THE TOLERANCE OF WW-IRON MASTER OLD WORLD BLUESTEM TO SALINITY AND LAND-APPLICATION OF SWINE EFFLUENT

By

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This thesis would not have been possible without the support and contributions of my wife, Cynthia Mann. Her strong back, uncanny ability to find my errors, and strong desire to live closer to her family qualified her to act as laborer, editor and motivator on this project.

I extend my thanks to all my committee members, Dr. Michael Kizer, Dr. Daren Redfearn, and Dr. Marvin Stone. I would particularly like to express my appreciation for Dr. Kizer who has been a tremendous advisor and friend. Likewise, I am grateful for Dr. Elliott who believed in me and provided me with the opportunity to earn this degree.

I would also like to acknowledge the enormous contribution to this thesis made by the cut and paste function of Microsoft "Word" ®, as well as the other editing functions found on modern computers. My heart goes out to the Old World bluestem plant family for the losses it suffered as a result of this research. My sympathy is particularly strong for those unfortunate plants whose noble death resulted from over application of swine effluent.

Finally, I would like to express my gratitude to my God, by whom all things are possible.

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Chapter I

Introduction

Statement of the Problem

A sizable portion of grassland in western Oklahoma and northwest Texas was seeded with WW-Iron Master Old World bluestems in the Conservation Reserve Program (CRP) (Harmoney and Hickman, 2004). However, the growing swine industry in the western parts of Oklahoma has found that Old World bluestems are sensitive to swine effluent application. A portion of this sensitivity may be the result of salt burns, likely chloride or sodium, left on foliage when swine effluent is applied during warm days with high solar radiation. Unfortunately, no information regarding the salinity tolerance of these grasses, or their potential for salt burns during effluent application exists in scientific literature. Information in this domain could improve grassland management and fill the existing gap in our understanding of the salinity tolerance of WW-Iron Master Old World bluestems.

Objectives of the Study

The objectives of this study are to:

1. Determine the salinity tolerance threshold for WW-Iron Master Old World bluestem;
2. Determine the fractional yield decline per unit increase in salinity beyond the threshold;

3. Determine if the time of day the effluent is applied to the plant has a significant effect on plant growth;
4. Determine the optimum dilutions for swine effluent when applied to WW-Iron Master Old World bluestem;
5. Verify that using the “Greenseeker” is an adequate method for determining salinity effects on plant growth;
6. Determine if a salt solution spray on foliage can cause plant damage;
7. Determine if foliage burn during swine effluent application is a result of chemical constituents other than salts; and to
8. Statistically evaluate effluent application data from the Conservation Reserve Program gathered from 1999-2005 by the Farm Service Agency.

Chapter II

Literature Review

Salinity is a significant factor for affecting plant growth in arid climates. For many plants, the values of salt tolerance and the fractional yield decline per unit increase in salinity are already known (Hoffman et al., 1980). However, salinity tolerance values for Old World bluestems, a group of grasses commonly grown for forage, have not been published.

Old World bluestems, which originate from Russia and surrounding Asian countries, were introduced into the United States around 1920. They are warm-season perennial bunchgrasses that are best adapted to loam or clay-loam soils (Redfearn, 2004). Old World bluestems begin growth during late spring and perform better during the hot parts of summer than other warm-season grasses. Old World bluestems are generally dormant from mid-September to mid-May (Bell and Caudle, 1994). However, because Old World bluestem is more receptive to late summer precipitation than other warm-season grasses, it can still experience significant growth in August and September.

There are many cultivars of Old World bluestems, with the most common being ‘Caucasian’, ‘Ganada’, ‘King Ranch’, ‘Plains’, ‘WW-Spar’, ‘WW-Iron Master’ and ‘WW-B Dahl’. Despite an increased tolerance for iron deficient soils, WW-Iron Master is a fairly representative variety of Old World bluestems (Redfearn, 2004).

To determine salt tolerance, a hydroponics solution is generally used to control nutrient availability. Because soil is not used, researchers can accurately test plant response to nutrient solutions. Consequently, hydroponics is ideal for salt tolerance determination. For plant growth it is essential that the nutrient solution contain relatively large concentrations of nitrogen, potassium, phosphorus, calcium, magnesium and sulfur, with smaller concentrations of iron, manganese, boron, zinc, and copper. Hydroponic solutions can be created from the formula developed by Dr. D.R. Hoagland (Jones, 1997; Hoagland and Arnon, 1950). However, quality solutions based on Dr. Hoagland's formula can be purchased commercially and still yield excellent results (Hydroponics as a Hobby, 2006).

Understanding how environmental conditions can affect water transport in plants has vast agricultural implications. This is particularly true in waste management applications. While extreme care is taken to ensure that land application of waste does not exceed nitrogen and phosphorous limits for crops, the effluent effect on the soil salinity is often overlooked. Our ability to apply animal waste to agricultural land in a sustainable manner is dependent on our understanding of the possible effects this salinity may have on plant growth.

Manure application on a crop can be accomplished through a variety of methods: 1) manure can be applied to ground before seeding; 2) topdressed over established stands; 3) flood applied to established stands; 4) applied after harvest. In the case of manure application on existing stands of Old World bluestem, some methods are better than others (Kelling, and Schmitt, 2003).

Application of manure before stand establishment is limited in scope. Perennial grasses like Old World bluestem are planted once and then maintained year after year for forage. While this method of application has been shown to significantly increase harvest yields, it is only applicable during planting (Kelling, and Schmitt, 2003).

The most common form of manure application to established stands of forage is topdress. This method is inherently dangerous to plant growth because it can damage plant crowns, result in runoff, and in some cases cause salt burn on forage material. Because swine effluent has a high salt concentration, topdress application must be done carefully to avoid salt burn. The burn potential of manure is directly related to its ammonium N and salt concentrations (Kelling, and Schmitt, 2003).

Flood application of effluent avoids some problems associated with topdress application but creates new difficulties. Physical damage to plant crowns and salt burns may be prevented through flood irrigation. However, these benefits are offset by the potential for uneven application and excessive runoff. Additionally, the topography of the land will likely make flood application impossible.

Finally, a topdressing application after harvest may be the most practical approach. Soon after a harvest the vegetated canopy of a plant will be limited and consequently its potential for salt burn will be minimized. However, factors such as runoff and crown damage are still present (Kelling, and Schmitt, 2003).

Water Transport into Roots and the Effect of Salinity

Water transport into roots is crucial to plant growth. Although the principle of water transport from a soil into a root is simple, the mechanisms are complicated and not completely understood. Mathematical models describing water and nutrient transport through a root have consistently been altered and revised as researchers have made new discoveries. However, the significant discovery of parallel pathways of water transport has lead to an improved understanding of root-soil interaction.

Understanding how environmental conditions can affect water transport into plants has vast agricultural implications. This is particularly true in waste management applications. While extreme care is taken to ensure that land application of waste does not exceed nitrogen and phosphorous limits for crops, the effluent's effect on the soil salinity is often overlooked. Our ability to effectively apply animal waste to forage is dependent on our understanding of the possible effects this salinity may have on plant growth.

Water Transport into Roots

There are many mechanisms by which water enters a plant through the root. Traditionally, water was assumed to only move radially through the root via the apoplast as shown in Figure II-a. It was thought that water moved around the outside of the protoplasts because they posed a greater hydraulic resistance than found in the apoplast. As water reaches the endodermis of the root, the Casparian band prevents further apoplast water movement. At this point water is transferred across the endodermis cell membrane and then out again into the xylem vessels located at the center of the root. However research has shown that there is a strong argument for an alternative method of water transport. This alternative route, known as the symplastic route, involves water entering plant cell membranes, traversing the cell and passing out again to enter the next cell as shown in Figure II-a (Cummings, 2006). Both the apoplastic and symplastic routes end in the water entering the xylem vessels where horizontal water transportation takes place.

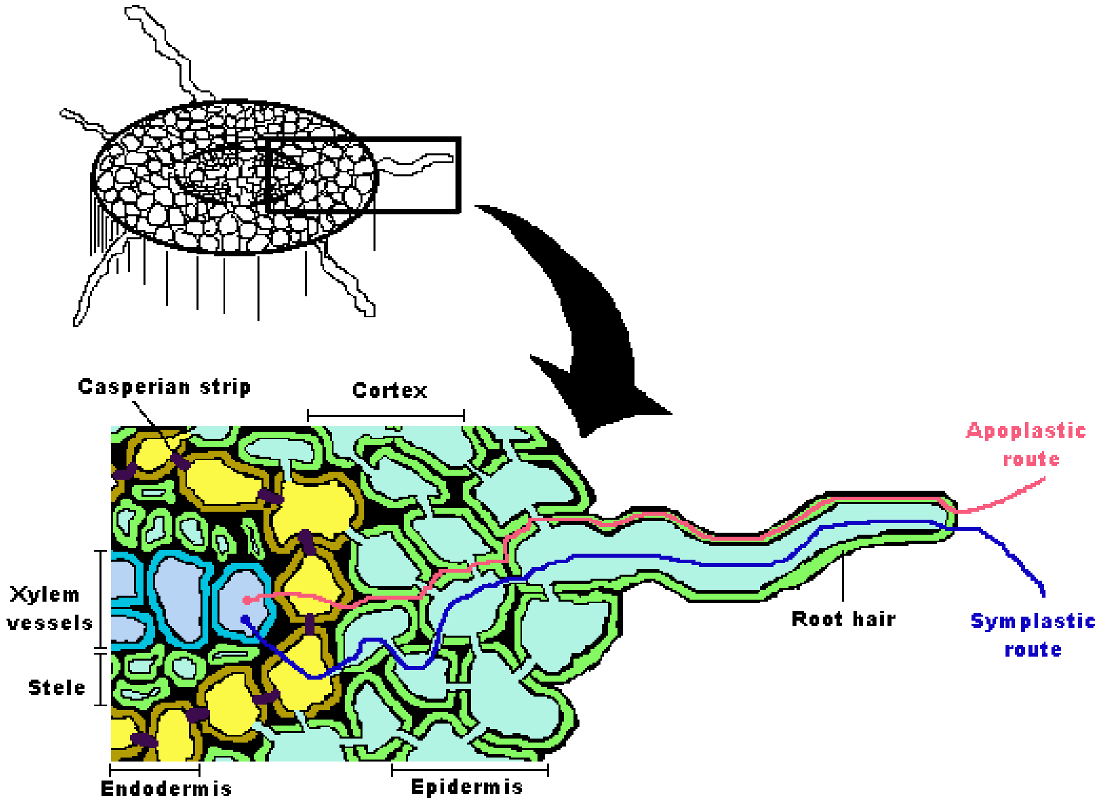

Figure II-a. The two most common methods of water transport into a root (adapted from Cummings, 2006)

Models for water transport have treated the root as a two-compartment system. Because this model only considers a single membrane barrier, the endodermis, it is known as the single-equivalent-membrane-model (Steudle, E. 1994). It describes water flow (J_{vr}) and nutrient flow (J_{sr}) as follows:

$$J_{vr} = -1/A_r * dV_x/d_t = Lp_r * P_r - Lp_r * \sigma_{sr} * RT * (C_s^x - C_s^o) \qquad \text{Equation II-a}$$

$$J_{sr} = -1/A_r * dn_s^x/d_t = P_{sr} * (C_s^x - C_s^o) + (1- \sigma_{sr}) * \hat{C}_s * J_{vr} + J_{sr}^* \qquad \text{Equation II-b}$$

Thus the water and nutrient flow per unit surface area of the root can be calculated from: the root surface area (A_r), volume of the mature xylem (V_x), root hydraulic conductivity (Lp_r), root pressure (P_r), the root reflection coefficient (σ_{sr}), the temperature (T), the gas constant (R), the concentration of solute in the medium (C_s^o), the concentration of solute in the xylem (C_s^x), the amount of solute in the xylem (n_s^x), the permeability coefficient of the root (P_{sr}), the mean concentration of solute in the root ($\hat{C}_s = (C_s^x + C_s^o)/2$), and the active solute flow (J_{sr}^*). Unlike previous models, these equations account for the alternative mechanisms of water transport. These alternative mechanisms are the passive transport of a solute across the root according to Fick's Law, and active transport of solute into the root through metabolism (Steudle, 1994).

However, experimental research shows deviation from the single-membrane-equivalent model. This deviation is a result of the incorrect assumption that water travels radially through a root via a single pathway. In truth, water enters the root through two parallel pathways, as mentioned earlier. To correct for parallel pathways, the new composite-transport-model of the root is used (Steudle, 1994). The composite pathway uses the equation established in the single-equivalent-membrane-model (Equations II-a and II-b) but adjusts the overall reflection coefficient (σ_{sr}) to correct for the alternative pathways. The corrected overall reflection coefficient is:

$$\sigma_{sr} = \gamma^{cc} * Lp^{cc}/Lp_r * \sigma_s^{cc} + \gamma^{cw} * Lp^{cw}/Lp_r * \sigma_s^{cw} \qquad \text{Equation II-c}$$

Where Lp_r is the overall hydraulic conductivity, Lp^{cc} is the hydraulic conductivity of the cell-to-cell and Lp^{cw} is the hydraulic conductivity of the apoplasmic pathway. Additionally, γ^{cc} and γ^{cw} are the fractional contributions of cross sectional areas of pathways to the overall root area (Steudle, 1994).

When the soil a plant is growing in becomes so dry that its water potential is less than the roots, water flow into the plant generally stops. To prevent reverse water flow during long dry periods the roots will suberize. Suberization is the deposition of a waterproof wax substance on the walls of plant cells to inhibit water flow. Renewed permeability of plant roots after suberization generally takes several days (Passioura, 1988).

Salinity Effect on Water Transport into Roots

Although it is well known that salinity has a detrimental effect on plant growth, the mechanisms of this inhibition remain a mystery. Additionally, the physiological differences between a salt tolerant and a salt sensitive plant are not completely understood. However, new research has produced evidence which indicates that salt tolerance is generally a result of one of two mechanisms. These mechanisms are first: transport and control of salt before and after entering the plant; and second: adjustment of other metabolic activities to adjust for the increased salinity (Cheeseman, 1988).

Most research on salt tolerance has focused on the transmembrane movement found in the roots. In the root tissue, a plant's tactic for accommodating high saline conditions generally designates it as a salt includer or salt excluder. A salt includer will allow salt to enter the roots and use it to create osmotic pressure, while a salt excluder will prevent salt from entering the roots. As salt levels inside the plant increase, some plants will store high saline solution in internal pools which are periodically emptied outside the root. Because of enzyme sensitivity, salts must be excluded from the cytoplasm. To protect the enzymes, salts are compartamentalized inside the cell. Additionally, plants have shown control over nutrient balances between the root and shoots. Consequently, it is reasonable to assume that plants possess the means to maintain normal salt concentrations in the shoots while still accumulating salt in the roots (Cheeseman, 1988).

The necessary metabolic adjustments a plant makes primarily involve its use of carbon. Carbon availability is the determinant for plant growth, energy storage, nutrient transport and cellular maintenance. High salinity's increased demands on cellular maintenance and nutrient transport have significant effects on carbon availability. As carbon levels drop, plant growth decreases significantly (Cheeseman, 1988).

According to O'Leary, the growth inhibition a plant growing in a saline solution experiences is not caused by physiological drought. Although the osmotic pressure in the root has been shown to increase with soil salinity, this does not necessarily mean that the plant is not reacting as it would to a drought. As the research by Cheeseman has shown, plant roots and shoots have specific reactions to saline conditions. Consequently, plant roots may prevent water from reaching shoots and the leaves will in fact experience a physiological drought while the roots will not. This reaction is favorable since it decreases water transpiration and allows the plant to better survive poor environmental conditions (O'Leary. J, 1969; Cheeseman, 1988).

Chapter III

Salt Tolerance of WW-Iron Master Old World Bluestem, Dichanthium spp.

By S. L. Mann, M. Kizer and D. Redfearn

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Abstract

Stands of Old World bluestem (*Dichanthium* spp.) are grown extensively in the Southern Great Plains. Swine production facilities have also increased significantly in this region. In some cases, swine effluent application on these stands has resulted in total stand loss. High salinity sensitivity of Old World bluestem was suspected as the cause and this study was conducted to determine its salinity sensitivity. WW-Iron Master Old World bluestem response in both shoot and root growth under various saline conditions was studied. Old World bluestem was grown in a greenhouse in hydroponic media at 1, 2, 3 5, 10, 20, and 30 dS/m (0, 19, 29, 49, 99, 198, and 298 mM NaCl) and was replicated four times. Shoot growth was harvested every fourteen days. With each successive harvest the effects of the saline solution on plant growth became more pronounced. This indicates that the effects of salinity on the growth of the Old World bluestem plant growth have a cumulative effect. After twenty eight days the effect of salinity on plant growth reached a steady state. The salinity threshold for Old World bluestem was found using the piecewise linear response model to be 1 ds/m and the fractional yield decline per unit increase in salinity beyond the threshold was 21 %. Additionally, the Na^+

accumulation in the shoots was much greater than the root tissue, indicating that Old World bluestem is unable to restrict Na^+ transport.

Introduction

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Old World bluestems, which originate from Russia and surrounding Asian countries, were introduced into the United States around 1920. They are warm-season perennial bunchgrasses that are best adapted to loam or clay-loam soils (Redfearn, 2004). Old World bluestems begin growth during late spring and perform better during the hot parts of summer than other warm-season grasses. Old World bluestems are generally dormant from mid-September to mid-May (Bell and Caudle, 1994). However, because Old World bluestem is more receptive to late summer precipitation than other warm-season grasses, it can still experience significant growth in August and September.

It is a common practice to use swine lagoon effluent for irrigation in the production of forages. Proper application of swine effluent requires careful analysis of the effluent constituents, the soil properties and the nutrient needs of the intended forage. Although nitrogen is the primary element in application analysis, other elements such as phosphorous, copper and zinc are also important to consider.

The Conservation Reserve Program (CRP) is a federal government program designed to help restore wildlife habitat, protect topsoil from erosion, and reduce water runoff and sedimentation. In locations where CRP land is near animal production facilities it is not uncommon for effluent from animal waste lagoons to be applied on CRP soil.

