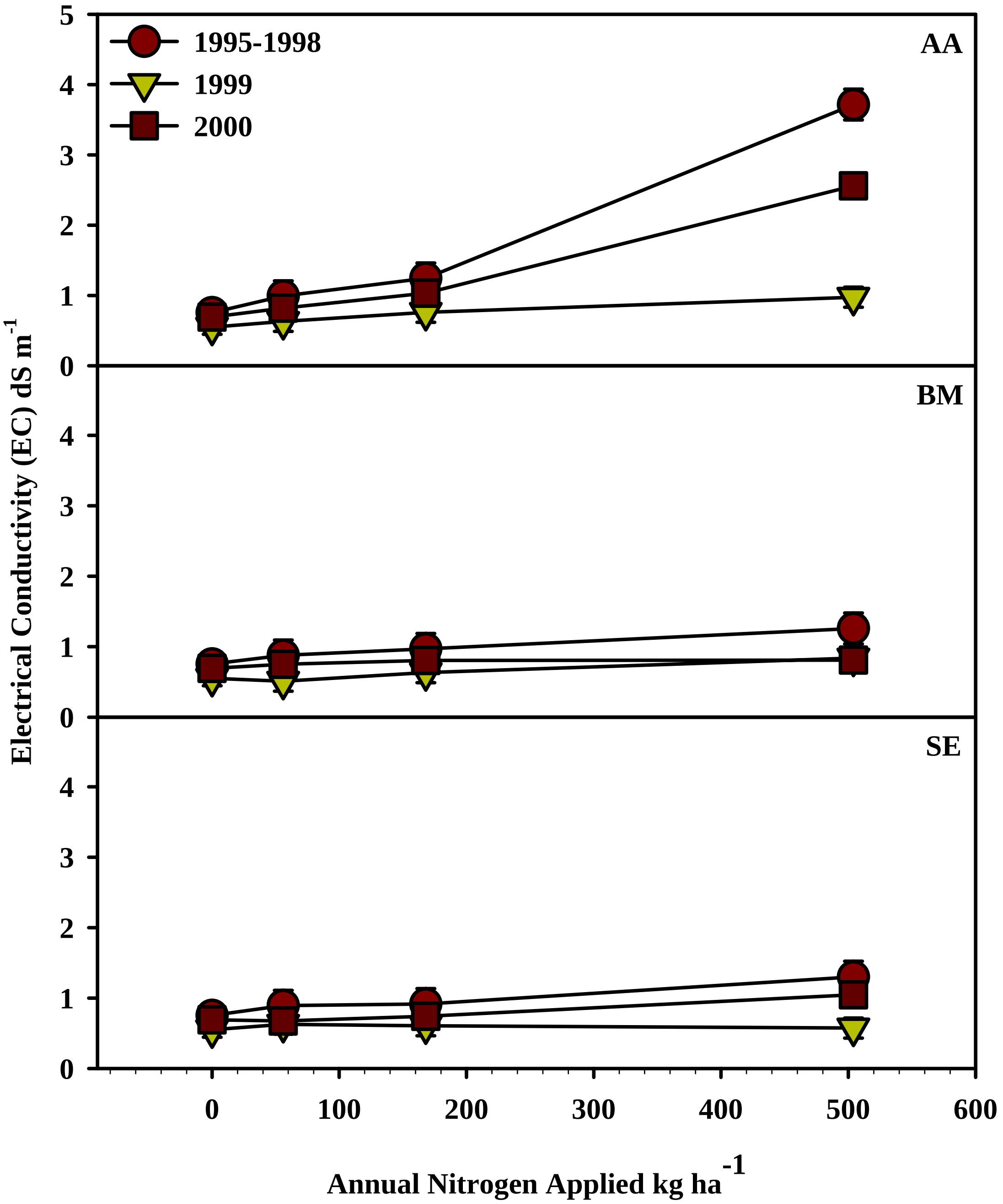

Figure 13 Electrical conductivity (EC) annual loading rate effects from cumulative applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) at 0, 56, 168, and 504 kg N ha^{-1} yr^{-1} in a continuously cropped, conventionally tilled corn study located at OPREC, Goodwell, OK (n=15). *Error bars are included.

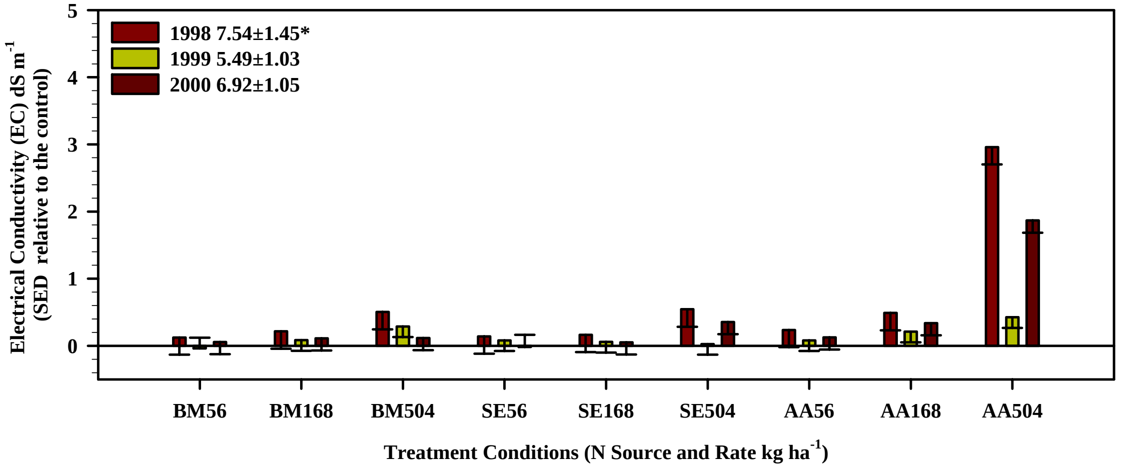

Figure 14 Electrical Conductivity (EC) in 1998-2000 at 0-120 cm depths where treatment means were compared to a control (0 kg N ha^{-1} yr^{-1}) to examine the effects of cumulative annual applications of beef manure (BM), swine effluent (SE), and anhydrous ammonia (AA) at loading rates of 56, 168, and 504 kg N ha^{-1} yr^{-1}. *Treatment mean and standard error of differences (SED) based on the combined 0 N rate replications for that year (the Y axis 0 is equal to the mean and standard error of differences for the control of that particular year; this is a Dunnett's test).