To determine salt tolerance, a hydroponics solution is generally used to control nutrient availability. Because soil is not used, researchers can accurately test plant response to nutrient solutions. Consequently, hydroponics is ideal for salt tolerance determination. For plant growth it is essential that the nutrient solution contain relatively large concentrations of nitrogen, potassium, phosphorus, calcium, magnesium and sulfur, with smaller concentrations of iron, manganese, boron, zinc, and copper. Hydroponic solutions can be created from the formula developed by Dr. D.R. Hoagland (Jones, 1997; Hoagland and Arnon, 1950). However, quality solutions based on Dr. Hoagland's formula can be purchased commercially and still yield excellent results (Hydroponics as a Hobby, 2006).

Understanding how environmental conditions can affect water transport in plants has vast agricultural implications. This is particularly true in waste management applications. While extreme care is taken to ensure that land application of waste does not exceed nitrogen and phosphorous limits for crops, the effluent effect on the soil salinity is often overlooked. Our ability to apply animal waste to agricultural land in a sustainable manner is dependent on our understanding of the possible effects this salinity may have on plant growth.

Material and Methods

To determine the salinity tolerance threshold and fractional yield decline per unit increase in salinity beyond the threshold, seven salinity treatments in hydroponics were used. The method used followed in part the procedure developed by Marcum and Murdoch (1990). Each of the seven treatments had three 6-inch pots in a solution tray. Each pot contained three Old World bluestem plants of the WW-Iron Master variety planted in five inches of silicon sand as shown in Figure III-a.

Figure III-a. Photo of actual experiment setup. Border trays limited edge effects of experiment design. Air pump and tubes maintained aeration of hydroponic solution.

Nutrients were supplied by Liquid Grow 7-9-5 (Dyna-Gro, www.dyna-gro.com) nutrient media mixed with water. The pH of the solution was adjusted using small amounts of sodium bicarbonate (Jones, 1997). Plants were trimmed to a height of four inches to encourage root development.

Salinity treatments began after plants were given 30 days to become established in the pots (Francois et al., 1990). Salinity treatments of 1, 2, 3, 5, 10, 20 and 30 ds/m (0, 19, 29, 49, 99, 198, and 298 mM NaCl) were used. Salinity levels for each treatment increased 2.8 g NaCl/liter every two days until the desired salinity was attained, see Table III-a. Every other day water purified by reverse osmosis was added to the solution trays to maintain 2 inches of media in the trays. Additionally, the media was drained and replaced with fresh media each week. Aeration was supplied both by the sand bedding and a tube network connected to an aquarium pump (Taliaferro et al., 1995; Marcum and Murdoch, 1990; Lee et al., 2005).

dS/m	mM NaCL	g NaCl/L	Days Required
1	0	0.0	0
2	19	1.1	0
3	29	1.7	0
5	49	2.8	0
10	99	5.6	2
20	198	11.2	6
30	298	16.8	10

Table III-a. Treatment preparation values.

When each of the desired salinity levels were reached the plant shoots were trimmed to a height of four inches. Every 2 weeks shoots were clipped for dry weight determination. All plant material was then dried at 70° C for 48 hrs (Marcum and Murdoch, 1990). This process continued for 4 harvests. After the final harvest, each of the plants was carefully removed from the sand bedding. Shoot and root samples were obtained from each treatment and tested for concentrations of Na^+ and K^+.

Data were then analyzed by the SALT program developed by van Genuchten and Hoffman (1980).

Results and Discussion

The effects of salinity on plant growth became more pronounced with time. Plants grown in a saline solution of 30 ds/m required two weeks before growth was stopped, while plants grown in 20 ds/m required four weeks before growth stopped. However, the effect of the saline media on plant growth seemed to stabilize after 6 weeks. The final effect of the salt solution can be seen in Figure III-b.

Figure III-b. Photo of final effect of salt solution. The photo shows the effect of each treatment starting with pure water (the tray missing one pot) and moving with increasing salinity to 30 ds/m (the second furthest tray in the middle).

Salt Program Analysis

The salt program developed by van Genuchten and Hoffman (1980) was used to analyze the data. The data best-fit Equation III-a and the SALT program calculated values for Y_m, C_{50} and P which would provide the lowest sum of squares residual for the data. Where Y_m is the yield under non-saline conditions, C_{50} is the salinity at which yield is reduced by 50%, p is an empirical constant, C is the salinity of the soil and Y is the expected dry mass in grams of plant growth at C (van Genuchten and Hoffman, 1980). Again, because of the cumulative effect of salinity on plant growth, the values for these variables changed with time. However, the curves for the third two-week period and the fourth two-week period are very similar. The variable values calculated by the SALT program for each period are shown in Table III-b. Additionally, the r^2 and RMSE values for the fitted curves in transformed space are also show in Table III-b; no trend was found in the plotted residuals.

$$Y = Y_m/[1+(C/C_{50})^p] \qquad \text{Equation III-a}$$

Variable	**Days 0-14**	**Days 14-28**	**Days 28-42**	**Days 42-56**
Y_m	0.20	0.12	0.13	0.21
C_{50}	7.30	7.51	3.74	2.75
P	1.38	3.23	3.42	2.97
r^2	0.32	0.54	0.76	0.81
RMSE	0.15	0.15	0.11	0.10

Table III-b. Variable and statistical values for each period as calculated by the SALT program using equation 1.

The fitted curves and data points as a percent of maximum growth for these four periods are shown in Figures III-c through III-f. The data in the figures are compared to the 100% maximum growth, which is the mean growth of plants grown without salt added to hydroponics solution.

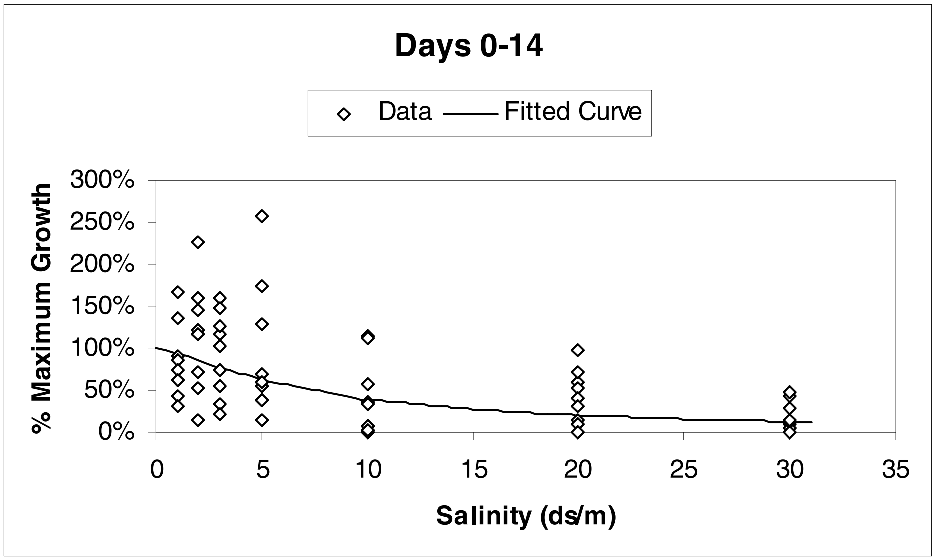

Figure III-c. Percent shoot growth for the first two-week period as influenced by salinity.

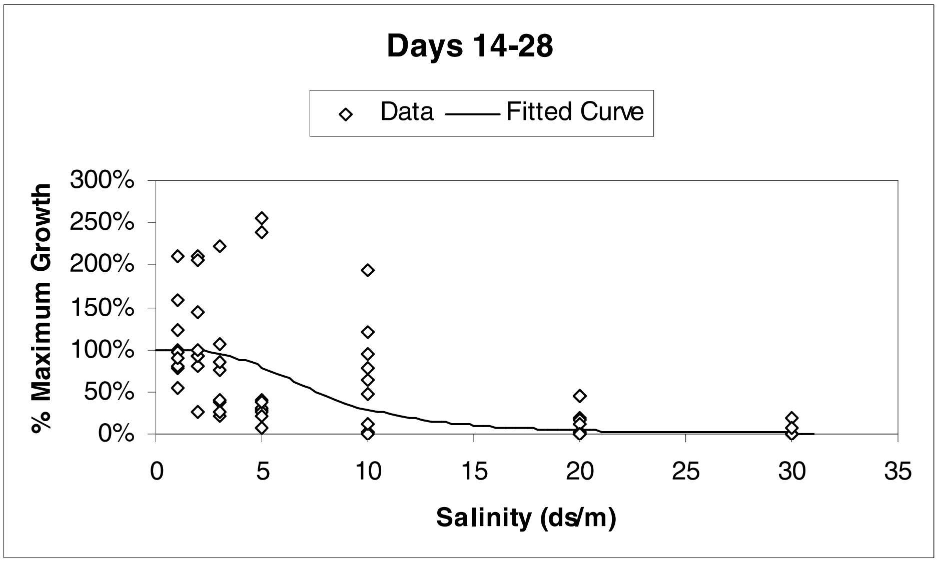

Figure III-d. Percent shoot growth for the second two-week period as influenced by salinity. (2 data points representing individual plants which grew more than 300% are not shown on graph.)

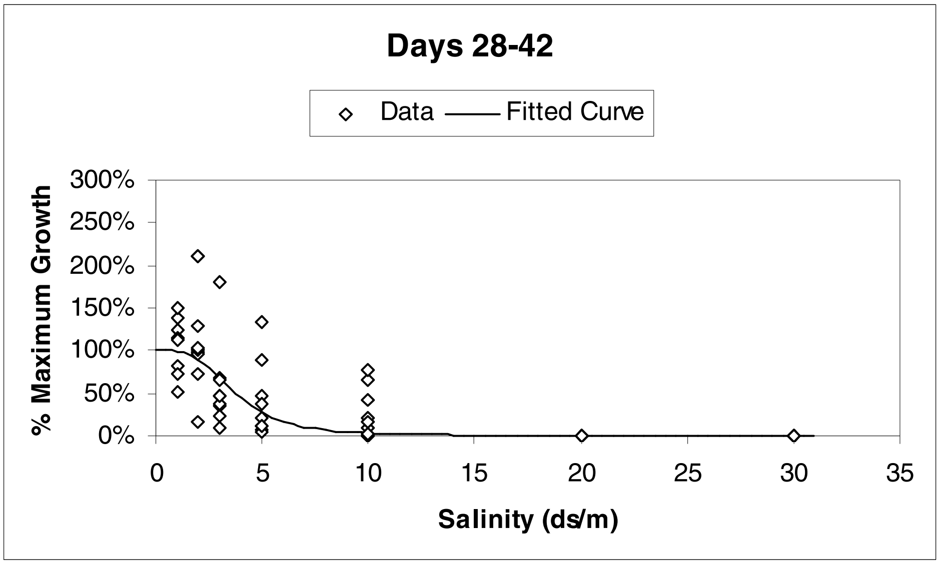

Figure III-e. Percent shoot growth for the third two-week period as influenced by salinity.

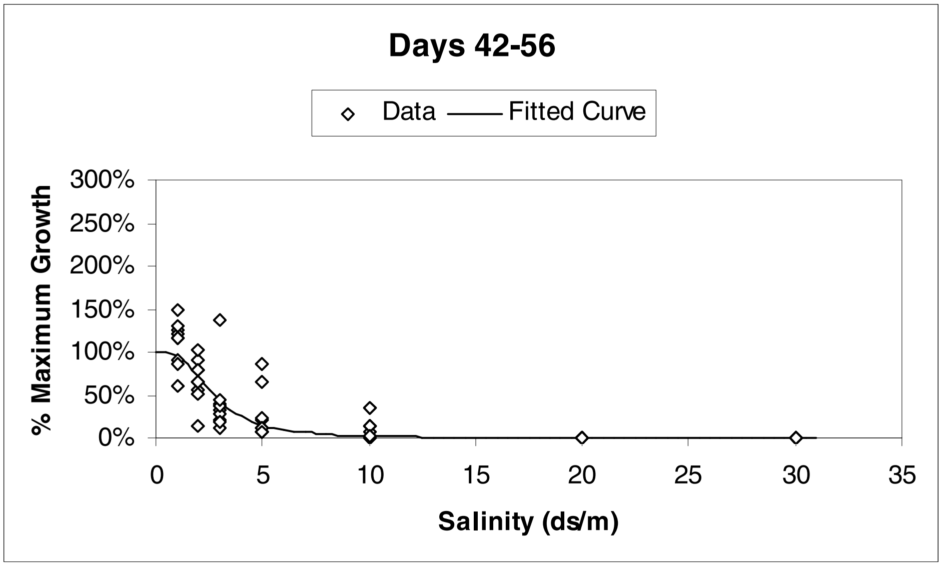

Figure III-f. Percent shoot growth for the fourth two-week period as influenced by salinity.

Comparison of Two Models

The data were also analyzed using the piecewise linear response model and compared against the fitted curves from the salt program (Figures III-g to III-j). For these comparisons, a single mean value of the nine replications was calculated for each of the salinity treatments to improve the readability of the graphs. The piecewise linear response model is based on Equation III-b, where Y is the expected growth as a percent of growth under non-saline conditions, c is the salinity, c_t is the salinity threshold value at which an increase in salinity has a negative effect on plant growth, c_0 is the x intercept of the slope or the salinity at which 0 growth is expected, Y_0 is the y intercept of the slope, and s is the slope or the fractional yield decline per unit increase in salinity beyond the threshold. The variables for the piecewise linear curve model are listed in Table III-c.

$$
\begin{array}{ll}
0 \le c \le c_t & 1 \\
c_t < c \le c_0 & Y = Y_0 - s * (c - c_t) \\
c > c_0 & 0
\end{array}
\qquad \text{Equation III-b}
$$

Variable	Days 0-14	Days 14-28	Days 28-42	Days 42-56
Y_0	156.02%	128.39%	126.95%	120.61%
s	11.16%	16.58%	19.68%	20.66%
c_t	5.02	1.71	1.37	1.00
c_0	13.98	7.74	6.45	5.84

Table III-c. Variables used in the piecewise linear response model for each period.

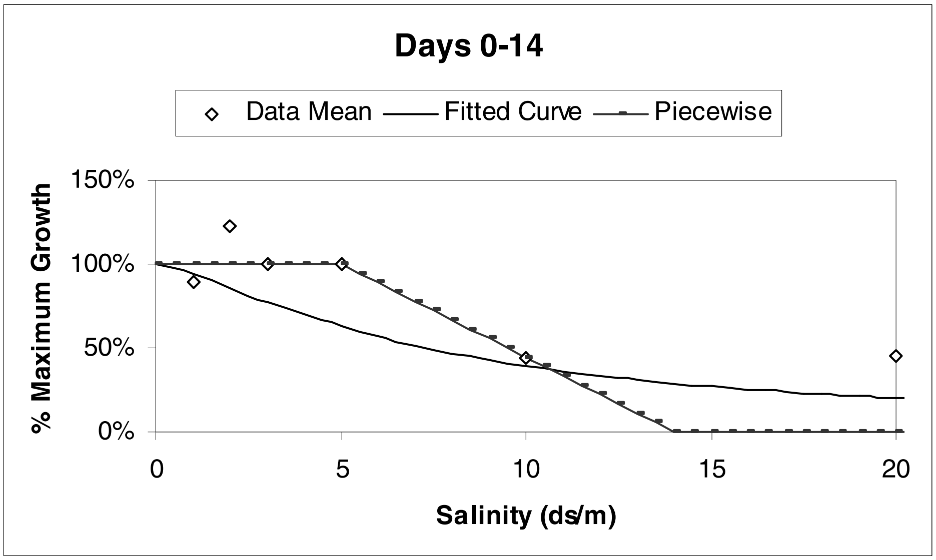

Figure III-g. Comparison of curves generated by the salt program and the piecewise linear response model for the first two-week period as influenced by salinity (each point is the mean of nine observations).

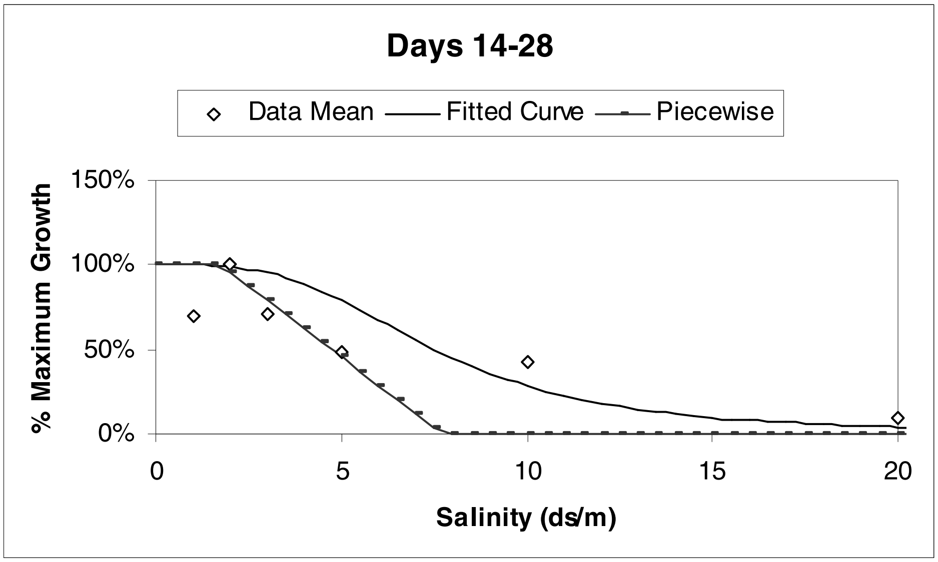

Figure III-h. Comparison of curves generated by the salt program and the piecewise linear response model for the second two-week period as influenced by salinity (each point is the mean of nine observations).