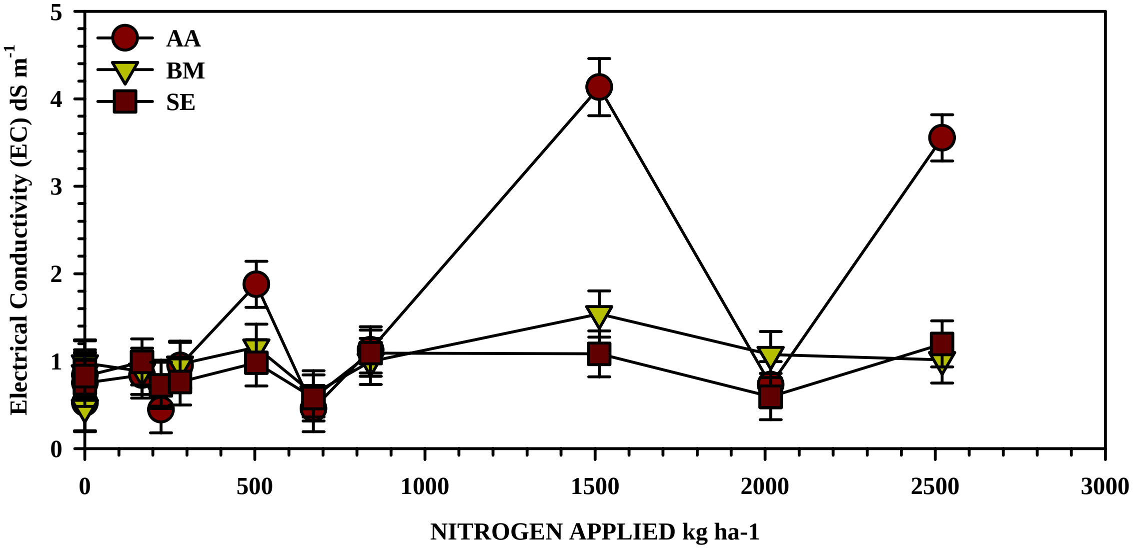

Figure 15 Electrical Conductivity (EC) at the 0-15 cm depth as a function of cumulative annual applications of anhydrous ammonia (AA), beef manure (BM), and swine effluent (SE) in a continuously cropped, conventionally tilled corn study located at OPREC, Goodwell, OK (n=3). Annual applications were from 1995-2000, but only data from 1998-2000 was plotted because of non existent data in the other years.

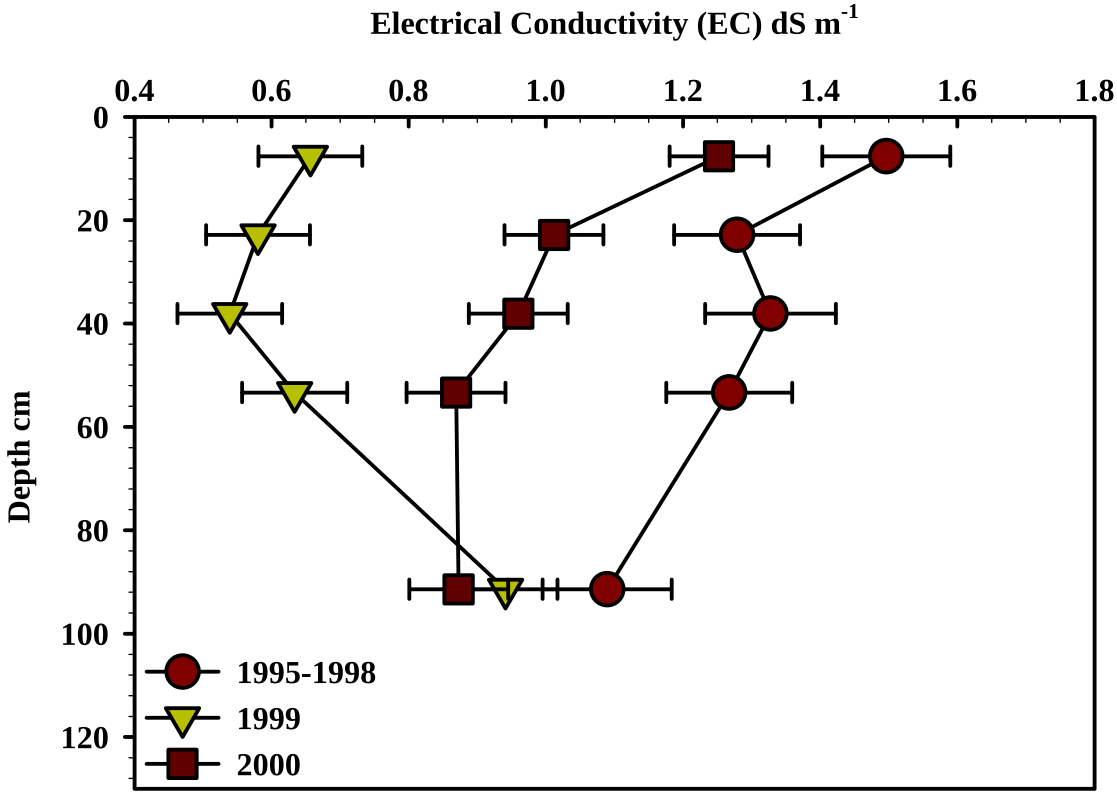

Figure 16 Electrical conductivity (EC) at 0-120 cm depths averaged across cumulative annual loading rates of anhydrous ammonia (AA), beef manure (BM), swine effluent (SE) at 0, 56, 168, and 504 kg N ha^{-1} yr^{-1} in a continuously cropped, conventionally tilled corn study located at OPREC, Goodwell, OK (N =36).