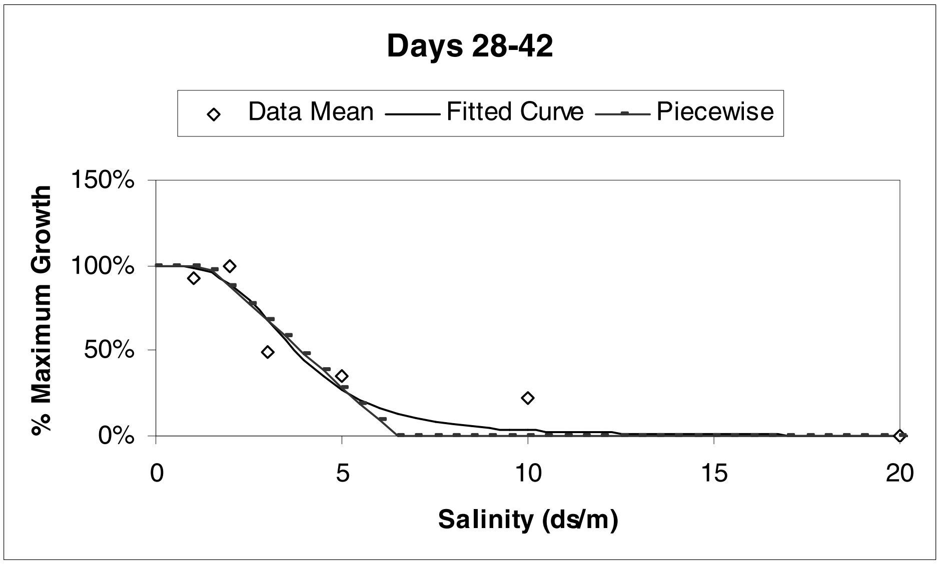

Figure III-i. Comparison of curves generated by the salt program and the piecewise linear response model for the third two-week period as influenced by salinity (each point is the mean of nine observations).

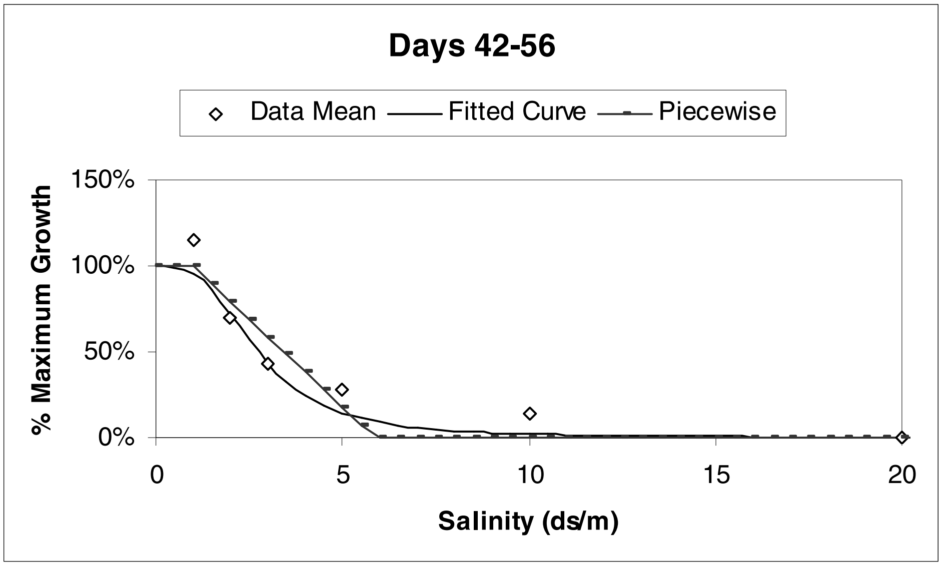

Figure III-j. Comparison of curves generated by the salt program and the piecewise linear response model for the fourth two-week period as influenced by salinity (each point is the mean of nine observations).

Plant Ion Concentrations

At the end of the fourth growth period, samples of plant shoots and roots were analyzed for Na^+ and K^+ concentration in the tissue. As shown in Figure III-k, the Na^+ concentration in the plant roots and shoots increased linearly with the increasing salinity of the media. However, the root tissue maintained a much lower Na^+ concentration than was found in the shoots. This indicates that Old World bluestem is incapable of restricting Na^+ from accumulating in the shoots, and is likely the cause of this plant's poor salinity tolerance.

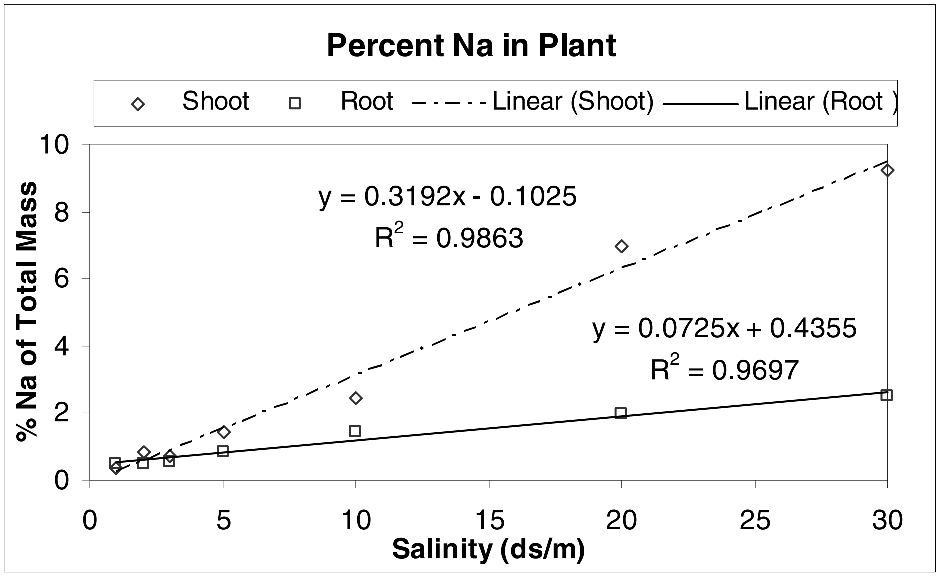

Figure III-k. Comparison between percent dry mass Na^+ composition of the shoots and roots as influenced by salinity.

As shown in Figure III-l, the concentration of K^+ was inversely proportionate to the Na^+ concentration in the root tissue. Many plants selectively uptake K^+ while restricting Na^+ uptake to handle saline growing conditions. In this case where the results indicate that the plant is unable to restrict salt uptake, the decrease in K^+ may be caused by a variety of factors. The increased concentration of Na^+ may make passive transport of K^+ impossible, while the remaining K^+ is slowly depleted with time. It is also possible that the plant depletes K^+ concentrations to offset the negative effects of saline growing conditions. However, there was very little effect of salinity on the K^+ levels in the shoots as shown in Figure III-m. This seems to indicate that the strong interaction between Na^+ and K^+ occurs only in the root tissue.

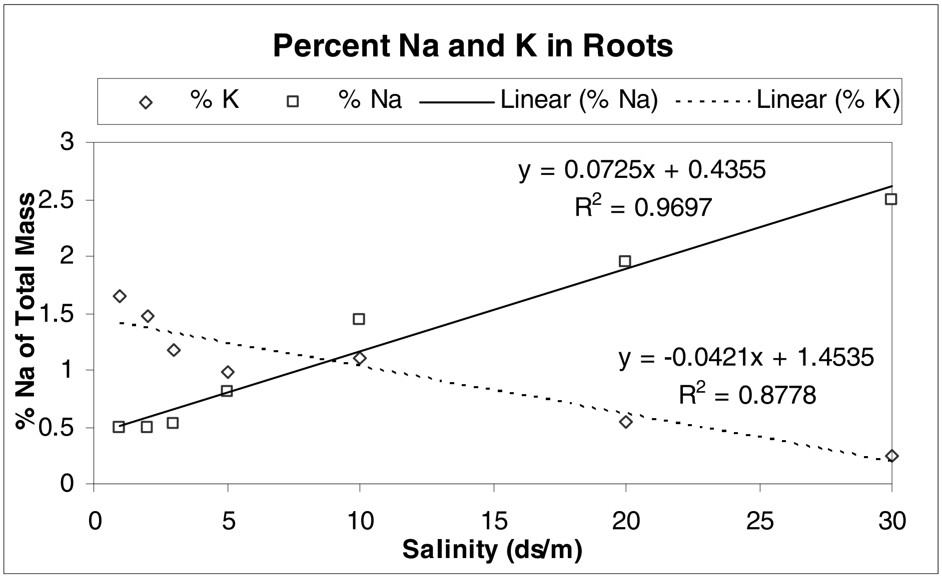

Figure III-l. Comparison of the percent dry mass Na^+ and K^+ composition in the roots as influenced by salinity.

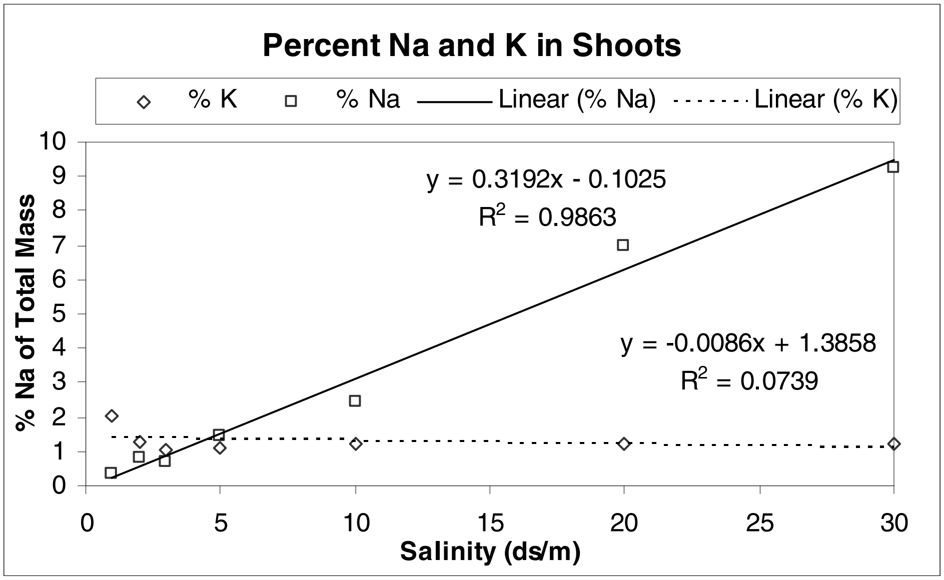

Figure III-m. Comparison of the percent dry mass Na^+ and K^+ composition in the shoots as influenced by salinity.

Conclusion

This research indicates that the effect of salinity on growth of WW-Iron Master Old World bluestem has a cumulative effect. Following forty two days the effect of salinity on plant growth reached a steady state and the salinity threshold for WW-Iron Master Old World bluestem was found using the piecewise linear response model to be 1 ds/m and the fractional yield decline per unit increase in salinity beyond the threshold was 21%. Both the piecewise linear response model and the salt program provided similar interpretations of the data. However, the piecewise linear response model may be considered superior because it is easier to interpret.

The mineral analyses of the root and shoot portions of the studied plants indicated an interaction between K^+ and Na^+ concentrations in the root tissue of WW-Iron Master Old World bluestem. With successively higher salinity treatments the increases in Na^+ were matched with decreases in K^+. However, the salinity treatment showed no effect on the K^+ concentration in the shoots. Because the Na^+ accumulation in the shoot tissue was much greater than in the root tissue it is concluded that WW-Iron Master Old World bluestem lacks the mechanisms necessary to restrict Na^+ transport to the shoots, which is likely the cause of its low salt tolerance.

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Chapter IV

Statistical Study of Swine Effluent Application on WW-Iron Master Old World Bluestem, Dichanthium spp.

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Abstract

Stands of Old World bluestem (*Dichanthium* spp.) are grown extensively in the Southern Great Plains. Swine production facilities have also increased significantly in this region. In some cases, swine effluent application on these stands has resulted in total stand loss. Stand loss may be a consequence of high soil salinity or salt burn on the foliage. Accumulated salts, generally chloride and sodium left on foliage after swine effluent application, can be absorbed into the plant and cause foliage damage. Salt burn effects appear to be most pronounced when application takes place by slowly rotating sprinklers during warm windy days with low humidity. For this study a statistical analysis was conducted on seven years of swine effluent application data on to CRP (Conservation Reserve Program) land in the Goodwell, Oklahoma area. This statistical approach considered 55 variables for 25 effluent application dates. The analysis indicated that with an alpha value of 10% there is statistical evidence that soil levels of both NO_3-N (lbs/A) and Cu (mg/l) are significantly correlated with stand loss for swine effluent application on stands of WW-Iron Master Old World bluestem.

Introduction

Old World bluestems, which originate from Russia and surrounding Asian countries, were introduced into the United States around 1920. They are warm-season perennial bunchgrasses that are adapted to a wide range of soil types (Harmoney and Hickman, 2004). Old World bluestems begin growth during late spring and perform better during the hot parts of summer than other warm-season grasses. Old World bluestems are generally dormant from mid-September to mid-May (Bell and Caudle, 1994). Because Old World bluestem is more receptive to late summer rain than other warm-season grasses, it can still experience significant growth in August and September.

There are many cultivars of Old World bluestems, with the most common being ‘Caucasian’, ‘Ganada’, ‘King Ranch’, ‘Plains’, ‘WW-Spar’, ‘WW-Iron Master’ and ‘WW-B Dahl’. Despite an increased tolerance for iron deficient soils, WW-Iron Master is a fairly representative variety of Old World bluestems (Redfearn, 2004).

Details on salt burn effects on plants are difficult to obtain because of the strong environmental influence on the results. Factors that have been shown to contribute to salt burn are air temperature, wind speed, sprinkler rotation speed, and droplet size (Ayers and Westcot, 1985). Additionally, plants with high sensitivity to salinity in soil have been shown to be particularly sensitive to foliar absorption of salts (Maas, 1984).

Material and Methods

Preliminary analysis of raw CRP effluent application data required some assumptions. These assumptions were:

1. Effluent application stopped when stand suffered loss;
2. Stand loss is either complete or non-existent after each application;

3. Effluent application took 2 weeks;
4. Rainfall data were only significant during application, one week before, and one week after;
5. Soil samples and lagoon samples were representative;
6. Effluent application was uniform throughout the field;
7. Application took place during the day; and
8. Weather conditions in Goodwell, Oklahoma represented conditions at all sites.

From May 11, 1999 to July 21, 2005, details of 25 CRP grassland effluent applications were collected. Based on previously stated assumptions, all consistently measured independent variables were input into a Microsoft Excel ® spreadsheet. This set of independent variables is shown in Table IV-a.

General Variables	Soil Test Variables	Effluent Test Variables
Application Volume (acre-inches/acre)	Organic Matter (%)	EC (µmho/cm)
Max Temp. (^{o}F)	pH	pH
Min Humidity (%)	EC (mmho/cm)	Org N (mg/l)
Max Wind During (mph)	NO_3-N (lbs/A)	Ammoniacal N (mg/l)
Rain During (in.)	Ca (mg/l)	Tot P (mg/l)
Rainfall Within Week After (in.)	Mg (mg/l)	Total Solids (mg/l)
Rainfall Within Week Before (in.)	K (mg/l)	TVS (mg/l)
Season	Na (mg/l)	TDS (mg/l)
Month	Cu (mg/l)	TSS (mg/l)
	CEC	Tot Ca (mg/l)
	K (%)	Tot Mg (mg/l)
	Mg (%)	Tot K (mg/l)
	Ca (%)	Tot Na (mg/l)
		K2O (mg/l)
		Chloride (mg/l)
		Adj. SAR
		Total Salts (mg/l)
		Tot S (mg/l)
		Tot Zn (mg/l)
		Tot Fe (mg/l)
		Bicarbonate (mg/l)

Table IV-a. Variables considered for development of unbiased model.

Because the data set had 24 degrees of freedom, the initial regression analysis was conducted with only the first 24 variables. The variable with the highest VIF (variable inflation factor) value above 10 was eliminated and the next independent variable was added. This process continued until all 55 variables had been added and those with high VIF values were eliminated. This analysis yielded the following set of potentially significant variables in Table IV-b.

General Variables	**Soil Test Variables**	**Effluent Test Variables**
Max Wind During (mph)	pH	EC (µmho/cm)
Rainfall Within Week After (in.)	EC (mmho/cm)	pH
Rainfall Within Week Before (in.)	NO_3-N (lbs/A)	Org N (mg/l)
	Cu (mg/l)	TDS (mg/l)
		Adj. SAR
		Tot S (mg/l)
		Tot Zn (mg/l)

Table IV-b. Potentially significant variables for development of unbiased model.

These variables were then analyzed for "best subset regression." The results are as follows.

Best Subsets Regression: Effect versus Max Wind During, ...

```
                                             R
                                           R a
                                           a i
                                           i n
                                           n f
                                           f a
                                           a l
                                           l l
                                           l
                                             W
                                           W i
                                           i t
                                         M t h     N
                                         a h i     i
                                         x i n     t
                                           n       r     O
                                         W   w     a     r
                                         i W e   E t     g
                                         n e e   C e
                                         d e k           N
                                           k     m N         a
                                         D   b   m       (   d
                                         u A e   h l     m   j T
                                         r f f   o b   p g     o
                                         i t o   / s   H / T S t
                       Mallows           n e r p c / C _ l D A
Vars  R-Sq  R-Sq(adj)       Cp        S  g r e H m A u 1 ) S R S
   1  24.5       19.8     20.7  0.44922            X
   1  22.2       17.4     21.8  0.45599              X
   2  53.2       46.9      9.5  0.36537            X X
   2  41.4       33.6     14.9  0.40871            X           X
   3  60.1       51.6      8.3  0.34897            X X         X
   3  55.3       45.7     10.6  0.36972            X X     X
   4  64.2       53.1      8.5  0.34346        X   X X         X
   4  62.7       51.2      9.2  0.35035            X X   X     X
   5  66.1       52.0      9.6  0.34766        X   X X   X     X
   5  65.9       51.7      9.7  0.34869        X   X X       X X
   6  69.3       52.5     10.1  0.34560  X     X X X     X     X
   6  69.0       52.0     10.3  0.34738        X   X X     X X X
   7  75.8       58.8      9.2  0.32208      X X   X X     X X X
   7  72.1       52.6     10.8  0.34553  X     X X X X   X     X
   8  78.2       58.8     10.0  0.32201      X X   X X   X X X X
   8  77.6       57.6     10.3  0.32659  X   X X   X X     X X X
   9  81.8       61.3     10.4  0.31199  X X X X X X   X X     X
   9  80.8       59.1     10.9  0.32076  X X X X   X X     X X X
  10  84.7       62.9     11.0  0.30553  X X X X   X X X   X X X
  10  84.3       61.8     11.2  0.30996  X X X X X X X X X     X
  11  85.7       59.6     12.6  0.31877  X X X X X X X X   X X X
  11  85.6       59.3     12.6  0.31997  X X X X   X X X X X X X
  12  89.1       63.0     13.0  0.30496  X X X X X X X X X X X X
```

From this analysis it was determined that a model based on soil values of NO_3-N (lbs/acre) and Cu (mg/l) provided the most significant basis for the model. Because the dependent variable was a binary response variable, logistics regression was used for model analysis. The results are as follows.

Binary Logistic Regression: Effect versus NO_3-N lbs/A, Cu

```
Response Information

Variable  Value  Count
Effect    1          7  (Event)
          0         11
          Total     18

* NOTE * 18 cases were used
* NOTE * 7 cases contained missing values

Logistic Regression Table
                                                             95% CI
Predictor            Coef    SE Coef       Z       P  Odds Ratio  Lower
Constant         -12.3700    6.19889   -2.00   0.046
NO3-N lbs/A      0.531762   0.305967    1.74   0.082        1.70   0.93
Cu                7.52229    3.91177    1.92   0.054     1848.79   0.87

Predictor             Upper
Constant
NO3-N     lbs/A        3.10
Cu               3950501.00

Log-Likelihood = -5.178
Test that all slopes are zero: G = 13.701, DF = 2, P-Value = 0.001

Goodness-of-Fit Tests

Method           Chi-Square  DF      P
Pearson             7.70999  11  0.739
Deviance            7.58365  11  0.750
Hosmer-Lemeshow     6.28842   8  0.615

Table of Observed and Expected Frequencies:
(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

                             Group
Value    1    2    3    4    5    6    7    8    9   10  Total
1
  Obs    0    0    0    0    1    0    1    1    2    2      7
  Exp  0.0  0.0  0.1  0.3  0.2  0.2  0.9  1.5  1.8  2.0
0
  Obs    1    3    1    3    0    1    1    1    0    0     11
  Exp  1.0  3.0  0.9  2.7  0.8  0.8  1.1  0.5  0.2  0.0
Total    1    3    1    3    1    1    2    2    2    2     18

Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs       Number  Percent  Summary Measures
Concordant      72     93.5  Somers' D              0.88
Discordant       4      5.2  Goodman-Kruskal Gamma  0.89
Ties             1      1.3  Kendall's Tau-a        0.44
Total           77    100.0
```

With an alpha value of 10% we can conclude that both NO_3-N (lbs/A) and Cu (mg/l) are significant factors in determination of the effect of swine effluent application on stands of Old World bluestem.

In addition to this unbiased approach to the data set, the above analysis was also conducted on a specific set of variables. This specific set of variables was chosen based on careful evaluation of the variables to determine their expected effect on the stands of Old World bluestem. These values are shown in Table IV-c.

General Variables	**Soil Test Variables**	**Effluent Test Variables**
Application Volume (acre-inches/acre)	EC (mmho/cm)	EC (µmho/cm)
Max Temp. (°F)		Chloride (mg/l)
Rainfall Within Week Before (in.)		

Table IV-c. Potentially significant variables chosen for development of biased model.

None of the specific set of variables had VIF values above 10, so all were included in the "best subset regression." The results are as follows.

Best Subsets Regression: Effect versus acre inches/acre, Max Temp., ...

```
Response is Effect
19 cases used, 6 cases contain missing values

                                              R
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                                              n
                                              f
                                              a
                                              l
                                              l

                                              W
                                              i
                                          a   t
                                          c   h
                                          r   i
                                          e   n

                                          i   w
                                          n   e E E
                                          c M e C C
                                          h a k     C
                                          e x   m u h
                                          s   b m m l
                                          / T e h h o
                                          a e f o o r
                                          c m o / / i
                        Mallows           r p r c c d
Vars  R-Sq  R-Sq(adj)        Cp        S  e . e m m e
   1  19.6       14.8       3.5  0.45734    X
   1   9.5        4.2       5.8  0.48520          X
   2  44.6       37.7      -0.2  0.39127          X X
   2  35.1       27.0       1.9  0.42350    X     X
   3  46.8       36.2       1.2  0.39600        X X X
   3  45.2       34.3       1.6  0.40175    X     X X
   4  47.8       32.9       3.0  0.40606  X     X X X
   4  47.1       32.0       3.2  0.40853      X X X X
   5  47.9       27.8       5.0  0.42108  X   X X X X
   5  47.8       27.7       5.0  0.42135  X X   X X X
   6  47.9       21.8       7.0  0.43822  X X X X X X
```

From this analysis it was determined that a model based on effluent values of EC (µmho/cm) and Cl (mg/l) provided the most significant basis for the specific subset model. Because the dependent variable was a binary response variable, logistics regression was used for model analysis. The results are as follows.

Binary Logistic Regression: Effect versus EC µmho/cm, Chloride

```
Link Function: Logit


Response Information

Variable  Value  Count
Effect    1          7  (Event)
          0         12
          Total     19

* NOTE * 19 cases were used
* NOTE * 6 cases contained missing values


Logistic Regression Table

                                                    Odds     95% CI
Predictor         Coef    SE Coef      Z      P  Ratio  Lower  Upper
Constant      -5.69397    3.65752  -1.56  0.120
EC umho/cm   0.0015331  0.0007731   1.98  0.047   1.00   1.00   1.00
Chloride    -0.0157826  0.0097811  -1.61  0.107   0.98   0.97   1.00


Log-Likelihood = -6.900
Test that all slopes are zero: G = 11.208, DF = 2, P-Value = 0.004


Goodness-of-Fit Tests

Method           Chi-Square  DF      P
Pearson             13.1116  13  0.439
Deviance            13.7997  13  0.388
Hosmer-Lemeshow      3.0304   8  0.932


Table of Observed and Expected Frequencies:
(See Hosmer-Lemeshow Test for the Pearson Chi-Square Statistic)

                             Group
Value    1    2    3    4    5    6    7    8    9   10  Total
1
  Obs    0    0    0    0    1    0    1    1    3    1      7
  Exp  0.0  0.0  0.0  0.1  0.4  0.7  1.0  1.2  2.6  1.0
0
  Obs    2    1    2    2    1    2    1    1    0    0     12
  Exp  2.0  1.0  2.0  1.9  1.6  1.3  1.0  0.8  0.4  0.0
Total    2    1    2    2    2    2    2    2    3    1     19


Measures of Association:
(Between the Response Variable and Predicted Probabilities)

Pairs        Number  Percent  Summary Measures
Concordant       76     90.5  Somers' D              0.81
Discordant        8      9.5  Goodman-Kruskal Gamma  0.81
Ties              0      0.0  Kendall's Tau-a        0.40
Total            84    100.0
```

Results and Discussion

From the model based on an unbiased evaluation of the variables we can derive the equation predicting stand loss based on NO_3-N (lbs/acre) and Cu (mg/l) in the soil. Since stand loss was considered complete or non-existent, complete stand loss is represented by an effect value of 1 or greater value and non-existent stand loss is represented by a 0 or less. The equation is as follows:

$$Effect = -12.370 + .532 * N + 7.523 * Cu$$

Where N is the lbs/acre of soil NO_3-N and Cu is mg/l of copper in the soil before application of swine effluent.

For the model based on biased evaluation of the variables we can derive the equation predicting stand loss based on effluent values of EC (umho/cm) and Cl (mg/l). The equation is as follows:

$$Effect = -5.6940 + 0.0015 * EC + -0.0158 * Cl$$

Where EC is the electro conductivity in umho/cm for the effluent and Cl is mg/l of chloride in the effluent.

The raw data and subsequent predictions of the two models are shown in Table IV-d.

Farm	Soil Nitrate N (lbs/A)	Soil Cu (mg/l)	Effluent EC (umho/cm)	Effluent Chloride (mg/l)	Unbiased Model Calculated Effect	Unbiased Model Translated Effect	Biased Model Calculated Effect	Biased Model Translated Effect	Observed Effect
121	5	0.5	8970	562	-5.95	0	-1.12	0	0
121	2	1.6	8560	460	0.73	0.73	-0.12	0	0
40	10	0.9	5060		-0.28	0	1.90	1	0
40	10	0.9	5060		-0.28	0	1.90	1	1
40	19		7240	358	-2.27	0	-0.49	0	1
337	5	0.5	8290	511	-5.95	0	-1.33	0	0
278	2	0.6	11330	1164	-6.79	0	-7.09	0	0
278	12	0.6	11330	1164	-1.48	0	-7.09	0	0
299	7		5360	362	-8.65	0	-3.37	0	0
299	10		5360	362	-7.05	0	-3.37	0	0
301	5		8770		-9.71	0	7.46	1	0
299	5		10790		-9.71	0	10.49	1	0
301	14	0.9	11020	604	1.85	1	1.29	1	1
299	10	1.4	11200	605	3.48	1	1.55	1	1
299	22	1	11200	605	6.85	1	1.55	1	1
299	5		10790		-9.71	0	10.49	1	1
217	5	0.4	6870	277	-6.70	0	0.23	0.23	0
217	24	1	8200	221	7.92	1	3.11	1	1
43	10	1.2	6450	244	1.98	1	0.13	0.13	1
42	5	1	2150	186	-2.19	0	-5.41	0	0
42	12		4110		-5.99	0	0.47	0.47	0
42	17	0.12	6200	577	-2.43	0	-5.51	0	0
122	5	1	8100	443	-2.19	0	-0.54	0	0
122	5	1	6490	484	-2.19	0	-3.61	0	0
122	2	1.3	7430	476	-1.53	0	-2.07	0	1

Table IV-d. Comparison of models developed from the two sets of variables.

Conclusions

The unbiased model suggests that both the soil NO_3-N (lbs/acre) and Cu (mg/l) in soil had negative impacts on plant growth. Generally elevated levels of soil NO_3-N only have a positive effect on plant growth; however, since no commercial fertilizer was used, the level of NO_3-N may actually be an indication of the amount of effluent that has been applied. For the unbiased model the effect of copper is somewhat suspect since 7 of the 25 data sets did not include a copper value for the soil. Additionally, it is possible that the significant effect of Cu and NO_3-N is an artifact of examining 55 possible variables for only 25 data sets. The limited number of data sets and the high number of potentially significant variables could lead to incorrectly identifying a variable as significant when it is in fact, only a coincidence.

Evaluation of the model based on carefully selected variables, or the biased model, yielded effluent values of EC (umho/cm) and Cl (mg/l) as potentially significant variables. However, as Table IV-d shows, the biased model was less accurate at predicting a negative stand impact than the unbiased model.

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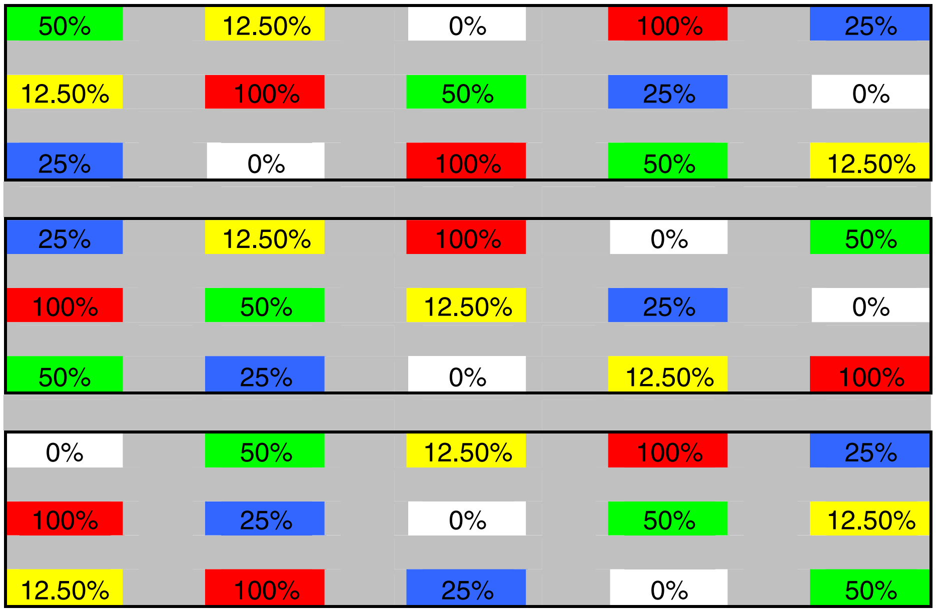
Chapter V

Related Experiments

Effluent Application at Farm

Material and Methods

A healthy stand of World bluestem of the WW-Iron Master variety was chosen within a mile of other stands allegedly impacted by swine effluent application. Two weeks before swine effluent application, an evenly vegetated 95 by 80 foot rectangle within the chosen stand of Old World bluestem was chosen and watered with several inches of water to encourage plant growth. The 95 by 80 foot rectangle was then divided into 5 by 10 foot plots. A five foot buffer zone separated all plots from each other as shown in Figure V-a.



50%	12.50%	0%	100%	25%
12.50%	100%	50%	25%	0%
25%	0%	100%	50%	12.50%
25%	12.50%	100%	0%	50%
100%	50%	12.50%	25%	0%
50%	25%	0%	12.50%	100%
0%	50%	12.50%	100%	25%
100%	25%	0%	50%	12.50%
12.50%	100%	25%	0%	50%

Figure V-a. Plot layout design.

The initial Normalized Difference Vegetation Index (NDVI) value was found for each plot using the GreenSeeker. This was accomplished by passing the sensor over the middle of each of the plots at a height of three feet while walking at a constant rate. Each plot was read in triplicate.The plots were divided into the three sub-treatments: morning, afternoon and evening effluent applications. Each sub-treatment contained three rows each containing five plots randomly marked for each of the five different effluent concentration applications. The red plots received undiluted swine effluent, the green plots received 1:1 dilution of swine effluent to water, the blue plots received 1:3 dilution of swine effluent to water, the yellow plots received a 1:7 dilution of swine effluent to water and the white blocks received pure water. All treatments received about 31 gallons of liquid, equivalent to one inch application depth.

Effluent application was divided into three portions of the day. The morning application started at about 7:00 a.m. and lasted until 10:00 a.m. The afternoon application began at 12:00 p.m. and ended at 3:00 p.m. The evening application began at 5:00 p.m. and ended at 8:00 p.m. To improve the chance of salt burn, application was performed during a hot day with high solar radiation.

To obtain an even application of the treatment solution a specially designed sprinkling system was used. The sprinkling system consisted of a 5’X10’ frame containing 4 quarter-circle sprinkler heads (Rain Bird, 8Q, www.rainbird.com) in each corner and 2 half-circle heads (Rain Bird, 8H, www.rainbird.com) in the middle of the 10 foot lengths as shown in Figures V-b and V-c.

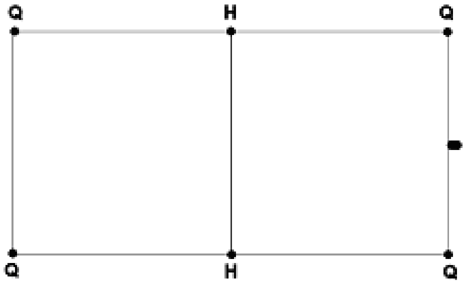


Figure V-b. Application apparatus.

Figure V-c. Photo of actual apparatus in field.

At the conclusion of each plot application, the sprinkler heads were inspected for clogging and repaired if needed.

Approximately one month after application the plots were analyzed for growth. First, each plot was read in triplicate by the GreenSeeker to determine treatment effect on the NDVI value. Second, the vegetation in each plot was trimmed 4 inches from the ground and harvested for analysis as shown in Figure V-d. Then harvested material from each plot was weighed. Next, dry mass was determined by removing a small sample of the harvested material from each plot and weighing it. These samples were then dried at 70° C for 48 hrs in an oven and weighed again (Marcum and Murdoch, 1990).

Figure V-d. Harvest of treated stands one month after application.

Reflectance Index Results

One month after application the stands were analyzed for treatment effects. One method of determining the effect of swine effluent application was to compare the initial and final reflectance index values measured by the Greenseeker. Although the detection limit for the Greenseeker is 0.05, each treatment was recorded in triplicate to improve testing resolution, the averages are shown in Table V-a. By measuring the difference between initial and final reflectance index values we were able to quantify the effects of the treatments. These results are summarized in Table V-b and Figure V-e.

Initial			Final			Difference
Overall			Overall			
c	Control	0.641	c	Control	0.678	0.037
e	Eighth	0.640	e	Eighth	0.660	0.020
q	Quarter	0.618	q	Quarter	0.682	0.064
h	Half	0.645	h	Half	0.670	0.026
f	Full	0.613	f	Full	0.675	0.063
	Average	0.631		Average	0.673	0.042
8 A.M.			8 A.M.			
c	Control	0.626	c	Control	0.622	-0.004
e	Eighth	0.632	e	Eighth	0.675	0.043
q	Quarter	0.638	q	Quarter	0.664	0.026
h	Half	0.632	h	Half	0.665	0.032
f	Full	0.600	f	Full	0.705	0.105
	Average	0.626		Average	0.666	0.040
2 P.M.			2 P.M.			
c	Control	0.654	c	Control	0.686	0.032
e	Eighth	0.690	e	Eighth	0.654	-0.036
q	Quarter	0.642	q	Quarter	0.657	0.015
h	Half	0.678	h	Half	0.677	-0.001
f	Full	0.657	f	Full	0.666	0.010
	Average	0.664		Average	0.668	0.004
8 P.M.			8 P.M.			
c	Control	0.644	c	Control	0.727	0.083
e	Eighth	0.597	e	Eighth	0.651	0.054
q	Quarter	0.575	q	Quarter	0.726	0.150
h	Half	0.624	h	Half	0.669	0.046
f	Full	0.594	f	Full	0.664	0.070
	Average	0.607		Average	0.687	0.081

Table V-a. The average initial and final reflectance index for each treatment and their difference.

		Overall	8 P.M.	2 P.M.	8 A.M.
c	**Control**	0.037	-0.004	0.032	0.083
e	**Eighth**	0.020	0.043	-0.036	0.054
q	**Quarter**	0.064	0.026	0.015	0.150
h	**Half**	0.026	0.032	-0.001	0.046
f	**Full**	0.063	0.105	0.010	0.070
	Average	0.042	0.040	0.004	0.081

Table V-b. The average difference in reflectance index for each treatment after application.