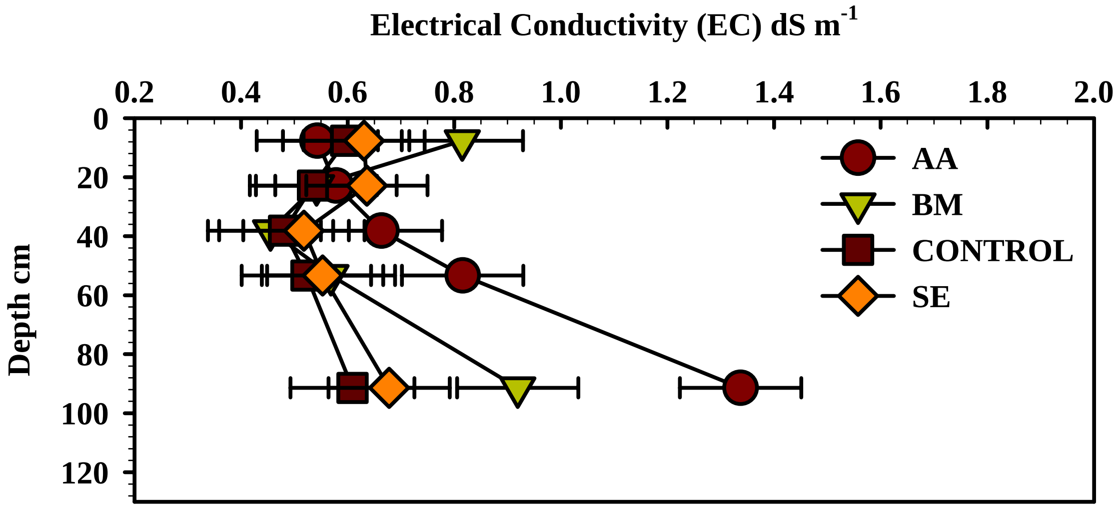

Figure 17 Electrical conductivity (EC) averaged across all loading rates for anhydrous ammonia (AA), beef manure (BM), swine effluent (SE) and the control (0 kg N ha^{-1} yr^{-1}) was separated in the soil profile in 1999 for a continuously cropped, conventionally tilled corn study located at OPREC, Goodwell, OK (n=36). In 1999, there was a source by depth interaction which was not found in 1998 or 2000.

VITA

Jason Clemn Turner

Candidate for the Degree of

Master of Science

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Institution: Oklahoma State University Location: Stillwater, Oklahoma

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ABSTRACT:

Scope and Method of Study: The objective of this research was to evaluate the effect of five annual applications of animal manures on soil electrical conductivity (EC) and sodium adsorption ratio (SAR) estimated from saturated soil-paste extracts. Swine effluent (SE), beef manure (BM), and anhydrous ammonia (AA) were annually applied at loading rates of 0, 56, 168, 504 kg N ha^{-1} to a irrigated conventionally tilled, continuous corn (*Zea mays* L.) cropping study in the Oklahoma panhandle.

Findings and Contributions: The cumulative effects of five annual N applications were examined in 2000. Changes to soil EC and SAR were observed in 2000 at the 0-15 cm soil depth. Beef manure and SE contributed 90 kg and 115 kg Na ha^{-1} yr^{-1}, respectfully at the highest N loading rate application. Manure EC was 12.7 and 9.5 dS m^{-1} for BM and SE, respectfully. Sodium adsorption ratios increased with SE additions at the high N loading rate application; however SAR decreased with the high AA loading applications, while SAR remained unchanged with BM applications. The SAR increased linearly with SE additions; whereas SAR decreased linearly with AA additions. Slow increases of SAR with high SE loading above the control in manure-applied treatments indicate potential for the soil to become sodic and disperse. Soil EC has not been adversely affected by BM or SE additions; however, EC levels increased 2.35 dS m^{-1} with the high AA loading rate above all other treatments. Soil EC levels have increased as a result of the high AA loading that future crop growth may be affected.

Advisor's Approval: Dr. Jeffory A. Hattey