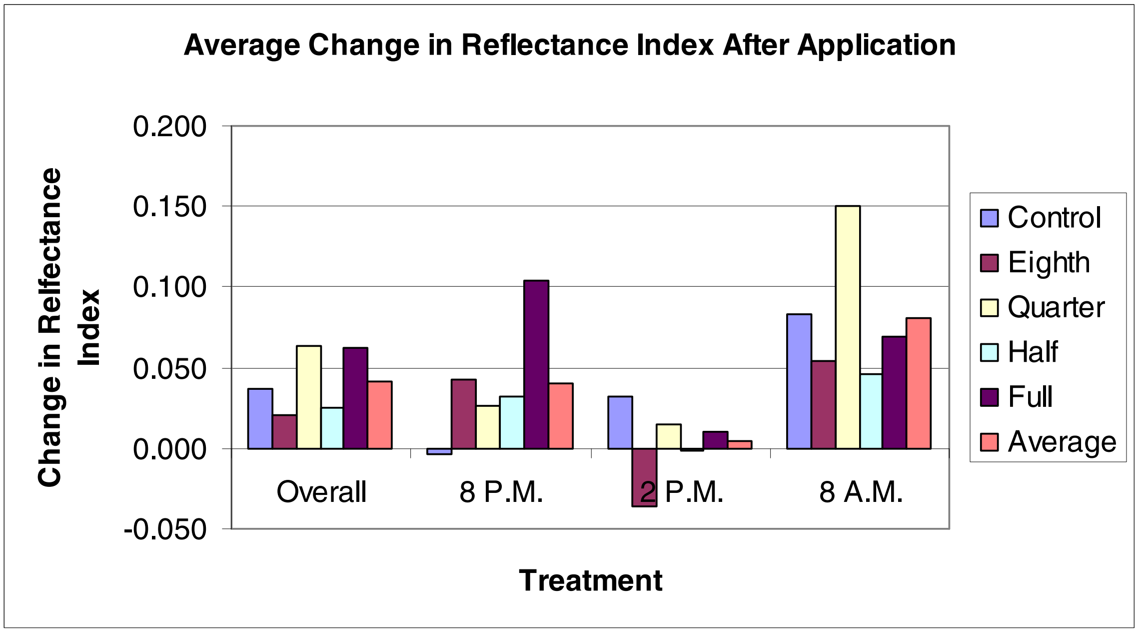


Figure V-e. The average difference in reflectance index for each treatment after application.

Statistical analysis of the reflectance index results began with a two-way ANOVA test to determine the effect of the time of application, the dilution of effluent, and their interaction. As the following analysis shows, both the treatment and interaction terms were insignificant at a 10% alpha value.

Two-way ANOVA: Change in Reflectance Index versus Time, Treatment

```
Source        DF        SS         MS     F      P
Time           2  0.031923  0.0159614  2.72  0.082
Treatment      4  0.008942  0.0022355  0.38  0.820
Interaction    8  0.035440  0.0044301  0.76  0.643
Error         30  0.175751  0.0058584
Total         44  0.252056

S = 0.07654   R-Sq = 30.27%   R-Sq(adj) = 0.00%
```

Analysis of the two-way ANOVA also indicated that a one-way ANOVA with a Tukey comparison of the change in the reflectance index versus time was also necessary.

One-way ANOVA: Change in Reflectance Index versus Time

```
Source  DF       SS       MS     F      P
Time     2  0.03192  0.01596  3.05  0.058
Error   42  0.22013  0.00524
Total   44  0.25206

S = 0.07240   R-Sq = 12.66%   R-Sq(adj) = 8.51%

Tukey 90% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 95.89%
Time = Evening subtracted from:

Time        Lower    Center     Upper
Morning  -0.09510  -0.03940   0.01630
Noon     -0.12044  -0.06473  -0.00903

Time        +---------+---------+---------+---------
Morning          (--------*---------)
Noon        (--------*--------)
            +---------+---------+---------+---------
         -0.120    -0.060     0.000     0.060

Time = Morning subtracted from:

Time     Lower    Center    Upper     +---------+---------+---------+---------
Noon  -0.08104  -0.02533  0.03037            (---------*--------)
                                      +---------+---------+---------+---------
                                   -0.120    -0.060     0.000     0.060
```

The Tukey comparison showed that the evening treatment was significantly different from the noon treatment at an alpha value of 5%.

Dry Weight Results

The second method of determining the effect of swine effluent application was to harvest the stands one month after application and compare their dry weight. Once again each treatment was recorded in triplicate and the averages are shown in Table V-c and Figure V-f.

		Overall	**8 P.M.**	**2 P.M.**	**8 A.M.**
c	**Control**	4.687	3.912	3.930	6.220
e	**Eighth**	4.182	3.560	3.949	5.037
q	**Quarter**	3.664	3.941	2.011	5.042
h	**Half**	5.093	5.175	6.006	4.403
f	**Full**	4.141	3.915	3.728	4.802
	Average	4.354	4.101	3.925	5.101

Table V-c. The average total dry weight of each treatment.

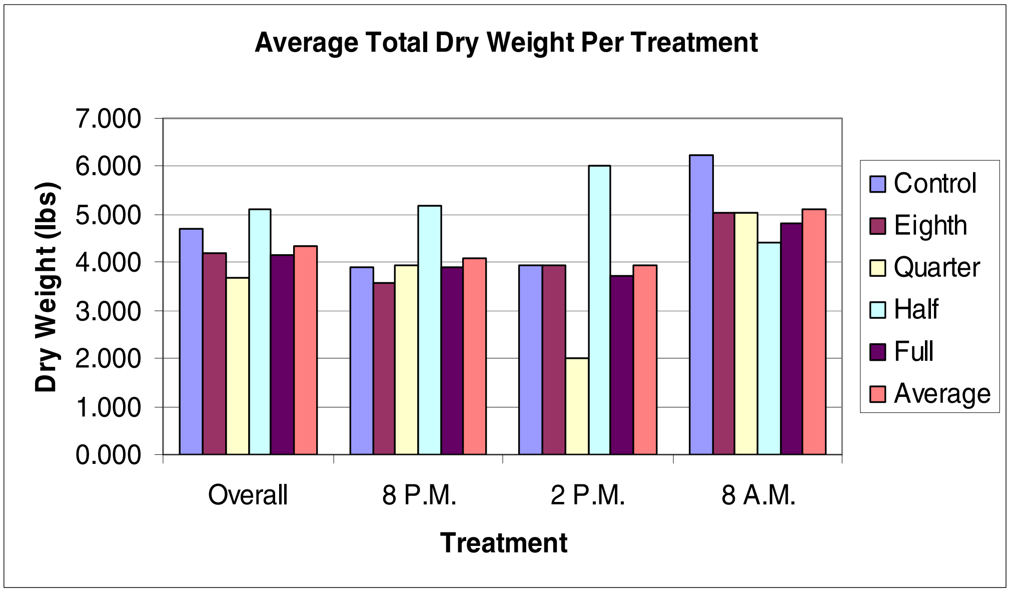


Figure V-f. The average total dry weight of each treatment.

Statistical analysis of the dry weight results began with a two-way ANOVA test to determine the effect of the time of application, the dilution of effluent, and their interaction. Like the statistical analysis comparing the reflectance index, both the treatment and interaction terms were insignificant at a 10% alpha value.

Two-way ANOVA: Total Dry Weight_1 versus Time, Treatment

```
Source       DF       SS       MS     F      P
Time          2  11.3809  5.69046  6.21  0.006
Treatment     4  12.5073  3.12684  3.41  0.021
Interaction   8  22.0762  2.75953  3.01  0.013
Error        30  27.5096  0.91699
Total        44  73.4741

S = 0.9576   R-Sq = 62.56%   R-Sq(adj) = 45.09%
```

Analysis of the two-way ANOVA also indicated that a one-way ANOVA with a Tukey comparison of the change in the dry weight versus time was also necessary.

One-way ANOVA: Total Dry Weight_1 versus Time

```
Source  DF      SS    MS     F      P
Time     2  11.38  5.69  3.85  0.029
Error   42  62.09  1.48
Total   44  73.47

S = 1.216   R-Sq = 15.49%   R-Sq(adj) = 11.47%


                             Individual 95% CIs For Mean Based on
                             Pooled StDev
Level       N   Mean  StDev  ---+---------+---------+---------+------
Evening    15  4.101  0.733     (--------*--------)
Morning    15  5.069  1.306                  (--------*--------)
Noon       15  3.925  1.480  (--------*--------)
                             ---+---------+---------+---------+------
                              3.50      4.20      4.90      5.60

Pooled StDev = 1.216

Tukey 90% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Time

Individual confidence level = 95.89%


Time = Evening subtracted from:

Time      Lower  Center  Upper  -------+---------+---------+---------+--
Morning   0.032   0.968  1.904                   (-------*-------)
Noon     -1.111  -0.176  0.760          (-------*------)
                                -------+---------+---------+---------+--
                                    -1.2       0.0       1.2       2.4


Time = Morning subtracted from:

Time   Lower  Center   Upper  -------+---------+---------+---------+--
Noon  -2.079  -1.144  -0.208  (------*-------)
                              -------+---------+---------+---------+--
                                  -1.2       0.0       1.2       2.4
```

The Tukey comparison showed that the morning treatment was significantly different from both the noon and the evening treatments at an alpha value of 5% for the change in the reflectance index data.

Conclusion

The experiment was designed to test the effect of various dilutions of swine effluent applied at three different times of day on stand loss. Statistical analysis of both the reflectance index and dry weight data indicated that the dilution had no significant effect on stand growth. However, the statistical analysis of both the reflectance index and dry weight data did indicate that the time of day of the application was significant at a 10% alpha level. A Tukey's 90% confidence test showed that for the reflectance index data the noon application was significantly different from the evening application. The Tukey's 90% confidence test for the dry weight data showed that the morning application was significantly different from both the evening and noon applications. These results are summarized in Table V-d and Figure V-g. While the reflectance index data and the dry weight data do not agree on the magnitude of the differences between each group, they do both indicate that an application of effluent at noon will result in the least positive effect on plant growth. This may be a result of the higher evaporation effects at noon, and subsequent decreased water available for plant growth.

	Morning	Noon	Evening
Change in Reflectance Index	0.0412	0.01587	0.0806
Average Total Dry Weight	5.069	3.925	4.101

Table V-d. Summary of the effects of the time of application.

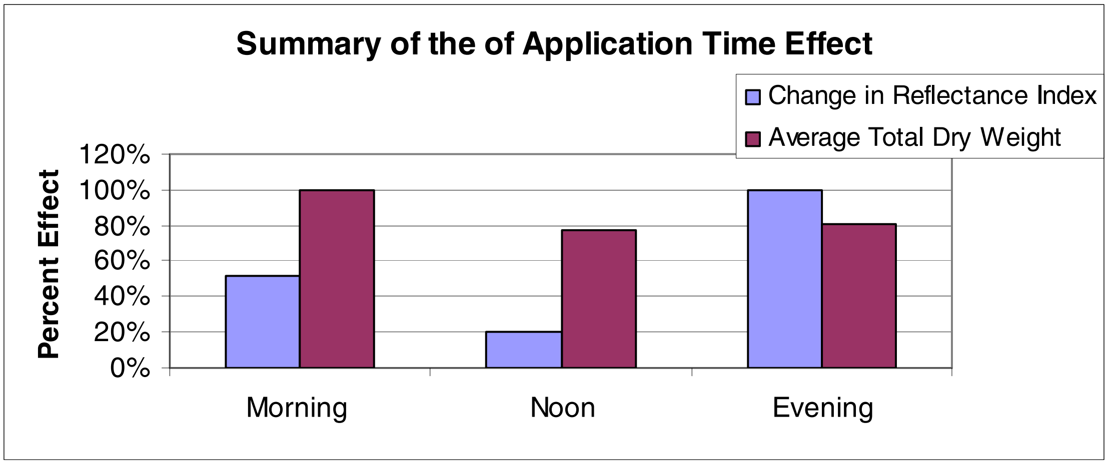


Figure V-g. Graphical comparison of application time effect. Percent effect is the percent of the maximum observed effect of its type each represented.

Salt Solution Spray in Greenhouse

Materials and Methods

Six saline treatments from 1-20 ds/m were used to determine the extent of foliage damage when saline solutions were applied to Old World bluestem. Each of the six treatments included three 6-inch pots stored in a universal hydroponics solution tray. Each pot contained three Old World bluestem plants of the WW-Iron Master variety planted in five inches of silicon sand. Nutrients were supplied by Liquid Grow 7-9-5 (Dyna-Gro, www.dyna-gro.com) nutrient media mixed with water. During the first two months plants were trimmed each week to a height of four inches to encourage root development. Each week the hydroponics media was drained and replaced with fresh media.

Once plants were established, the reflectance index for each pot was tested using the Greenseeker. To obtain optimal Greenseeker readings, the Greenseeker was mounted on a table while the pots were passed underneath. Care was taken to ensure the pots were scanned by the Greenseeker at a nearly constant speed. Additionally, a defined track for pot movement was created to ensure that the pots moved the same distance. Because the detection limit of the Greenseeker is 0.05, each pot was scanned seven times and averaged to minimize the variation.

The initial reflectance index values were used to order the pots by increasing reflectance index. From this list the most uniform section of 18 pots was selected for the study. To increase the uniformity of the treatments, the 18 pots were distributed amongst the treatments so that the average of the initial reflectance index of each treatment was nearly equal. The number for each pot and its corresponding treatment were recorded.

The pots then received their salinity treatments of 1, 2, 3, 5, 10 and 20 dS/m (9, 19, 29, 49, 99 and 198 mM NaCl). Treatments were applied by uniformly spraying 8 ml of designated solution on each pot. When all treatments had been applied, the pots were randomly placed back in the universal hydroponics tray.

One week after application pots were again tested for their reflectance index. Experiment analysis was based on the difference between the initial and final reflectance index to eliminate some of the small variations in testing conditions.

Results and Discussion

Figure V-h shows a summary of the recorded effect on the reflectance index from the various treatments.

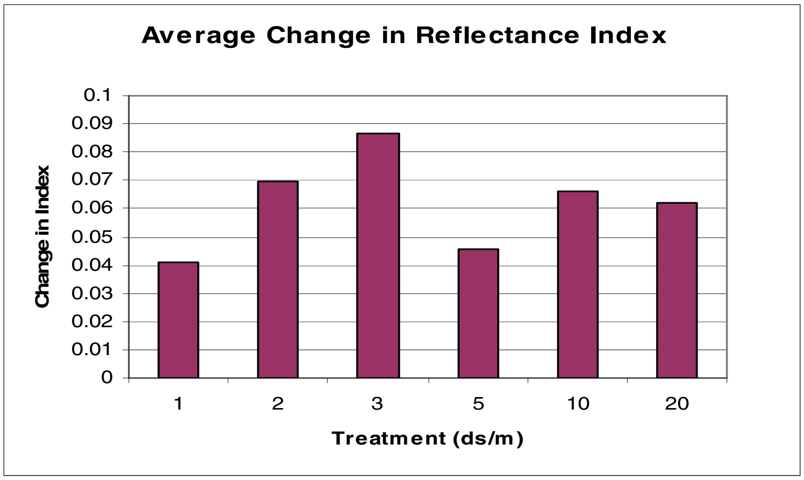


Figure V-h. Summary of the effect of salinity on the change in reflectance index.

A one-way ANOVA analysis was conducted on the results to determine if any of the treatments were significantly different at a 5% alpha level.

One-way ANOVA: Average Change in Reflectance Index versus Treatments

```
Source      DF        SS        MS     F      P
Treatments   5  0.004191  0.000838  2.58  0.083
Error       12  0.003905  0.000325
Total       17  0.008096

S = 0.01804   R-Sq = 51.76%   R-Sq(adj) = 31.66%
```

The ANOVA test did not yield a significant difference between treatments at a 5% alpha value for the reflectance index data.

Conclusion

At a 5% alpha level we conclude that none of the treatments had a significant effect on the average change in the reflectance index. Additionally, since the average reflectance index increased for all treatments, we may conclude that under these conditions the plants did not suffer a significant salt burn effect. This may be because the greenhouse environment was not an accurate representation of the conditions at the CRP land, or because the application method was flawed.

Spray in Greenhouse with Quick Dry

Materials and Methods

The materials and methods for this experiment were the same as the previous experiment with the exception of the treatments and the drying method used. For controls, one treatment received no application while another received water at about 1ds/m. To test the potential for a salt burn from a pure salt solution, a solution of salt was prepared at 100 ds/m (1000 mM NaCl). Additionally, 100%, 50% and 25% solutions of swine effluent were also prepared for application. The swine effluent used was taken from the waste stream of a shallow pit from a farrrowing barn. Treatments were applied by uniformly spraying 16 ml of designated solution to each pot. Immediately following application the plants were blown with 40^{o} C air until all droplets on foliage had dried. Heated air was provided by a hair dryer maintained 3 feet from the plants to imitate wind during a hot day common to the CRP land. When all treatments had been applied, the pots are randomly placed back in the universal hydroponics tray.

Results and Discussion

Figure V-i shows a summary of the recorded effect on reflectance index from the various treatments.

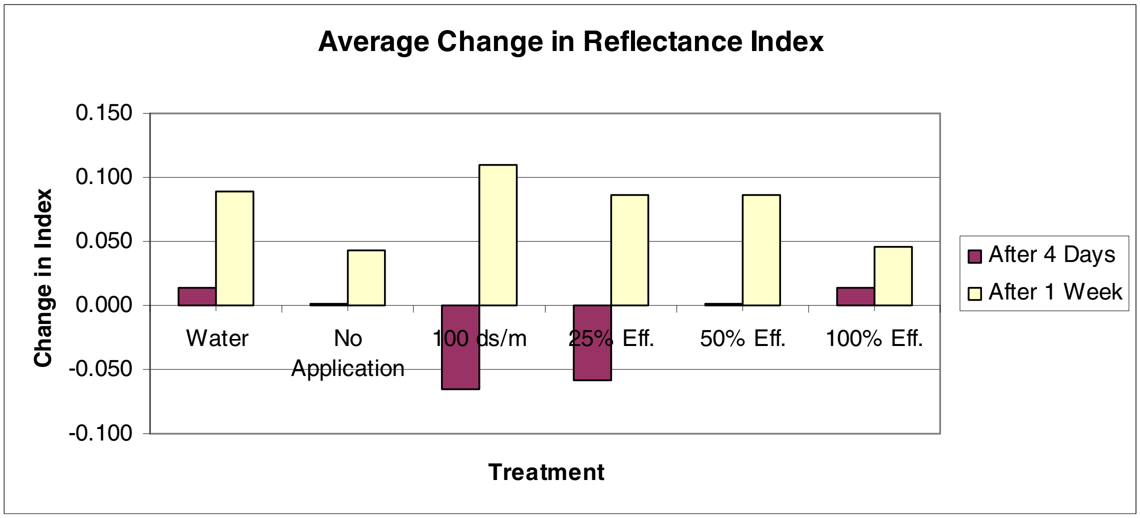


Figure V-i. Summary of the effect of salinity on the change in the reflectance index.

A one-way ANOVA analysis was conducted on the change in the reflectance index after both 4 days and one week data sets to determine if any of the treatments were significantly different at a 5% alpha level.

One-way ANOVA: Average Change in Reflectance Index After 4 Days versus Treatments

```
Source      DF        SS        MS     F      P
Treatments   5   0.01760   0.00352  1.47  0.270
Error       12   0.02876   0.00240
Total       17   0.04636

S = 0.04895   R-Sq = 37.96%   R-Sq(adj) = 12.12%
```

One-way ANOVA: Average Change in Reflectance Index After 1 Week versus Treatments

```
Source      DF        SS        MS     F      P
Treatments   5   0.01423   0.00285  0.91  0.504
Error       12   0.03737   0.00311
Total       17   0.05159

S = 0.05580   R-Sq = 27.57%   R-Sq(adj) = 0.00%
```

Neither of the ANOVA tests yielded a significant difference between the treatments from the reflectance index data.

Conclusion

At a 5% alpha level we conclude that none of the treatments produced a significant average change in the reflectance index for either the 4 day or 1 week data sets. Additionally, since the average reflectance index after one week increased for all treatments, we may conclude that under these conditions the plants did not suffer a significant salt burn effect. It is interesting that plants sprayed with 100 ds/m solution and a 25% effluent dilution did show a reflectance index reduction after 4 days, but seemed to recover by the end of the week. It is possible that no effect was found from the salt solution and swine effluent because the greenhouse environment was not an accurate representation of the conditions at the CRP land, or because the application method was flawed.

Chapter VI

Conclusions

The objectives and conclusions of this study were:

1. Determine the salinity tolerance threshold for WW-Iron Master Old World bluestem;

   The salt tolerance study indicated that WW-Iron Master Old World bluestem is a highly salt sensitive plant. The salinity threshold for WW-Iron Master Old World bluestem was found using the piecewise linear response model to be 1 ds/m. A mineral analysis of the root and shoot portions of the studied plants indicated an interaction between K^+ and Na^+ concentrations in the root tissue of WW-Iron Master Old World bluestem. Additionally, the Na^+ accumulation in the shoots was much greater than in the roots, indicating that WW-Iron Master Old World bluestem is unable to restrict Na^+ transport.

2. Determine the fractional yield decline per unit increase in salinity beyond the threshold;

   The fractional yield decline per unit increase in salinity beyond the threshold for WW-Iron Master Old World bluestem was found using the piecewise linear response model to be 21%.

3. Determine if the time of day the effluent is applied to the plant has a significant effect on plant growth;

From the statistical analysis of the results from the field study of swine effluent application, both the reflectance index and dry weight data did indicate that the time ofday of the application was significant at a 10% alpha level. A Tukey's 90% confidence test showed that for the reflectance index data the noon application was significantly different from the evening application. The tukey's 90% confidence test for the dry weight data showed that the morning application was significantly different from both the evening and noon applications. While reflectance index data and the dry weight data do not agree on the magnitude of the differences between each group, they do both indicate that an application of effluent at noon will result in the least positive effect on plant growth. This may be a result of the higher evaporation effects at midday, and subsequent decreased water available for plant growth.

4. Determine the optimum dilutions for swine effluent when applied to WW-Iron Master Old World bluestem;

   From the field study of swine effluent application, no effect on plant growth was statistically significant due to the effluent dilutions.

5. Verify that using the "Greenseeker" is an adequate method for determining salinity effects on plant growth;

   The "Greenseeker" was shown capable of quantifying plant growth in a non-invasive manner. However, because salt burn studies were unable to produce a negative impact on plant tissue, the experiments could not test the suitability of the "Greenseeker" for determining salt burn effects on plant growth.

6. Determine if a salt solution spray on foliage can cause plant damage;

Greenhouse studies investigating salt burn never produced a statistically significant effect of salt or swine effluent dilutions on WW-Iron Master Old World bluestem. Since the average reflectance index after one week increased for all treatments, with and without quick drying conditions, we may conclude that under these conditions the plants did not suffer a significant salt burn effect.

7. Determine if foliage burn during swine effluent application is a result of chemical constituents other than salts;

   Neither the salt solutions nor the swine effluent solutions caused a burn effect on the plant tissue. Consequently, no evidence was provided that non-salt constituents of swine effluent could cause salt burns on WW-Iron Master Old World bluestems.

8. Statistically evaluate application data from the Conservation Reserve Program.

The unbiased model suggests that both the soil NO_3-N (lbs/acre) and Cu (mg/l) in soil had negative impacts on plant growth. However, the limited number of data sets and the high number of potentially significant variables could lead to incorrectly identifying a variable as significant when it is in fact only a coincidence. Evaluation of the model based on carefully selected variables, or the biased model, yielded effluent values of EC (umho/cm) and Cl (mg/l) as potentially significant variables. However, the biased model was less accurate at predicting a negative stand impact than the unbiased model.

Recommendations for Future Studies

Although the studies completed in this thesis show that Old World bluestem is a highly salt-sensitive plant, further investigation is needed to determine under what conditions, if any, application of effluent will result in salt burn on the leaves. Studies of salt burn effects in this thesis were never able to replicate the reported effects on CRP land. Further studies should consider the possibility for sequential wetting and drying cycles during a single application of effluent. This would require application during hot windy days with an application apparatus that does not provide continuous wetting. A slow moving big gun assembly may be the missing element in the salt burn studies conducted in this thesis.

The statistical approach to the data gathered from the CRP land requires more replications to provide reliable interpretation. Additionally, statistical analysis would improve with a more complete data set that required fewer assumptions. It is recommended that further research includes an on-site observation of soil and effluent sample collection and land application methods.

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Appendices

Appendix A: Relevant Tables and Figures for Hydroponics Salt Tolerance Study.

Table A.1 Raw data table for salt tolerance hydroponics study days 1-14.

Treatment ds/m	Pot	Dry Weight 1	2	3
1	25	0.177	0.169	0.326
1	45	0.144	0.084	0.06
1	20	0.263	0.12	0.12
2	31	0.103	0.44	0.313
2	27	0.228	0.14	0.029
2	2	0.282	0.235	0.227
3	30	0.105	0.067	0.199
3	1	0.143	0.313	0.229
3	10	0.247	0.043	0.287
5	5	0.252	0.106	0.075
5	44	0.133	0.075	0.03
5	23	0.118	0.503	0.341
10	24	0.014	0	0.113
10	3	0.224	0.013	0.006
10	12	0.068	0.067	0.219
20	22	0.115	0.102	0.078
20	37	0.027	0.061	0.018
20	13	0.138	0.192	0
30	8	0.082	0.055	0.02
30	26	0.01	0.094	0.011
30	6	0.024	0.027	0

Table A.2 Raw data table for salt tolerance hydroponics study days 14-28.

Treatment ds/m	Pot	Dry Weight 1	2	3
1	25	0.15	0.094	0.255
1	45	0.119	0.098	0.117
1	20	0.065	0.11	0.193
2	31	0.031	0.112	0.096
2	27	0.175	0.111	0.12
2	2	0.255	0.589	0.25
3	30	0.092	0.026	0.047
3	1	0.104	0.49	0.129
3	10	0.049	0.032	0.269
5	5	0.288	0.01	0.035
5	44	0.038	0.032	0.048
5	23	0.025	0.046	0.31
10	24	0.094	0.057	0.002
10	3	0	0.015	0.115
10	12	0.078	0.234	0.146
20	22	0.054	0	0.024
20	37	0.004	0.021	0
20	13	0.053	0.014	0
30	8	0.024	0	0
30	26	0	0	0
30	6	0	0	0.01

Table A.3 Raw data table for salt tolerance hydroponics study days 28-42.

Treatment ds/m	Pot	Dry Weight 1	Dry Weight 2	Dry Weight 3
1	25	0.153	0.185	0.166
1	45	0.154	0.109	0.149
1	20	0.069	0.098	0.201
2	31	0.023	0.282	0.132
2	27	0.128	0.133	0.172
2	2	0.098	0.137	0.281
3	30	0.047	0.063	0.089
3	1	0.049	0.241	0.062
3	10	0.032	0.011	0.086
5	5	0.008	0.017	0.027
5	44	0.061	0.005	0.05
5	23	0.016	0.117	0.179
10	24	0.029	0	0
10	3	0.014	0.021	0.057
10	12	0.002	0.088	0.103
20	22	0	0	0
20	37	0	0	0
20	13	0	0	0
30	8	0	0	0
30	26	0	0	0
30	6	0	0	0

Table A.4 Raw data table for salt tolerance hydroponics study days 42-56.

Treatment ds/m	Pot	Dry Weight 1	2	3
1	25	0.187	0.176	0.258
1	45	0.25	0.238	0.307
1	20	0.127	0.239	0.268
2	31	0.028	0.134	0.116
2	27	0.161	0.185	0.135
2	2	0.107	0.163	0.211
3	30	0.023	0.043	0.068
3	1	0.06	0.284	0.084
3	10	0.076	0.039	0.09
5	5	0.041	0.015	0.013
5	44	0.049	0.023	0.026
5	23	0.014	0.133	0.177
10	24	0.031	0	0
10	3	0.028	0.013	0.03
10	12	0.006	0.072	0.07
20	22	0	0	0
20	37	0	0	0
20	13	0	0	0
30	8	0	0	0
30	26	0	0	0
30	6	0	0	0

Table A.5 Raw nutrient concentration data table showing mineral content from bi-weekly cuttings for salt tolerance hydroponics study. When plant growth was insufficient for nutrient analysis an "x" was used to represent the missing data points.

Period	ds/m	%P	%Ca	%K	%Mg	%Na	%S	ppm Fe	ppm Zn	ppm Cu	ppm Mn
Days 1-14	**1**	0.42	0.19	2.12	0.12	0.03	0.11	119.36	26.52	28.03	69.02
	2	0.51	0.16	2.24	0.11	0.09	0.10	84.67	60.69	89.33	95.30
	3	0.30	0.09	1.27	0.07	0.06	0.06	32.24	13.61	12.28	63.54
	5	0.26	0.07	1.37	0.07	0.12	0.06	42.07	20.00	26.35	49.37
	10	0.50	0.14	2.25	0.11	0.52	0.10	77.21	43.14	80.86	134.83
	20	0.42	0.16	2.20	0.11	1.49	0.12	87.01	26.34	33.88	144.72
	30	0.39	0.13	2.19	0.11	2.68	0.14	72.44	168.86	274.87	148.10
Days 14-28	**1**	0.44	0.20	2.39	0.11	0.03	0.09	56.77	37.76	46.62	55.55
	2	0.50	0.17	2.34	0.10	0.07	0.09	58.94	25.23	33.23	104.98
	3	0.46	0.15	2.28	0.12	0.11	0.08	58.66	29.40	25.40	104.90
	5	0.46	0.12	2.44	0.10	0.59	0.10	67.73	29.46	29.31	97.56
	10	x	x	x	x	x	x	x	x	x	x
	20	x	x	x	x	x	x	x	x	x	x
	30	x	x	x	x	x	x	x	x	x	x
Days 28-42	**1**	0.53	0.22	3.03	0.12	0.03	0.09	57.77	27.60	27.75	40.99
	2	0.52	0.18	2.38	0.11	0.09	0.08	56.63	18.34	17.56	101.07
	3	0.64	0.24	2.63	0.15	0.23	0.10	53.97	62.35	88.77	140.71
	5	0.56	0.22	3.10	0.14	0.77	0.15	112.74	26.86	31.24	130.83
	10	0.50	0.17	2.50	0.14	0.70	0.15	359.74	50.73	217.80	255.84
	20	x	x	x	x	x	x	x	x	x	x
	30	x	x	x	x	x	x	x	x	x	x
Days 42-56	**1**	0.58	0.22	3.37	0.12	0.03	0.09	49.76	23.45	21.57	34.77
	2	0.66	0.21	3.00	0.12	0.18	0.10	71.69	29.44	38.17	90.99
	3	0.73	0.21	3.09	0.15	0.34	0.10	58.41	20.48	18.15	118.05
	5	0.59	0.16	2.87	0.11	1.19	0.14	55.47	82.32	127.78	116.34
	10	x	x	x	x	x	x	x	x	x	x
	20	x	x	x	x	x	x	x	x	x	x
	30	x	x	x	x	x	x	x	x	x	x

Table A.6 Raw nutrient concentration data table showing final mineral content for the bottom 4" of foliage and the root tissue used in the salt tolerance hydroponics study. Foliage content above 4" is shown in earlier data table.

ds/m	Sample	%P	%Ca	%K	%Mg	%Na	%S	ppm Fe	ppm Zn	ppm Cu	ppm Mn
1	Below 4"	0.51	0.25	2.06	0.13	0.36	0.05	182.69	48.48	64.60	177.74
1	Root Zone	0.86	0.44	1.65	0.15	0.49	0.10	1947.65	94.32	277.97	391.62
2	Below 4"	0.70	0.41	1.26	0.14	0.81	0.07	773.61	89.09	284.87	194.02
2	Root Zone	0.78	0.29	1.48	0.12	0.50	0.10	1590.21	83.25	276.14	509.96
3	Below 4"	0.49	0.12	1.05	0.08	0.70	0.05	268.36	36.96	65.21	164.59
3	Root Zone	0.57	0.36	1.17	0.12	0.53	0.11	1840.97	59.75	196.32	448.74
5	Below 4"	0.50	0.21	1.08	0.10	1.43	0.07	373.30	55.88	112.33	238.00
5	Root Zone	0.61	0.36	0.98	0.10	0.80	0.10	1843.22	48.15	190.98	303.44
10	Below 4"	0.63	0.15	1.21	0.12	2.46	0.12	367.50	58.39	151.12	269.70
10	Root Zone	0.87	0.28	1.11	0.11	1.44	0.11	1445.67	58.66	155.00	468.74
20	Below 4"	0.59	0.37	1.20	0.12	6.95	0.11	1021.46	55.32	202.44	221.18
20	Root Zone	0.77	0.29	0.55	0.10	1.94	0.16	1595.94	46.94	177.80	239.21
30	Below 4"	0.43	0.25	1.23	0.13	9.24	0.11	414.53	61.45	200.09	175.99
30	Root Zone	0.43	0.23	0.25	0.08	2.50	0.14	1493.68	38.27	155.26	165.01

Figure A.1 Comparison of basic mineral composition of roots from plants grown in various salt concentrations for salt tolerance hydroponics study.

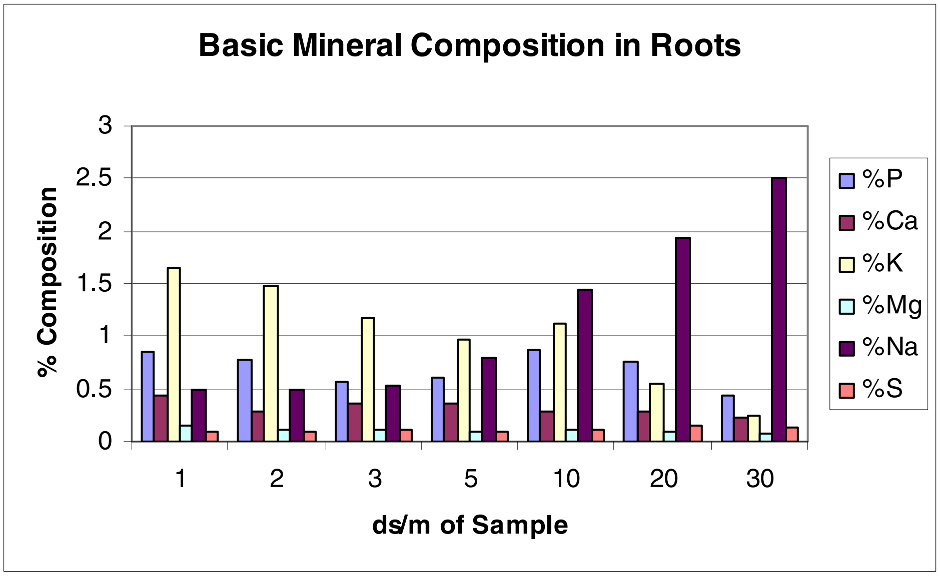


Figure A.2 Comparison of comparing trace mineral composition of roots from plants grown in various salt concentrations for salt tolerance hydroponics study.

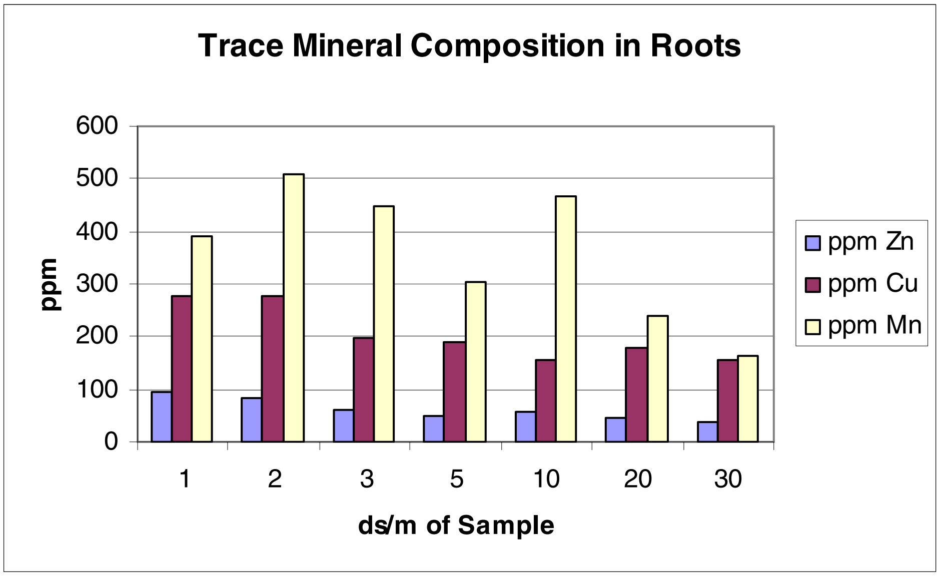


Figure A.3 Comparison of basic mineral composition of bottom 4” of shoots from plants grown in various salt concentrations for salt tolerance hydroponics study.

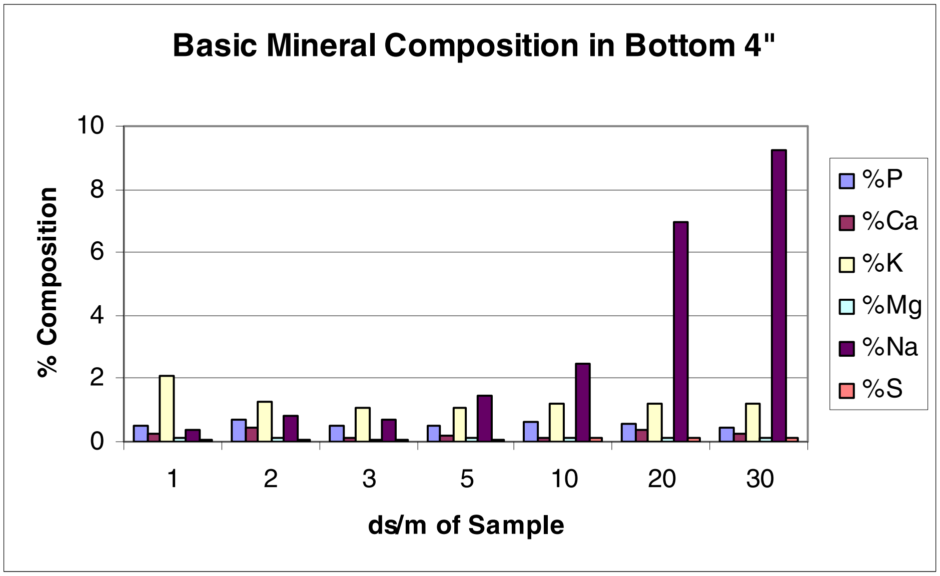
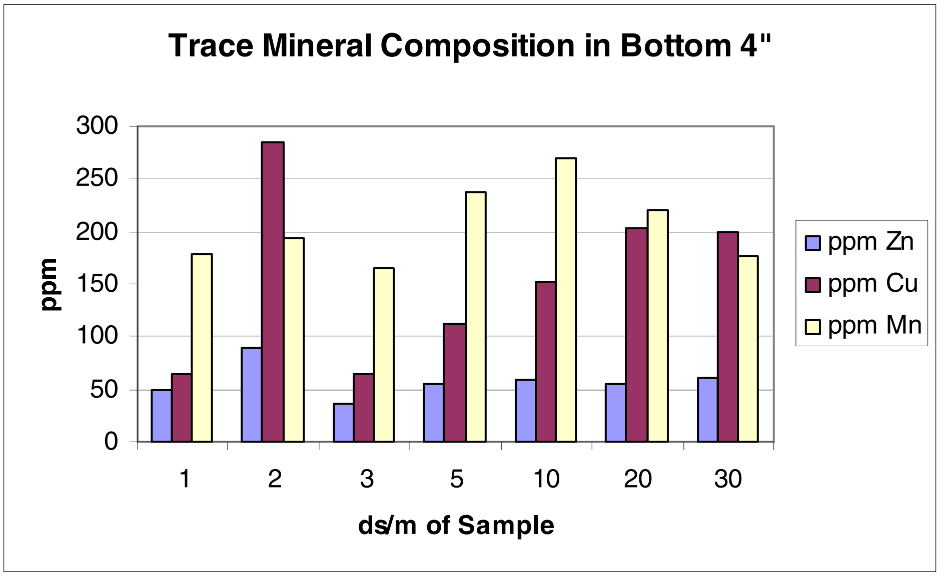


Figure A.4 Comparison of trace mineral composition of bottom 4" of shoots from plants grown in various salt concentrations for salt tolerance hydroponics study.



Appendix B: Relevant Tables and Figures for Statistical Study of Swine Effluent Application on Old World Bluestem.

Table B.1 Variables used to link application dates with specific fields.

Field Identification Data							
ID #	**Farm**	**Name**	**#**	**Application Date**	**Coordinates**	**Field**	**Effect**
1	121	Morris	418	4/1/2004	09-04-12	SE	0
2	121	Morris	418	7/21/2005	09-04-12	SE	0
3	40	Long	4917	6/28/1999	27-04-11	SW	1
4	40	Long	4917	5/24/1999	27-04-11	NW	1
5	40	Long	4917	4/19/2002	27-04-11	SW	1
6	337	Roberts	4574	7/21/2003	07-05-17	SE	0
7	278	Beelman	4606	12/21/2003	09-01-17	SE	0
8	278	Beelman	4606	12/15/2003	09-01-17	NE	0
9	299	Reust	2748	7/26/1999	20-01-15	SW	1
10	299	Reust	2748	7/19/1999	20-01-15	WNE	1
11	301	Reust	2748	9/24/2001	20-01-15	NW	1
12	299	Reust	2748	8/30/2001	20-01-15	SW	1
13	301	Reust	2748	9/3/2003	20-01-15	NW	1
14	299	Reust	2748	8/25/2003	20-01-15	SW	1
15	299	Reust	2748	8/14/2003	20-01-15	WNE	1
16	299	Reust	2748	8/27/2001	20-01-15	NE	1
17	217	Mouser	4720	5/11/1999	15-06-16	SW	1
18	217	Mouser	4720	9/11/1999	15-06-16	SW	1
19	43	Cliff	5321 4615	8/22/1999	05-04-10	SW	1
20	42	Hixon	4600	7/12/1999	11-04-10	NE	0
21	42	Hixon	4600	9/7/2001	11-04-10	NE	0
22	42	Hixon	4600	11/14/2002	11-04-10	SE	0
23	122	Hill	1913	8/24/1999	34-02-14	NW	1
24	122	Hill	1913	4/29/2003	34-02-14	NW	1
25	122	Hill	1913	7/20/2005	34-02-14	NW	1

Table B.2 General application conditions.

General Application Conditions									
ID #	Acre Inches/Acre	Max Temp.	Min Humidity	Max Wind During	Rain During	Rainfall Within Week After	Rainfall Within Week Before	Season	Month
1	0.89	87	6	43	0.05	0.57	0	Spring	3
2	0.42	101	18	34.5	0	0.01	1.39	Summer	7
3	0.90	102	13	40.8	0.01	1.27	0.93	Summer	6
4	1.62	89	13	48.9	0.03	0.62	0	Spring	5
5	0.62	92	6	53.7	0.27	0.14	0	Spring	4
6	0.94	108	9	42.6	0.29	0	0	Summer	7
7	0.92	65	11	32.6	0	0.04	0.14	Winter	12
8	0.81	72	18	59.3	0.14	0.04	0	Winter	12
9	1.47	101	19	37.8	0.13	0	0.07	Summer	7
10	1.54	98	21	35.6	0.2	0	0	Summer	7
11	0.81	91	10	34.8	0.26	0	0	Fall	9
12	0.67	99	13	42.4	0.61	0	0.07	Summer	8
13	0.62	103	17	43.9	0.52	0.51	0	Summer	8
14	0.76	103	17	43.9	0	0.52	0.67	Summer	8
15	0.60	103	16	60	0.67	0	1.58	Summer	8
16	0.75	99	13	42.4	0.63	0	0.05	Summer	8
17	1.12	84	15	48.9	2.26	0	0.59	Spring	5
18	1.76	101	9	36	0.4	0.24	0	Fall	9
19	1.71	102	34	39.5	0.6	0.28	0.41	Summer	8
20	2.15	98	25	43.5	1.34	0.13	0	Summer	7
21	1.89	98	11	51.2	0	0.15	0.19	Summer	8
22	1.23	78	13	43.9	0.11	0	1.51	Fall	11
23	2.11	102	11	39.5	0.06	0.28	0.41	Summer	8
24	0.66	86	11	67.3	0.49	0	0	Spring	4
25	0.78	101	19	37	0	0.01	1.39	Summer	7

Table B.3 Soil conditions before application.

SOIL DATA													
ID #	**Org. Matter %**	**pH**	**EC mmho/ cm**	**Nitrate N lbs/A**	**Ca (mg/l)**	**Mg (mg/l)**	**K (mg/l)**	**Na (mg/l)**	**Cu**	**CEC**	**%K**	**%Mg**	**%Ca**
1	0.9	8	0.2	5	1896	115	181	13	0.5	11	4.2	8.7	86.6
2	0.7	8.3	0.2	2	2281	78	350	17	1.6	13	6.9	5	87.5
3	1.5	8.4	0.33	10	5063	236	370	11	0.9	28	3	7	90
4	1.4	8.5	0.44	10	5535	381	510	40	0.9	32	4	10	86
5	1.3	8.3	0.2	19	2760	262	451	19					
6	0.7	8	0.2	5	1672	129	222	10	0.5	10	5.7	10.8	83.1
7	1.9	8.3	0.2	2	2409	173	343	10	0.6	14.4	6.1	10	83.6
8	2.2	8.1	0.2	12	2383	170	500	11	0.6	14.7	8.7	9.6	81.4
9	1.8	8.3	0.43	7	5791	304	427	6		33	3	8	89
10	2.3	8.3	0.42	10	5615	281	496	6		32	4	7	89
11	1.6	8	0.2	5	2868	284	437	13					
12	2	8.1	0.2	5	2737	270	446	10					
13	1.5	8.5	0.2	14	2612	201	598	18	0.9	16.3	9.4	10.3	79.8
14	1.6	8.5	0.3	10	2575	308	716	21	1.4	17.4	10.6	14.8	74.1
15	1.6	8.4	0.2	22	2601	244	695	22	1	16.9	10.5	12	76.9
16	1.6	8	0.2	5	2868	284	437	13					
17	0.7	8.2	0.14	5	3824	112	180	14	0.4	21	2	5	93
18	0.5	7.6	0.2	24	1109	87	242	17	1	7	9	10	80
19	1.4	7.7	0.39	10	4165	570	678	23	1.2	27	6	17	76
20	1.5	7.7	0.39	5	2881	560	509	41	1	21	3	23	70
21	1.2	7.9	0.3	12	2793	538	485	30					
22	0.9	7.5	0.4	17	2163	603	551	17	0.12	17.3	8.2	29	62.4
23	1.7	8.3	0.38	5	5786	197	371	11	1	32	3	5	92
24	1.7	8.3	0.38	5	5786	197	371	11	1	32	3	5	92
25	1.4	8.2	0.3	2	3064	166	435	16	1.3	17.9	6.2	7.7	85.7

Table B.4 Application effluent properties Part 1

Application Effluent Data Part 1

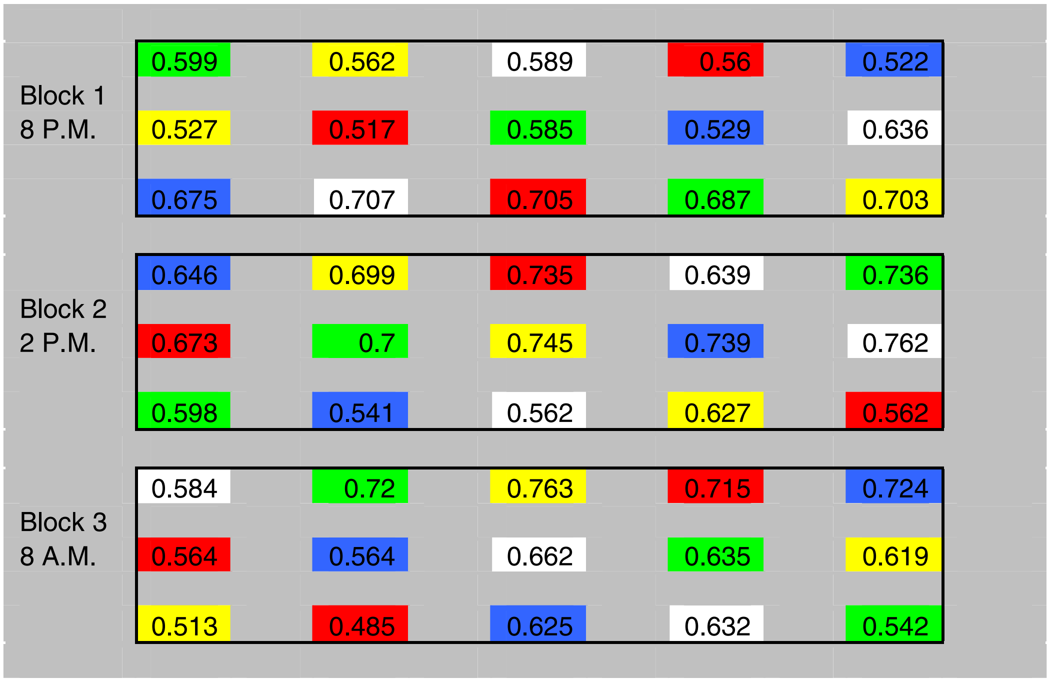
ID #	EC umho /cm	pH	Org N (mg/l)	Ammoniacal N	Tot P (mg/l)	Total Solids (mg/l)	TVS	TDS	TSS	Tot Ca (mg/l)
1	8970	8.13	116	517	40.4	5685	1895	5275	410	97.7
2	8560	7.91	157	553	59.7	5315	2630	4270	1045	141
3	5060	8.4	40		35	2000	1000	3238	1000	90
4	5060	8.4	40		35	2000	1000	3238	1000	90
5	7240	7.74	227	673	41.3	3640	1880	4706	220	82.5
6	8290	8.06	50	581	57.5	4240	1410	4040	200	77.7
7	11330	8.21	141	259	85.9	10305	3295	8142	2163	125
8	11330	8.21	141	259	85.9	10305	3295	8142	2163	125
9	5360	8	110	830	57	5000	2000	3430	3000	120
10	5360	8	110	830	57	5000	2000	3430	3000	120
11	8770	8.26	144		34.3	6624		5613	255	76
12	10790	8.09		774	30.1	5476	1732		495	92.9
13	11020	8.11	141	832	53.4	6065	1870	5843	222	65.2
14	11200	8.18	103	761	61.2	7190	2465	6957	233	54.1
15	11200	8.18	103	761	61.2	7190	2465	6957	233	54.1
16	10790	8.09		774	30.1	5476	1732		495	92.9
17	6870	8.7	120	780	44	3000	1000	4397		80
18	8200	7.9	90	770	53	3000	1000	5248		80
19	6450	8.4	70	630	61	3000	1000	4128		80
20	2150	8.7	10		26	2000	0	2150		70
21	4110	8.17	15		53.5	2800		2630	340	123
22	6200	8.2	105	271	44.4	4635	1975	4030	208	48.1
23	8100	7.4	30	540	44	5000	2000	5171		110
24	6490	8.3	140	476	37.1	5680	2315	5370	310	89.7
25	7430	8.12	125	340	41.7	5125	1920	4.617	508	104

Table B.5 Application effluent properties Part 2

Application Effluent Data Part 2											
ID #	Tot Mg (mg/l)	Tot K (mg/l)	Tot Na (mg/l)	K2O	Cl	adj SAR	Total Salts	Tot S	Tot Zn	Tot Fe	Bicarbonate
1	15.7	1343	375	366.1	562	31.6	2348	19.6	2.42	2.95	3874
2	24.8	1175	273	320.3	460	20.2	2167	21	9.88	6.47	3801
3	24	328	200	380		15.1		20	1	2	2814
4	24	328	200	380		15.1		20	1	2	2814
5	8.29	476	285		358	27.2	852	23.2	0.16	1.19	2852
6	13.8	934	317		511	28.7	1923	11.6	0.3	2.51	3558
7	45.5	2200	660	599.7	1164	46.1	3289	29.9	1.31	8.12	4419
8	45.5	2200	660	599.7	1164	46.1	3289	29.9	1.31	8.12	4419
9	12	991	260	1150	362	19.5		20	2	7	4136
10	12	991	260	1150	362	19.5		20	2	7	4136
11	40	2553	681			54.88	3350	25.3	1.45	2.36	3590
12	37.7	462	261					18	0.12	0.72	5106
13	19.8	1349	296		604	27.1	2562	18.5	1.23	2.78	5228
14	14.6	1601	368		605	36.5	2799	20.2	1.29	3.51	5456
15	14.6	1601	368		605	36.5	2799	20.2	1.29	3.51	5456
16	37.7	462	261					18	0.12	0.72	5106
17	6	767	190	890	277	17		20	1	1.9	4214
18	18	776	200	900	221	15.9		20	1	2	3088
19	12	474	230	550	244	19.8		10	1	2	3569
20	12	353	190	410	186	15.3		20	<1	1	1777
21	28.1	1376	306			22.61	1833.1	22	1.78	4.53	1660
22	14.4	833	445		577	46.1	1340	25.3	0.17	1.88	2242
23	18	1138	260	1320	443	19		20	8	4	3630
24	14.4	1226	276		484	24.1	2084	23.1	8.69	4.64	3544
25	14.4	1319	253	359.5	476	21.4	2030	17.2	5.93	5.07	3190

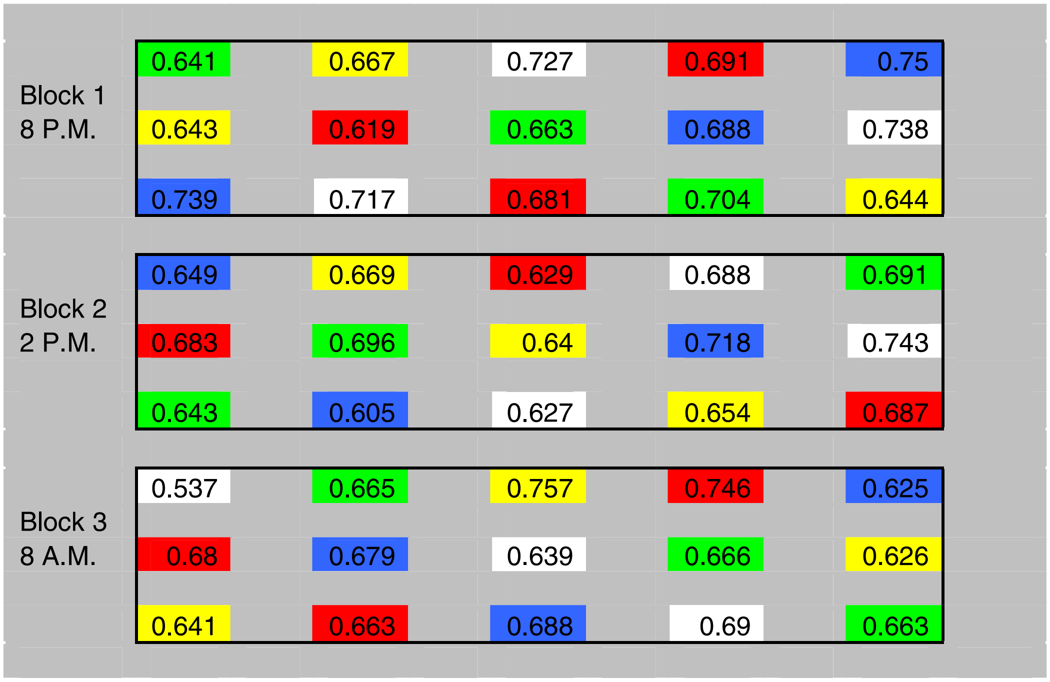
Appendix C: Relevant Tables and Figures for Related Experiments.

Figure C.1. Reflectance index from plots before swine effluent application for panhandle study.



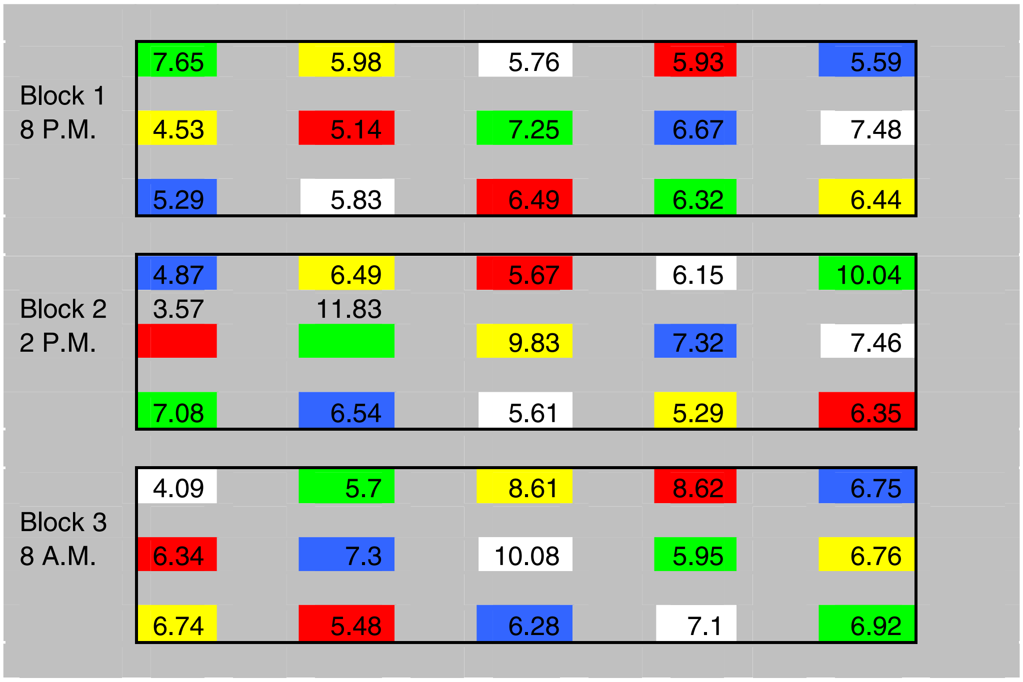
Block 1 8 P.M.	🟩 0.599	🟨 0.562	⬜ 0.589	🟥 0.56	🟦 0.522
	🟨 0.527	🟥 0.517	🟩 0.585	🟦 0.529	⬜ 0.636
	🟦 0.675	⬜ 0.707	🟥 0.705	🟩 0.687	🟨 0.703
Block 2 2 P.M.	🟦 0.646	🟨 0.699	🟥 0.735	⬜ 0.639	🟩 0.736
	🟥 0.673	🟩 0.7	🟨 0.745	🟦 0.739	⬜ 0.762
	🟩 0.598	🟦 0.541	⬜ 0.562	🟨 0.627	🟥 0.562
Block 3 8 A.M.	⬜ 0.584	🟩 0.72	🟨 0.763	🟥 0.715	🟦 0.724
	🟥 0.564	🟦 0.564	⬜ 0.662	🟩 0.635	🟨 0.619
	🟨 0.513	🟥 0.485	🟦 0.625	⬜ 0.632	🟩 0.542

Figure C.2. Reflectance index from plots after swine effluent application for panhandle study. The red plots received undiluted swine effluent, the green plots received 1:1 dilution of swine effluent to water, the blue plots received 1:3 dilution of swine effluent to water, the yellow plots received a 1:7 dilution of swine effluent to water and the white blocks received pure water



Block 1 8 P.M.	🟩 0.641	🟨 0.667	⬜ 0.727	🟥 0.691	🟦 0.75
	🟨 0.643	🟥 0.619	🟩 0.663	🟦 0.688	⬜ 0.738
	🟦 0.739	⬜ 0.717	🟥 0.681	🟩 0.704	🟨 0.644
Block 2 2 P.M.	🟦 0.649	🟨 0.669	🟥 0.629	⬜ 0.688	🟩 0.691
	🟥 0.683	🟩 0.696	🟨 0.64	🟦 0.718	⬜ 0.743
	🟩 0.643	🟦 0.605	⬜ 0.627	🟨 0.654	🟥 0.687
Block 3 8 A.M.	⬜ 0.537	🟩 0.665	🟨 0.757	🟥 0.746	🟦 0.625
	🟥 0.68	🟦 0.679	⬜ 0.639	🟩 0.666	🟨 0.626
	🟨 0.641	🟥 0.663	🟦 0.688	⬜ 0.69	🟩 0.663

Figure C.3. The final weight in lbs of harvested material from plots for panhandle study.



Block 1 8 P.M.	🟩 7.65	🟨 5.98	⬜ 5.76	🟥 5.93	🟦 5.59
	🟨 4.53	🟥 5.14	🟩 7.25	🟦 6.67	⬜ 7.48
	🟦 5.29	⬜ 5.83	🟥 6.49	🟩 6.32	🟨 6.44
Block 2 2 P.M.	🟦 4.87	🟨 6.49	🟥 5.67	⬜ 6.15	🟩 10.04
	🟥 3.57	🟩 11.83	🟨 9.83	🟦 7.32	⬜ 7.46
	🟩 7.08	🟦 6.54	⬜ 5.61	🟨 5.29	🟥 6.35
Block 3 8 A.M.	⬜ 4.09	🟩 5.7	🟨 8.61	🟥 8.62	🟦 6.75
	🟥 6.34	🟦 7.3	⬜ 10.08	🟩 5.95	🟨 6.76
	🟨 6.74	🟥 5.48	🟦 6.28	⬜ 7.1	🟩 6.92

Table C.1. Initial pot reflectance index for salt spray application without quick dry.

Treatment	Pot Name	1	2	3	4	5	6	7	Average
1	43	0.185	0.17	0.194	0.185	0.195	0.184	0.196	0.187
2	14	0.22	0.2	0.203	0.221	0.242	0.251	0.223	0.222857
3	40	0.23	0.233	0.239	0.22	0.236	0.22	0.234	0.230286
5	15	0.232	0.233	0.236	0.225	0.243	0.228	0.234	0.233
10	11	0.232	0.236	0.237	0.231	0.218	0.239	0.244	0.233857
20	29	0.235	0.229	0.246	0.241	0.244	0.241	0.267	0.243286
1	32	0.248	0.235	0.246	0.245	0.244	0.252	0.247	0.245286
2	9	0.253	0.248	0.255	0.253	0.243	0.252	0.239	0.249
3	21	0.235	0.259	0.26	0.254	0.253	0.25	0.255	0.252286
5	42	0.268	0.249	0.253	0.255	0.234	0.256	0.258	0.253286
10	38	0.259	0.257	0.273	0.27	0.27	0.2585	0.271	0.2655
20	7	0.274	0.295	0.26	0.272	0.273	0.28	0.274	0.275429
1	4	0.285	0.27	0.288	0.266	0.273	0.29	0.273	0.277857
2	16	0.291	0.309	0.3	0.307	0.298	0.29	0.294	0.298429
3	19	0.302	0.29	0.294	0.317	0.311	0.307	0.306	0.303857
5	33	0.284	0.294	0.318	0.305	0.316	0.314	0.309	0.305714
10	39	0.322	0.349	0.339	0.353	0.359	0.345	0.344	0.344429
20	34	0.396	0.399	0.429	0.414	0.418	0.394	0.409	0.408429

Table C.2. Final pot reflectance index for salt spray application without quick dry.

Treatment	Pot Name	1	2	3	4	5	6	7	Average
1	43	0.213	0.208	0.215	0.198	0.209	0.205	0.2	0.206857
2	14	0.272	0.272	0.267	0.284	0.264	0.246	0.257	0.266
3	40	0.327	0.34	0.339	0.327	0.314	0.321	0.334	0.328857
5	15	0.262	0.262	0.264	0.254	0.266	0.26	0.271	0.262714
10	11	0.272	0.293	0.288	0.275	0.285	0.279	0.286	0.282571
20	29	0.307	0.315	0.308	0.312	0.307	0.313	0.322	0.312
1	32	0.286	0.29	0.312	0.31	0.297	0.305	0.293	0.299
2	9	0.327	0.34	0.339	0.327	0.314	0.321	0.334	0.328857
3	21	0.333	0.324	0.327	0.333	0.331	0.322	0.341	0.330143
5	42	0.324	0.299	0.3	0.288	0.291	0.287	0.269	0.294
10	38	0.306	0.333	0.333	0.312	0.325	0.331	0.319	0.322714
20	7	0.323	0.34	0.322	0.362	0.339	0.333	0.35	0.338429
1	4	0.32	0.344	0.306	0.326	0.315	0.331	0.345	0.326714
2	16	0.355	0.412	0.395	0.369	0.369	0.39	0.394	0.383429
3	19	0.401	0.396	0.397	0.395	0.382	0.371	0.372	0.387714
5	33	0.358	0.372	0.399	0.372	0.367	0.377	0.364	0.372714
10	39	0.44	0.425	0.449	0.445	0.432	0.432	0.44	0.437571
20	34	0.46	0.45	0.467	0.461	0.468	0.463	0.464	0.461857

Table C.3. Initial pot reflectance index for salt and effluent spray application with quick dry.

Treatment	Pot Name	1	2	3	4	5	6	7	Average	Group
Water	40	0.49	0.382	0.421	0.393	0.389	0.402	0.401	0.411143	0.451381
Water	9	0.406	0.443	0.418	0.444	0.429	0.442	0.439	0.431571	
Water	16	0.479	0.526	0.523	0.53	0.517	0.497	0.508	0.511429	
None	43	0.281	0.26	0.26	0.271	0.256	0.27	0.267	0.266429	0.314571
None	15	0.308	0.334	0.352	0.304	0.319	0.321	0.334	0.324571	
None	21	0.363	0.319	0.367	0.371	0.348	0.34	0.361	0.352714	
100 ds/m	29	0.403	0.43	0.418	0.417	0.42	0.392	0.415	0.413571	0.449619
100 ds/m	11	0.413	0.423	0.445	0.444	0.442	0.441	0.427	0.433571	
100 ds/m	34	0.5	0.5	0.499	0.5	0.514	0.507	0.492	0.501714	
25% Eff.	19	0.423	0.426	0.435	0.424	0.432	0.391	0.394	0.417857	0.450429
25% Eff.	38	0.445	0.437	0.43	0.414	0.435	0.451	0.451	0.437571	
25% Eff.	32	0.473	0.506	0.512	0.498	0.485	0.497	0.5	0.495857	
50% Eff.	7	0.442	0.397	0.402	0.385	0.396	0.468	0.446	0.419429	0.450476
50% Eff.	14	0.438	0.456	0.422	0.404	0.465	0.454	0.43	0.438429	
50% Eff.	39	0.529	0.477	0.472	0.494	0.496	0.498	0.489	0.493571	
100% Eff.	33	0.425	0.413	0.421	0.418	0.431	0.414	0.442	0.423429	0.449286
100% Eff.	42	0.446	0.464	0.444	0.404	0.461	0.416	0.45	0.440714	
100% Eff.	4	0.498	0.498	0.502	0.473	0.476	0.48	0.459	0.483714	

Table C.4. Pot reflectance index after 4 days for salt and effluent spray application with quick dry.

Treatment	Pot Name	1	2	3	4	5	6	7	Average	Group
Water	40	0.466	0.433	0.476	0.466	0.463	0.468	0.47	0.463143	0.461048
Water	9	0.384	0.38	0.382	0.392	0.386	0.39	0.383	0.385286	
Water	16	0.523	0.518	0.528	0.542	0.547	0.55	0.535	0.534714	
None	43	0.269	0.286	0.259	0.251	0.273	0.262	0.252	0.264571	0.322238
None	15	0.339	0.332	0.346	0.339	0.325	0.325	0.328	0.333429	
None	21	0.363	0.369	0.369	0.328	0.386	0.38	0.386	0.368714	
100 ds/m	29	0.384	0.38	0.39	0.388	0.387	0.399	0.363	0.384429	0.38919
100 ds/m	11	0.444	0.454	0.432	0.425	0.45	0.435	0.435	0.439286	
100 ds/m	34	0.356	0.339	0.353	0.363	0.336	0.32	0.34	0.343857	
25% Eff.	19	0.344	0.318	0.364	0.325	0.368	0.376	0.341	0.348	0.399714
25% Eff.	38	0.45	0.442	0.445	0.434	0.438	0.428	0.427	0.437714	
25% Eff.	32	0.4	0.418	0.415	0.422	0.419	0.419	0.401	0.413429	
50% Eff.	7	0.378	0.364	0.369	0.403	0.391	0.393	0.398	0.385143	0.446143
50% Eff.	14	0.447	0.435	0.476	0.478	0.465	0.459	0.455	0.459286	
50% Eff.	39	0.415	0.49	0.515	0.525	0.5	0.496	0.517	0.494	
100% Eff.	33	0.481	0.469	0.483	0.493	0.492	0.496	0.516	0.49	0.470619
100% Eff.	42	0.46	0.442	0.45	0.431	0.448	0.472	0.411	0.444857	
100% Eff.	4	0.493	0.458	0.478	0.488	0.464	0.492	0.466	0.477	

Table C.1. Pot reflectance index after 1 week for salt and effluent spray application with quick dry.

Treatment	Pot Name	1	2	3	4	5	6	7	Average	Group
Water	40	0.375	0.352	0.419	0.378	373	0.384	0.4	53.61543	18.1071
Water	9	0.328	0.339	0.33	0.339	0.358	0.323	0.319	0.333714	
Water	16	0.376	0.362	0.366	0.405	0.352	0.381	0.363	0.372143	
None	43	0.241	0.26	0.244	0.239	0.234	0.245	0.248	0.244429	0.28019
None	15	0.307	0.272	0.305	0.327	0.292	0.309	0.298	0.301429	
None	21	0.316	0.293	0.29	0.288	0.297	0.292	0.287	0.294714	
100 ds/m	29	0.31	0.317	0.311	0.289	0.301	0.295	0.318	0.305857	0.332
100 ds/m	11	0.393	0.4	0.381	0.404	0.411	0.433	0.408	0.404286	
100 ds/m	34	0.288	0.3	0.283	0.298	0.27	0.285	0.277	0.285857	
25% Eff.	19	0.316	0.334	0.329	0.32	0.34	0.328	0.322	0.327	0.35719
25% Eff.	38	0.375	0.381	0.411	0.388	0.377	0.389	0.402	0.389	
25% Eff.	32	0.363	0.355	0.347	0.366	0.368	0.329	0.361	0.355571	
50% Eff.	7	0.269	0.25	0.284	0.309	0.295	0.283	0.265	0.279286	0.378905
50% Eff.	14	0.439	0.391	0.411	0.406	0.383	0.389	0.405	0.403429	
50% Eff.	39	0.477	0.445	0.441	0.459	0.442	0.478	0.436	0.454	
100% Eff.	33	0.398	0.409	0.404	0.406	0.39	0.411	0.4	0.402571	0.401714
100% Eff.	42	0.399	0.337	0.36	0.389	0.356	0.358	0.371	0.367143	
100% Eff.	4	0.465	0.431	0.404	0.459	0.416	0.432	0.441	0.435429	

Table C.1. Treatment characteristics for salt and effluent spray application with quick dry.

	100% Eff.	50% Eff.	25% Eff.	100 ds/m
Dry Matter	0.80%	0.40%	0.20%	
EC ds/m	11.09	5.545	2.7725	100
Soluable Salts (ppm)	7430	3715	1857.5	.051g NaCl/ml
Phosphorus (P2O5) (ppm)	510.1	255.05	127.525	
Calcium (Ca) (ppm)	231.7	115.85	57.925	
Potassium (K2O) (ppm)	985.4	492.7	246.35	
Magnesium (Mg) (ppm)	125.8	62.9	31.45	
Sodium (Na) (ppm)	268.2	134.1	67.05	
Sulfur (S) (ppm)	112.2	56.1	28.05	
Iron (Fe) (ppm)	15.99	7.995	3.9975	
Zinc (Zn) (ppm)	8.69	4.345	2.1725	
Copper (Cu) (ppm)	1.28	0.64	0.32	
Manganese (Mn) (ppm)	3.29	1.645	0.8225	
Total C	0.45%	0.23%	0.11%	
Total N	0.12%	0.06%	0.03%	

VITA

Spencer Lee Mann

Candidate for the Degree of

Master of Science

Thesis: THE TOLERANCE OF WW-IRON MASTER OLD WORLD BLUESTEM TO SALINITY AND LAND-APPLICATION OF SWINE EFFLUENT

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